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Environmental Management at the Government Museum and Art Gallery, Chandigarh

Analysis and Strategies

Project Report

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The Getty Conservation Institute works internationally to advance conservation practice in the visual arts—broadly interpreted to include objects, collections, architecture, and sites. The Institute serves the conservation community through scientific research, education and training, field projects, and the dissemination of information. In all its endeavors, the Institute creates and delivers knowledge that contributes to the conservation of the world's cultural heritage.

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Cover image: View of the Great Hall at the Government Museum and Art Gallery. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

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INTRODUCTION

Background

In 2019, the Getty Conservation Institute (GCI) and the Government Museum and Art Gallery in Chandigarh, India, developed a work plan in which the GCI, assisted by museum staff, would investigate the environmental conditions at the museum through extensive monitoring and data analysis. Based on this investigation, the GCI developed recommendations for environmental improvements to the building that would benefit its occupants and collection, while maintaining the historic integrity of the building.

This environmental improvements project was conceived as a complement to the Conservation Management Plan (CMP) prepared for the Government Museum and Art Gallery by the Indian heritage consultant Development and Research Organisation for Nature, Arts and Heritage (DRONAH), which was funded through a Keeping It Modern Grant from the Getty Foundation. The GCI saw the Government Museum and Art Gallery's environmental project as an opportunity to leverage its experience in the areas of collection environment and conservation of modern heritage to develop a case study to demonstrate low-energy solutions for climate management in museums from the modern era. This experience came from many years of research studying museum environments through the Managing Collection Environments Initiative and in conserving modern places through the Conserving Modern Architecture Initiative. Developing strategies for improvements to the Government Museum and Art Gallery has the potential to assist other museums in similar hot and humid climates and will be of increasing value as the climate crisis continues.

Prior to this partnership with the Government Museum and Art Gallery, the GCI had conducted a workshop in India in 2018 for representatives from the three museums, all of which were designed by the French Swiss architect Le Corbusier. Two are located in India, the Sanskar Kendra in Ahmedabad and the Government Museum and Art Gallery in Chandigarh, and the third is located in Japan, the National Museum of Western Art in Tokyo. This workshop gave GCI an understanding of how the Government Museum and Art Gallery fit into this family of similar buildings, as the three museums were all based on a prototype developed by Le Corbusier to create the ideal museum (Arato Gonçalves, McCoy, and Macdonald 2019).

A Significant Modern Museum

Based on a master plan by Le Corbusier, who is considered one of the Modern Movement's leading and most celebrated figures, Chandigarh is an outstanding example of modern urban planning, and its buildings are iconic works of modern architecture. He conceptualized Chandigarh as an ideal modernist city at the request of Prime Minister Jawaharlal Nehru, who wanted the new capital of the Indian state of Punjab and Haryana to be a symbol of the country's post-independence democracy. Following the partition of India and Pakistan in 1947, Punjab was in need of a new capital city after the original, Lahore, became part of Pakistan. The Government Museum and Art Gallery was envisioned by Le Corbusier to be a central part of Chandigarh's cultural core, which occupies the city's sector 10, and was completed in 1968.

The building that houses the Government Museum and Art Gallery is both an iconic work of modern architecture and a vessel to protect and display a significant and renowned collection of artworks (fig. 0.1). It has all the design elements that define Le Corbusier's modernist works and addresses the Indian climate. Le Corbusier familiarized himself with local annual temperature fluctuations, rainfall, and wind direction. Natural ventilation and natural lighting became key aspects of the building's design and are reflected in the form of the building (fig. 0.2). Raising the first floor of this reinforced concrete structure on pilotis allows breezes to enter through openings in the ground-floor walls. Vertical aerators located on all sides of the building's exterior provide cross-ventilation throughout the museum and gallery spaces, allowing for occupant-controlled natural conditioning of the interior (fig. 0.3). On each facade, large undulatory windows, which have fixed glazing occasionally alternating with aerators, let in direct sunlight (fig. 0.4). Rooftop clerestories, which cover the entire roof of the museum (fig. 0.5), bring in indirect light, while a series of angled baffles prevents direct sunlight from entering the building in the hottest months.

FIGURE 0.1.
Southwest exterior view of the Government Museum and Art Gallery, showing pilotis at the ground floor, a mostly solid first floor and second floor, and rooftop clerestories with angled fins. © Fondation Le Corbusier. Photo: Ana Paula Arato Gonçalves, 2018, © J. Paul Getty Trust.

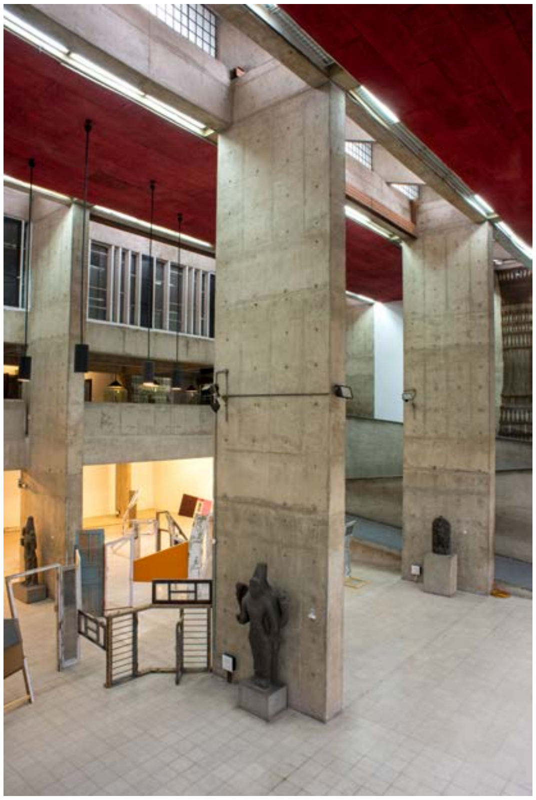


FIGURE 0.2.
The soaring Great Hall, three stories in height, is the museum's central core, with a ramp (background, right) connecting to the main gallery floor. Controlled natural daylight from the clerestories above brightens the space. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

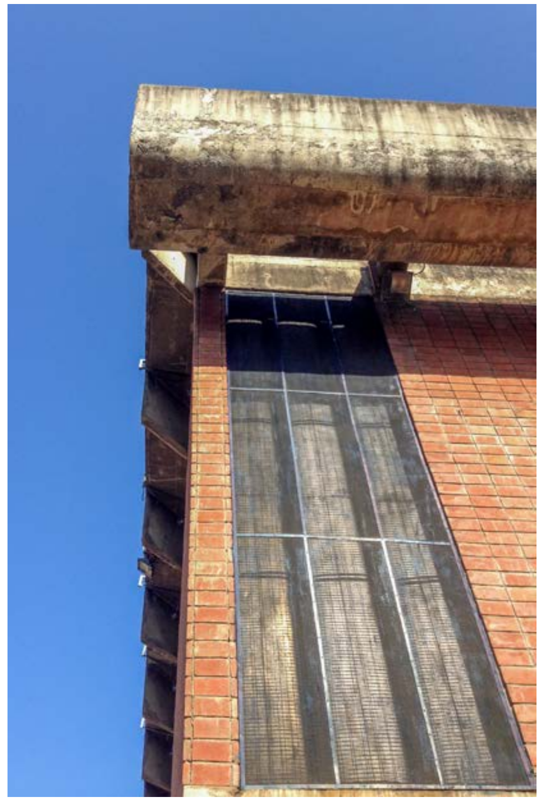


FIGURE 0.3.
Vertical metal aerators in the south corner of the museum. © Fondation Le Corbusier. Photo: Chandler McCoy, 2017, © J. Paul Getty Trust.

FIGURE 0.4.
Undulatory windows grouped on each side of the building admit light into the galleries at eye level and alternate with opaque aerators to allow ventilation. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

FIGURE 0.5.
Eight parallel rows of clerestories fill the museum's rooftop. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

A Significant Collection of Art and Artifacts

The museum's collection has a rich history dating back to the partition of the country in 1947. Following the division of Punjab into East Punjab and West Punjab, the Central Museum in Lahore split its holdings between the two newly independent nations. India received 40% of this collection, which eventually found a home at the Government Museum and Art Gallery in Chandigarh. In addition, Dr. M. S. Randhawa, the first commissioner of Chandigarh and an art connoisseur, spearheaded a remarkable acquisition of antiquities and modern Indian art for the Government Museum and Art Gallery. With the assistance of dedicated individuals such as the architects Pierre Jeanneret, S. D. Sharma, and M. N. Sharma, as well as chief engineer Kulbir Singh and designer Ratna Fabri, the museum was inaugurated in 1968.

Today, the Government Museum and Art Gallery stands as a testament to the foresight of Chandigarh's founders in meeting the cultural needs of a modern city in post-independence India. The collection includes outstanding Gandhara sculptures (fig. 0.6), Pahari miniature paintings from the eighteenth and nineteenth centuries (fig. 0.7), and modern Indian art from the post-independence era (fig. 0.8). Masterpieces by renowned miniature artists like Pandit Seu, Manaku, Nainsukh, and Purkhu, and artworks by modern artists such as Nicholas Roerich, Tyeb Mehta, Sobha Singh, S. L. Parasher, M. F. Husain, and many more, attract visitors from across the country and abroad. The museum also boasts impressive collections of textiles, coins, metal sculptures, decorative arts, and pottery.

FIGURE 0.6.
Stone sculpture of a standing bodhisattva. Photo: © Government Museum and Art Gallery.

FIGURE 0.7.
Folio from the Bhagavata Purana*, ca. 1780, opaque watercolor on paper, Pahari miniature painting. Photo: © Government Museum and Art Gallery.*

FIGURE 0.8.
Maqbool Fida Husain, Blue Head*, 1961, oil on canvas. Photo: © Government Museum and Art Gallery.*

The Importance of the Exhibition Display Furniture

In addition to the collection and the building, the original exhibition display furniture within the museum has high heritage value. The furniture, including cases, stands, pedestals, and movable partitions for mounting art, was designed by the noted artist-designer Ratna Fabri. Her work complements the modernist building and provides a carefully considered way to accommodate the wide-ranging types, shapes, and sizes of the artworks. Constructed of wood, glass, and steel, these pieces have been engineered to show the varied works in their best light and, when necessary, can be used to create smaller, more intimate environments within Le Corbusier's lofty interiors (figs. 0.9–0.11). The CMP rates the original Fabri display furniture as having exceptional significance. Many newer pieces have been added over the years in the style of the original works, and it is sometimes difficult to ascertain exactly which pieces are attributable to Fabri; nevertheless, the overall impression is that the display furniture is mostly well coordinated and suits its purpose.

FIGURE 0.9.
Stone sculptures are displayed on steel and wood pedestals and stands, allowing viewers to experience the three-dimensionality of the forms. © Fondation Le Corbusier. Photo: Sagar Studio, 1968, © Government Museum and Art Gallery archive.

FIGURE 0.10.
Miniature art is displayed on freestanding panels, creating an intimate viewing space. The works are covered by a canopy that reflects uplighting while also providing protection from daylight entering from above. © Fondation Le Corbusier. Photo: Sagar Studio, 1968, © Government Museum and Art Gallery archive.

FIGURE 0.11.
Contemporary art is displayed on freestanding panels supported by metal stands that span from floor to ceiling. Mounting on panels instead of directly on masonry walls avoids moisture transfer from the walls to the paintings. © Fondation Le Corbusier. Photo: Sagar Studio, 1968, © Government Museum and Art Gallery archive.

Challenges

Providing an interior environment conducive to preventive conservation of the collection and human thermal comfort in a hot-humid climate without compromising the architectural integrity of a naturally ventilated building poses significant challenges. Adding to this challenge was the need to increase security by installing grates and grilles (figs. 0.12–0.14) and closing off access to balconies after a theft occurred in the 1970s. Currently, only portions of the building are air-conditioned, leading to varying temperature and relative humidity levels throughout the museum. Electric supply disruptions, particularly in the summer months, affect climate control systems in air-conditioned areas, impacting the preservation of delicate artifacts. To mitigate these challenges, museum staff continuously monitor displayed collections, periodically rotating organic materials. Silica gel is used in selected galleries to help manage humidity levels, such as in miniature showcases. During summer, aerators remain open during museum hours, while pedestal fans provide additional air movement. In winter, portable electric heaters are used to counter cold temperatures, although these measures are not always sufficient.

Despite these challenges, the museum remains a cultural hub, with an average daily visitation of around two hundred people. It continues to host regular temporary exhibitions, workshops, talks, and lectures, reinforcing its significance as a cultural cornerstone of the city and region.

FIGURE 0.12.
Metal grates are installed in front of the undulatory windows in all galleries. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

FIGURE 0.13.
Detail of a metal grate installed in front of an exterior balcony door. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

FIGURE 0.14.
Metal grille installed in an interior opening to prevent passage between two galleries. © Fondation Le Corbusier. Photo: Foekje Boersma, 2017, © J. Paul Getty Trust.

Cultural Significance and Applicable Guidance

The 2019 CMP for the Government Museum and Art Gallery, Chandigarh, establishes the cultural significance of this place in terms of the values sustained by its different elements. For example, the landscape and its location make the building an integral and contributing part of the modern urban ensemble that is Chandigarh, and its historic association with the creation of modern independent India. As a key feature in Chandigarh's cultural core, the museum plays an important role in the cultural life of the city. The building has great architectural value, as it illustrates Le Corbusier's integration of modern architecture principles and local climate and context. It also represents the influential exchange between Western and Indian modern architecture. In addition, this building is the third and final application of Le Corbusier's concept for the Museum of Unlimited Growth. The collection contained inside the museum has artistic and historic value not only for its antiquities and its contemporary art objects but also for its historic association with the partition of India and Pakistan. Fabri's exhibition design was created to display this highly varied collection of miniatures, small metal sculptures, midsize stone sculptures, contemporary works on canvas, and so forth. Her modern designs embody aesthetic values by responding to the architecture that surrounds them while creating the appropriate context and scale for viewing the individual components of the collection (DRONAH 2019, 125–29).

Statement of Significance

"The Government Museum and Art Gallery, Chandigarh, is an exceptional national example of modern architecture in India. It simultaneously illustrates formal, technological and material innovation in modernism to reflect post-independence ideals of nation building along with new ideas in museum design. Additionally, it is part of an ensemble of outstanding modern architecture of Chandigarh that marks the transnational exchange of architectural ideas and its subsequent impact on Indian and Western architecture, which lasted for more than three decades. It is an iconic modern museum building designed by Le Corbusier as the final realization of his concept for the Museum of Unlimited Growth."

—DRONAH 2019, 87

The authors of the 2019 CMP explain the heritage framework in India, noting that there are still challenges in the recognition of modern architecture as heritage. The national and state heritage protection agencies only list sites more than one hundred years old, effectively excluding most modern structures from this type of protection. However, there have been successful local initiatives, beginning with those undertaken by Mumbai in 1996, to recognize and protect buildings younger than the national age limit (DRONAH 2019, 123).

In Chandigarh, the importance of modern heritage is recognized and protected. The Chandigarh Master Plan 2031 acknowledges the city's original plan and its modern buildings as heritage under the categories of Heritage Zones, Heritage Precincts, and Heritage Buildings. Within these categories, buildings are graded and protected as either Grade I, II, or III, based on their cultural significance (Chandigarh Administration 2015, 493). All listed heritage zones, precincts, and buildings require approval of the Special Heritage Committee before any changes or interventions can be carried out. The Government Museum and Art Gallery is located within Heritage Zone X, which is identified as a heritage precinct, and has been recognized as a Grade I Heritage Building (Chandigarh Administration 2015, 486). The Chandigarh Master Plan states that Grade I buildings must be protected and permits only those changes that are essential. Minimal changes would be allowed as long as they are in conformity with the original (DRONAH 2019, 123).

Purpose and Scope of the Work

The work defined for the environmental improvements project reviewed how the building's occupants and its collection are affected by the internal environment, as well as the role of the building, its operation, and its display cases in managing the external climate. The project was implemented in two parts. The first part collected environmental data for approximately eighteen months from sensors installed throughout the building (fig. 0.15), inside display cases, and from a roof-mounted weather station (fig. 0.16). The second part was composed of analysis of environmental data, collection risk assessment, and development of proposals for improvements in consultation with staff at the Government Museum and Art Gallery and other stakeholders.

FIGURE 0.15.
Two sensors measuring temperature and relative humidity installed in the Miniatures Gallery at different heights (indicated by dotted circles). © Fondation Le Corbusier. Photo: Vincent Laudato Beltran, 2020, © J. Paul Getty Trust.

FIGURE 0.16.
Weather station mounted on the roof of the museum in 2020 for the collection of data on external weather conditions, including wind direction and wind speed. © Fondation Le Corbusier. Photo: Vincent Laudato Beltran, 2020, © J. Paul Getty Trust.

This monitoring system was installed in late 2019, and data collection began in January 2020. Variations in interior and exterior conditions were recorded, including relative humidity, temperature, visible and UV light, and atmospheric pollutants in the air.

While the collected environmental data were being analyzed, a risk assessment was done for the collection. First, the value of the collection was assessed in terms of its rarity, cultural significance, and replacement cost. Next, agents of deterioration that could affect the condition of the collection were identified, including the effects of high relative humidity and dew point, light, high temperature, and air pollution.

Based on analysis of the data collected, strategies for environmental improvements were developed by the project team in collaboration with the Government Museum and Art Gallery's curatorial staff. This was done in three online workshops: The first was aimed at identifying objectives for improving the collection's environments, the second focused on environmental assumptions and findings from environmental monitoring, and the third one discussed proposed strategies with key stakeholders. The final strategies provide recommendations for how to manage heat gain and interior moisture; improve natural ventilation; manage temperature and relative humidity extremes; limit damage to collections from visible light, UV light, and particulates; and improve human thermal comfort.

Environmental Guidance for Collections in Museums

The GCI's monitoring results indicated that four of the ten widely acknowledged agents of deterioration for collections are present in the Government Museum and Art Gallery's environment: pollutants, light and UV radiation, incorrect temperature, and incorrect relative humidity. This is an expected result for buildings designed to manage their interior environments with natural daylighting and natural ventilation, which creates an interior environment that fluctuates with exterior conditions. In the case of many museums in Europe and North America, the general role of the building's exterior construction, or envelope, is to limit or manage the influence of these factors on the interior environment. In addition to the building envelope, artificial lighting and mechanical systems for filtering and conditioning the interior air are usually employed to reduce the risk to collections from these agents of deterioration. However, effective mechanical air-conditioning requires a sufficiently airtight building envelope to limit the exchange of thermal energy, moisture vapor, and air between the interior and exterior.

The challenges of using mechanical air-conditioning for museums in South Asia and Southeast Asia were first noted nearly fifty years ago. In his writings dating from the early 1970s, the conservationist O. P. Agrawal recognized that in this region, air-conditioning systems can be installed readily, but their long-term operation is often too expensive to sustain and requires maintenance by trained personnel. Instead of reliance on mechanical air-conditioning, he advocated that museums in South and Southeast Asia address their climate conditions through design (Agrawal and Baxi 1974).

Technological advances in today's mechanical air-conditioning systems further compound the problem noted by Agrawal because they contain sophisticated electronics that require stable, high-quality electrical power and whose controls often require wireless internet access and internet communications. To achieve effective and energy-efficient mechanical air-conditioning throughout the Government Museum and Art Gallery, extensive and unacceptable alterations to Le Corbusier's building design would be required, such as the need to seal the building envelope to limit the exchange of thermal energy, air, and moisture vapor between the exterior and interior. It would also be necessary to guarantee steady, uninterrupted power to the building 24 hours a day, which is currently not feasible. For this reason, this report does not recommend air-conditioning or complex lighting systems as the solution to the building's environmental challenges (and as a way of protecting the collection) but instead examines the original architecture and exhibition furniture and seeks inspiration from Le Corbusier's design to devise a plan to sustain and enhance the building's ability to provide natural ventilation and natural daylight.

In resolving the challenges presented by climate conditions, architectural constraints, human thermal comfort, and collection conservation, the recommendations in this report have been informed by the following publications:

- *Environmental Management for Collections: Alternative Preservation Strategies for Hot and Humid Climates* (Maekawa, Beltran, and Henry 2015)
- "Museums, Galleries, Archives, and Libraries," chapter 24 in ASHRAE handbook (ASHRAE 2023)
- "Agents of Deterioration" (Canadian Conservation Institute 2017)
- Design of Indoor Conditions per Adaptive Thermal Comfort Model, in *National Building Code of India 2016* , (National Building Code Sectional Committee 2016, 19, section 6.2, subsection a)

Organization of This Report

This report is organized into six chapters followed by four appendices. In chapter 1, the climate of Chandigarh is discussed, along with projections of how climate change will affect local climate and an examination of atmospheric pollution. Chapter 2 explains how the building's existing environmental systems currently operate to modify conditions, including a description of both mechanical and non-mechanical systems. Chapter 3 discusses the collection, describing what objects it includes and how it is valued, and provides an assessment of its significance and its vulnerabilities.

In chapter 4, the environmental monitoring program and the methodology for data collection are described. Data results are shown in a series of charts and graphs with an explanation of their meaning. Chapter 5 presents the recommended strategies to improve environmental management at the Government Museum and Art Gallery, based on the data results from chapter 4. These strategies were developed to manage heat gain and interior moisture vapor, improve natural ventilation, manage temperature and relative humidity extremes, and limit damage from light and UV to the collection. Each strategy is presented on an individual data sheet that provides a description of the strategy, the environmental factors addressed, the current situation at the museum, the actions required to implement and operate the strategy, and any potential risks. Finally, the steps involved in the decision-making process of reviewing, selecting, and implementing the environmental management strategies are discussed in chapter 6. The appendices include architectural drawings as well as reference documentation of equipment installation, sensor location, and environmental data.

CHAPTER 1

THE CLIMATE OF CHANDIGARH

This chapter focuses on the climate contexts of the Government Museum and Art Gallery, Chandigarh, including the classification of the climate of the recent past, seasonal characterization, future projections for climate change, and presence of pollutants.

Exterior environmental conditions and a more nuanced determination of the seasons during the monitoring period are presented in chapter 4 in addition to information on pollutants during the monitoring period.

Classification of the Climate

An understanding of the past climate of the Government Museum and Art Gallery is helpful. There are two methods for classifying the climate: the Köppen system, based in large part on vegetation, and the ANSI/ASHRAE method, based on thermal loads for heating and/or cooling and on moisture loads for humidification and/or dehumidification.

The Köppen classification for Chandigarh has been reported as Cwa (Wikipedia, n.d.), defined as a humid subtropical climate with a dry winter (fig. 1.1). The available statistical data (Government of India, Ministry of Earth Sciences, India Meteorological Department 2010) support this classification using the driest winter month and the wettest summer month (Maekawa, Beltran, and Henry 2015, appendix 2); however, it should be noted that over the year, the driest months actually occur in spring (April) and autumn (November) (Government of India, Ministry of Earth Sciences, India Meteorological Department 2010).

The second method, ANSI/ASHRAE Standard 169, *Climatic Data for Building Design Standards* (American National Standards Institute/ASHRAE 2020), assigns a numeric thermal zone designation ranging from 0 (extremely hot) to 8 (subarctic/arctic) and a letter moisture zone designation of A (Humid), B (Dry), or C (Marine). The thermal zones are based on heating or cooling degree days, and the moisture zones are based on a process of elimination that starts with characteristics of C (Marine) zones and ends with A (Humid) zones, using criteria that include combinations of average monthly temperature and average monthly precipitation patterns.

ANSI/ASHRAE Standard 169 lists the climate zone classification for hundreds of cities worldwide and provides climate data summaries for each location. It does not list Chandigarh, presumably because the World Meteorological Organization monitoring station (WMO 42103) at Chandigarh was closed in 1979 (Government of India, Ministry of Earth Sciences, India Meteorological Department 2010). ANSI/ASHRAE Standard 169 includes a map of climate zones in India, but the map is low resolution with large pixels and shows Chandigarh at the intersection of two climate zones, 1A (Very Hot-Humid) and 2A (Hot-Humid), and adjacent to 1B (Very Hot-Dry).

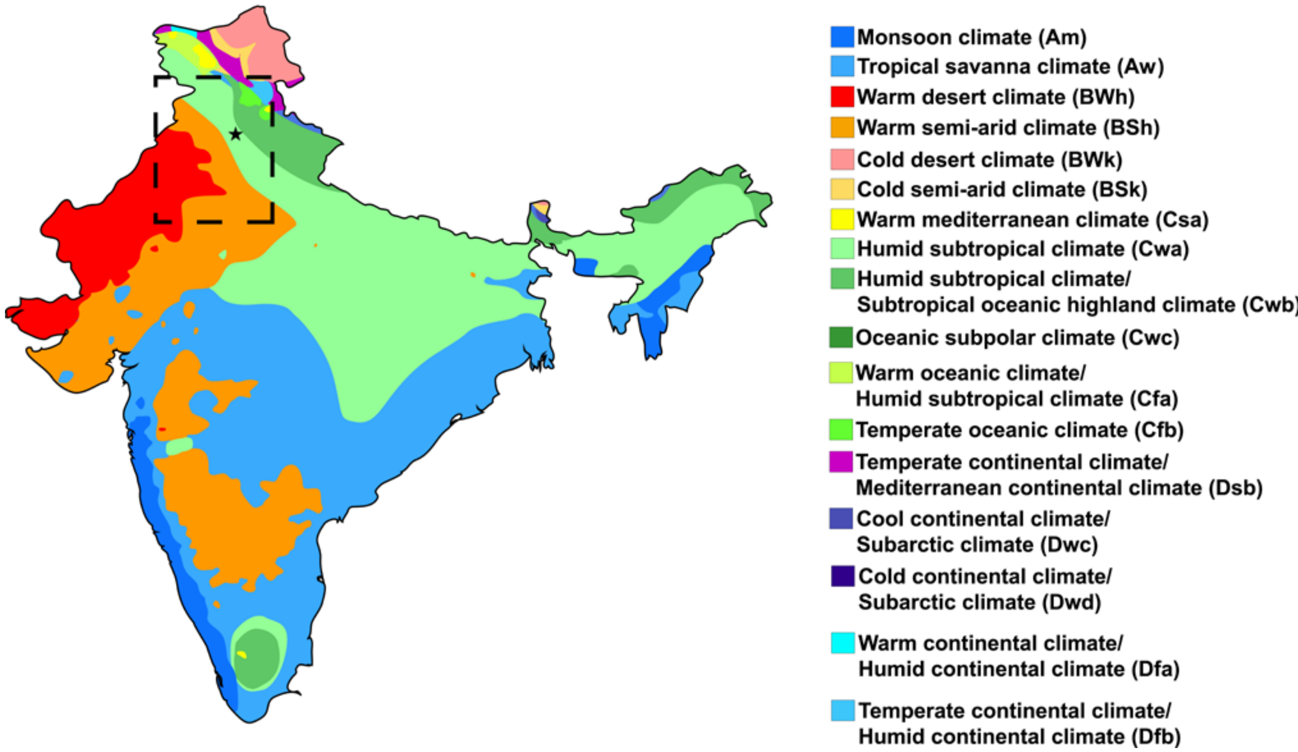


FIGURE 1.1.

Map showing Köppen climate zones for India. Dashed box indicates the area occupied by the states of Punjab and Haryana, with the approximate location of Chandigarh (starred). Image: Ali Zifan (enhanced, modified, and vectorized), licensed under CC BY-SA 4.0.

Estimation of the Chandigarh climate classification using the ANSI/ASHRAE Standard 169 map of climate zones in India can be verified by considering the three cities nearest to Chandigarh that are listed and classified: Patiala, Dehradun, and Hisar (table 1.1). Comparison of the salient data used for ANSI/ASHRAE Standard 169 climate classification for these locations and data from the India Meteorological Department for the period from 1961 to 1977 leads to the reasonable conclusion that the ASHRAE classification of the Chandigarh climate is Zone 1A (Very Hot-Humid).

Seasonal Characterization of the Climate

The India Meteorological Department identifies four principal seasons in the Chandigarh climate: winter (January to February); pre-monsoon (March to May); monsoon (June to September); and post-monsoon (October to December) (India Meteorological Department 2023).

TABLE 1.1

Climate Classification of Chandigarh and Nearest Cities

City	Patiala		Dehradun		Hisar		Chandigarh
Location	30.3578N, 76.4499E		30.317N, 78.033E		29.1736N, 75.7393E		30.7505N, 76.7876E
Elevation	251 m		682 m		231 m		320 m
Location Relative to Chandigarh	57 km southwest, 69 m lower		127 km southeast, 362 m higher		205 km southwest, 89 m lower		
WMO	421010		421110		421310		42103
Data Source	IMD Climatological Normals	ASHRAE 169 – 2020	IMD Climatological Normals	ASHRAE 169 – 2020	IMD Climatological Normals	ASHRAE 169 – 2020	IMD Climatological Normals
Period	1961–90	1994–2019	1961–90	1994–2019	1961–90	1994–2019	1961–77
Thermal Cooling Load (CDD10°C)	Not available	5158	Not available	4513	Not available	5784	Not available
Thermal Class	Not available	Zone 1 (5000 < CDD10°C ≤ 6000)	Not available	Zone 2 (3500 < CDD10°C ≤ 5000)	Not available	Zone 1 (5000 < CDD10°C ≤ 6000)	Zone 1 estimated
Average Annual Temperature	24.2°C	24.1°C	22.1°C	22.4°C	25.5°C	25.8°C	25.2°C
Total Annual Precipitation	819 mm	599 mm	2250 mm	2118 mm	491 mm	463 mm	1064 mm
April–September Precipitation	695 mm	516 mm	2013 mm	1873 mm	431 mm	404 mm	898 mm
April–September/ Annual Precipitation	84%	86%	89%	88%	88%	87%	84%
ASHRAE 169 Dry/Humid Threshold	766 mm	762 mm	722 mm	728 mm	790 mm	796 mm	784 mm
Moisture Zone	819 > 766 mm A (Humid)	516 < 762 mm B (Dry)	2250 > 722 mm A (Humid)	2118 > 728 mm A (Humid)	491 < 790 mm B (Dry)	463 < 796 B (Dry)	1064 > 898 mm A (Humid)
Climate Zone (Current)	1B (Very Hot-Dry) ASHRAE		2A (Hot-Humid) ASHRAE		1B (Very Hot-Dry) ASHRAE		1A (Very Hot-Humid) estimated

Projections for Climate Change

Historical data are helpful in understanding the past and recent climate of Chandigarh; however, the potential trends and changes in climate must also be considered. Data involving future changes cannot be quantified to the same extent as past data, but the science-based projections for future trends are informative when considering management of the interior environment of the building.

The Ministry of Earth Sciences of the Government of India summarized projected changes in temperature in India as follows:

> The frequency and intensity of warm days and warm nights are projected to increase over India in the next decades, while that of cold days and cold nights will decrease (high confidence). The changes will be more pronounced for cold nights and warm nights. The pre-monsoon season heatwave frequency, duration, intensity and areal coverage over India are projected to increase substantially during the twenty-first century (high confidence). (Krishnan et al. 2020, 42)

The ministry also summarized projected changes in precipitation as follows:

> Global as well as regional models project an increase in seasonal mean rainfall over India while also projecting a weakening monsoon circulation. However, this weakening of circulation is compensated by increased atmospheric moisture content leading to more precipitation. Frequency of extreme precipitation events may increase all over India, and more prominently so over the central and southern parts as a response to enhanced warming. Monsoon onset dates are likely to be early or not to change much, and the monsoon retreat dates are likely to be delayed, resulting in lengthening of the monsoon season. (Krishnan et al. 2020, 66–67)

With respect to extreme storms, the ministry summarized the following projected changes:

> Localized convective storms such as thunderstorms over the Indian subcontinent indicate a declining frequency by 34% in the post-1980 period which is suggestively attributed to reductions in rainfall activity and in the moisture amount due to a fall in the frequency of monsoon depressions, and enhanced intensities of natural variability climate drivers. Although short-lived cloudburst and mini-cloudburst occurrences generally indicate a decline in frequency in the recent decades, it is observed that there is a significant increase in these events along the Himalayan foothills (1 per decade) and west coast of India (5 per decade). (Krishnan et al. 2020, 169)

In response to projected future changes in climate, the Union Territory of Chandigarh prepared a report titled *U.T. Chandigarh Action Plan on Climate Change* (Chandigarh Administration, n.d.), which lists infrastructure improvements for resiliency and guidance for site and building design to reduce the city's anthropogenic impacts on climate. The government has also published the *Greening Chandigarh Action Plan 2020–2021* (Department of Forests and Wildlife, Chandigarh Administration 2020).

Pollutants

The World Health Organization defines *air pollution* as "contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere." Air pollution encompasses a range of agents such as particulate material (including PM_{10}), sulfur dioxide, and nitrogen dioxide, and sources can be domestic, vehicular, or industrial. Exposure to elevated air pollution levels increases the occurrence of respiratory and other diseases and mortality rates (World Health Organization, n.d.).

South Asia is particularly vulnerable to the health burdens brought on by air pollution, as the region includes the four most polluted countries in the world (encompassing 22.9% of the world population): Bangladesh, India, Nepal, and Pakistan. The Northern Plains region of India, where Chandigarh is situated, is the most polluted (Greenstone and Hasenkopf 2023). Local sources of air pollution in Chandigarh include fossil fuel emissions from automobiles and industry, residential combustion, biomass and waste burning, and construction (Bhargava et al. 2018; Guttikunda et al. 2019; Ravindra et al. 2020).

Environmental conditions can also impact air pollution levels. Rain can act as a pollutant scavenger, with removal rates proportional to the intensity of the rainfall (Ravindra et al. 2006; Shukla et al. 2008; Yoo et al. 2014). Increases in air temperature and wind speed can mitigate pollutant levels: Higher temperatures during summer destabilize the atmosphere and promote vertical mixing (Ravindra et al. 2019; Cichowicz et al. 2017; Akpinar et al. 2008), while elevated wind speeds disperse pollutants and particulate material.

CHAPTER 2

THE BUILDING AND ITS ENVIRONMENTAL MANAGEMENT

The significance of Le Corbusier's architecture and its international influence are well documented in the academic literature and scholarly research. The Conservation Management Plan written by the Development and Research Organisation for Nature, Arts and Heritage (DRONAH 2019) refers to this significance and influence in its analysis of the Government Museum and Art Gallery in Chandigarh and its formulation of the museum's statement of significance.

This chapter looks at Le Corbusier's work in a more focused way to understand how the architect's approach to and interest in climate response shaped his built work, including the Government Museum and Art Gallery, and to assess the effectiveness of his design in producing a suitable museum environment.

Modernism and the Hot and Humid Environment

Le Corbusier's design work for India began in the early 1950s, when he was involved in planning not only the new capital city of Chandigarh but also several independent commissions in Ahmedabad (figs. 2.1, 2.2). In all of these projects, he was confronted with the need to design buildings for a climate that was different from what he was accustomed to in Europe. However, he was not the first European modernist to face the challenge of working in both hot and dry and hot and humid climates. The exploration of a distinctive modernism that responded to these two different climate conditions, frequently referred to as "tropical modernism," began in the 1940s with the knowledge shared between modernist European and North American architects and their counterparts in Africa, South America, and South Asia. Antonin Raymond, a Czech American architect practicing in Japan, and George Nakashima, a Japanese American architect and craftsman working for Raymond, are credited with creating India's first modern building. Their Golconde Ashram Dormitory in Pondicherry, completed in 1942 (Gupta, Mueller, and Samii 2021), was designed to respond to the local

FIGURE 2.1.
Villa Shodan, Ahmedabad (1954), one of several concurrent projects of Le Corbusier's while he was planning Chandigarh. The villa is open to the elements and uses a brise-soleil to shade the building. © Fondation Le Corbusier. Photo: Susan Macdonald, 2013, © J. Paul Getty Trust.

FIGURE 2.2.
Mill Owners Association Building, Ahmedabad (1954), includes brise-soleils on both east and west elevations. © Fondation Le Corbusier. Photo: Ana Paula Arato Gonçalves, 2018, © J. Paul Getty Trust.

climate (fig. 2.3). Raymond and Nakashima used reinforced concrete for the structure (also a first in India at the time) and elevated it on pilotis above the garden level to allow breezes to pass under the dorm block. The dormitory is oriented at an angle on the site to provide only northern and southern exposures. The exposed concrete frame on the north and south sides is filled from floor to ceiling with operable cement-board louvers to block the sun and provide effective cross-ventilation through the narrow building

FIGURE 2.3.
Golconde Ashram Dormitory, Pondicherry (1942), designed by Antonin Raymond and George Nakashima for the region's hot and humid climate. Elevated off the ground on pilotis to enhance airflow, the building's operable north- and south-facing exterior louvers allow for control of sunlight. Photo: © William Whitaker.

footprint. Its arched roof is composed of a double layer of concrete with an air gap in between that insulates the interior from solar radiation.

Edwin Maxwell Fry and Jane Drew were English architects who practiced tropical modernism in West Africa in the final days of the British colonial government and continued to work there after its demise. Focusing on climatically responsive design, they completed seventeen modern educational buildings in Nigeria, Ghana, and Togoland (the latter is currently divided between Togo and Ghana) from 1946 to 1956 (fig. 2.4). Because of their reputations, they were then recruited by Indian officials to work on the new city of Chandigarh and convinced Le Corbusier to join the team, which also included his cousin Pierre Jeanneret (Jackson and Holland 2014, 215). Le Corbusier designed the Capitol Complex buildings and the Government Museum and Art Gallery, and Fry, Drew, and Jeanneret and a group of younger Indian architects took charge of the remaining residential, commercial, and institutional structures. All were concerned with designing buildings that worked with the climate; according to Jane Drew, it was the determining factor in Chandigarh's architecture (Jackson and Holland 2014, 230).

Long before his involvement in India, Le Corbusier was interested in how his buildings interacted with their physical environment; his earlier projects had provided building occupants with abundant amounts of daylight and access to fresh air. His most canonical work, the Villa Savoye

FIGURE 2.4.
Residential building at Ibadan University, Nigeria (1948–58), designed by Edwin Maxwell Fry and Jane Drew. Photo: Leendert Adriaan van Es, 1962, licensed under CC 4.0 BY-SA.

FIGURE 2.5.
Villa Savoye, Poissy, France (1928–29), was designed to allow a maximum amount of daylight into the interior and provide direct access from the interior to the exterior courtyard and roof terrace. © Fondation Le Corbusier. Photo: Ana Paula Arato Gonçalves, 2023, © J. Paul Getty Trust.

(1928–29), demonstrated his approach to architecture and its relationship to the physical environment through its white forms, slender pilotis, and horizontal ribbon windows (Curtis 2015, 98). The villa maximized the ingress of daylight with its wrapping steel casement windows. The semi-enclosed courtyard, elevated to the level of the main floor, was readily accessed and separated from the living spaces only by a steel-and-glass wall containing operable windows and doors, and its roof terrace further connected the occupants to the sun, views, and breezes (fig. 2.5).

Management of the interior environment occupied Le Corbusier's thinking during the 1920s and '30s, as he sought ways to create a functional architecture that also provided for human thermal comfort. Le Corbusier's early interest in environmental systems focused on two approaches: *l'air exact*, or manufactured air, which controls temperature and humidity, supplied by mechanical systems; and *le mur neutralisant*, a sealed wall enclosure that neutralizes temperature exchange between indoors and outdoors (Sobin 1996). These ideas came together in the architect's renowned Cité de Refuge in Paris (1929–33) (fig. 2.6), built for the French Salvation Army to provide social services and temporary housing for those in need. The south-facing facade of the thin residential slab was a single glazed, sealed 10,000 sq. ft. glass-and-metal wall (*le mur neutralisant*) with forced-air ventilation for heating and cooling (*l'air exact*). This system never functioned as intended and overheated severely in the summer during its first year. The mechanical ventilation

FIGURE 2.6.
La Cité de Refuge, Paris (1929–33), originally featured a sealed metal-and-glass curtain wall on its south facade with mechanical ventilation. This system was not sufficient to provide thermal comfort to the building's occupants. After the structure suffered damage during World War II, a brise-soleil was added, as shown here. © Fondation Le Corbusier. Photo: Fred Romero, 2016, licensed under CC BY-SA 2.0 Generic.

and automation systems available in 1929 were not advanced enough to produce the results Le Corbusier sought. After the original facade was destroyed during World War II, Le Corbusier was able to redesign it, this time with operable windows and an exterior shading device that later became one of his signature postwar design elements, the *brise-soleil* (Sobin 1996, 221).

By the 1930s, Le Corbusier had turned away from his reliance on mechanical air-conditioning systems and toward a more natural approach to managing the interior environment. Two phases of design work emerged from this approach (Requena-Ruiz 2012). In the first, dating to 1930–50, Le Corbusier focused on analysis of solar radiation patterns and moderation of heat gain from solar radiation by introducing the aforementioned brise-soleil. These were usually integrated into the building's structure. The High Court of Justice (1951–54), in the Capitol Complex at Chandigarh, is perhaps the best example of this (fig. 2.7). In the second phase, from 1950 to 1965, Le Corbusier looked to vernacular and passive solutions for use in tropical regions to manage the climate. In 1951, his atelier adopted a new methodological tool, the *grille climatique*, or climate grid. The climate grid was used in Chandigarh to identify the conditions that should be considered: protection from sunlight, ensuring good natural ventilation and avoiding humidity in spring, protecting the building from summer rain, and bringing in sunlight while blocking out wind in autumn. Le Corbusier's atelier developed individual building features to address each of these conditions.

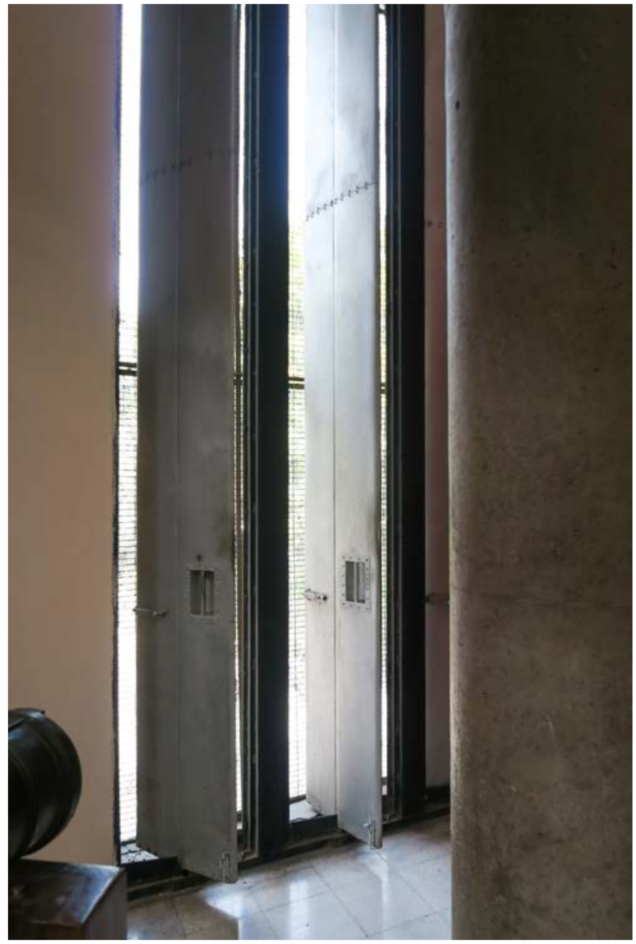


FIGURE 2.7.
High Court of Justice, Chandigarh Capitol Complex (1951–54). Brise-soleils break the sun while operable vertical aerators allow air into the building. The massive roof, separated from the interior spaces, acts as a giant parasol to shade the spaces below. © Fondation Le Corbusier. Photo: Ana Paula Arato Gonçalves, 2018, © J. Paul Getty Trust.

FIGURE 2.8.
Metal vertical aerators with an aerodynamic shape are used throughout the Government Museum and Art Gallery. © Fondation Le Corbusier. Photo: Foekje Boersma, 2017, © J. Paul Getty Trust.

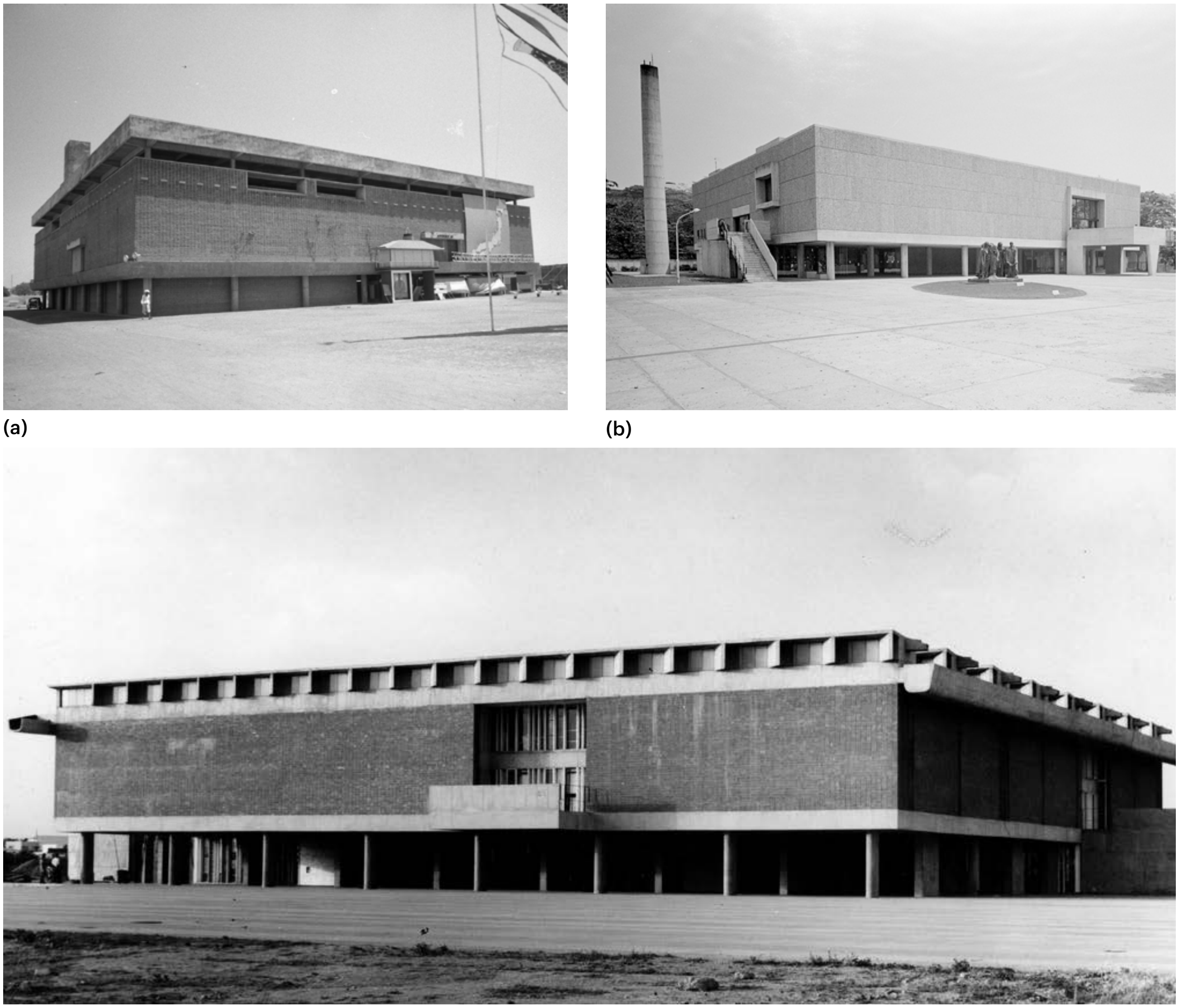
Also in the early 1950s, Le Corbusier introduced two building elements he called the *pan de verre undulatoire*, or undulatory window wall, which was an enclosure consisting of vertical, irregularly spaced members (usually concrete) with narrow panes of floor-to-ceiling fixed glass in between, and the vertical *aerateur*, or aerator, a term he coined in 1957 for his ventilation window (Sobin 1996, 225). At first, the aerator was an opaque hinged door or casement inserted into a section of solid wall or into a window wall system whose purpose was to provide controllable ventilation. Later he created a second type of aerator, fabricated from aluminum with a more aerodynamic shape, that pivoted on its center vertical axis to open and close and that would be used in the construction of the Government Museum and Art Gallery (fig. 2.8).

Aerators also would be incorporated into Le Corbusier's High Court of Justice in Chandigarh in the form of narrow, hinged wood doors inserted in the walls and used for ventilation. By 1953, the aerator had become a standard element in his architectural vocabulary (Sobin 1996, 224).

Both the undulatory window wall and—for the first time—the aerodynamic aerator were used in Le Corbusier's design for Sainte-Marie-de-la-Tourette Monastery, Eveux-sur-l'Arbresle, France (1953–60). The undulatory window wall, featuring vertical concrete elements, faces the monastery's interior courtyard and parts of the outward-facing exterior walls (fig. 2.9). The aerodynamic aerators are incorporated into the undulatory window wall. These elements are used throughout La Tourette in such quantity that they are one of the monastery's key design elements.

The Government Museum and Art Gallery is informed by Le Corbusier's long-standing interest in climate response, yet it is unusual among the other buildings he designed in Chandigarh in that it is based on a previously developed design prototype that determined its primary form. What he called the Museum of Unlimited Growth, originally conceived and developed in the 1930s, consists of a series of rectangular galleries elevated on pilotis and organized around a central square atrium. The galleries could presumably be expanded infinitely, forming a square spiral around the central space (Chin 2016). The first of these museums to be built was the Sanskar Kendra in Ahmedabad, completed in 1954, followed by the National Museum of Western Art in Tokyo (1959); the Government Museum and Art Gallery was the last, in 1968 (figs. 2.10a–c). Though the design of the latter was started at Le Corbusier's atelier in the late 1950s, construction was not completed until three years after the architect's death.

FIGURE 2.9.
Undulatory window walls with aerators are used throughout La Tourette monastery (1953–60). © Fondation Le Corbusier. Photo: Sara Lardinois, 2016, © J. Paul Getty Trust.



(a) (b) (c)

FIGURE 2.10.
(a) Sanskar Kendra museum, Ahmedabad (1954). © Fondation Le Corbusier. Photo: Lucien Hervé, 1954–57, © J. Paul Getty Trust. Getty Research Institute, Los Angeles (2002.R.41). (b) National Museum of Western Art, Tokyo (1959). © Fondation Le Corbusier. Photo: Lucien Hervé, 1957, © J. Paul Getty Trust. Getty Research Institute, Los Angeles (2002.R.41). (c) Government Museum and Art Gallery, Chandigarh (1968). © Fondation Le Corbusier. Photo: Sagar Studio, 1968, © Government Museum and Art Gallery.

All three museums follow the same conceptual scheme and function in a similar way, but each is different in terms of its response to the local context and specific climate. For example, Ahmedabad, 950 km southwest of Chandigarh, has a hot, semiarid climate, and the Sanskar Kendra has a number of features to help keep the building cool during the long periods of heat in this region. The roof was originally designed to be covered with plant material, and the tall, ventilated attic story isolates the interior from extreme solar radiation. A roofless central atrium allows air to flow freely from below and up through the center of the building, encouraging both stack-effect ventilation and cross-ventilation (fig. 2.11). All three museums have a central atrium or Great Hall with different

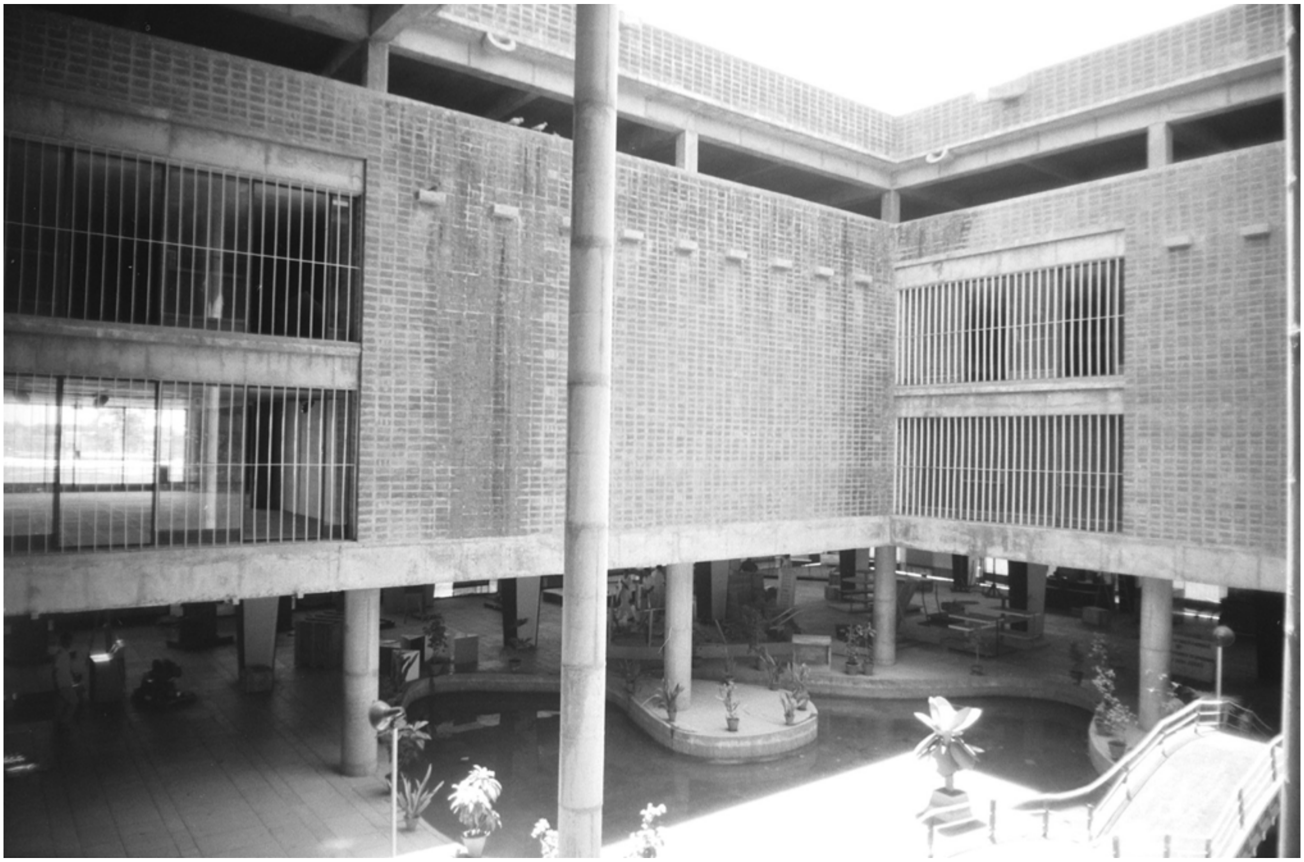


FIGURE 2.11.
Sanskar Kendra, Ahmedabad, the first of Le Corbusier's three museums to be constructed, includes an open courtyard at its center. © Fondation Le Corbusier. Photo: Lucien Hervé, 1954–57, © J. Paul Getty Trust. Getty Research Institute, Los Angeles (2002.R.41).

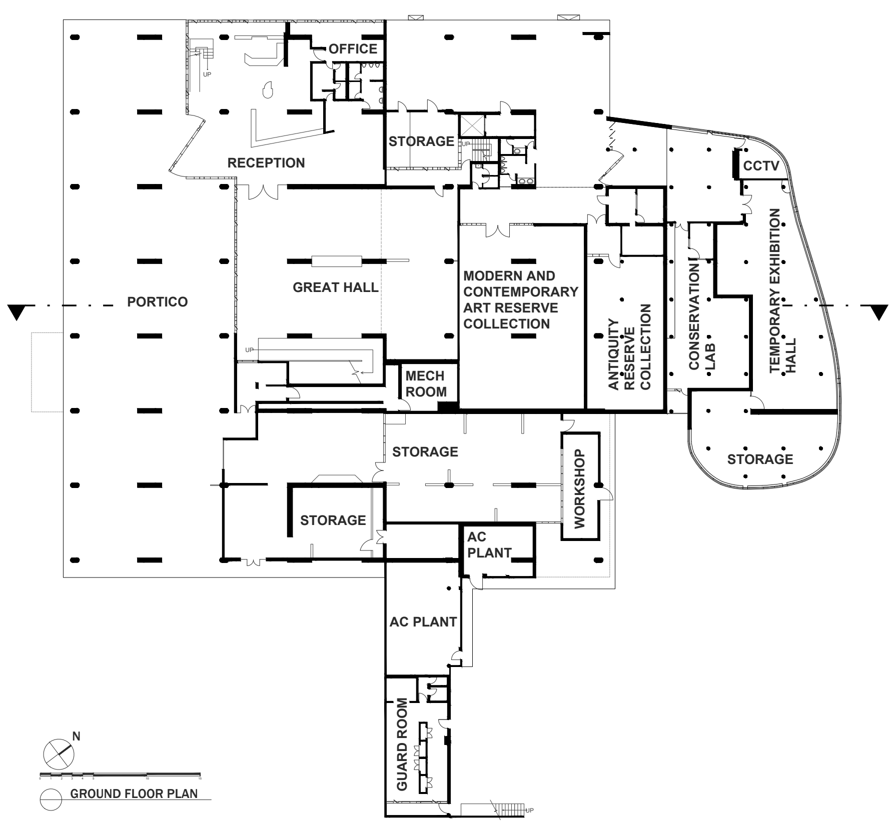
features according to the local climate. Tokyo's National Museum of Western Art is in a temperate climate with four distinct seasons, including hot summers and cold winters, and as such has a closed atrium (fig. 2.12) and the fewest wall openings of the three museums. The Chandigarh museum experiences cool winters, which may explain why it has a roof over the central atrium.

Le Corbusier designed the Government Museum and Art Gallery to respond to its hot and humid climate by drawing on familiar elements and features he had used in previous projects at the Chandigarh Capitol Complex and from his large portfolio of European buildings. He began by elevating the museum's first floor off the ground, supporting it with an alternating pattern of structural concrete piers and rounded pilotis. This lifted the principal gallery space above the ground floor, which was to be occupied by the main entrance, reception area, collections storage, and originally the workshop and canteen. Plans for the ground floor and first and second floors, as well as a longitudinal section of the building, are shown in figure 2.13. As the building was originally constructed, about half of the ground-floor space was open to the outdoors but covered by the first floor above. Over time, this space has been gradually filled in to provide new, enclosed rooms for specific museum use or activities such as additional storage or to accommodate the Child Art Gallery, currently used as storage. On the southwest side of the building, this open space serves as a colonnaded portico at the building's entrance facade and provides a shaded, breezy area to

FIGURE 2.12.
Central atrium at the National Museum of Western Art, Tokyo. This is the most enclosed of the three museums, a response to Japan's temperate climate. © Fondation Le Corbusier. Photo: Lucien Hervé, 1957, © J. Paul Getty Trust. Getty Research Institute, Los Angeles (2002.R.41).

enjoy the outdoor sculptures. Finally, Le Corbusier designed the long expanses of blank exterior wall with thermal breaks in the form of air gaps between interior and exterior surfaces to limit heat transmission to the building's interior.

Le Corbusier also employed the undulatory window walls he had used at the High Court of Justice and at La Tourette monastery. In place of the solid wood aerator featured at the High Court, he used the aerodynamic aerator. Le Corbusier's use of undulatory windows at the museum is as prolific as it was at the High Court building and La Tourette, but at the museum a considerably higher number of aerators were installed to allow as much air movement as possible. On each elevation, he stacked undulatory window walls equipped with operable aerators. Off-center on the northwest elevation is a bank of undulatory windows, vertically arranged over all three stories of the building rising from the ground level, with aerators to capture breezes (fig. 2.14). In addition, these undulatory window walls are used on the building's interior to enclose the mezzanines (second-floor levels) overlooking the gallery spaces below, which include the former director's office (currently the Bir room, housing Sikh scriptures), the library, and the conference room (currently the chairman room). The three-story-high Great Hall, located at the center of the building, opens to all levels by way of undulatory windows with aerators at ground level, balconies at first floor, and undulatory windows with aerators at mezzanine level. As a result, the Great Hall offers the best opportunity for cross-ventilation augmented by interior stack effect between floor levels, allowing breezes to enter the building from below and circulate to the galleries above. On the two-story-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TEMPORARY EXHIBITION HALL
MECH ROOM
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STORAGE
AC PLANT
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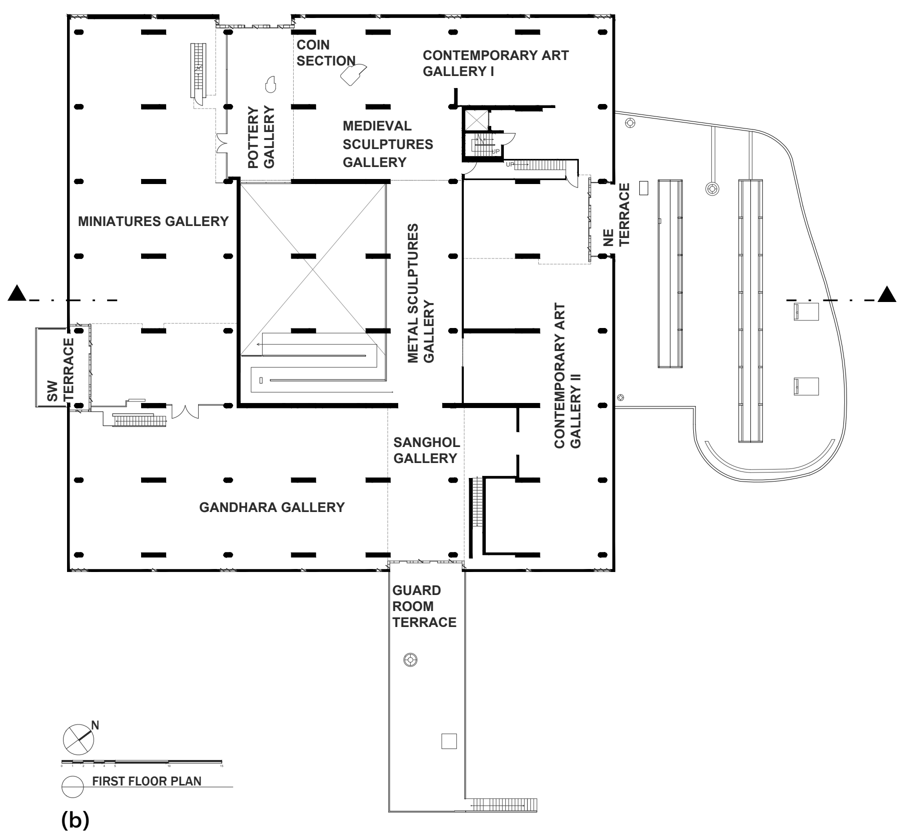
GUARD ROOM
N
GROUND FLOOR PLAN

(a)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POTTERY GALLERY
MEDIEVAL SCULPTURES GALLERY
MINIATURES GALLERY
NE TERRACE
METAL SCULPTURES GALLERY
CONTEMPORARY ART GALLERY II
SW TERRACE
SANGHOL GALLERY
GANDHARA GALLERY
GUARD ROOM TERRACE
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FIRST FLOOR PLAN

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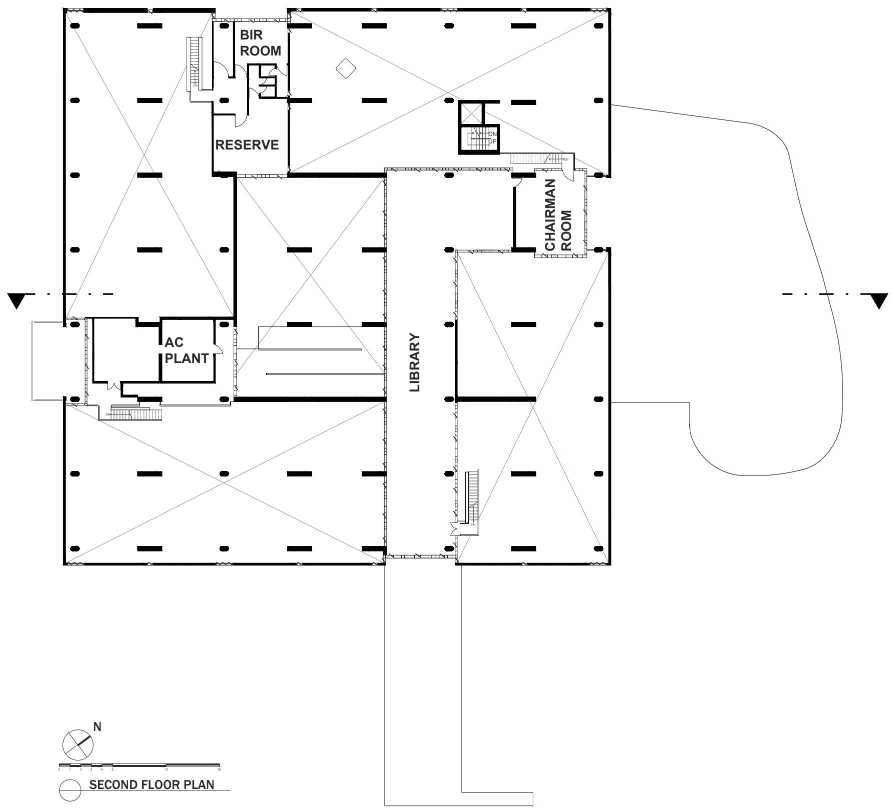

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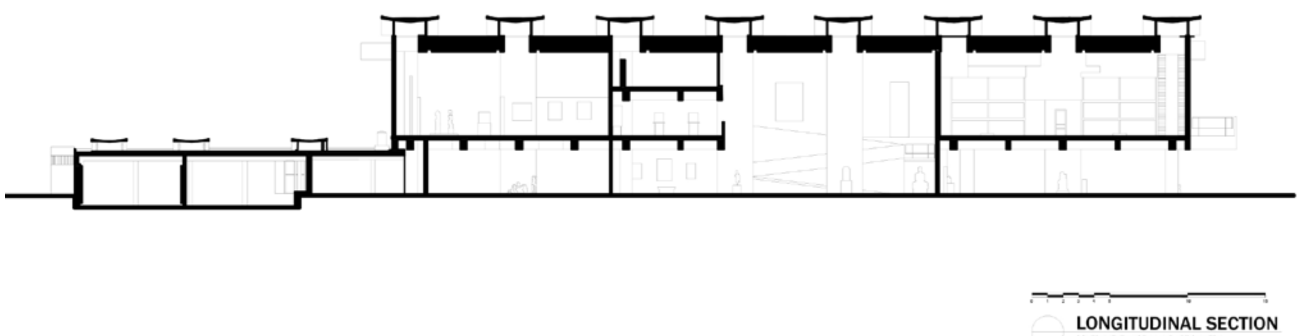


(d)

FIGURE 2.13.

Floor plans for the Government Museum and Art Gallery: (a) ground floor; (b) first floor; (c) second floor; (d) longitudinal section. © Fondation Le Corbusier. Drawings: DRONAH, modified by Timothy Augustus Y. Ong, Tahmida Afroze, and Hongye Wang. Image: © J. Paul Getty Trust.

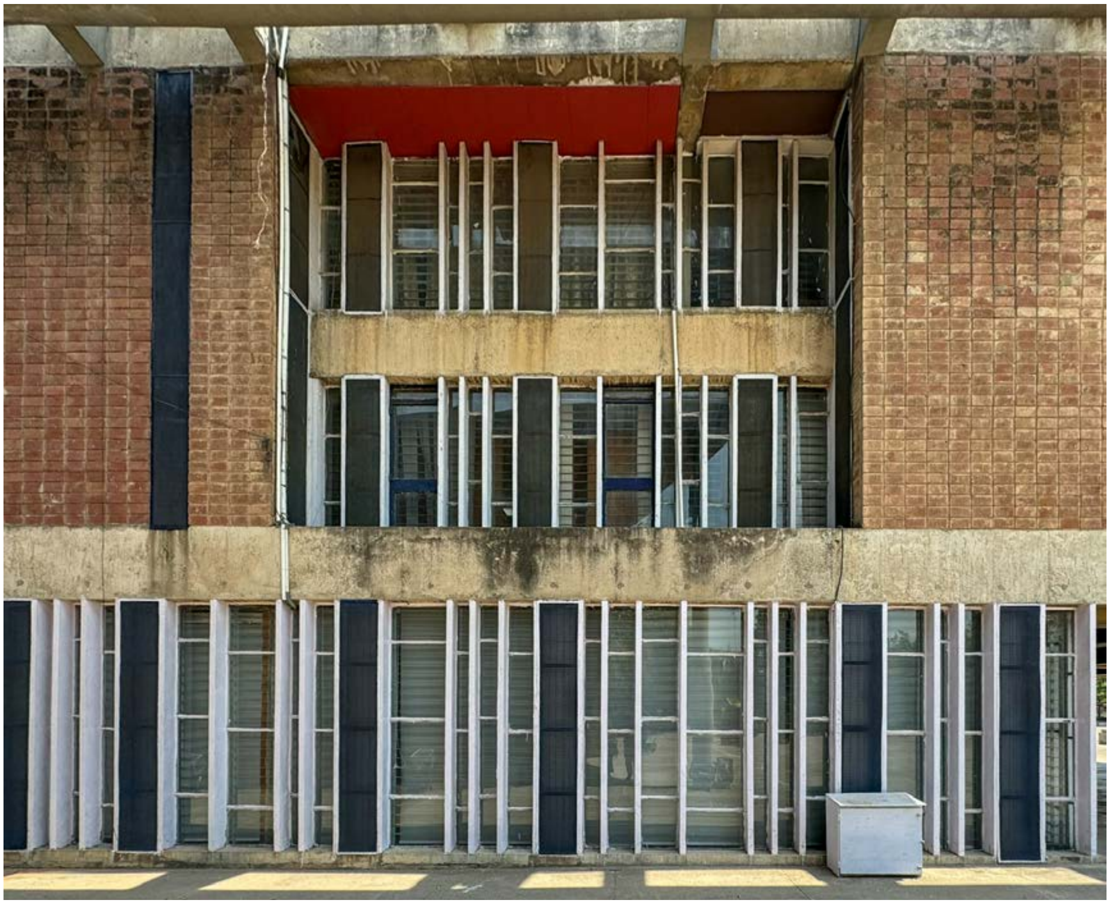


FIGURE 2.14.
Northwest elevation of the museum, showing three stories of undulatory windows. The aerators are obscured in this view by metal screening that has been added for security. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

high gallery spaces located on the first floor, aerodynamic aerators are used on the southeast and northwest facades to provide ventilation—they appear either as single aerators or in trios, in a total of nine locations in each facade, including two that are set perpendicular to the facade, creating a recessed area where the mezzanines and the facades meet.

Because fenestration above the piloti level is limited in all three museums, there is little need for vertical brise-soleils as part of the exterior wall structure. However, for the Government Museum and Art Gallery, Le Corbusier employed the concept of the brise-soleil on the roof clerestories, which are arrayed in rows across the roof of the building to provide even distribution of natural daylight to all spaces below (see fig. 2.13d). In a sense, the entire roof of the museum acts as a brise-soleil in that it performs in the same manner as the more common vertical systems do: Because of its angles and shape, the roof controls how sunlight enters the building on a seasonal basis. Sun shading was achieved by careful design of the overhang of the clerestory roof combined with a series of angled concrete fins arranged along the entire length of each clerestory. These angled fins are labeled "brise-soleil" on some of the developmental sketches (fig. 2.15) and are placed at 135-degree angles relative to the geometry of the building, which corresponds to true north and south.

Environmental Management in Hot and Humid Climates

Management of interior environments of buildings in hot and humid climates such as that of Chandigarh utilizes one or more of the approaches below. The first three are considered non-mechanical because they do not require equipment to move or alter the temperature or the moisture content of the air.

- Heat gain reduction
- Natural ventilation
- Natural conditioning
- Mechanical ventilation
- Mechanical conditioning

Heat Gain Reduction

Heat gain in the building's interior results when thermal energy is transmitted through the walls and roof of a building envelope by conduction. It also occurs when the infrared component of solar radiation penetrates windows and openings in the walls and roof. Heat gain reduction is an essential element in design for buildings in hot climates and includes elements such as building orientation, shading of window openings to minimize penetration of solar radiation, and thermal breaks in wall and roof assemblies to reduce thermal conductivity.

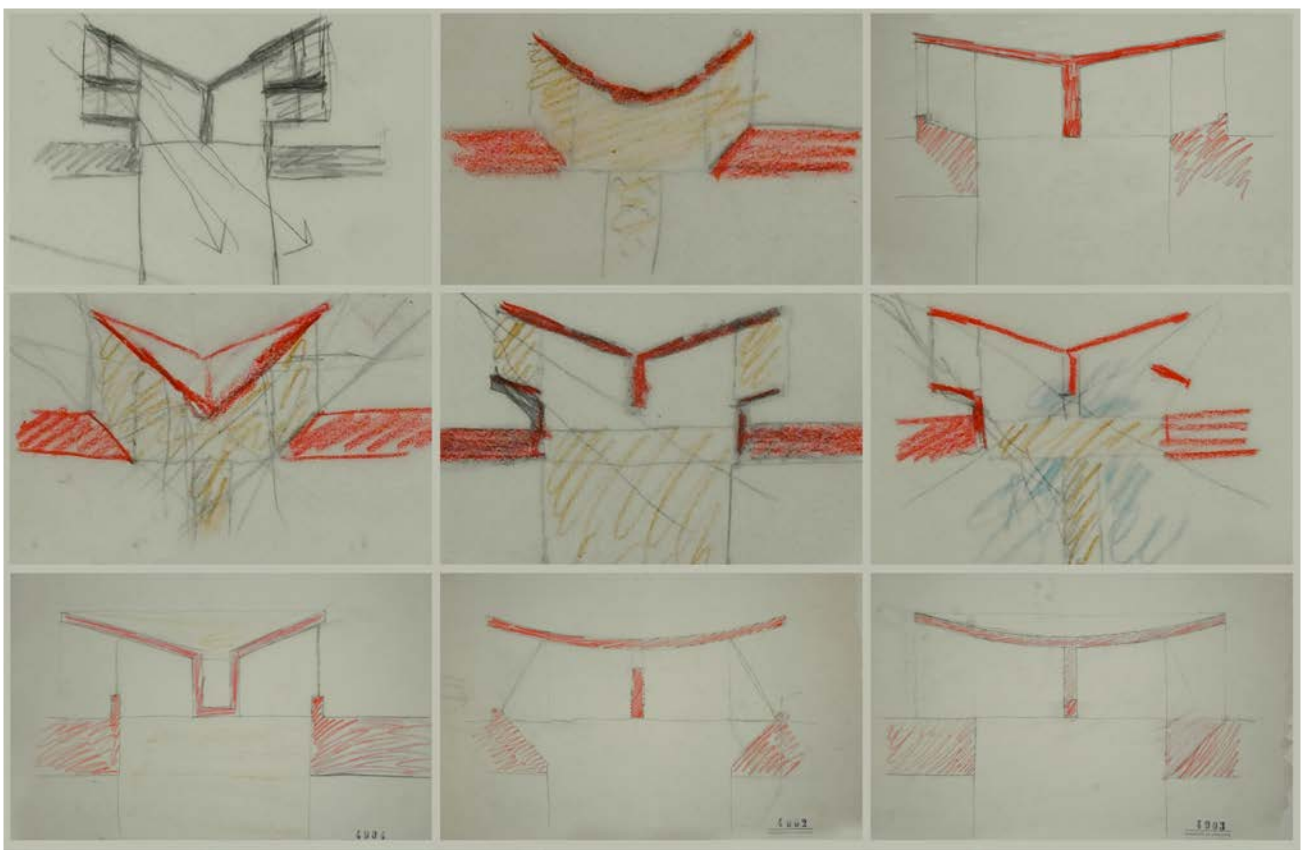


FIGURE 2.15.
Sectional sketches of the museum from Le Corbusier's atelier, used to study possible configurations of clerestories with attention paid to sun angles and shading. Images: © Fondation Le Corbusier Archives.

Natural Ventilation

Natural ventilation is the introduction of outside air into a building without the use of fans or other mechanical means to force air movement in order to improve the quality of the interior air. Two non-mechanical forces drive natural ventilation: buoyancy and wind.

Stack-effect ventilation, or buoyancy-driven ventilation, occurs because warm air is less dense than cool air, resulting in a slight difference in pressure. When indoor air is warmed by interior surfaces, occupants, lighting, or equipment, it rises in the space. The difference in pressure between the warm interior air and the cooler exterior air causes the warm air to escape through openings in the ceiling or roof or high in the walls. The escaped warm air is replaced by cooler outside air entering through openings in the floor or low in the walls. In a multistory building with a large open space connecting multiple levels, such as an atrium or large stair hall, warm air will escape through openings in the walls or roof of the upper stories, and cooler air will enter through openings in the walls of the lower stories.

Cross-ventilation, or wind-driven ventilation, occurs when there is a difference in pressure between opposing sides of a building, causing outside air to pass through inlets in the windward wall and interior air to exit through outlets in the leeward wall. For best effect, the interior air movement from windward inlet to leeward outlet should not be obstructed, and the maximum distance between opposing facades must be less than five times the floor-to-ceiling height (Irving, Ford, and Etheridge 2005, 16).

Stack-effect ventilation and cross-ventilation may be combined.

The efficiency of natural ventilation is dependent on several factors:

- The outlet openings should be larger than the inlet openings.
- Restrictions to airflow through the inlet and outlet openings must be minimized. Examples of restrictive elements include bars, grilles, screens, shades, drapes, and exhibit panels or cabinets. These restrictions cause a pressure drop through the openings.
- Outlet openings for stack-effect ventilation should be at the highest point in the building and, if possible, should extend above the roof.
- Internal heat sources such as lighting loads, and heat gain from solar radiation through windows, should be minimized.

Natural Conditioning

Natural conditioning results from natural ventilation when the temperature and relative humidity of the replacement (outside) air improves the thermal comfort of the building's occupants (Simmonds and McConahey 2021, chap. 2). Natural conditioning is predicated on the exterior air being within the range of acceptable conditions for human thermal comfort, for preventive conservation of the collection, or both.

Mechanical Ventilation

Mechanical ventilation may be necessary to supplement stack-effect ventilation and cross-ventilation in order to achieve the desired ventilation rate. An example of mechanical ventilation is when one or more electric-powered exhaust fans are used to increase the outward flow of air from the building. Inlets must be open when mechanical ventilation is used in this manner.

Mixed-mode ventilation utilizes both natural ventilation and mechanical ventilation.

Mechanical Conditioning

Mechanical conditioning of interior air and air for ventilation may be necessary if natural ventilation and natural conditioning cannot achieve the desired interior environmental conditions for occupants or the collection. Depending on climate and the internal heating loads of the building, mechanical conditioning may include heating, cooling, and dehumidification or humidification of the air.

For energy-efficient mechanical conditioning, infiltration of outside air and exfiltration of conditioned air from the mechanically conditioned spaces must be minimized.

Mixed-mode conditioning applies when mechanical conditioning is required for extreme seasonal conditions and natural conditioning is suitable for the balance of the year.

Non-Mechanical Environmental Management at the Government Museum and Art Gallery

The main block of the museum incorporates several features for heat gain reduction:

- Solar radiation for illumination of the interior enters through eight longitudinal roof-mounted lanterns or clerestories, with deep overhangs and vertical concrete daylight baffles set at an angle to the fixed glazing on either longitudinal side of each clerestory (see fig. 2.13d). The clerestories provide diffuse natural light while reducing the amount of direct natural light striking, and warming, interior surfaces. However, because the clerestories are not ventilated, they function as a heat trap for hot interior air.
- The ground-floor exterior walls and glazed openings are shaded by orientation or by the overhanging first floor formed by the pilotis (fig. 2.16).
- Glazed openings, one on each of the four first-floor exterior walls, consisting of full-height undulatory windows, are set back from the exterior wall plane. The four glazed panels constitute less than 15% of the total surface area of the first-floor walls.
- The first-floor exterior walls incorporate a thermal break, or air space, between the tile panels on the exterior and the structural concrete on the interior (fig. 2.17). The wall assembly appears to be a variant of Le Corbusier's concept for a mur neutralisant cavity wall or double-glazed wall. As reported by S. D. Sharma in an interview conducted on-site with the authors on 12 February 2018, the wall assembly consists of the following layers, which are listed from exterior to interior (measurements were originally given in imperial units):

  A. 2 in. (5 cm) thick fired clay tile
  B. 6 to 8 in. (15.3 to 20.3 cm) thick reinforced concrete
  C. 3 in. (7.6 cm) wide air space
  D. 9 in. (22.9 cm) thick brick
  E. Plaster with paint

FIGURE 2.16.
The first floor of the museum, supported by pilotis, provides shade over the ground floor along the southwest facade. © Fondation Le Corbusier. Photo: Ana Paula Arato Gonçalves, 2018, © J. Paul Getty Trust.

The main block incorporates several features for natural ventilation:

- A centrally located atrium, or Great Hall, 10.7 m high, open to all three stories and occupying 25% of the enclosed area of the ground floor and 12% of the enclosed area of the first floor, provides stack-effect ventilation (fig. 2.18).
- Aerators approximately 2.8 m high are set in undulatory windows in the exterior walls of the ground floor in the office, reception area, and Great Hall.
- Thirty aerators approximately 5 m high are set in the exterior walls of the first-floor, two-story-high gallery spaces and are distributed as follows: fifteen on the northwest facade and fifteen on the southeast facade.
- Aerators approximately 2.2 m high are set in the interior walls of the second-floor (mezzanine) spaces overlooking the first floor. The interior aerators allow cross-ventilation through the library, the present HVAC mezzanine above the Miniatures Gallery, the reserve collections for pottery and Gandhara sculptures, and the Bir room.

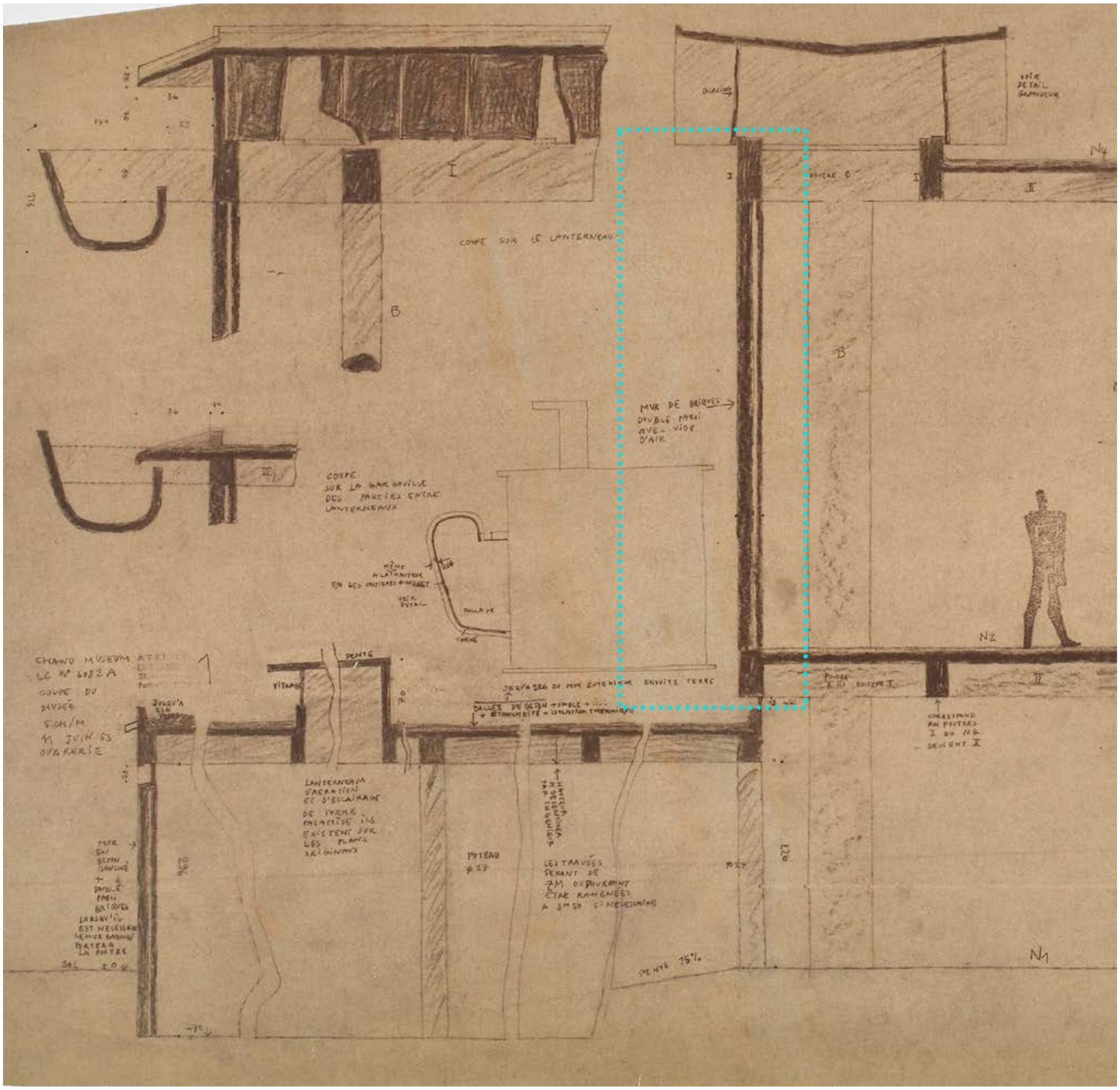


FIGURE 2.17.
Location of the cavity wall (indicated by dotted rectangle), shown in a drawing dated 11 June 1963. The label within the rectangle reads "mur de briques double paroi avec vide d'air" (brick wall double wall with air void). Image: © Fondation Le Corbusier Archives.

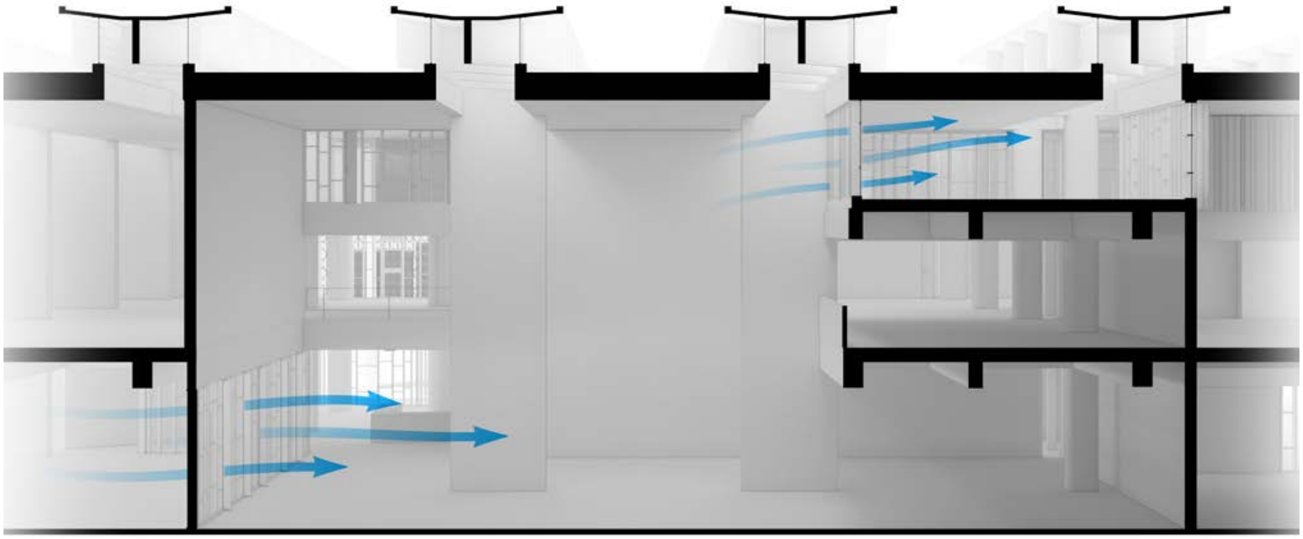


FIGURE 2.18.
The Great Hall opens to all three stories and provides stack-effect ventilation. © Fondation Le Corbusier. Image: Timothy Augustus Y. Ong, © J. Paul Getty Trust.

The effectiveness of the original non-mechanical environmental management features of the museum is compromised by the following:

- Due to the original placement of aerators, cross-ventilation is highly dependent on the availability of wind from the northwest and southeast directions.
- Functionality of aerators may be reduced by limited range of movement due to corrosion or debris in the pivot joints.
- Exhibit casework and security grilles placed in air pathways between spaces and in front of aerators reduce cross-ventilation (fig. 2.19).
- Cross-ventilation has been reduced by the installation of glazed partitions and doors at the entrance to the Miniatures Gallery. This was done to help contain airflow when the gallery was air-conditioned in 2003 (fig. 2.20).
- Stack-effect ventilation is limited due to the lack of air outlets at the clerestory and roof level.
- Stack-effect ventilation is reduced by closure of interior and exterior aerators in second-floor (mezzanine) spaces, including the library (fig. 2.21), the reserve collections for pottery and Gandhara sculptures, the Bir room, and the HVAC mezzanine.
- Stack-effect ventilation is reduced by elimination of exterior aerators at the ground floor due to partial enclosure of spaces in the original piloti zone.

FIGURE 2.19.
Exhibit casework and security grilles that block openings, such as the one shown here between the Medieval Sculptures Gallery and Metal Sculptures Gallery, reduce cross-ventilation. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

FIGURE 2.20.
Glazed partitions and doors installed at the entrance to the Miniatures Gallery reduce cross-ventilation. © Fondation Le Corbusier. Photo: Michael C. Henry, 2018, © J. Paul Getty Trust.

Mechanical Environmental Management at the Government Museum and Art Gallery

Mechanical environmental management at the museum includes the following equipment and systems:

- Two exhaust fans for mechanical ventilation are located in the clerestory above the mezzanine overlooking the Miniatures Gallery (fig. 2.22). Date of installation of these units has not been determined, and they are no longer operating.
- Temperature and humidity in the Miniatures Gallery is controlled by an air-handling unit with particulate filtration and heating and cooling coils located on the mezzanine above the gallery (fig. 2.23). Chilled water and hot water are provided by mechanical equipment in the southeast wing. The four chilled-water units are rated at 40 tons each and are set to deliver chilled water at 7°C to 8°C. The two hot-water generators are rated at 90 kW and are set to deliver hot water at 42°C. This system was installed in 2003, and the chilled-water units were replaced in 2022.
- The ground-floor collections storage room in the main block is heated, cooled, and humidified by two fan coil units in a mechanical room and two 17.5-ton air-cooled condensers mounted on the roof of the rear block (installed in 2010).
- The ground-floor temporary exhibition gallery in the rear block is served by approximately fifteen ductless heating and cooling units in the spaces with twenty-two air-cooled condensers (1- to 2-ton capacity) mounted on the roof of the rear block (fig. 2.24).

FIGURE 2.21.
Bookcases in the second-floor library block operation of aerators that face the gallery space below. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

FIGURE 2.22.
One of two exhaust fans for mechanical ventilation installed in the clerestory and no longer operating. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

FIGURE 2.23.
Air vents for the HVAC system installed above the Miniatures Gallery. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

FIGURE 2.24.
Air-cooled condensers mounted on the roof of the rear block. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

- The second-floor library and conference room are served by four ductless heating and cooling units in the spaces, with two 2-ton air-cooled condensers mounted next to the first-floor undulatory window and aerators on the northeast wall and two 2-ton air-cooled condensers on the roof of the main block.
- Ductless air conditioners are installed in the library, with air-cooled condensers located on the roof of the rear block now housing the temporary exhibition gallery (fig. 2.25). These units were replaced in 2021.

The effectiveness of the mechanical environmental management features of the museum has been compromised by the following:

- The two exhaust fans in the clerestory above the mezzanine overlooking the Miniatures Gallery may not be usable without repairs.
- During the monitoring period, the chilled-water units were not able to maintain temperature of the chilled water. This issue reportedly has been resolved by replacement of the units in 2022.
- The ductless air-conditioning units in the library have a high failure rate. This is apparently due to variability in the quality of the incoming electrical power.
- Museum staff report a high failure rate of the mechanical equipment, generally attributed to instability of the electrical voltage or frequency; stabilizers have been fitted to most of the equipment. This suggests that the electrical supply to the museum is inadequate in terms of either service capacity or quality of the utility output. Museum staff also report that electricity, and consequently all mechanical equipment, is turned off when the museum is closed; critical security and fire detection systems remain powered.

FIGURE 2.25.
Ductless air conditioners installed on a wall of the library. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

CHAPTER 3

ASSESSMENT OF THE COLLECTION

This chapter presents the preliminary results of a collection assessment at the Government Museum and Art Gallery in Chandigarh, conducted to identify potential risks to the collection and their probable causes. The assessment was carried out by the Getty Conservation Institute in collaboration with museum staff. Data were gathered through collection observations during a site visit from 6 to 24 January 2020, environmental monitoring results, and staff interviews.

Background Information on the Collection

The collection of the Government Museum and Art Gallery consists of 12,012 items, with coins (37%), miniature paintings (35%), contemporary paintings (11%), and Gandhara sculptures (5%) representing the largest groups of objects. The three most valuable groups are Pahari miniature paintings on paper from the eighteenth and nineteenth centuries; Indian paintings from the post-independence era in a variety of supports and materials; and Gandhara stone sculptures. This collection is currently managed by two professional staff and two support staff (at this time, five professional staff positions related to collection care remain open). Museum administration has eight staff (with one vacant position at the time of writing), and museum operations has thirty-five staff (also with one vacant position at the time of writing).

Stakeholders

Stakeholders who have a decision-making role in relation to the collection and conservation thereof are described below:

- The Chandigarh administration (governor, secretary of culture, and museum director): funds daily museum operations, maintenance, and acquisitions; hires permanent staff; authorizes requests for grants to external institutions; and approves the long-term strategic plan of the Government Museum and Art Gallery as one of the four Chandigarh government museums.
- Museum staff (curator and curatorial assistant): coordinate daily museum operations and collaborate with all other external stakeholders. They are consulted during the decision-making process, are responsible for coordinating the long-term strategic actions to improve future collection care, and are involved in acquisitions.

Mission Statement

"Our mission is to encourage appreciation of values embedded in Art and bring it close to the lives of people through interpretation of its rich collection and innovative programs." (Government Museum and Art Gallery, n.d.)

Other stakeholders who may influence decisions regarding the collection include the following:

- External experts: advocate for the museum collection worldwide and use the museum's collection for research. They play a role in acquiring new works that fall within their domain of expertise.
- The Development and Research Organisation for Nature, Arts and Heritage (DRONAH): engaged by Punjab Engineering College to conduct research into the building, landscape, and interiors; coordinated efforts to write a Conservation Management Plan (CMP) for the museum, including its collection; and assists in developing the necessary documentation to request government funding to realize the CMP.
- The Getty Conservation Institute: through its Managing Collection Environments and Conserving Modern Architecture Initiatives, collaborates with museum staff to provide advice related to care of the collection.
- Local community members and visitors: the main museum audience. They play an important role in influencing how the collection and museum spaces are used.

Storage

Staff at the museum indicate that acquisitions have slowed due to lack of storage space. This has a particular impact on the collection of contemporary art. In response, capacity of the current storage spaces may be enlarged slightly by adding additional archival storage systems, but this will not entirely resolve the problem of needing more storage. Proposed actions elsewhere in the museum may further impact the limited storage space, including

- removal or repurposing of current indoor storage spaces;
- removal of the Child Art Gallery as recommended by the CMP, which is a space that could function as storage if it were retained;
- relocation of objects in the Bir room on the second floor due to this room's unsuitable environment, a move that would put further strain on existing storage areas; and
- designation of temporary collections storage that will be needed during any future building renovation campaigns.

Loans

Each year, the museum receives several national and international loan requests that are predominantly for items in the miniatures collection. Some administrative and logistic support for outgoing loans is currently being provided by staff at the National Museum in Delhi. For the most part, however, the museum staff must travel with the works that leave Chandigarh.

Several museum stakeholders have shown an interest in getting objects loaned from other institutions as part of future exhibition programs. This is challenging due to the lack of environmental control at the museum. Staff express a desire to focus their energy and attention on exhibitions primarily on India and on requesting loans from other Indian museums. Likewise, this is also a challenge due to the diverse climate conditions throughout India.

Programming

Stakeholders express a wish for the museum to become a cultural hub, with temporary exhibitions as part of its programming. While there is a need for a more specific definition of the type of programming desired, presumably the building and the collection can accommodate a variety of programs and exhibits taking place simultaneously. There is a particular interest in the creation of an expertise center for Pahari miniatures.

Staffing Needs

At present, the museum has a small staff compared to the size of its collection, its mission and programming, and its aspiration to increase its lending and borrowing with other museums. Curatorial and other staff have multiple duties that include organization of exhibitions and oversight of programming, documentation, and basic conservation functions, particularly for collections in storage. Although staff work hard to juggle this heavy and disparate workload, it would be helpful for the museum's directorate to consider adding more curatorial, conservation, and administrative positions.

The current number of staff limits their ability to focus on preventive conservation and to address security issues that could leave the museum vulnerable to additional risks. At the time of the January 2020 visit and assessment, the museum had no integrated pest management or emergency planning and preparedness protocols. The museum's plan to increase loans in the future could be compromised by lack of staff with experience in environmental and other requirements of objects on loan.

As the museum plans the future development of its spaces and programming, the addition of a conservator or conservation technician trained in preventive conservation in future development proposals and budgeting requests would be advisable. The appointment of such a specialist would better position the museum to fulfill its ambitions.

Exhibition Design

As discussed in the introduction to this report, the designer Ratna Fabri's exhibition furniture was intended to complement the building and create appropriate ways to display the varied collections in the expansive gallery spaces designed by Le Corbusier. The exhibition design is therefore identified in the museum's CMP as having exceptional significance and the need to be preserved and retained wherever possible (DRONAH 2019). However, it is important to recognize that some of the display cases are difficult to operate and may require adaptations that respect their cultural significance.

Some of the measurements taken during the assessment were used to analyze the microenvironment of the display cases. Environmental monitoring results have found them to be effective in reducing the range of fluctuations in relative humidity within the cases.

Composition of the Collection

This collection is part of the government museums that administratively belong to the Union Territory of Chandigarh. Other museums in this group are the Chandigarh Architecture Museum and the Natural History Museum, which, like the Government Museum and Art Gallery, are in sector 10 of the city, and the National Gallery of Portraits, located in sector 17.

The composition of the collection and its historical relevance are adequately described in the CMP (DRONAH 2019, 40–41, 105–16). Table 3.1 and figure 3.1 summarize the quantity of each type of object in the collection. Table 3.2 and figure 3.2 indicate how much each type of object contributes to the overall value of the collection.

The following observations can be made on the composition and value of the collection:

- Paper is a large and highly valued part of the collection (miniatures, manuscripts, and scrolls). This excludes the collection of letters on the development of Chandigarh, present in the library. Many of these works are small and intended to be viewed at close range so that the viewer can properly engage with them and appreciate the details.
- Metal (sculptures and coins) represents a large number of items but with relatively less value. Coins, in particular, can be stored and displayed in a compact way.

TABLE 3.1.
Number of Objects per Group in the Museum Collection

Group	% (No. of Objects)
Coins	37 (4,419)
Miniature paintings	35 (4,267)
Contemporary paintings	11 (1,300)
Gandhara sculptures	5 (627)
Textiles	1 (259)
Pottery	2 (225)
Stone sculptures	2 (217)
Decorative arts	2 (200)
Contemporary sculptures	1 (167)
Manuscripts	1 (103)
Metal sculptures	1 (100)
Terracotta	1 (72)
Wasli	<1 (34)
Glass paintings	<1 (14)
Scrolls	<1 (8)
Total	**100 (12,012)**

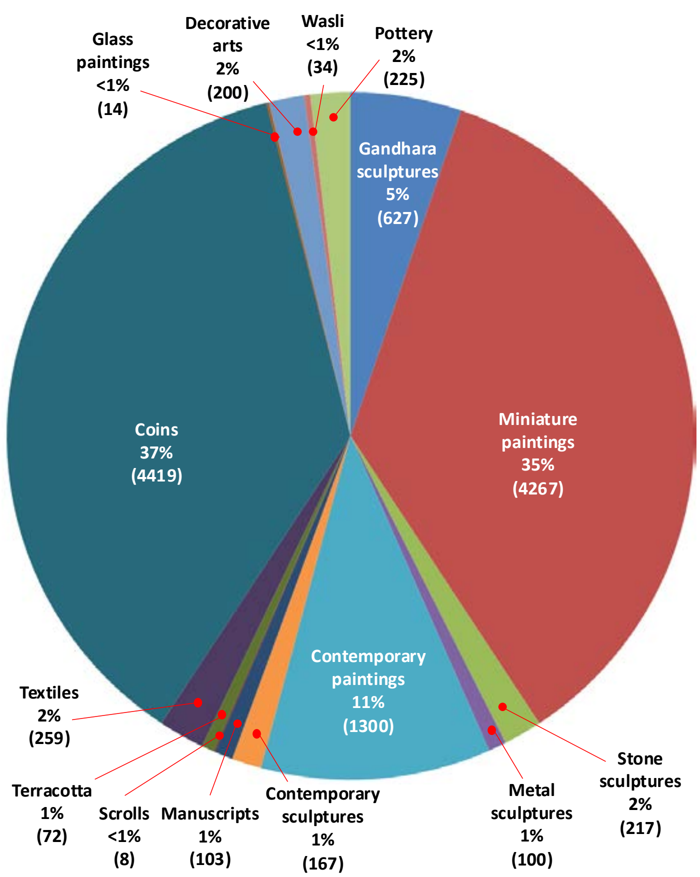


FIGURE 3.1.
Composition of the collection of the Government Museum and Art Gallery by percentage and number (in parentheses). Chart: Cecília Winter, © J. Paul Getty Trust.

TABLE 3.2.

Value of Each Group in the Museum Collection as a Percentage of the Collection's Overall Value

Group	%
Miniature paintings	35
Contemporary paintings	15
Gandhara sculptures	15
Stone sculptures	10
Metal sculptures	7
Contemporary sculptures	5
Textiles	3
Manuscripts	2
Coins	2
Terracotta	1
Scrolls	1
Glass paintings	1
Decorative arts	1
Wasli	1
Pottery	1
Total	**100**

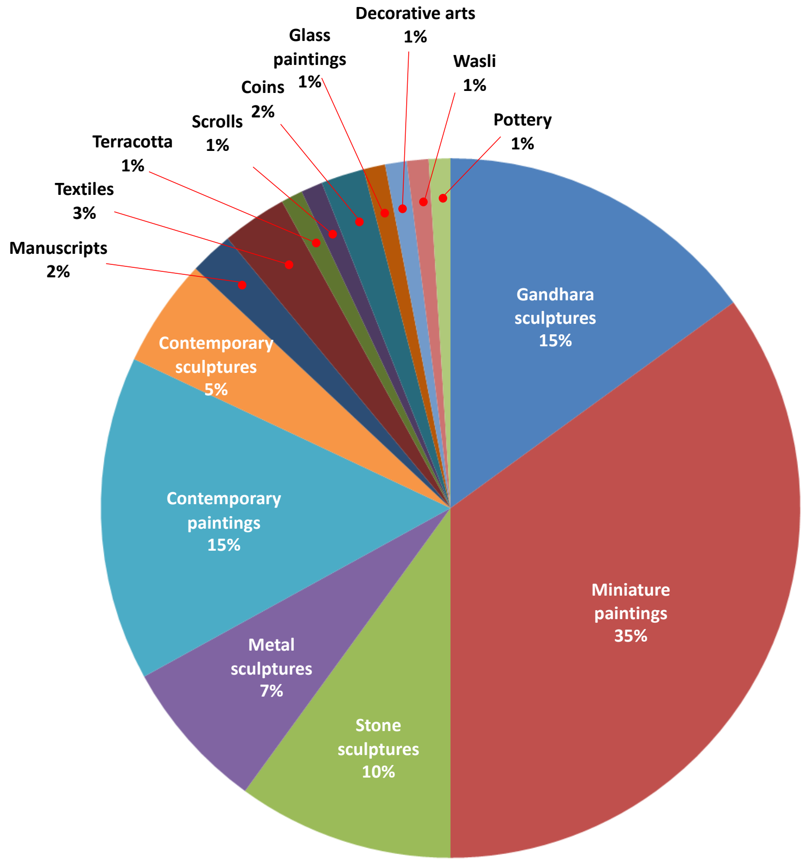


FIGURE 3.2.

Percentage of value of each group in the collection. Chart: Cecília Winter, © J. Paul Getty Trust.

- Larger sculptures (Gandhara sculptures, stone sculptures, and contemporary sculptures) are numerically a smaller part of this collection but take up considerable space in both storage and exhibition. Works can be heavy to handle. Materials vary (different types of stone, wood, plaster, and other materials).
- Contemporary paintings are an important part of the collection, but due to lack of storage space there has been no active acquisitions in recent years. A variety of supports and painting materials are used.
- The Holy Sikh scriptures (scrolls and manuscripts) are largely stored in the Bir room. The scriptures in this room can be consulted and handled under certain conditions and only by Sikh personnel at the museum.
- Textiles are not among the most valuable groups in the collection. Only a limited number of pieces were on display at the time of assessment.

Preliminary Assessment of the Collection

The goal of this assessment is to improve collection care by targeting specific issues and suggesting short-, mid-, and long-term changes without increasing risk. A collection environment should be thought of as an organism in which small changes can have a large impact. More in-depth assessment was conducted in collaboration with museum staff and based on environmental monitoring to allow for a better understanding of the different agents of deterioration that affect the collection and the relationships between them.

Method

This assessment used the agents of deterioration (Canadian Conservation Institute 2017) and the ABC method to assess risks to the collection (Canadian Conservation Institute 2021). These agents (fire, vandalism, and water, among others) can, in certain quantities, have a negative impact on the life of a collection. Understanding them is useful in developing strategic plans for the preventive conservation of a collection.

Every agent has a source and follows a path that leads to an effect. For example, discoloration (an effect) can be caused by light (an agent) or by exposure (a source) that is introduced through clerestories (a path). The landscape and the building envelope are considered the first line of defense to interrupt the path of a source, keeping it from entering the building. Therefore, the importance of understanding the building envelope cannot be underestimated.

Some of these agents are discussed in the CMP for the Government Museum and Art Gallery, in particular chapter 5, section 5.5: Collection (DRONAH 2019, 205–11), and section 5.8: Risk Assessment (217–34). The results presented below can be considered as an addition to these discussions and may repeat some findings to confirm or contextualize the results brought forth in the CMP.

Process

During the January 2020 visit, installation of the environmental monitoring equipment was completed and some data were collected on light and microenvironments. This included spot readings of UV and visible light values that were measured throughout the exhibition spaces in five directions (upward, northeast, southeast, southwest, and northwest).

Over several weeks, measurements in the miniatures and contemporary art storages focused on buffering qualities of the archival furniture and materials, as well as the influence of the HVAC installation on different spaces in the storage.

In addition, targeted observations of the collection and the building envelope were made in relation to the collection. The second part of the inspection was minimal since DRONAH had conducted a detailed condition assessment of the building envelope and interiors.

This information was later complemented by the findings of the environmental monitoring, which are presented in detail in chapter 5 of this report.

Agents of Deterioration

Figure 3.3 summarizes the results of the risk assessment for the museum's collection. It is important to note that this report focuses on proposing strategies to improve the environment for the collection and building occupants; therefore, these strategies may have a significant impact on lowering some of the current risks, but they do not target all risks. Current risks targeted by strategies proposed in this report are highlighted in boldface in figure 3.4. Some of the major risks identified, such as risk of fire or physical damage from moving display cases, are not part of the scope of work for this project; development of a plan to manage these risks remains of utmost importance.

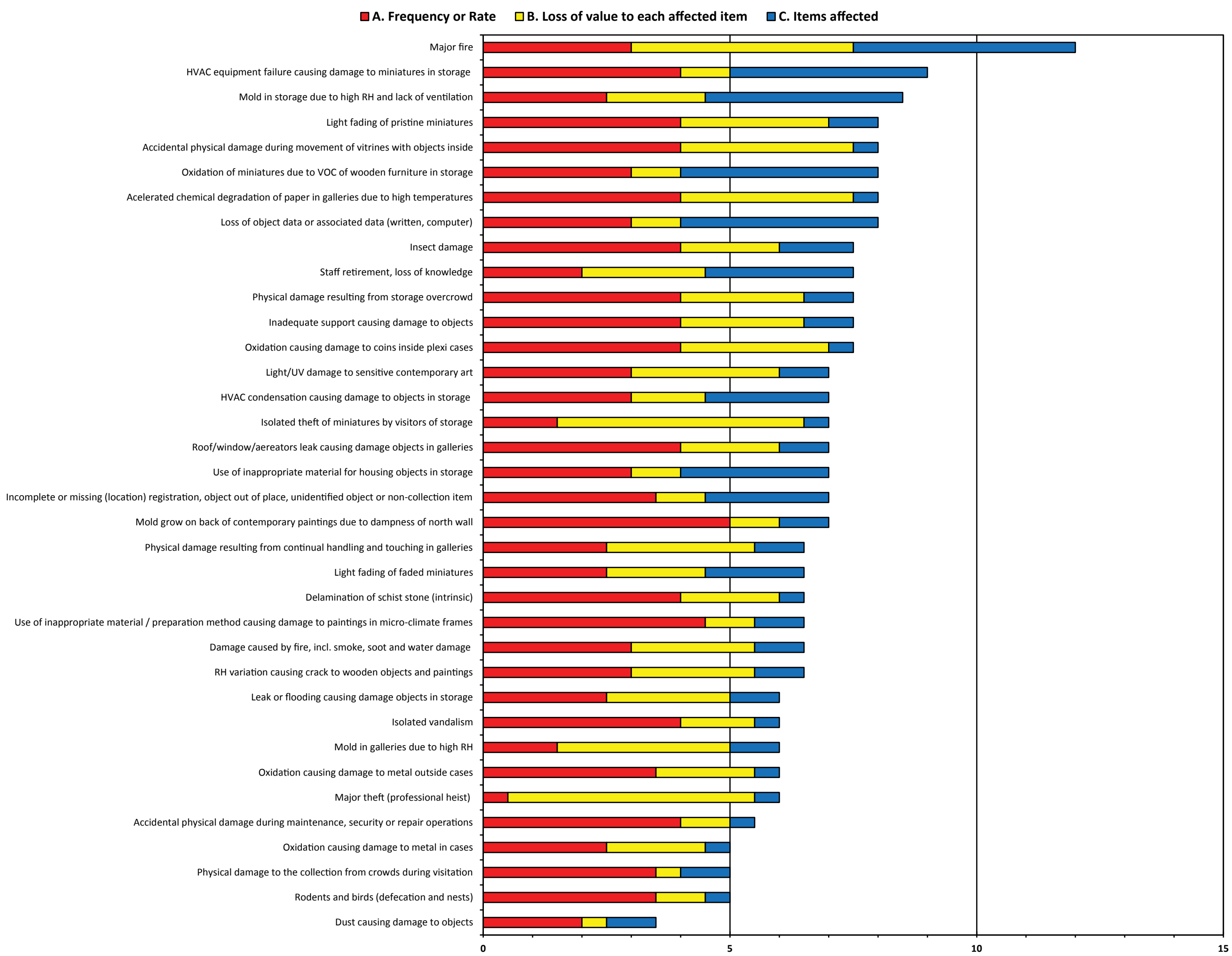


FIGURE 3.3.

Magnitude of risks identified for the collection. Chart: Cecília Winter, © J. Paul Getty Trust.

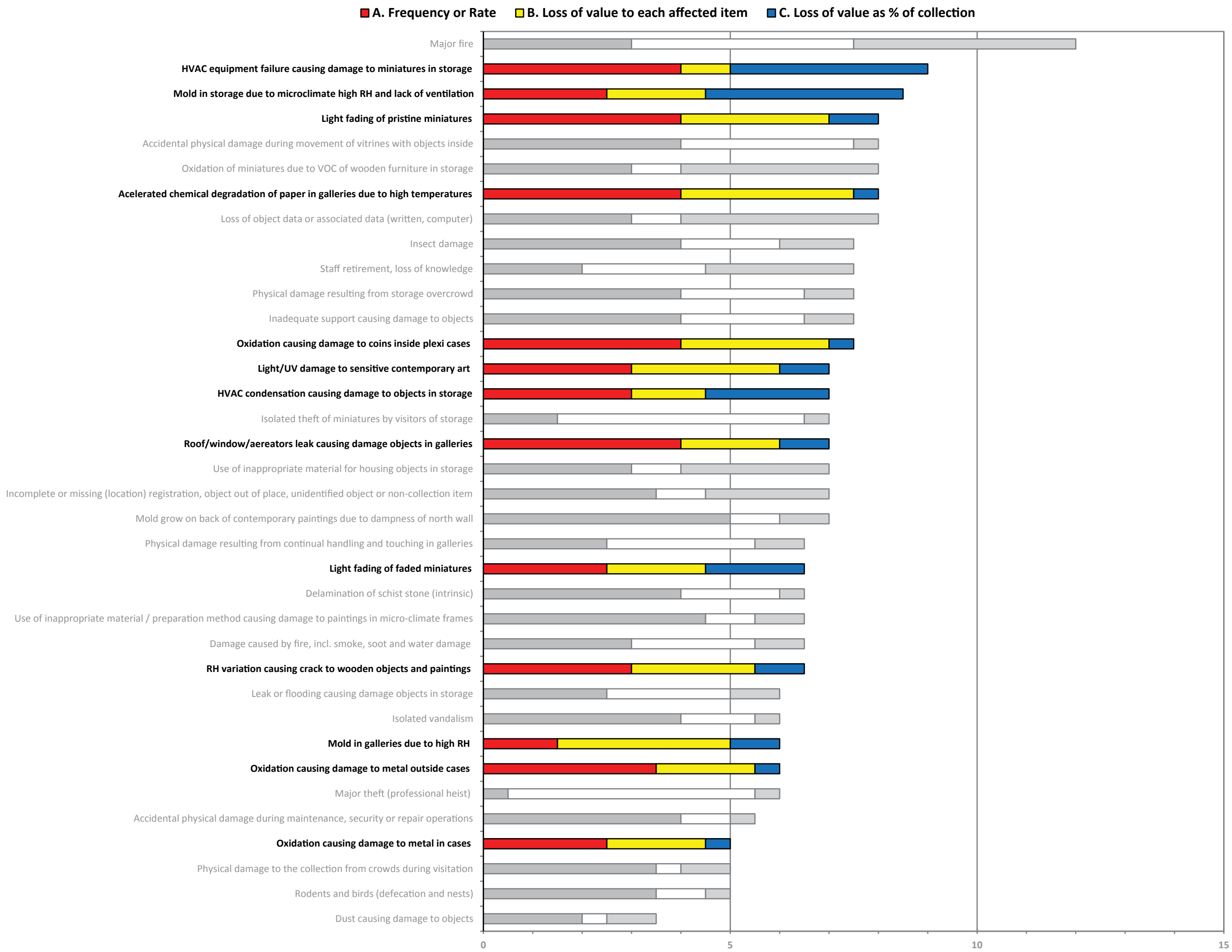


FIGURE 3.4.

Highlighted risks (in boldface) can be affected by environmental management of the collection and are the focus of this report and the proposed strategies in chapter 5. Chart: Cecília Winter, © J. Paul Getty Trust.

The scale of the risks identified in figure 3.3 should be analyzed according to table 3.3.

Fire

Fire, manifesting either indoors or outdoors, can cause total or partial destruction of a collection and can cause damage due to exposure to soot or smoke.

Sources. The main potential source of damage at the museum seems to be dated electrical wiring and use of older electrical equipment. Moreover, the pest problem faced by the museum increases the risk of short circuits (fig. 3.5). A positive factor, however, is that the main power supply to the museum is disconnected outside of opening hours.

Paths. Any fire originating in the surrounding sector or within the building would be fueled by air movement caused by cross-ventilation within the building, which occurs when the exterior and interior aerators are open. This is less of a concern in storage rooms where cross-ventilation does not take place. Timely fire control will likely be challenging due to the museum's lack of a fire protocol,

TABLE 3.3.
Magnitude of Risk Scale with Implications

Magnitude of Risk	General Implications of the Range
15–13½	Catastrophic Priority: All or most of the asset value is likely to be lost in a few years or less.
13–11½	Extreme Priority: Significant damage to all the heritage asset or total loss of a significant fraction of the heritage asset is possible in a decade or less.
11–9½	High Priority: Significant loss of value to a small fraction of the heritage asset is possible in a decade, or significant loss to most of the collection is possible in a century.
9–7½	Medium Priority: Moderate damage or likelihood of loss over many decades. Or significant loss over most of the heritage asset that is expected to take many millennia.
7–5½	Negligible Priority: This level of risk means one expects tiny or miniscule damage to occur to a tiny fraction of the heritage asset value in centuries.

Source: Canadian Conservation Institute 2021, table 23.

a complicated key system (keys are divided among various personnel authorized to open different doors), and lack of a smoke-detection or automated fire-extinguishing system. Additionally, the distance to a number of fire exits exceeds 30 m (around 100 ft.) because of blocked stairways or partitions.

It is unclear if the fiberboard used as ceiling coverings is flammable. Combined with pests and old wiring systems, this material could become fuel for a potential fire. However, fire propagation will likely be slowed by the relatively large distance between objects on display; by the use of other, less flammable construction materials (mainly concrete, glass, terrazzo tiles, metals); and by non-original partitions in the building.

Observed effects. Evidence of short-circuiting of the electrical system was observed in one location. The CMP mentions past incidents of short circuits and observation of soot deposits on aerators (fig. 3.6) (DRONAH 2019).

Potential effects. Both objects and people are in danger due to the potentially slow response in the event of a fast-spreading fire. Organic materials are most at risk, though the display cases provide some protection from both open flames and soot deposits.

Water

Water can cause damage in its extreme form such as natural disasters, as well as gradual damage over time through leaks (from the roof, wall openings, and pipes), condensation, rising groundwater, or even an accidental spill.

FIGURE 3.5.
Rodent droppings at the bottom of a fuse box in the Gandhara Sculptures Gallery. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.6.
Soot deposit on an aerator as seen from the Medieval Sculptures Gallery toward the reserve collection of sculptures and pottery. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Sources. The main source of water damage comes from minor to heavy rainfall, especially during the monsoon season (fig. 3.7). Malfunctioning air-conditioning or condensation around such equipment could be another source of water damage. Flooding on the ground floor or through aerators could increase the relative humidity indoors, leading to mold and mildew outbreaks, and damage objects and display cases.

Paths. The predominant paths through which water enters the museum are the roof and clerestories. Museum staff report that whenever a roof leak is repaired, the water finds another way to enter, indicating that a comprehensive roof covering replacement is likely needed. Additionally, the CMP (DRONAH 2019) mentions that leakage has occurred through aerators during heavy rain and wind events. Objects and exhibition furniture affected by leaks are currently protected by plastic sheeting (fig. 3.8) or have been relocated. In the exhibition spaces, the majority of objects are elevated off the floor on pedestals and/or in display cases; however, this is not the case in the storage spaces, where bulky items are stored on the ground due to lack of suitable storage furniture and space (fig. 3.9). These objects have limited or no barrier to protect them from potential damage from flooding or leaks.

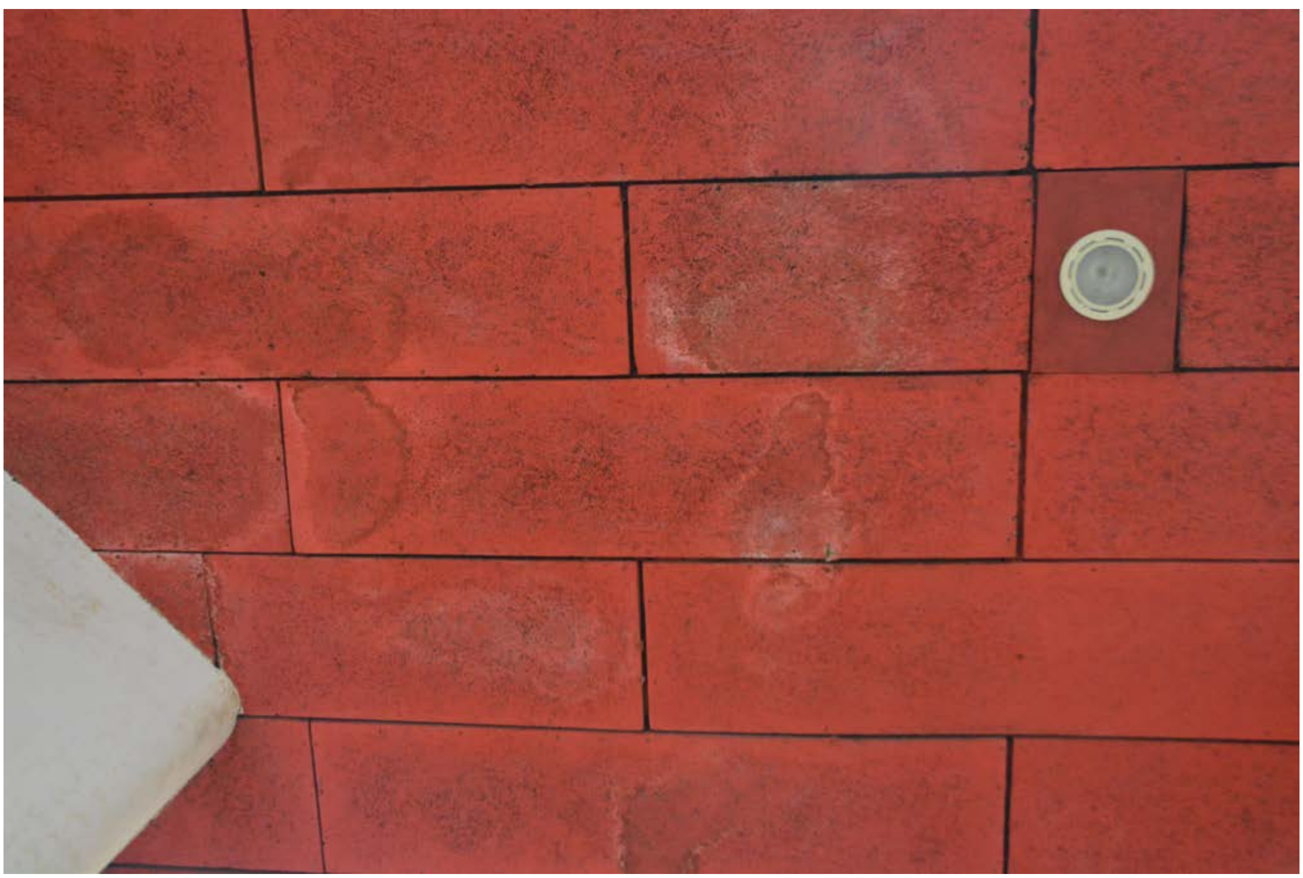


FIGURE 3.7.
Water damage to the fiberboards on the ceiling caused by rain seeping through the roof of the Coin Section. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.8.
Plastic sheeting is used to protect exhibition furniture from leakage in the roof in the Gandhara Sculptures Gallery. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.9.
In the storage space for miniatures, larger objects are placed against cabinets, some objects are stored on top of shelving units, and some are protected by plastic sheeting. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Observed effects. Salt deposits were observed on floors (fig. 3.10), as was staining on exhibition furniture (fig. 3.11) and on objects due to water.

FIGURE 3.10.
Salt deposits caused by water percolating through the concrete roof and landing on the floor. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.11.
Detail of staining from water on exhibition furniture in the Gandhara Sculptures Gallery. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Potential effects. Continuous roof leaks can lead to deterioration of the fiberboard ceiling and potentially result in partial collapse if left untreated. This can cause mechanical damage to objects in addition to further staining, warping, and increased development of mold.

Damage such as staining, mold outbreaks, structural weakening, deformation, and bleeding is likely for all objects, but especially for objects on the ground floor and predominantly in the storage facilities.

Light Exposure

Light damage can occur through exposure to both natural and artificial light. Damage can be caused by visible light, UV light, and infrared radiation. While natural light is often considered the brightest and therefore the most damaging, artificial sources such as ceiling lights, object-specific lighting, emergency lighting, and flash photography can contain high levels of light over the whole spectrum.

Sources. Light measurements (visible light and UV) have indicated that light levels throughout the exhibition spaces are high overall. The predominant source is natural light. Artificial-light levels change throughout the exhibition due to the various types of fixtures and light bulbs in use.

Paths. The predominant sources of high levels of light are the clerestories, which are located above all exhibition spaces that are two or three stories tall (fig. 3.12). The large window openings located on all four sides of the building also let in natural light, but because these windows face rooms that are only one story tall and are recessed a few meters from the main building facade,

FIGURE 3.12.
Sunlight penetrating exhibition spaces through clerestories in Contemporary Art Gallery II during winter. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

they are somewhat protected and thus also allow in less light (fig. 3.13). Furthermore, these windows are always equipped with some type of blind or curtain. High levels of light are also measured next to open aerators; this light path as well is local, can be traced, and is often blocked by concrete columns (fig. 3.14).

Artificial light is provided by either original fixtures or new systems. The original fixtures are often in close proximity to the object, which can overexpose and overheat the object (fig. 3.15). Various types of light bulbs are used throughout the museum.

The works in the Contemporary Art Galleries and the Miniatures Gallery can be considered permanent or semipermanent. While light from the terrace windows is sometimes filtered by UV film on the glass and by curtains or blinds, clerestories are not currently equipped with any type of light management. Light-meter readings taken in January 2020 indicate the collection is exposed to high levels of light during the day. In addition, they are constantly exposed to artificial lighting during opening hours.

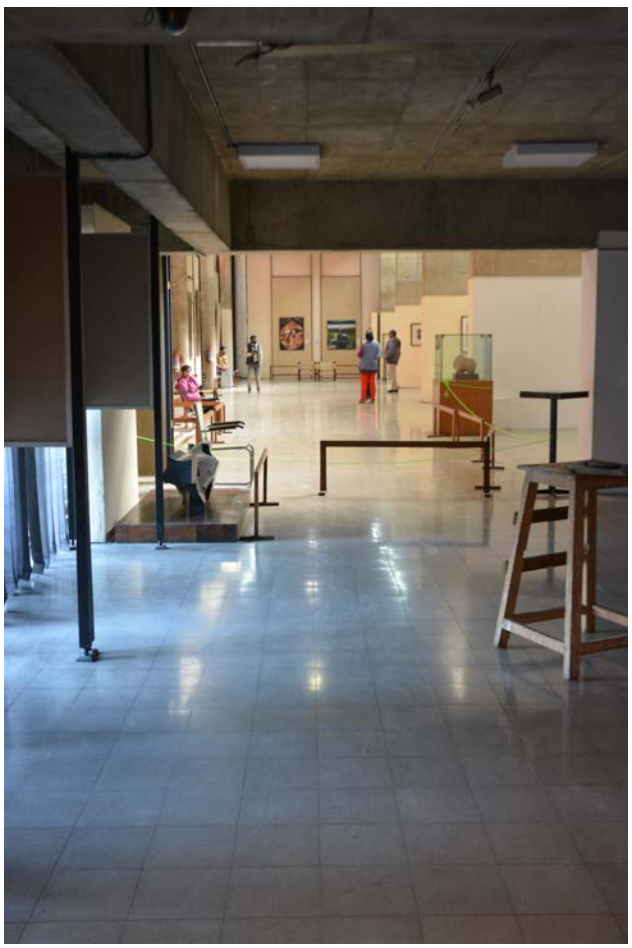


FIGURE 3.13.
Natural light is filtered through the northeast terrace window coverings in Contemporary Art Gallery II. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.14.
Natural light penetrating through aerators and clerestories in the Gandhara Sculptures Gallery. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.15.
Original light fixtures in the Gandhara Sculptures Gallery. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Observed effects. Three material types are particularly sensitive to light damage: paper (fig. 3.16), textiles (of which there were only few on exhibition at the time of assessment), and all contemporary art materials. Fading of the miniatures has been reported based on comparison with historical photographs of these objects. Exhibition furniture textiles also clearly show signs of fading (fig. 3.17).

Potential effects. While clear signs of fading were observed, there have been no visible signs of structural instability of artworks believed to be caused by light exposure. However, if artworks sensitive to light damage remain on display for long periods of time unprotected from natural light, they will decay further and fade, and it will become increasingly challenging for the visitor to appreciate their details (this is of great importance for the miniature paintings). If curtains or blinds are removed, objects will need additional protection from exposure to daylight.

FIGURE 3.16.
Miniature paintings exposed to natural light from the clerestory above. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.17.
Fading of textiles on freestanding panels became evident after artworks were removed in Contemporary Art Gallery I. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Pests and Plants

Pests, other animals, and plants can cause all types of damage. (For mold, see the section "Incorrect Temperature and Relative Humidity" below.) Under the right conditions, pests and plants can spread rapidly and exponentially.

Sources. Insects, rodents, and birds can find their way inside the building in different ways. Plants were not identified as posing any risks to the collection at the Government Museum and Art Gallery.

Paths. Pests can penetrate the building envelope in several places. At the museum, there appear to be two predominant paths of entry. The first is the museum's reception area, where both the main entrance door and the door to the Great Hall stay open during opening hours. The second path is through the fiberboard used on the ceiling outdoors above the recessed windows (fig. 3.18). This fiberboard is showing signs of decay and may provide a way for small- to medium-size animals to enter the interstitial ceiling space and spread throughout the museum undetected. While storage areas are accessed through a separate entrance and do not have fiberboard ceilings, they are connected to the mechanical room and to one another. Therefore, if an animal enters one of these spaces, it may gain access to the others as well (fig. 3.19). In some cases, screens have been installed in cavities connecting rooms to prevent animals from traveling between them (fig. 3.20). Another issue is the consumption of food in museum spaces. This could attract larger animals such as rodents, birds, and squirrels.

FIGURE 3.18.
Damaged fiberboard panels on the ceiling of an exterior recessed window allow pests to enter interstitial ceiling space. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.19.
Wall openings connect the contemporary art storage and miniatures storage with the mechanical room. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Observed effects. Signs of the presence of rodents were observed in the exhibition hall, library, storage areas, and director's office during the 2020 visit. Evidence of animals and insects was also found in exhibition spaces and in the ceiling space (fig. 3.21). However, few objects show visible damage from insects or rodents.

Potential effects. If the interstitial ceiling space is found to have large quantities of dead animals or insects and their droppings, cleaning that space would constitute a health hazard and require workers to wear appropriate protective equipment. On the other hand, not addressing this issue could pose a major fire risk for the museum.

Damage caused by pests over the long term can weaken objects structurally, stain them, and create losses. At major risk for the Government Museum and Art Gallery is the textiles collection; not only is it vulnerable to this type of damage, but it is also monitored and inspected less frequently because of its lower value compared to that of other collections.

FIGURE 3.20.
Screen separating two spaces to avoid circulation of birds and larger animals between rooms. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.21.
Dead insects visible inside a light fixture mounted in the ceiling. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Food inside the building obviously attracts pests. Lack of an appropriate space for food storage and for eating meals outside the museum, especially for staff, makes it difficult to completely deter staff and visitors from bringing food into museum spaces.

Physical Forces

This category includes all physical forces that have an impact on objects, including gravity, wear, and handling by museum personnel, visitors, and other external factors. Like fire and water, physical forces can also occur in extreme forms such as natural disasters.

Sources. People handling the objects are the most significant source of damage due to physical forces.

Paths. Museum personnel's lack of training in art handling can result in damage due to accidents. Because most display cases are labor-intensive to open, they are sometimes moved with the objects inside. Additionally, there are often no barriers between visitors and objects, particularly concerning the indoor and outdoor sculptures, which can lead to both unintentional and intentional damage.

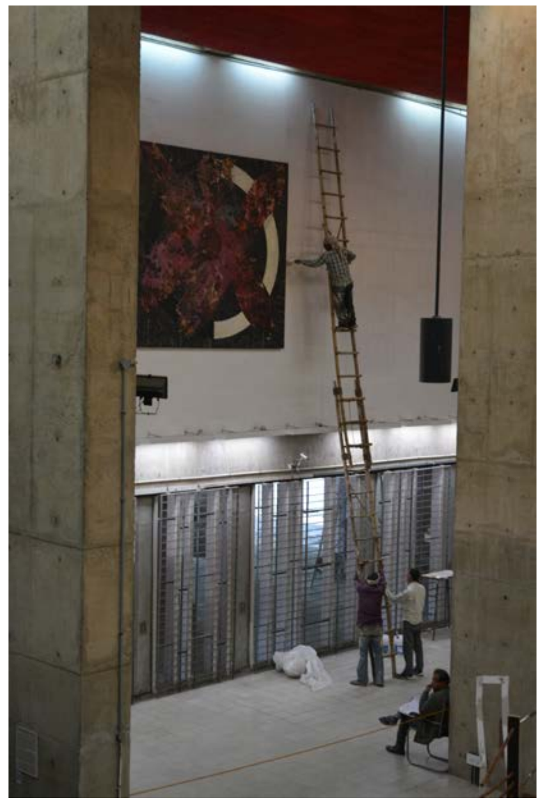


FIGURE 3.22.
Painting without removal of contemporary artwork in the Great Hall. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

The condition of some exhibition furniture or architectural elements, such as the fiberboard ceiling, can make them unstable, posing risk to nearby objects. Another potential issue is the use of unsuitable mounts for hanging fragile objects. Further, not removing all objects from a space that is being prepared for a new exhibition or that is being renovated can also present the risk of damage (fig. 3.22).

Observed effects. Scratches (fig. 3.23), impact damage leading to loss (fig. 3.24), and paint splatters (fig. 3.25) have been found on works of art caused either by improper handling or by insufficient protection when mounting an exhibit. The rope used to hang two-dimensional works is often made of cotton, an organic material that deteriorates over time and is not recommended for heavier objects. Other mounting techniques were found to cause cracks from the back to the front of the object, weakening its stability. Some book supports are unsuited (fig. 3.26), both in the library and for the exhibition of manuscripts. More well-suited mounts were observed elsewhere in the museum (fig. 3.27), and the way these are used in consultations in the Bir room is appropriate. An angled support for consultation or display of books is recommended, as it causes less strain on the book cover and binding.

FIGURE 3.23.
Scratches likely caused by a sharp object or by movement from an object in close proximity in Contemporary Art Gallery II. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.24.
Dent on a Gandhara sculpture that could have been caused by improper handling of the object. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

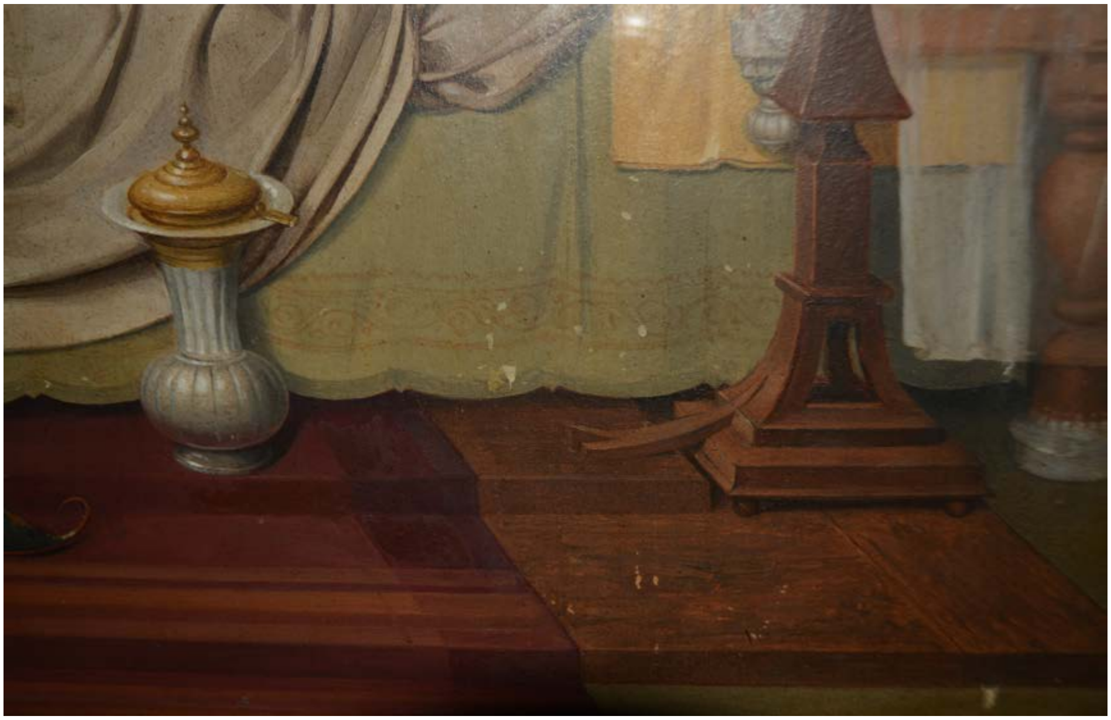


FIGURE 3.25.
Paint splatters on an artwork in Contemporary Art Gallery I, likely originating when the gallery wall was painted in the past. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

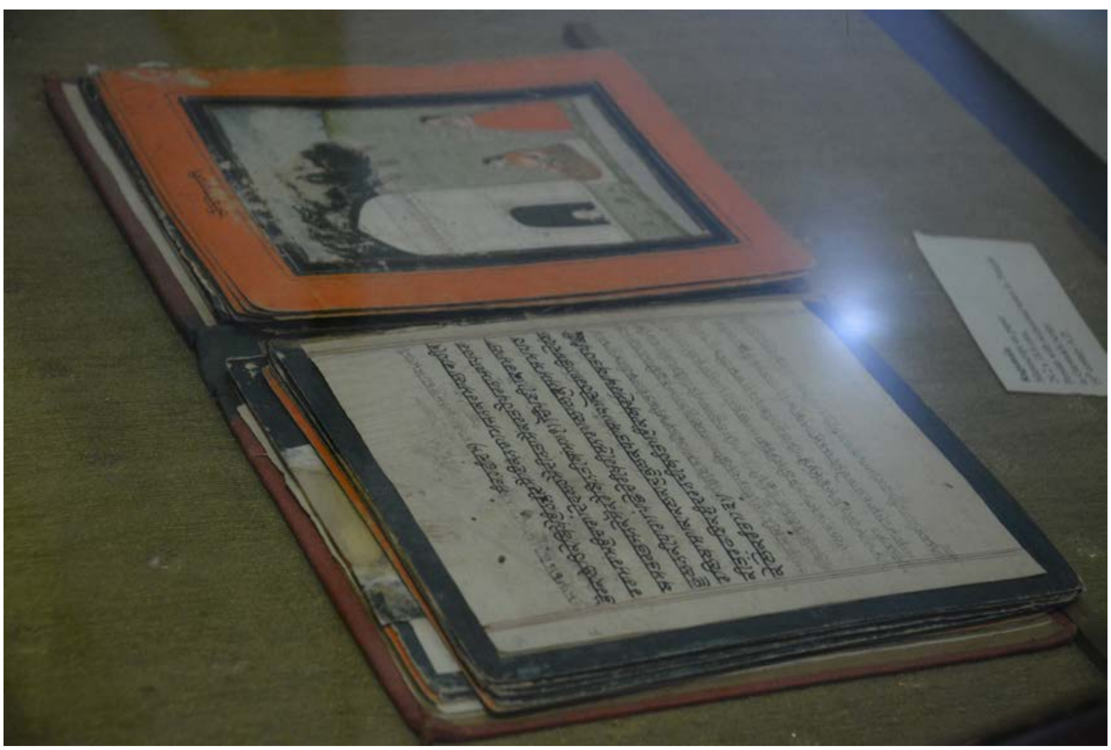


FIGURE 3.26.
This support is flat and not high enough, making it unsuited for book display in the Miniatures Gallery. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

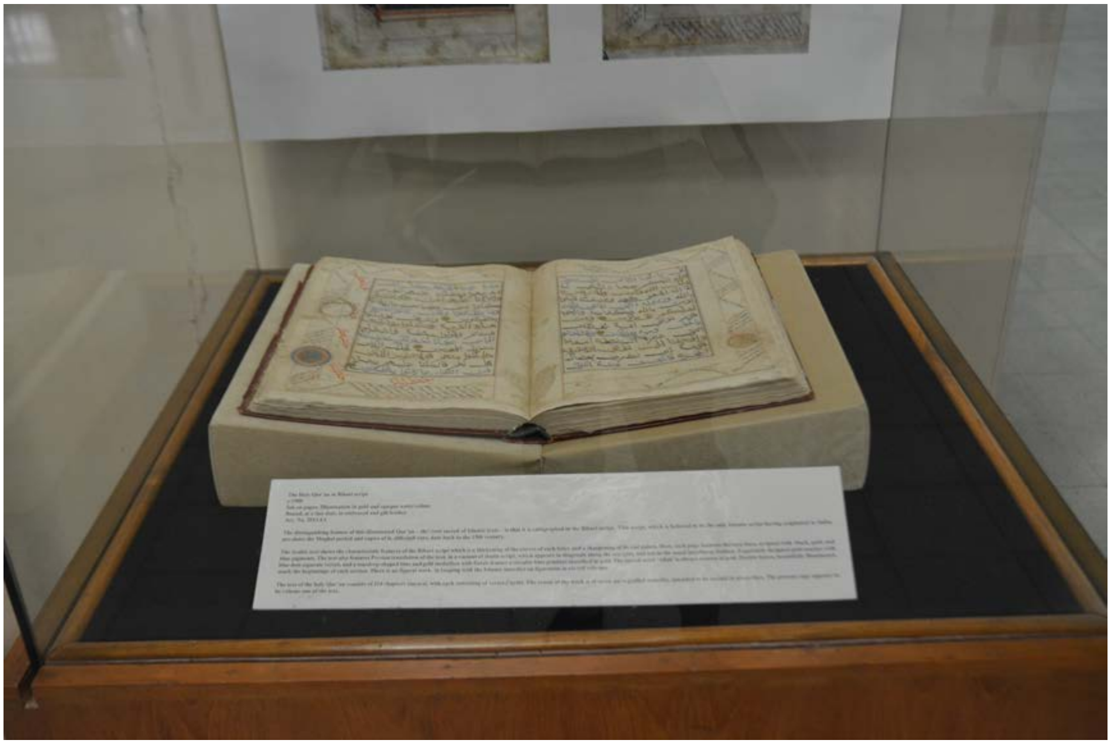


FIGURE 3.27.
An angled, raised support is the recommended method for book display, as shown in the Miniatures Gallery, similar to the support used to consult Sikh manuscripts. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Potential effects. Handling and transport will become more important if the museum increases its number of loans.

Contaminants

Contaminants include the effects of gases, vapors, liquids, or dust on objects. These contaminants can be related to different types of outdoor pollution entering the museum or can originate within the museum itself. Objects in the textiles collection that are currently stored in small wooden cabinets need to be folded or rolled to avoid cracks over time.

Sources. Indoor sources of contaminants are predominantly products used within the museum mainly for maintenance, including cleaning products, paint, and pesticides. Additional sources are animal droppings, urine, or carcasses of pests. Newer mounting materials and display case materials can also be sources of contaminants.

Outdoor sources include urban pollution from fuel burning for heating and cooking and from combustion vehicles.

Paths. Natural ventilation can draw in outside pollution. Conversely, ventilation can play a positive role in venting out harmful indoor pollutants. Indoor pollutants potentially come from the storage of chemical products, such as for cleaning, in exhibition spaces or other spaces close to collection objects.

Objects in display cases are partially protected from both particle and gaseous pollutants. However, when display cases are cleaned with aggressive products and not allowed to air out, gaseous pollutants cannot escape and can create a long-lasting, hazardous environment for the objects housed within.

Overall, the exhibition rooms and storage areas are clean, but traces of excessive cleaning were noted on display cases and construction materials. The smell of most of the maintenance products used (paint, floor cleaning product, and glass cleaner used to clean the interior of display cases and other surfaces) was extremely strong; these products should be evaluated for aggressive gaseous pollutants.

Dust deposits were rarely observed, and the choice of packing materials is relatively good.

Observed effects. The clear acrylic material used in the coins display cases is showing signs of deterioration (fig. 3.28). This material presumably can generate gaseous pollutants that can cause corrosion. In addition, aggressive cleaning materials, combined with other agents, can play a role in the corrosion of metal sculptures and staining of the display case lining. Stains on the lining may also be caused by the board underneath the lining, since these stains have been frequently observed in different types of cases and on non-enclosed exhibition furniture throughout the museum (fig. 3.29).

FIGURE 3.28.
Coins case made of clear acrylic, showing visible deterioration that can potentially generate gaseous pollutants. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.29.
Staining of display case lining in the Metal Sculptures Gallery, most probably caused by a combination of factors, including the board used underneath the lining and high humidity. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Potential effects. A new ventilation protocol can change the environmental dynamic of the building.

Incorrect Temperature and Relative Humidity

Incorrect temperature and relative humidity (RH) accelerate chemical degradation, promoting biological activity and inducing mechanical stress. Inappropriate RH levels lead to mold growth, metal corrosion, and swelling of organic materials, while low RH causes drying, shrinkage, and cracking. Extreme variations in RH and temperature create stress on objects, especially those made from composite materials, leading to warping, delamination, or joint failure.

Sources. The predominant source of incorrect temperature and RH is the outdoor climate and sunlight. Indoors, artificial light is an additional source of high temperatures.

Paths. The building envelope is by nature open to natural ventilation through the use of aerators. All gallery spaces in the museum closely follow the trends in exterior air temperature, humidity ratio, and RH. However, the building envelope clearly has a buffering effect. The Miniatures Gallery is the only exhibition room controlled by an HVAC installation (fig. 3.30), but the environmental monitoring data suggest that the environments in the galleries with and without air-conditioning were largely identical (see chap. 4, p. 85).

The storage spaces have no natural ventilation and are controlled by an HVAC system. While the contemporary artworks are predominantly stored on metal shelving units, the miniatures are stored in wooden boxes placed in metal or wooden cabinets. The HVAC system serving the miniatures storage room appears to perform well (see chap. 4, p. 88). The small volume of the space, its minimal external heat and moisture loads, and a simple HVAC system contribute to its good performance.

Display cases were found to be effective in reducing the range of fluctuations in RH within the cases but had little effect on temperature (see chap. 4, p. 90).

FIGURE 3.30.
HVAC installation in the Miniatures Gallery. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Observed effects. The observed effects are often caused by a combination of factors. In the examples chosen, temperature and RH may have played a predominant role in causing these effects.

Some of the works on paper show signs of undulation, or curling (fig. 3.31). Corrosion was observed on metal objects (fig. 3.32), and staining was evident on exhibition textiles. Also noted was deterioration of manuscripts, delamination of paint layers on polychrome wooden sculptures (fig. 3.33), and possibly nonhistorical cracks in wooden sculptures (fig. 3.34).

Potential effects. Improper maintenance and operation of HVAC systems and improper management of natural ventilation can increase the risk of mold outbreak.

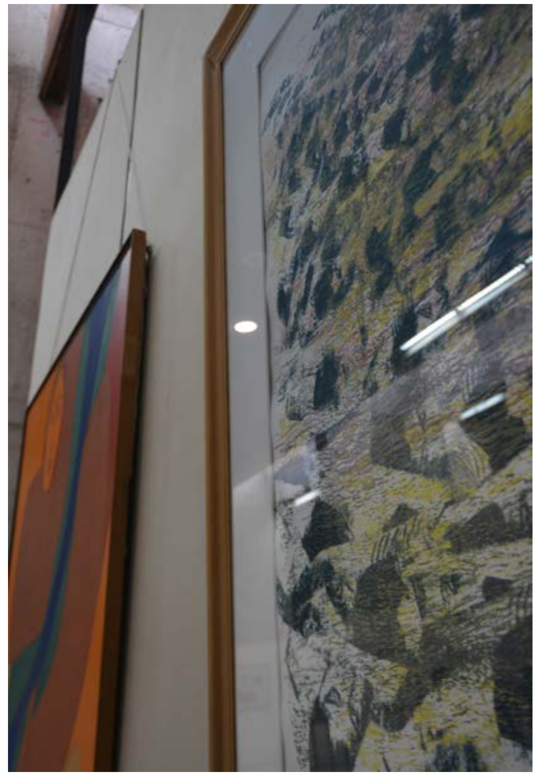


FIGURE 3.31.
Undulation, or curling, appears in a framed artwork on paper in Contemporary Art Gallery II. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.32.
Corrosion of a metal sculpture in a display case. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.33.
Detachment of paint layer on a polychrome wooden sculpture in the Medieval Sculptures Gallery. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

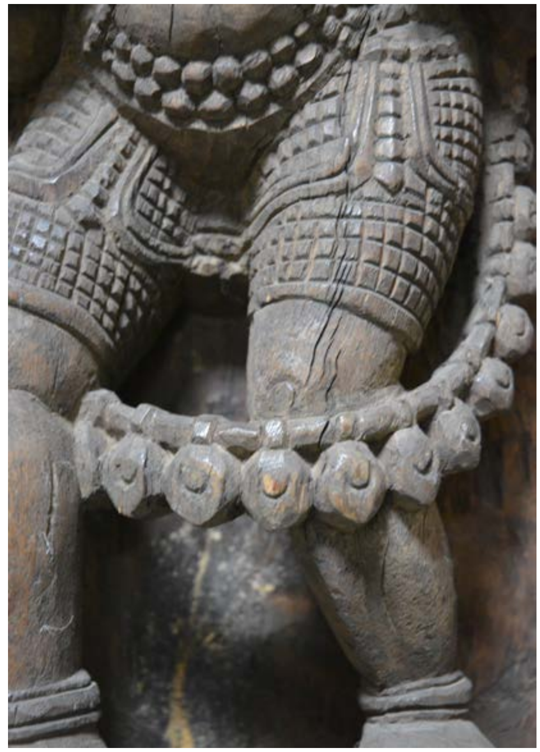


FIGURE 3.34.
Cracks in a wooden sculpture. Some cracks are presumably historical, but others seem more recent. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Theft and Vandalism

Theft and vandalism are perpetrated by people, known or unknown, who intentionally steal or damage collection items during or outside of opening hours.

Sources. Visitors, personnel, and professional thieves can be sources of theft and vandalism. After a professional break-in took place in the 1970s at the museum, metal grilles were installed on windows and doors (fig. 3.35).

Paths. The current system, which allows different people to open different doors, combined with the closing ceremony of the museum (during which the main entrance is sealed with wax for the night), is relatively safe against theft by a third party but presents challenges in situations that may require an emergency response, as mentioned above in the section "Fire."

Window grilles protect against external intruders outside of museum hours. During the 2020 visit, a ladder was found outside next to one of the terraces (fig. 3.36). This can allow a thief or vandal easy access to some of the terraces.

The mounting system for the contemporary art collection consists of hooks and cotton ropes. These make the objects easy to remove. However, the works are large and difficult to steal during opening hours. Smaller objects are overall secured. Security cameras are present throughout the museum (fig. 3.37). The extent to which the CCTV system is maintained is unclear.

FIGURE 3.35.
Grilles were installed on windows and doors after a theft occurred at the museum in the 1970s. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 3.36.
Equipment such as this ladder, lying next to the museum building, can facilitate access for intruders. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

During museum hours, at least two staff monitor the exhibition rooms. These personnel do not always move through the spaces in a coordinated way. At nighttime, after the main entrance door of the museum is closed and sealed, security guards keep watch outdoors. Security cameras indoors stay active 24/7.

While active vandalism has not been reported, visitors do touch objects occasionally out of curiosity.

Observed effects. There were no observed effects during the visit.

Potential effects. If grilles are removed, additional steps need to be taken to maintain the existing security levels.

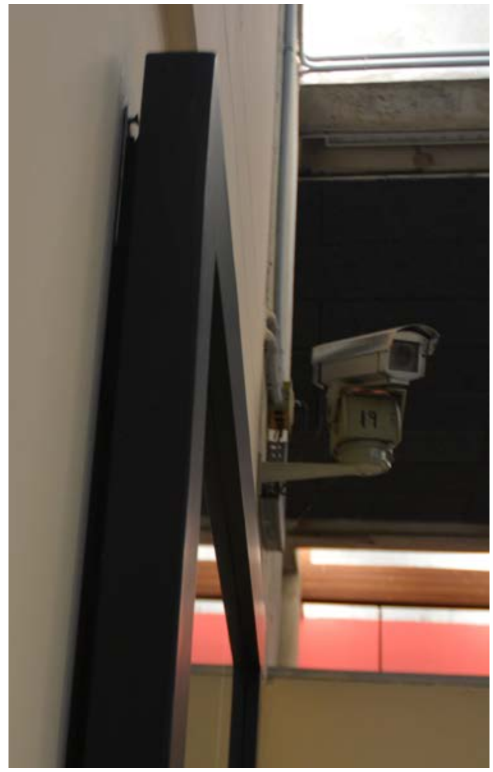


FIGURE 3.37.
A security camera mounted on a museum wall. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Dissociation

Dissociation is the detachment of objects from the information about these objects; for example, information indicating where the object is located or the different parts of the object. This can occur due to loss of archival resources, undocumented knowledge of museum personnel, or loss of identification numbers.

Sources. Dissociation can occur through improper implementation of museum protocols of acquisition and displacement of objects.

Paths. The museum's paper archives have been only partially digitized. However, these registration procedures seem to work for museum staff, and photos are available for almost all objects.

Observed effects. No dissociation effects were observed during the visit.

Potential effects. During construction work, many objects need to be moved, and these relocations must be logged carefully. Loss of institutional knowledge and understanding of the collection due to retirement and other staffing changes pose future challenges in the management of the museum.

Conclusions

Decision-makers for the Government Museum and Art Gallery should consider that the risk of a major fire has been identified as the largest risk and the only one in this assessment to rise to the level of extreme priority. However, developing strategies to manage this risk are outside the scope of this report.

All other risks identified can be considered medium priority risks or lower. This report focuses on the medium priority risks that can be affected by the environmental management of the collection and that are targeted by the proposed strategies discussed in chapter 5. These risks are as follows:

- HVAC equipment failure causing damage to miniatures in storage
- Mold in storage due to microclimate high RH and lack of ventilation
- Light fading of pristine miniatures
- Accelerated chemical degradation of paper in galleries due to high temperatures

As this risk assessment reflects conditions at the time it was conducted, it is recommended that a new risk assessment be carried out after significant changes have been made, such as changes to the building, exhibitions, or institution.

CHAPTER 4

ENVIRONMENTAL CONDITIONS

This chapter discusses the methodology employed to collect and analyze environmental data from the Government Museum and Art Gallery in Chandigarh. Results of the data analysis are also presented. The primary variables of interest were temperature, relative humidity, dew point temperature, and humidity ratio, with data collected for the museum building's exterior, in various spaces in the interior, and within select display cases; other variables considered were light, pollutants, and particulates. Gaining an understanding of how the environment and building interact provides insight into the assessment of both environmental risk to the collection and human comfort. This information provided the basis for the development of potential mitigation strategies, discussed in chapter 5.

Environmental Monitoring Program for the Government Museum and Art Gallery

The environmental monitoring program for the museum consisted of monitoring and analysis of selected interior conditions and their probable exterior influences for a period of eighteen months. The program's primary objectives were as follows:

- Understanding the thermal and hygric behavior of the naturally ventilated building and the spaces that are mechanically conditioned, except for the temporary exhibition gallery—located behind the main block of the museum—which was not included in the building monitoring program
- Understanding the environmental risks to the exhibited and stored collections in terms of temperature, relative humidity, light, corrosion and particulates, and the effect of the various display cases in terms of mitigating or attenuating the ambient interior conditions
- Understanding human thermal comfort

Building Behavior

Monitoring of building behavior was directed toward understanding the relationship between external environmental conditions and the conditions in naturally ventilated and mechanically conditioned museum spaces.

Exterior measured variables included the following:

- Exterior temperature, relative humidity, and calculated moisture content
- Rainfall, wind direction, and wind speed
- Solar radiation on the roof plane and the planes of the northeast, southeast, and southwest exterior walls

Interior measured variables included the following:

- Interior temperature and relative humidity in the Great Hall, at three locations in the first-floor galleries, and in the second-floor library
- Interior surface temperature of the envelope on the underside of the library's clerestory roof and at one location on the interior surface of the southwest wall
- Solar radiation (horizontal plane) at one point under the library's clerestory roof

The building monitoring system utilized HOBO RX3000 data loggers and a weather station kit from Onset Computer Company (https://www.onsetcomp.com/), and the collected data were transmitted via the museum's wireless internet connections to Onset's HOBOlink secure site (https://www.onsetcomp.com/products/software/hobolink). Below are the locations of the three HOBO RX3000 data loggers and the associated environmental sensors:

- CGMAG1 (nine sensors and sixteen data channels): exterior conditions at the roof-mounted sensor mast/weather station (air, wind, rain, and solar radiation) and Contemporary Art Gallery I (first- and second-floor levels).
- CGMAG2 (nine sensors and twenty-one data channels): entrance; the Great Hall (ground-, first- and second-floor levels), library, and library lantern, and the particulate monitor.
- CGMAG3 (seven sensors and nineteen channels): Miniatures Gallery (first floor low and high); Miniatures Gallery HVAC (supply air and return air); Gandhara Sculptures Gallery (first floor low and high); and Gandhara Sculptures Gallery exterior wall.

Methods of Data Collection

The environmental monitoring system used the following instrumentation:

- HOBO RX3000 data loggers to collect data on building behavior
- Met One Instruments ES-642 remote dust monitor to gather particulate data
- Standalone HOBO UX100-011 data logger to complement data collection on building behavior and on behavior of display cases
- ELSEC 765 environmental monitor to measure visible and UV light
- Blue Wool cards to assess light exposure
- Purafil coupons to assess pollution exposure

Building Behavior: HOBO RX3000 Data Loggers

The HOBO RX3000 data loggers recorded measurements at 15-minute intervals, and data uploads to the HOBOlink website were scheduled at one-hour intervals. Data transfer was dependent on the availability and capacity of the wireless internet access connection and the internet connection. The HOBO RX3000 loggers have robust (32 MB) memory relative to the size of the typical data packets (~1.5 MB) for CGMAG1 and CGMAG3, but the particulate data packets from CGMAG2 were much larger (10.5 MB).

The HOBO RX3000 data loggers were installed in late January 2020. Final configuration of the three data loggers and the associated sensors for air temperature, relative humidity, surface temperature, and exterior climatic variables was achieved remotely on 6 February 2020.

Incidents during the monitoring period included the following:

- CGMAG3 had infrequent connectivity issues, which museum staff and service technicians resolved.
- Normal museum operations were disrupted due to the COVID-19 pandemic, which resulted in loss of monitoring data from CGMAG2 and CGMAG3 for the period from 9 July 2020 to 5 August 2020 and from April to June 2021.
- The southwest-facing solar radiation sensor entered failure mode on 2 August 2020.
- The wind speed sensor reported infrequent erratic data starting on 13 May 2021.
- The roof-mounted mast containing wind and solar radiation sensors overturned during a wind event around 1 November 2021.

Particulate Size: Met One Instruments ES-642 Remote Dust Monitor

Particulate data were collected in the library using a Met One Instruments ES-642 remote dust monitor equipped with a PM_{10} sharp-cut cyclone inlet; the latter sets the size threshold to particulates with a diameter of 10 microns (µm) or smaller. The instrument was mounted on a tripod and positioned within the library next to southeast-facing exterior windows (fig. 4.1). The dust monitor was connected to a HOBO RX3000 data logger in the library (CGMAG2) and collected data (units: $\mu g/m^3$) at one-minute intervals. Retrieval of this particulate data occurred during periodic remote downloads from the HOBO RX3000 data logger.

FIGURE 4.1.
Met One Instruments ES-642 remote dust monitor positioned next to the southeast-facing windows in the library at the Government Museum and Art Gallery. © Fondation Le Corbusier. Photo: Vincent Laudato Beltran, 2020, © J. Paul Getty Trust.

Particulate data were collected during museum visiting hours (roughly 10:00 to 16:30) from February 2020 to August 2021; the lack of data available during closed periods was due to a nightly electrical shutdown (note that the ES-642 was powered independently from the HOBO RX3000s in the library). Prolonged periods of missing data occurred from March to June 2020, July to August 2020, and April to June 2021.

Building and Display Case Behavior: HOBO UX100-011 Data Loggers

Complementing the sensors wired to the three HOBO RX3000 data loggers, nine standalone HOBO UX100-011 data loggers measuring air temperature and relative humidity were positioned throughout the museum, including two in storage, four in galleries, and three in display cases (fig. 4.2). Retrieval of these data required museum staff to connect a wire between each data logger and a computer, and data files were periodically shared with the Getty Conservation Institute (GCI). Data were collected at 30-minute intervals from March 2020 to February 2021.

Handheld Light Measurements: ELSEC 765 Environmental Monitor

Spot measurements of visible light (units: lux) and UV light (units: μW/lumen) were taken with an ELSEC 765 environmental monitor (fig. 4.3). Data were collected between 11:00 and 14:00 from 13 to 19 January 2020. At each location, data were recorded orienting the sensor in five different directions, each corresponding to a letter: (a) facing upward, (b) facing southwest, (c) facing northwest, (d) facing northeast, and (e) facing southeast.

FIGURE 4.2.
One of nine standalone HOBO UX100-011 data loggers, deployed in a display case with a Corrosion Classification Coupon. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

FIGURE 4.3.
Measurement of visible and UV light in the Miniatures Gallery using an ELSEC 765 environmental monitor. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Light Exposure: Blue Wool Cards

Blue Wool (BW) cards consist of eight strips of dyed wool, with BW1 considered the most light sensitive and BW8 the most lightfast (fig. 4.4). These cards can be deployed as dosimeters to gauge the level of light exposure at a particular location. Various locations throughout the museum were identified for placement of BW cards, informed by spot measurements of visible and UV light. At each location, BW cards were oriented in multiple directions, similar to the protocol for handheld light measurements.

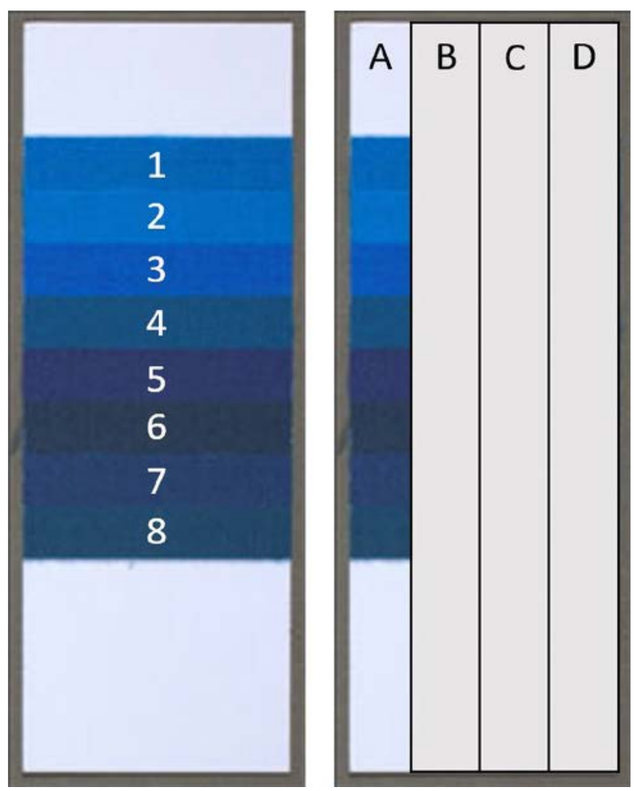


FIGURE 4.4.
Left: Blue Wool (BW) card with eight strips of dyed wool; BW1 is the most sensitive to light and BW8 is the most lightfast. Right: Schematic of covered BW card with area A initially exposed. Photo: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

The BW cards were initially deployed in August 2020. Three-fourths of each card was covered with aluminum foil, and the remaining exposed area was labeled A (see fig. 4.4). In December 2020, the left one-third of the foil was removed from each card, exposing areas A and B. In April 2021, the adjacent one-third of the foil was removed to expose area C in addition to A and B. In August 2021, each BW card was entirely re-covered with foil and all sets were sent to the GCI. Note that the final one-third of the foil was not removed; this unexposed area was labeled D and served as the control. This protocol resulted in the exposure to light of areas A, B, and C for twelve, eight, and four months, respectively.

After receipt by the GCI, the color differences (ΔE00) between areas A and D, B and D, and C and D were measured with an X-Rite eXact handheld spectrophotometer using an aperture of 1.5 mm. This involves collecting spectra for each area; defining their L*, a*, and b* colorimetric coordinates (2° standard observer, D65 illuminant); and calculating the distance in CIE L*a*b* color space using the 2000 ΔE equations (CIE = Commission Internationale de l'Eclairage/International Commission on Illumination).

Pollution Exposure: Purafil Coupons

Corrosion Classification Coupons (CCCs) by Purafil are reactivity monitors that passively assess the quality of ambient air (fig. 4.5; see also fig. 4.2). CCCs consist of strips of copper and silver that are exposed to the environment; the observed level of corrosion over time coarsely indicates the pollution level. Following exposure, the CCCs are sent to Purafil for analysis, with results ranging from class 1 (Extremely Pure) to class 5 (Polluted).

An initial set of six CCCs was installed in January 2020 at three storage locations and within three display cases and recovered in June 2020. A second set was immediately redeployed at the same locations and recovered in November 2020. In November 2020, a third set was positioned in six different locations—including a cupboard, a filing cabinet, two display cases, a manuscript bed, and in the Miniatures Gallery—and recovered in April 2021. The duration of each exposure was six months. Upon recovery, the coupons were sent to Purafil for analysis.

FIGURE 4.5.
A Corrosion Classification Coupon by Purafil, which consists of reactive copper and silver strips. Photo: Purafil Inc.

Data Analysis Methodology

Seasons

The India Meteorological Department (IMD) has defined four seasons: winter (January–February), pre-monsoon (March to May), monsoon (June to September), and post-monsoon (October to December) (India Meteorological Department 2023). Based on analysis of on-site exterior climate data from February 2020 to August 2021, the GCI team was able to review these seasonal distinctions.

The collected exterior data aligned relatively well with these seasonal periods regarding air temperature, dew point (calculated from concurrent air temperature and relative humidity data), and rainfall (fig. 4.6). A point of discussion was a period of rising dew point occurring in June, which marks the start of the monsoon season; in contrast, dew point remains relatively constant throughout the remainder of this season. For purposes of this analysis, which emphasizes the impact of exterior moisture content on interior spaces, separation of these two periods was preferred. Thus, the monsoon season would be narrowed from July to September, and pre-monsoon would encompass the month of June. A fifth season, spring, would extend from March to May (previously defined as pre-monsoon). Additionally, the winter and post-monsoon seasons were defined as December to February and October to November, respectively, reflecting prior classifications by the IMD.

Air Temperature and Relative Humidity

The analysis period for air temperature and relative humidity data was limited to twelve months, extending from March 2020 to March 2021; this ensured that seasonal variations were captured. Two of the three HOBO RX3000s (CGMAG2 and CGMAG3) were missing data from July to August 2020 (during the monsoon season), so data from July to August 2021 were used to fill this gap (fig. 4.7). For consistency, this data replacement was also made in the sets collected by the third HOBO RX3000 (CGMAG1) and the standalone HOBO UX100-011 data loggers.

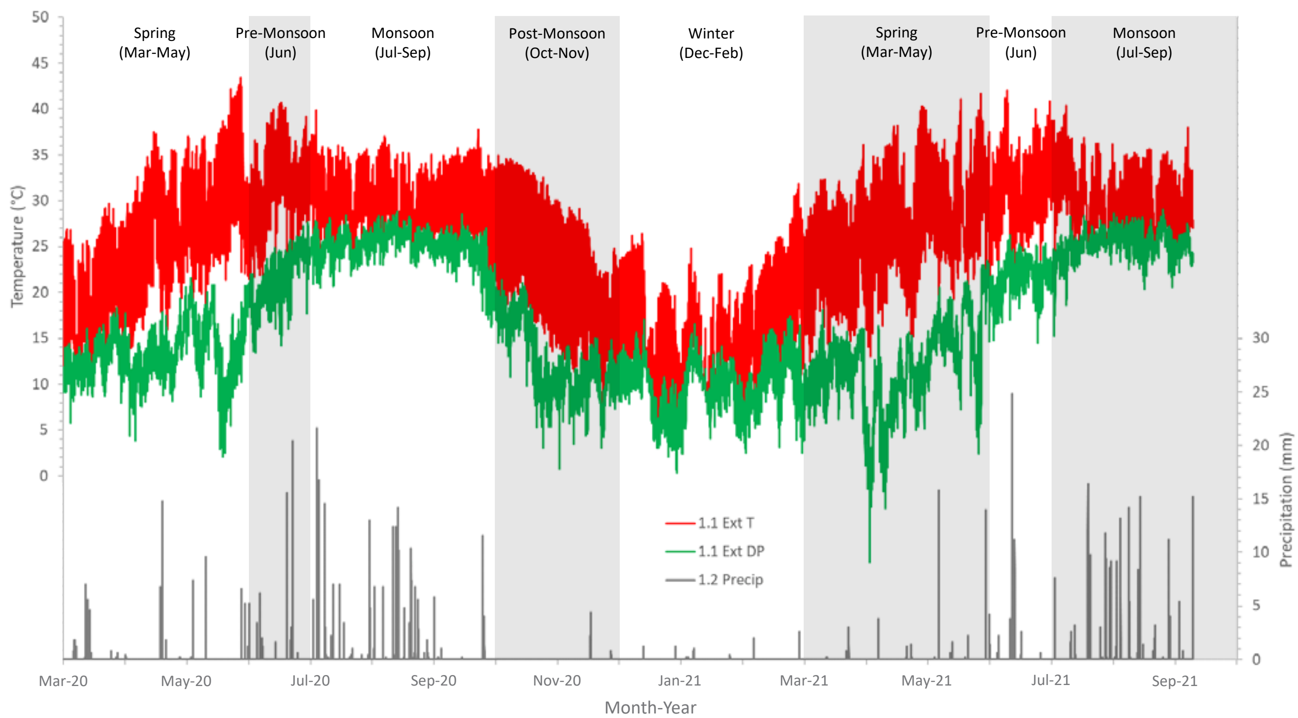


FIGURE 4.6.
Exterior air temperature, dew point, and precipitation, overlaid with modified seasons, from March 2020 to August 2021. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

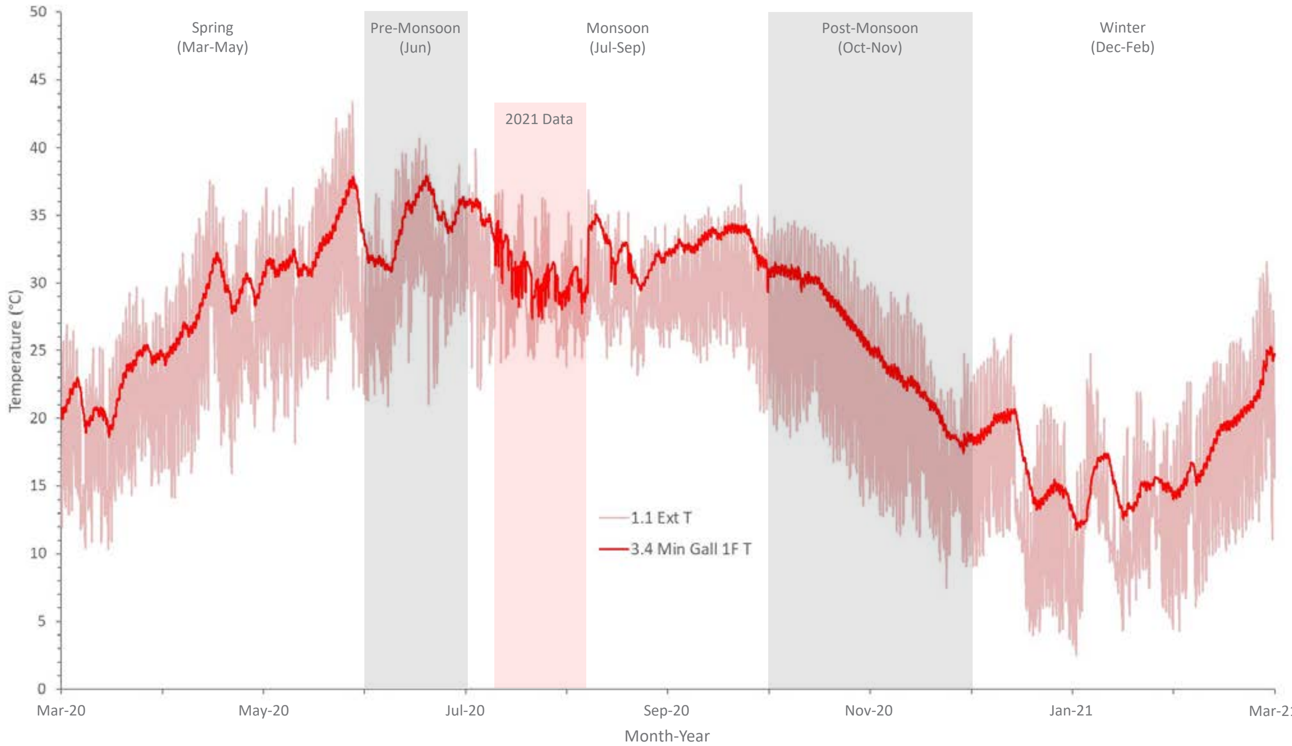


FIGURE 4.7.

Time series of exterior and Miniatures Gallery (first floor) temperature from March 2020 to March 2021. The pink vertical rectangle indicates the period of missing data replaced with values from the same period in 2021. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

To take advantage of their psychrometric relation, measurements of dew point (units: °C) and humidity ratio (units: gram of water vapor/kilogram of dry air, assumed an elevation of 334 m for the Government Museum and Art Gallery) were calculated from concurrent air temperature and relative humidity data using the GCI Excel Tools (Cosaert et al. 2022, appendix 3.1). Whereas relative humidity is dependent on both air temperature and moisture content, dew point and humidity ratio, which reflect the moisture content of the air, are independent variables (as is air temperature) and can provide more insight into the driving factors for the interior environment. Statistical analysis of the data (also using the GCI Excel Tools) examined short-term variation (moving 24-hour range), seasonal averages, and percentiles. Visualizations of air temperature, relative humidity, dew point, and humidity ratio included time series, box plots, and psychrometric charts.

Though not discussed in this report, the interior environment can be classified using criteria from various guiding resources, including ASHRAE's 2023 handbook (ASHRAE 2023, chap. 24, table 13A), the classification protocol from the GCI publication *Environmental Management for Collections: Alternative Preservation Strategies for Hot and Humid Climates* (Maekawa, Beltran, and Henry 2015), preservation metrics from the eClimateNotebook web-based tool (Image Permanence Institute 2025), and risk indices from the online platform HERIe (HERIe 2020).

Environmental Guidance

The 1978 publication of The Museum Environment by Garry Thomson underscored the concept of environmental management as a means of preventive conservation. Continued research, practice, and discourse on the topic (for example, Michalski 2007; ICOM-CC 2014; Stauderman and Tompkins 2016; IIC 2021) have impacted the development of recent guidance on collection environments, which integrates risk management principles, aims toward sustainability, and allows for classification of the interior environment based on air temperature and relative humidity criteria. This heritage-focused environmental guidance includes but is not limited to the following:

- Environmental Management for Collections: Alternative Preservation Strategies for Hot and Humid Climates (Maekawa, Beltran, and Henry 2015)
- British Standards (BS) EN 16893:2018: Conservation of Cultural Heritage: Specifications for Location, Construction and Modification of Buildings or Rooms Intended for the Storage or Use of Heritage Collections (BSI 2018)
- ASHRAE handbook, chapter 24, "Museums, Galleries, Archives, and Libraries" (ASHRAE 2023)
- Australian Institute for the Conservation of Cultural Material (AICCM) Environmental Guidelines (AICCM 2022)
- Bizot Green Protocol, updated in 2023 by the National Museum Directors' Council (Bizot Group 2023)

Light

Handheld measurements of visible and UV light were recorded on a floor plan of the museum, with the data at each location reflecting the five sensor orientations as noted above.

Continuous solar radiation data were collected in the library lantern (connected to CGMAG2), as were directional solar data at the weather station on the museum's roof (connected to CGMAG1). These datasets were compared using time series.

Analysis of the Blue Wool coupons focused on the color difference of BW1 (the most light-sensitive wool) between area A (twelve months of light exposure) and area D (control) and visualized the data using bar charts.

Particulates

Monthly average PM_{10} data (particulate matter with a diameter of 10 µm or smaller) were obtained for sector 17-C (the closest location with data) from the Chandigarh Pollution Control Committee (CPCC). To facilitate comparison, the interior PM_{10} data, which were collected in the library at one-minute intervals, were recalculated as a monthly average. Both the one-minute data and monthly PM_{10} data were visualized using time series.

Pollution

Analysis of the copper and silver CCCs by Purafil resulted in a class designation for each, ranging from class 1 (Extremely Pure) to class 5 (Polluted). These coarse pollution levels were visualized using bar charts.

Results

The discussion of environmental monitoring data collected at the Government Museum and Art Gallery focuses on the following topics:

- Exterior climate
- Gallery comparison
- Gallery and storage comparison
- Gallery and case comparison
- Daily variation
- Data distribution
- Seasonal variation
- Stratification of the Great Hall
- Particulates and pollution
- Light measurements

Exterior Climate

The outside climate is a driving factor for the interior conditions at the Government Museum and Art Gallery. This climate is defined by five distinct seasons, shown in figure 4.8 in alignment with exterior air temperature, dew point, and relative humidity from March 2020 to March 2021.

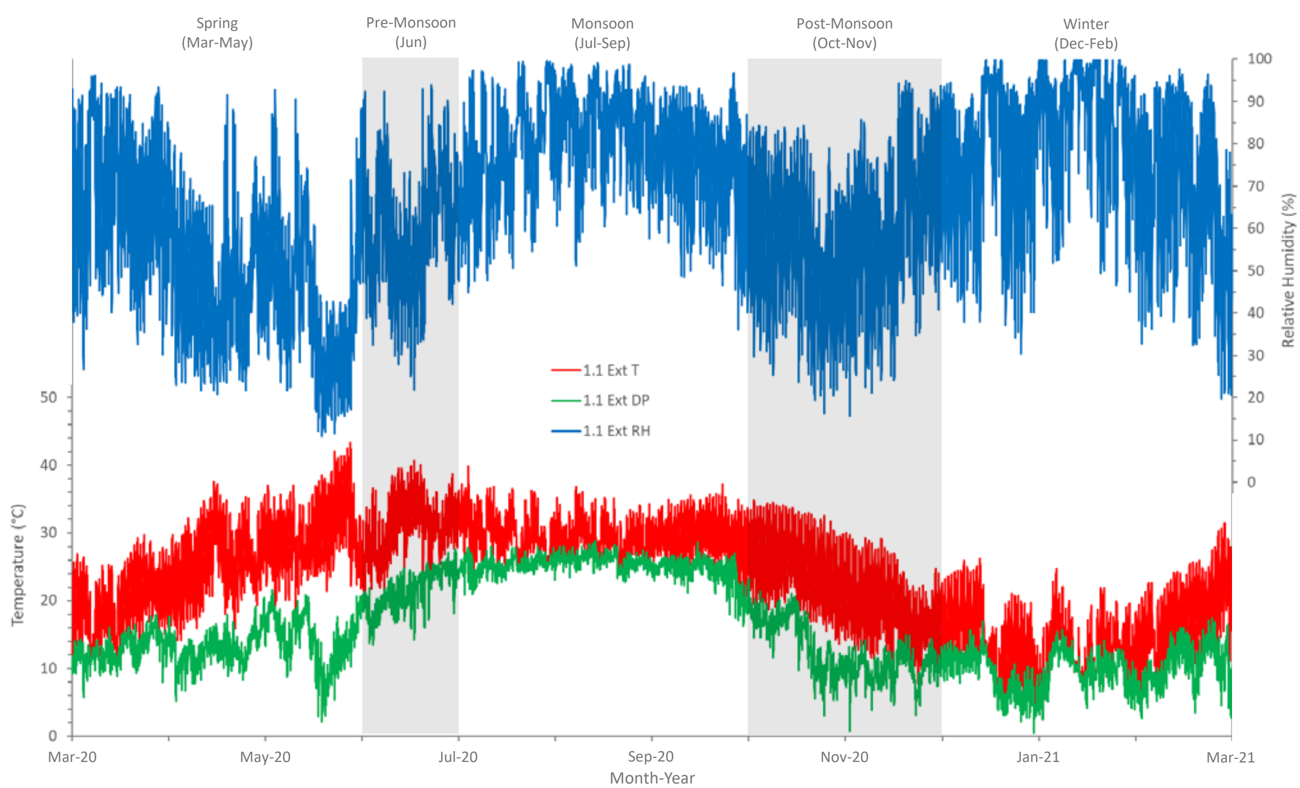


FIGURE 4.8.
Exterior air temperature, relative humidity, and dew point (calculated), using data collected from the museum's weather station. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

As indicated in figure 4.8, air temperature increases through spring (March to May), peaking at 43.4°C near season's end, and stays relatively constant (though slightly lower) through pre-monsoon (June) and monsoon (July to September). Subsequently, air temperature decreases through post-monsoon (October to November) to a minimum of 2.5°C in winter (December to February).

Following a period of fluctuation during spring, dew point steadily increases during pre-monsoon and remains relatively constant during monsoon, peaking at 28.8°C. Dew point then decreases steadily during post-monsoon to a minimum of 0.4°C in winter, when it begins to fluctuate again.

Prolonged periods of high relative humidity occur during the monsoon and winter months, when air temperature and dew point are similar. Note that dew point is less than or equal to air temperature, and saturation or 100%RH occurs when air temperature and dew point are the same. Air temperature and dew point coincide at high values during monsoon, and at low values during winter. Periods of lower relative humidity are observed in spring, pre-monsoon, and post-monsoon, when air temperature and dew point diverge.

Gallery Comparison

Beyond the collections they house, the museum's first-floor galleries are differentiated by their climate control strategies. The Miniatures Gallery is a physically isolated space air-conditioned by a mechanical climate control system. In contrast, the remaining galleries, including both Contemporary Art Galleries and the Gandhara Sculptures Gallery, rely on the building's architecture and envelope to manage their environment and do not have mechanical air-conditioning. Despite these differences, review of the data from March 2020 to March 2021 suggests that the environments in the galleries with and without air-conditioning were largely identical. It should be noted that a difference was observed in the Miniatures Gallery data from around 6 July to 6 August, with slightly cooler temperatures compared to the Contemporary Art Galleries and Gandhara Sculptures Gallery; recall that this set of data is from the same period in 2021 and was used to fill a gap in the 2020 dataset.

All gallery spaces in the museum closely follow the trends in exterior air temperature, humidity ratio, and relative humidity. However, the building envelope clearly has a buffering effect on the interior variations in air temperature and relative humidity, while interior humidity ratio closely matches exterior values (fig. 4.9). The interior air temperature exhibits a narrower daily variation (mean rolling 24-hour range: 0.9°C) than the exterior air temperature (mean rolling 24-hour range: 11.5°C), with the interior air temperature situated toward the higher end of the exterior temperature range (fig. 4.10). Interior relative humidity similarly shows a narrower variation (mean rolling 24-hour range: 7%RH) when compared to the exterior (mean rolling 24-hour range: 39%RH), with interior relative humidity situated toward the lower end of the exterior relative humidity range (fig. 4.11).

As an example of the typical environment observed in gallery spaces, figure 4.12 shows air temperature, dew point, and relative humidity in the Miniatures Gallery. The exterior data reveal relative humidity peaks during monsoon and winter, when the differential between dew point and air temperature is small.

Gallery and Storage Comparison

The ground-floor storage for the miniatures collection is mechanically air-conditioned, and the impact of this system can be observed in the dew point, air temperature, and relative humidity data.

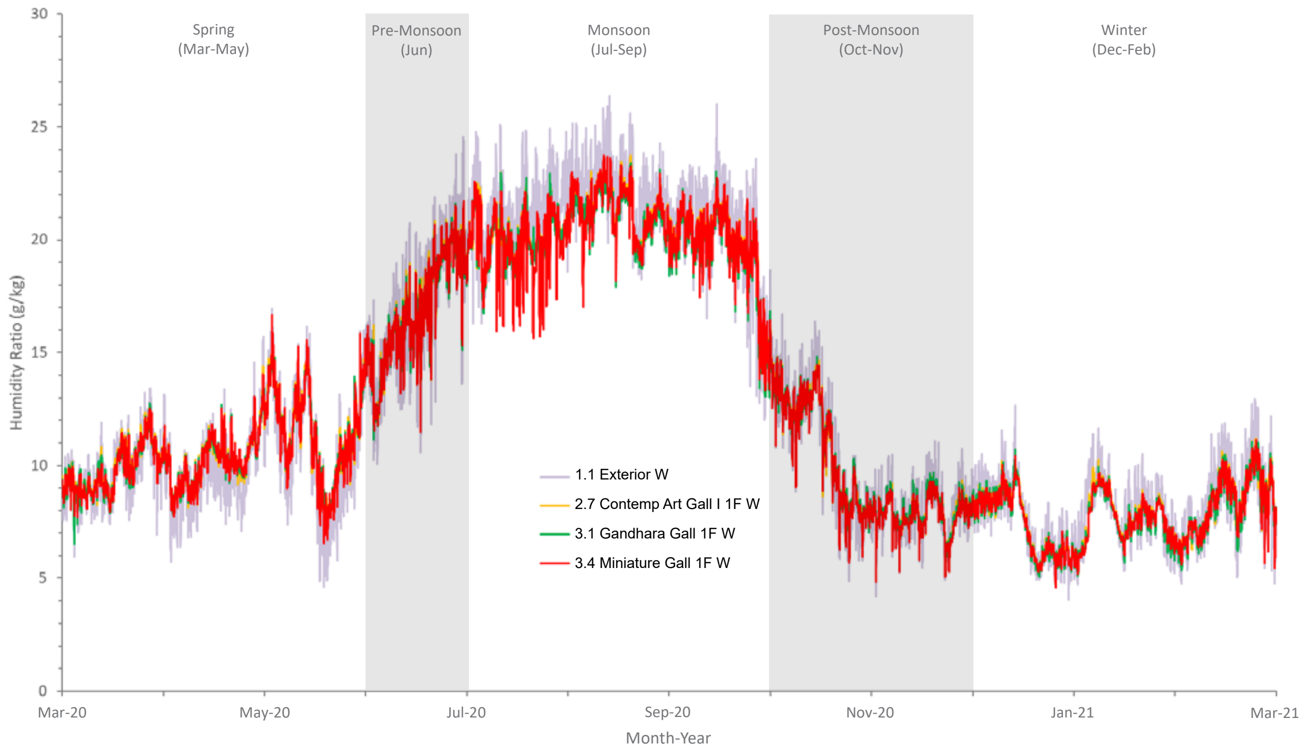


FIGURE 4.9.

Humidity ratio in galleries and the exterior. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

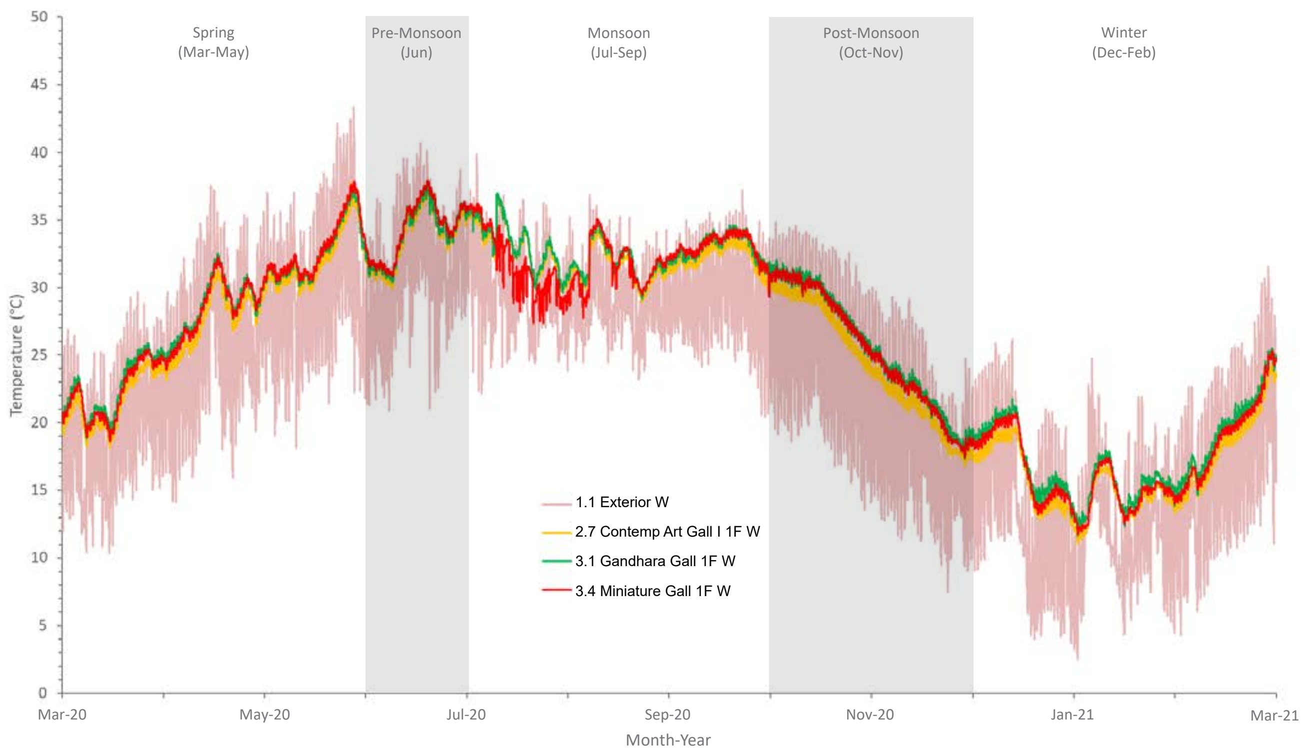


FIGURE 4.10.

Air temperature in galleries and the exterior. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

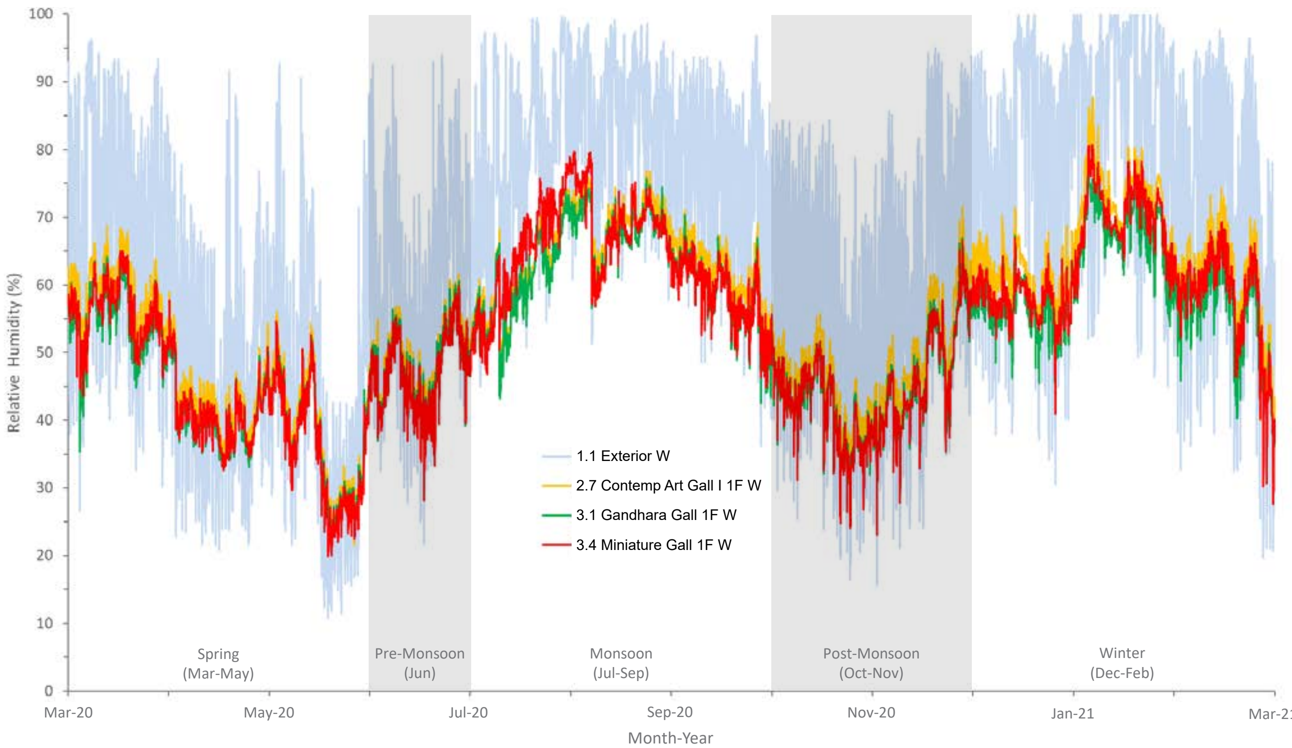


FIGURE 4.11.
Relative humidity in galleries and the exterior. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

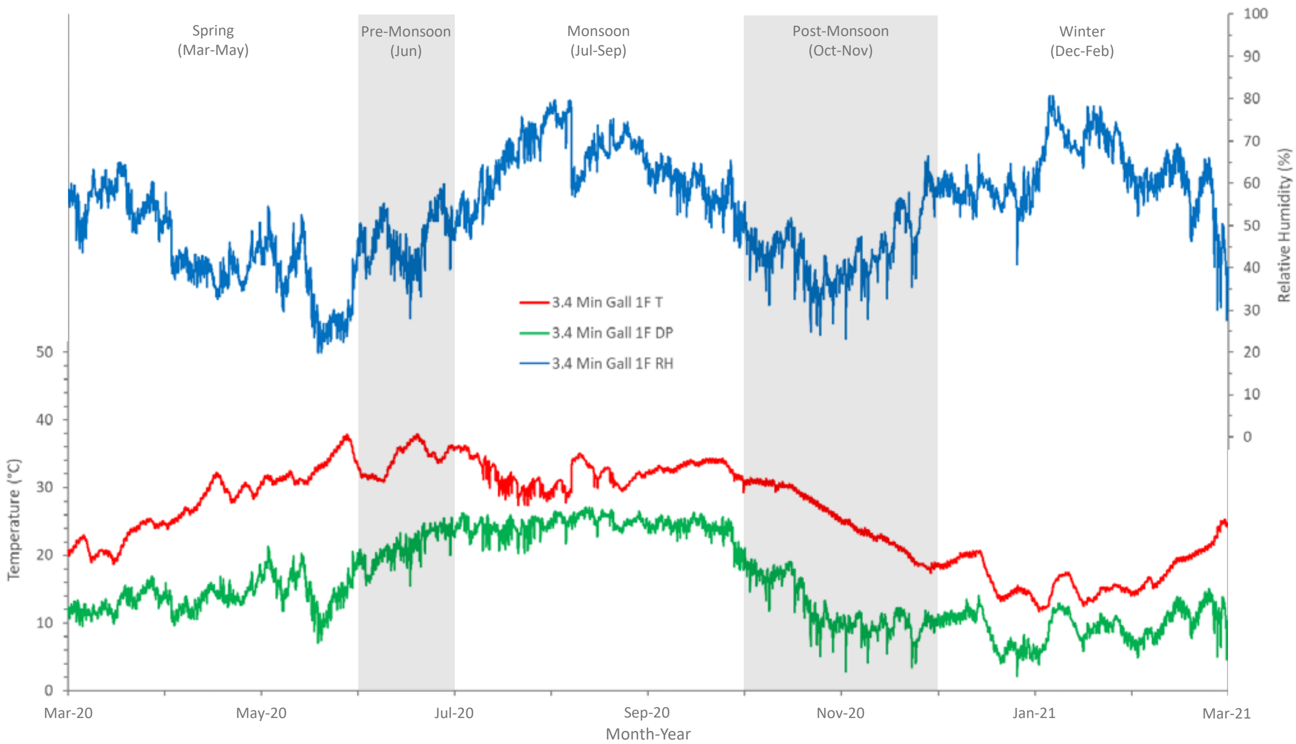


FIGURE 4.12.
Air temperature, dew point, and relative humidity in the Miniatures Gallery. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

From early spring to late post-monsoon (coinciding with the warmest exterior temperatures), the air temperature of the storage is significantly reduced compared to that of the Miniatures Gallery; during winter, storage and gallery air temperature is similar (though storage temperature is slightly higher) (fig. 4.13). With respect to humidity ratio, storage values are lower than those in the gallery from late pre-monsoon to the middle of post-monsoon season (coinciding with the highest exterior humidity ratios) (fig. 4.14).

Compared to the gallery, relative humidity in storage is relatively stable (fig. 4.15). The interquartile range (IQR) (defined by the 25th and 75th percentiles) for storage relative humidity ranges from 53% to 60%, with a maximum of 74%. In contrast, the IQR for gallery relative humidity is 44% to 62%, with a maximum of 81%. The stability of storage relative humidity is reflected in the more consistent difference between dew point and air temperature (fig. 4.16).

Gallery and Case Comparison

Within the gallery spaces, cases are used for the display and physical protection of objects. These cases can also establish a microclimate that can be different than the gallery environment. The environmental monitoring program at the Government Museum and Art Gallery examined several display cases, and the findings below compare their interior conditions—focusing on cases in the Coin Section and Miniatures Gallery—to the ambient conditions in the Miniatures Gallery.

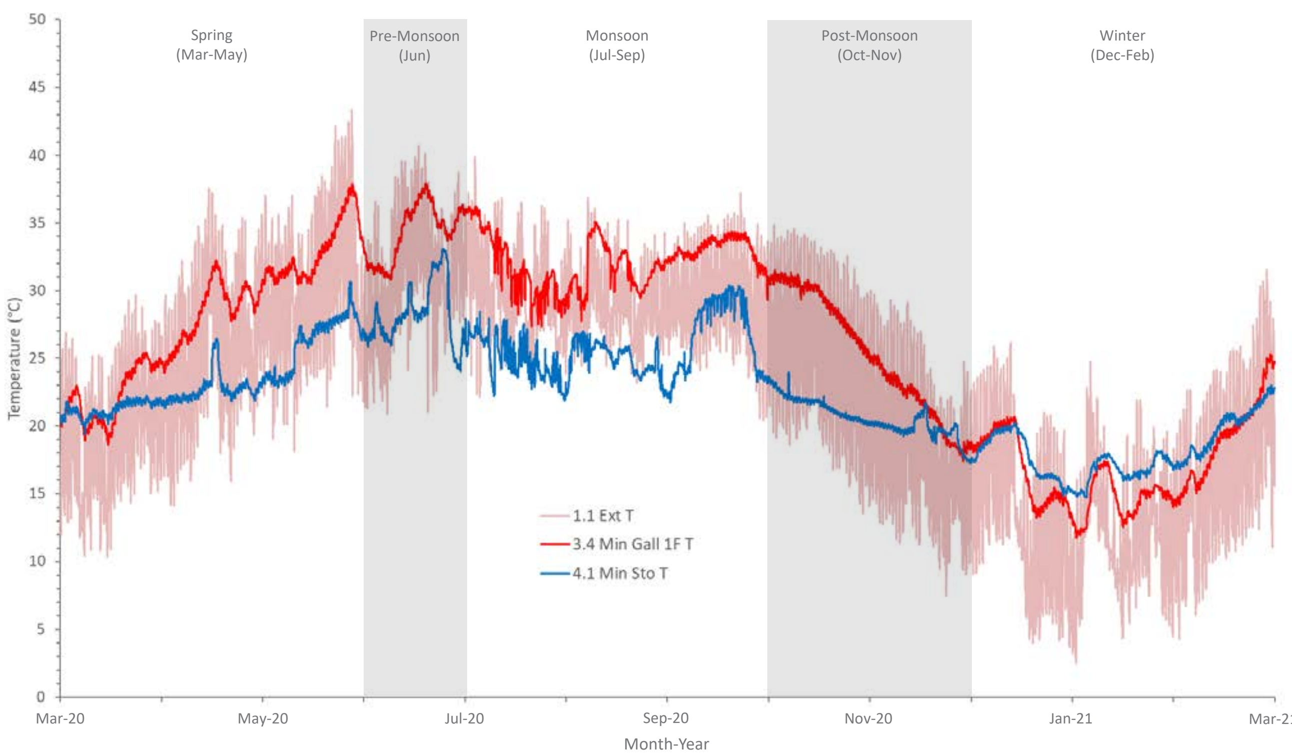


FIGURE 4.13.
Air temperature in the Miniatures Gallery, miniatures storage, and the exterior. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

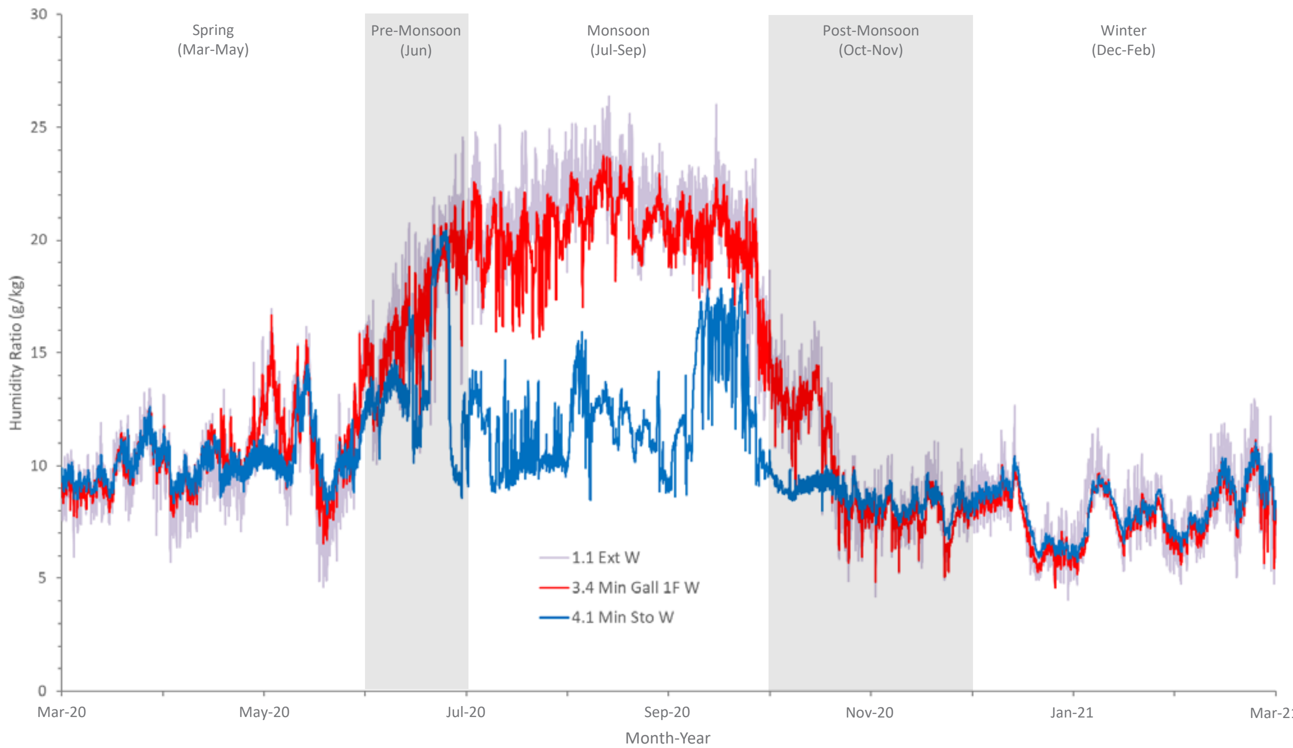


FIGURE 4.14.
Humidity ratio in the Miniatures Gallery, miniatures storage, and the exterior. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

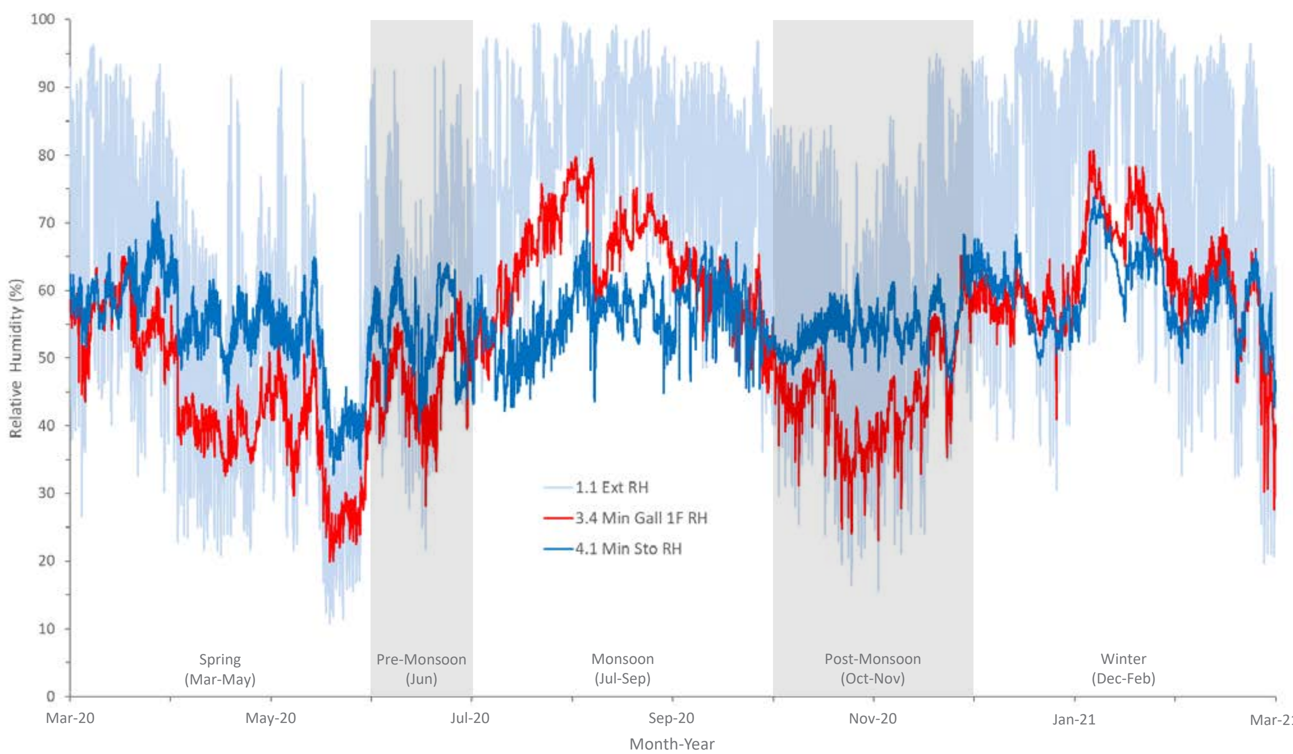


FIGURE 4.15.
Relative humidity in the Miniatures Gallery, miniatures storage, and the exterior. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

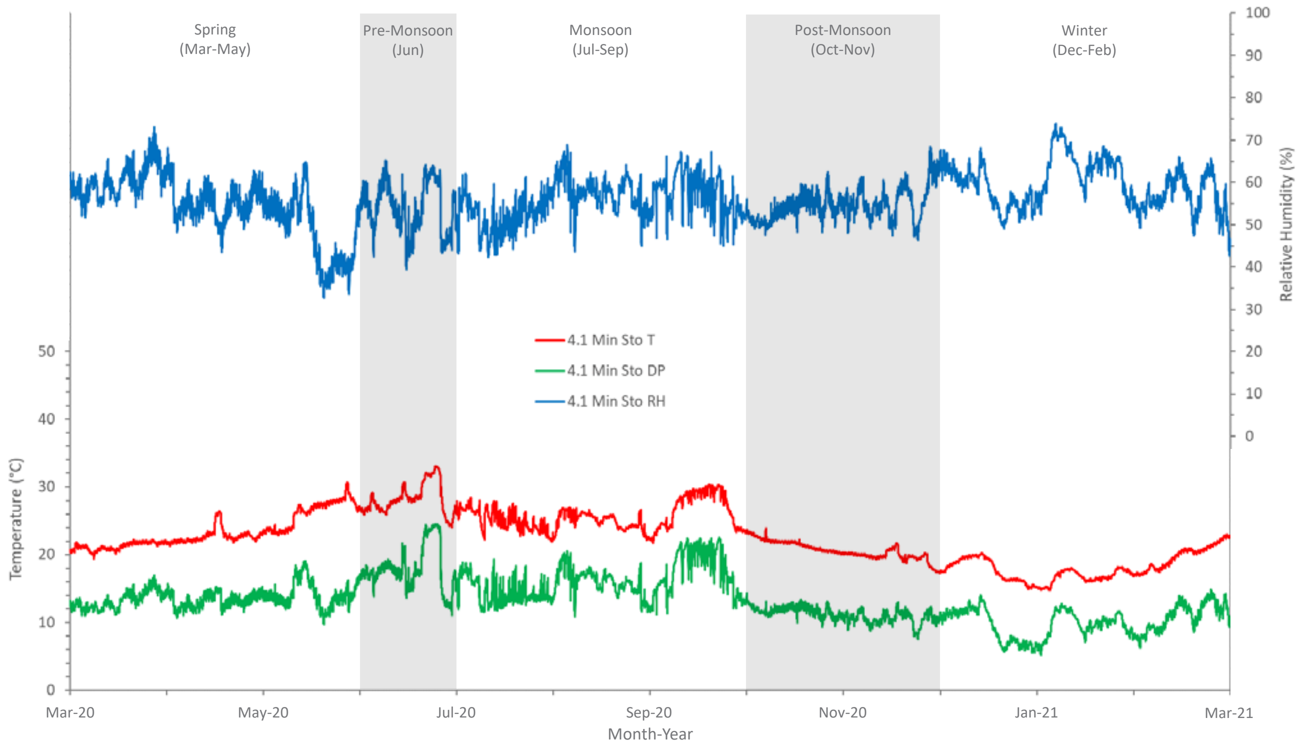


FIGURE 4.16.

Air temperature, dew point, and relative humidity in the miniatures storage. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

With respect to air temperature, the interior of a display case closely matches the ambient gallery conditions throughout the year (fig. 4.17). This indicates that the case materials provide little thermal insulation against the gallery environment. However, the humidity ratio within the case, which reflects the interior moisture content, begins to deviate from the humidity ratio of the gallery; in particular, the daily variation in case humidity ratio (mean rolling 24-hour range: 1.0 g/kg for miniatures case, 0.8 g/kg for coins case) is smaller than that in gallery humidity ratio (mean rolling 24-hour range: 2.0 g/kg) (fig. 4.18). Case relative humidity shows a similar trend, with the daily variation within the case (mean rolling 24-hour range: 1.2%RH for miniatures case, 1.8%RH for coins case) below that of the gallery space (7.1%) (fig. 4.19). Additionally, the range of relative humidity in the miniatures and coins cases (minimum and maximum of ~40%RH and ~67%RH, respectively) is less than that in the Miniatures Gallery (minimum and maximum of ~20%RH and ~80%RH, respectively), and case relative humidity exhibits a delayed trend compared to gallery conditions. Figure 4.20 shows data results of the interaction of air temperature and dew point in the miniatures case and its resulting relative humidity behavior.

Daily Variation

The exterior climate is a driving factor for interior conditions, but the building envelope and operation can mitigate this impact, particularly in the short term. This interaction was examined by comparing the daily variation in air temperature and relative humidity outside and inside the museum. Rather than rely on daily or weekly time series, which can vary with changing environments, the following analysis considers two one-month periods—mid-August to mid-September 2020 during monsoon, and mid-October to mid-November 2020 during post-monsoon—and focuses

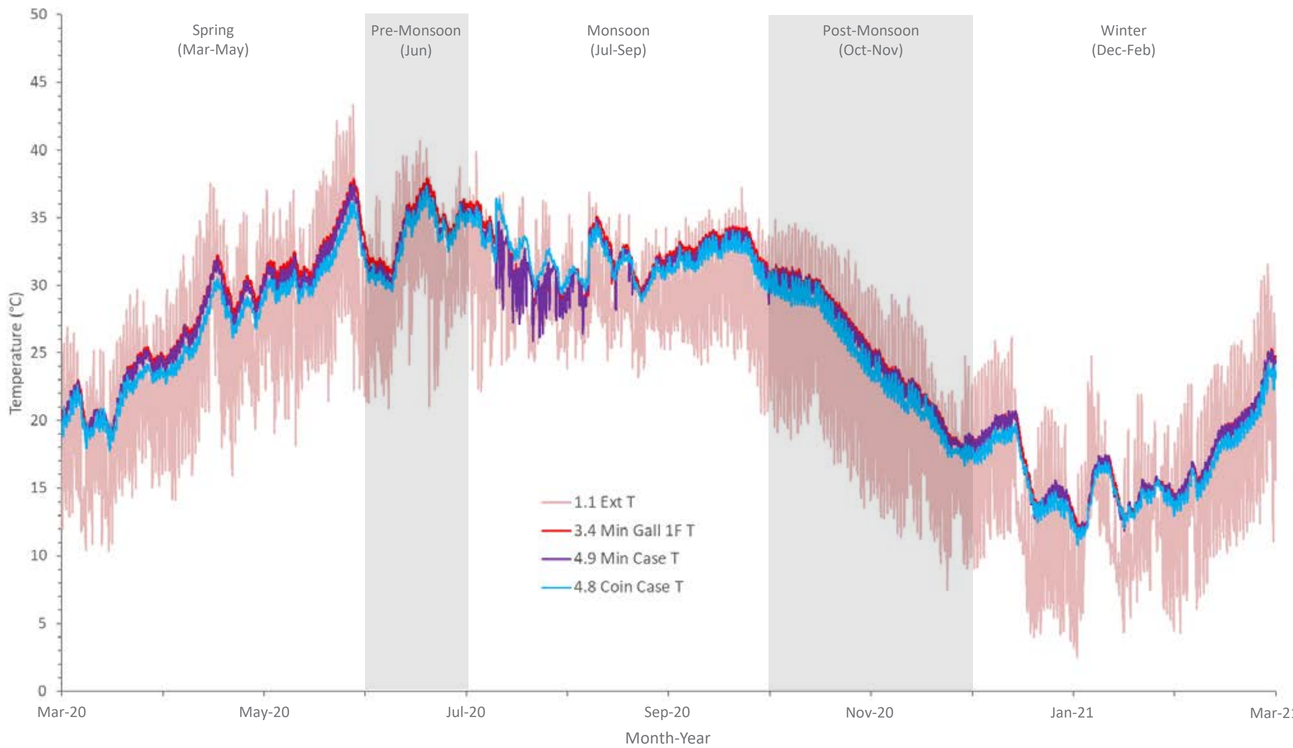


FIGURE 4.17.

Air temperature in the Miniatures Gallery, miniatures case, coins case, and the exterior. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

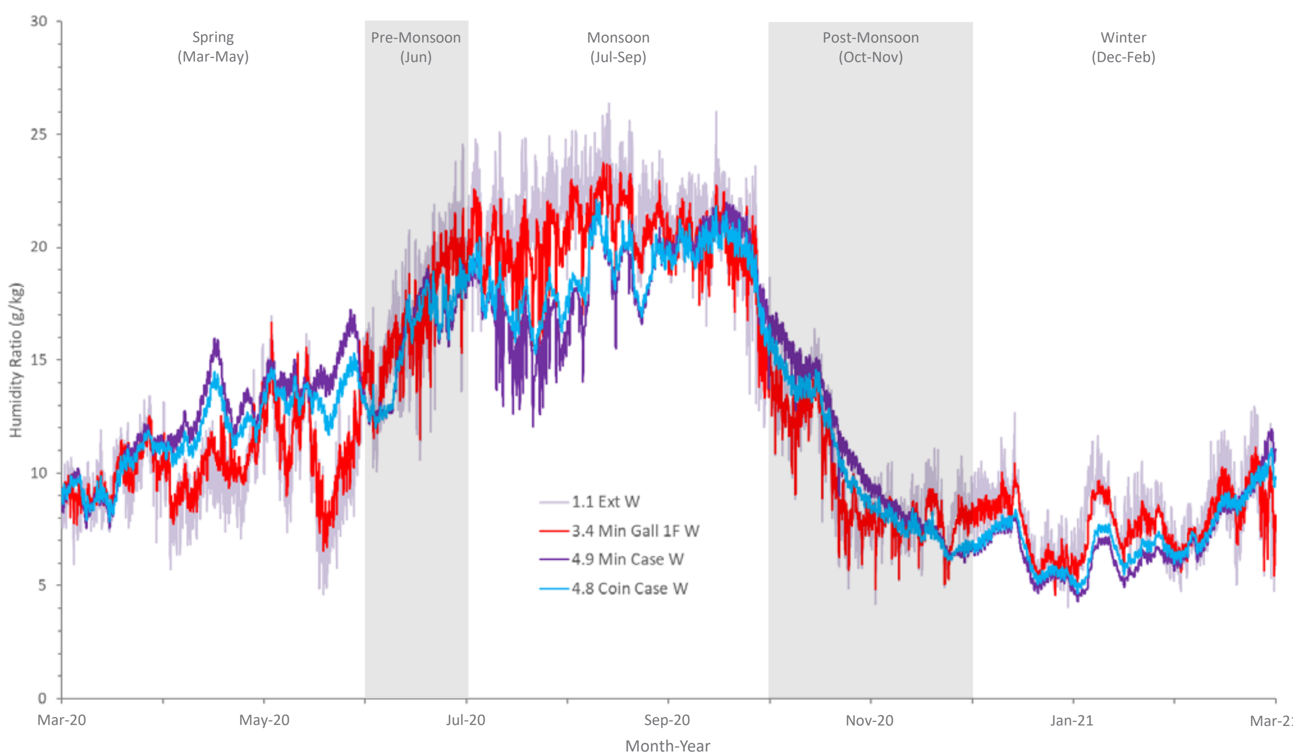


FIGURE 4.18.

Humidity ratio in the Miniatures Gallery, miniatures case, coins case, and the exterior. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

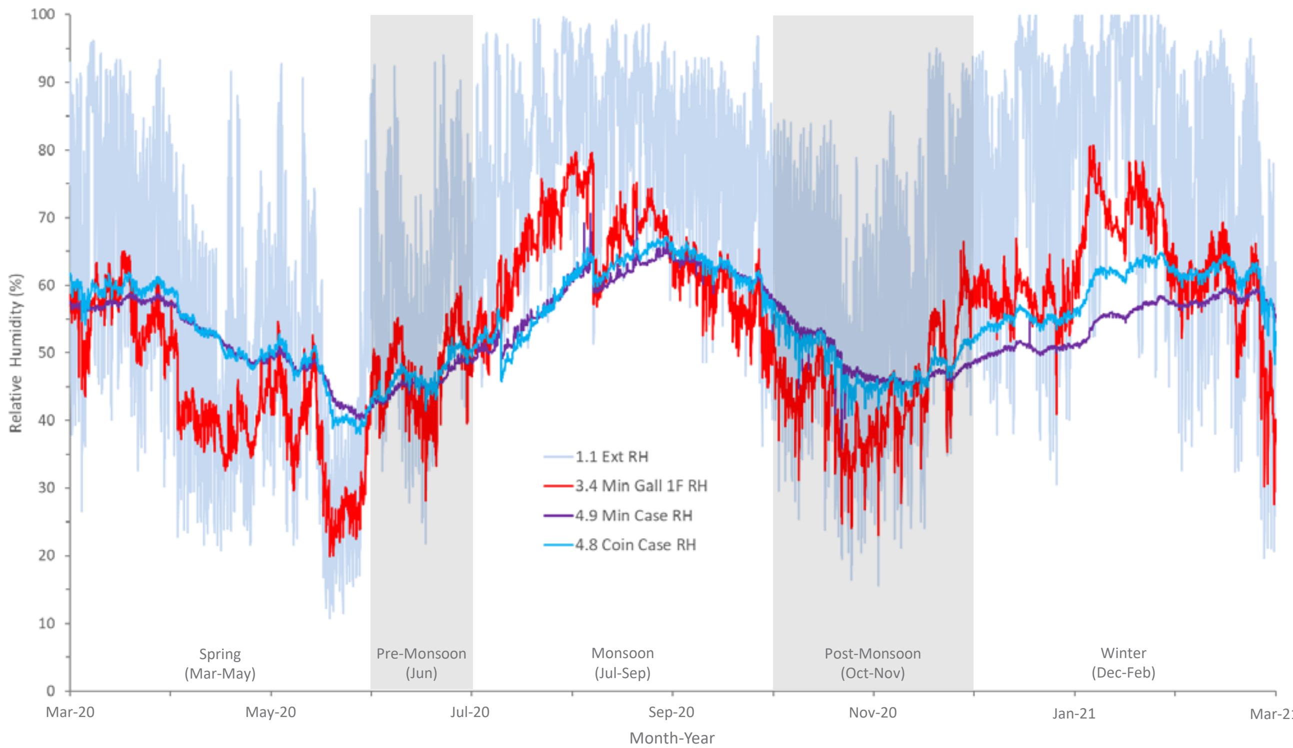


FIGURE 4.19.
Relative humidity in the Miniatures Gallery, miniatures case, coins case, and the exterior. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

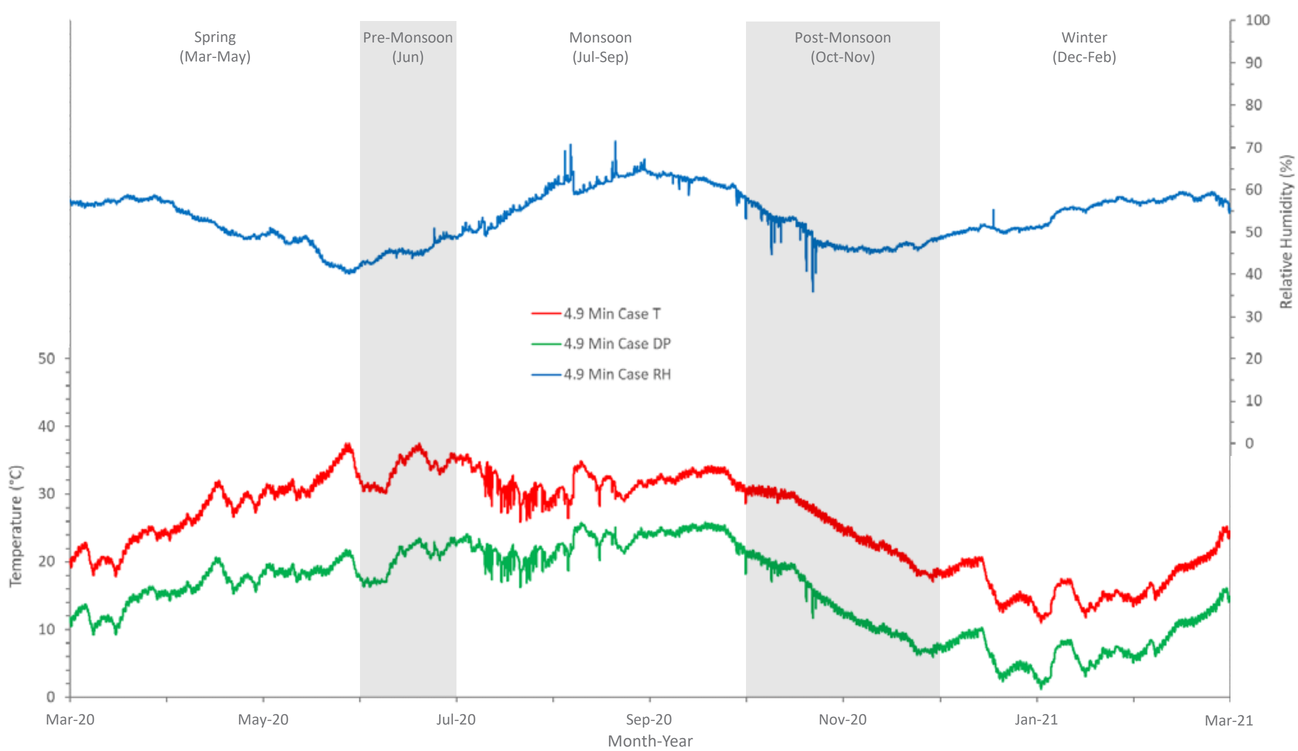


FIGURE 4.20.
Air temperature, dew point, and relative humidity in the miniatures case. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

on exterior and Miniatures Gallery data. These two seasons were selected because they exhibit different environmental trends; monsoon air temperature and relative humidity are near the annual peak and are relatively constant, whereas these variables transition to lower values during the subsequent post-monsoon (relative humidity increases again as winter approaches). The Miniatures Gallery data are further separated into data collected on the days the museum is closed (Mondays) and the days it is open (Tuesday to Sunday). These three datasets were then binned hourly and box plots created to visualize the daily variation over these one-month periods.

As expected, exterior air temperature and relative humidity exhibit strong diurnal variation. Exterior air temperature peaks at 14:00 (median values: 33.1°C in monsoon, 29.4°C in post-monsoon) and is at its lowest at 05:00 and 06:00 (median values: 26.1°C in monsoon, 14.9°C in post-monsoon) (figs. 4.21, 4.22). Relative humidity shows the opposite trend, with peak values observed at 06:00 and 07:00 (median values: 92%RH in monsoon, 73%RH in post-monsoon) and minimum values occurring from 14:00 to 16:00 (median values: 66%RH in monsoon, 27%RH in post-monsoon) (figs. 4.23, 4.24).

In contrast, the interior air temperature and relative humidity indicate relatively stable conditions. Median interior air temperature has a daily range of 0.7°C on closed days and 0.5°C on open days during monsoon (exterior daily median range during monsoon: 5°C), and 0.7°C (closed/open) during post-monsoon (exterior daily median range during post-monsoon: 14.5°C) (see figs. 4.21, 4.22). For interior relative humidity, median values show a daily range of 3%RH (closed) and 1%RH (open)

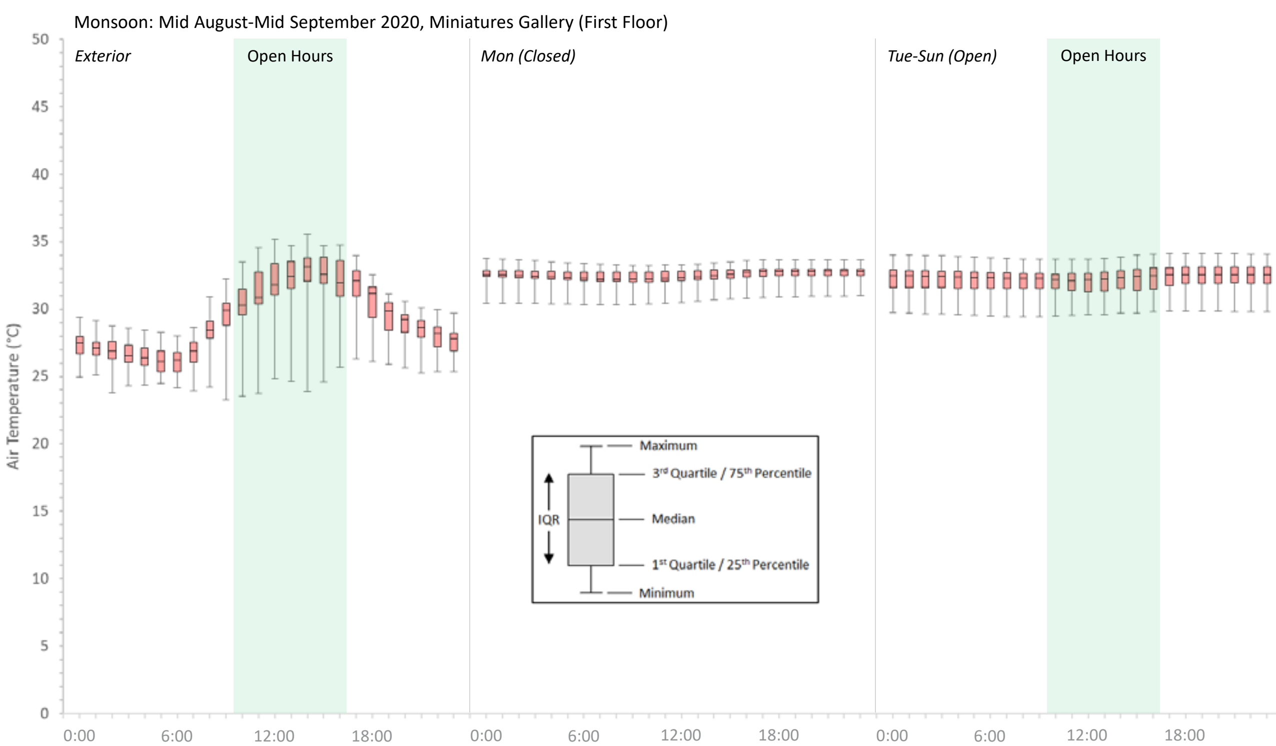


FIGURE 4.21.

Hourly air temperature box plots for data collected from mid-August to mid-September 2020 (monsoon season). From left: exterior, Miniatures Gallery on closed Mondays, and Miniatures Gallery on open days. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

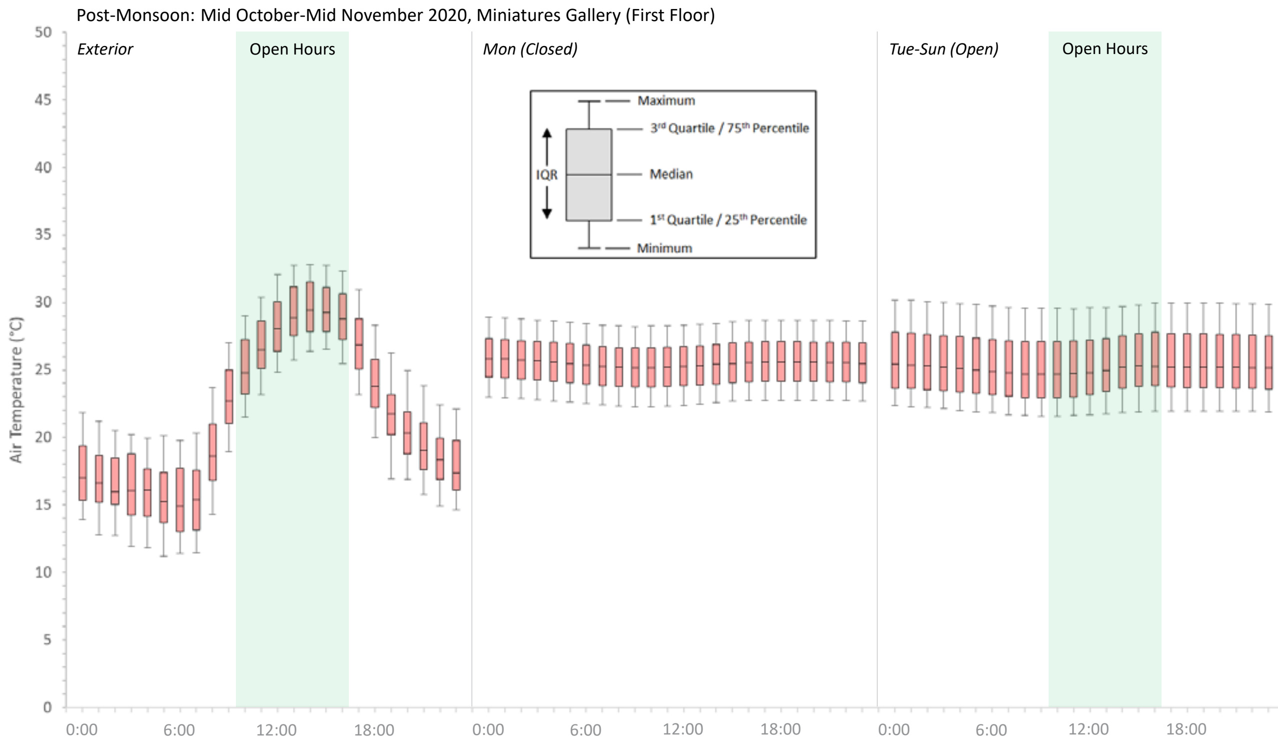


FIGURE 4.22.

Hourly air temperature box plots for data collected from mid-October to mid-November 2020 (post-monsoon season). From left: exterior, Miniatures Gallery on closed Mondays, and Miniatures Gallery on open days. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

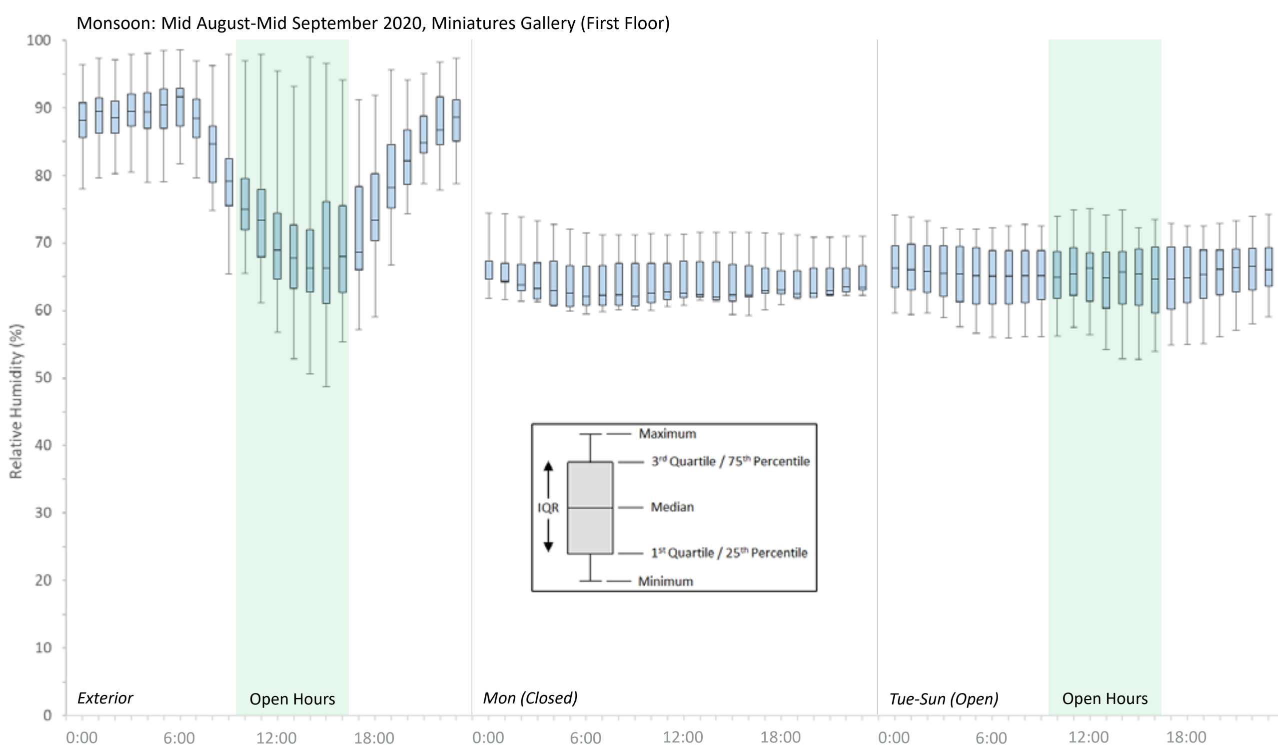


FIGURE 4.23.

Hourly relative humidity box plots for data collected from mid-August to mid-September 2020 (monsoon season). From left: exterior, Miniatures Gallery on closed Mondays, and Miniatures Gallery on open days. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

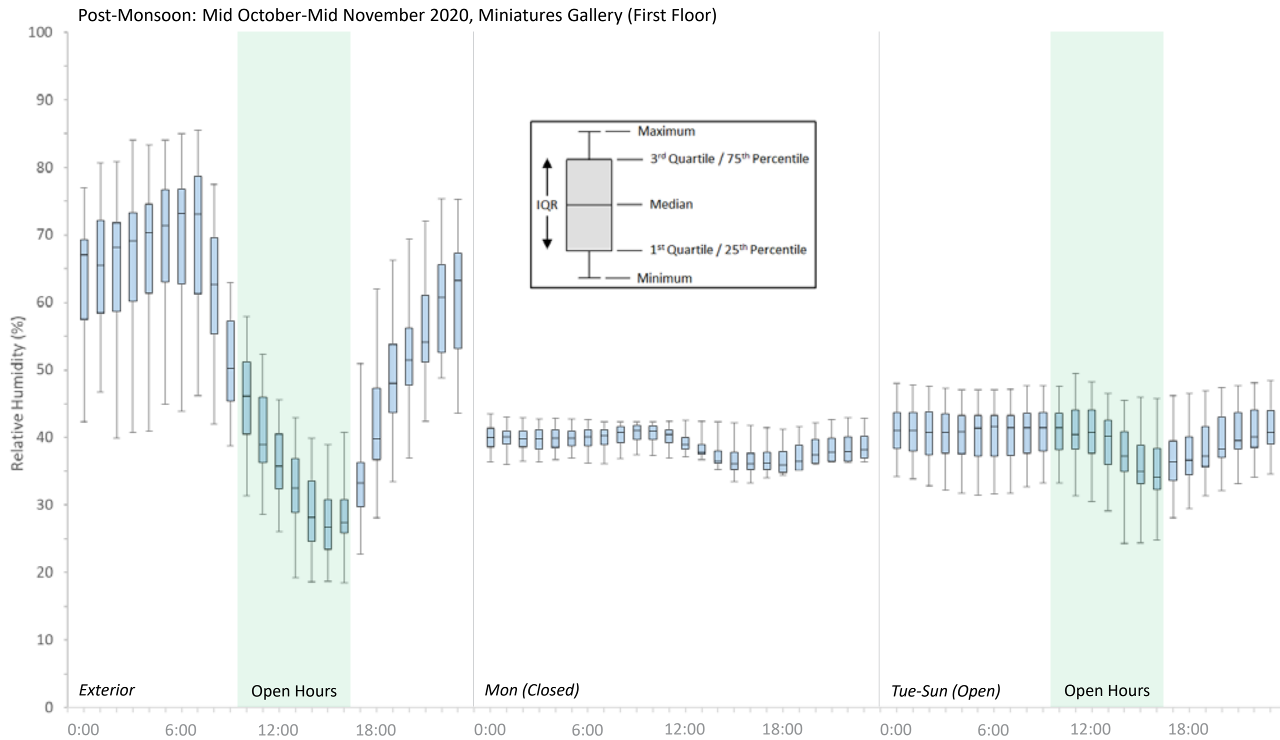


FIGURE 4.24.

Hourly relative humidity box plots for data collected from mid-October to mid-November 2020 (post-monsoon season). From left: exterior, Miniatures Gallery on closed Mondays, and Miniatures Gallery on open days. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

during monsoon (exterior daily median range during monsoon: 26%RH), and 5%RH (closed) and 6%RH (open) during post-monsoon (exterior daily median range during post-monsoon: 46%RH) (see figs. 4.23, 4.24).

When examining interior conditions during closed and open periods, we also see a wider variability in air temperature and relative humidity during both seasons when the museum is open for visitation.

Data Distribution

Examinations beyond the time-series domain can offer additional insights into the environmental data. Figures 4.25 and 4.26 show plots of cumulative relative frequency (CRF) for air temperature and relative humidity, respectively. These figures allow the exploration of the spread or distribution of data and, assuming the data are continuous (as the Government Museum and Art Gallery data are), can indicate percentages of time above or below specific thresholds.

Focusing on air temperature, thresholds of 35°C, 30°C, and 25°C were chosen as a means of comparing exterior and interior trends (see fig. 4.25). While 4% (CRF = 0.96) of the exterior data exceeds 35°C, this value is exceeded in 7% (CRF = 0.93) and 5% (CRF = 0.95) of the Miniatures Gallery and case data, respectively. In contrast, maximum air temperature (33.1°C) in the miniatures storage never exceeds this threshold. As the threshold is decreased to 30°C, data for the exterior, Miniatures Gallery, and miniatures case exceed this 23%, 44%, and 40% of the time, respectively; the higher percentage of elevated interior temperatures in both the Miniatures Gallery and miniatures

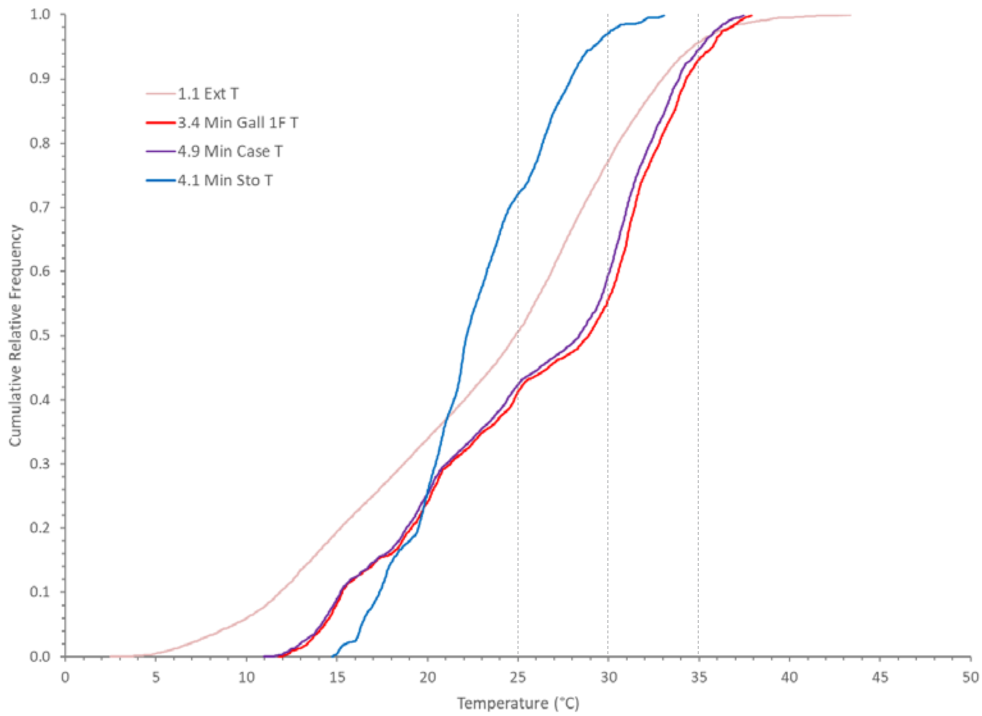


FIGURE 4.25.
Cumulative relative frequency of air temperature for the exterior, Miniatures Gallery, miniatures case, and miniatures storage. Thresholds of 35°C, 30°C, and 25°C are shown on the plot. Chart: Vincent Laudato Beltran and Jenny You-kyoung Kim, © J. Paul Getty Trust.

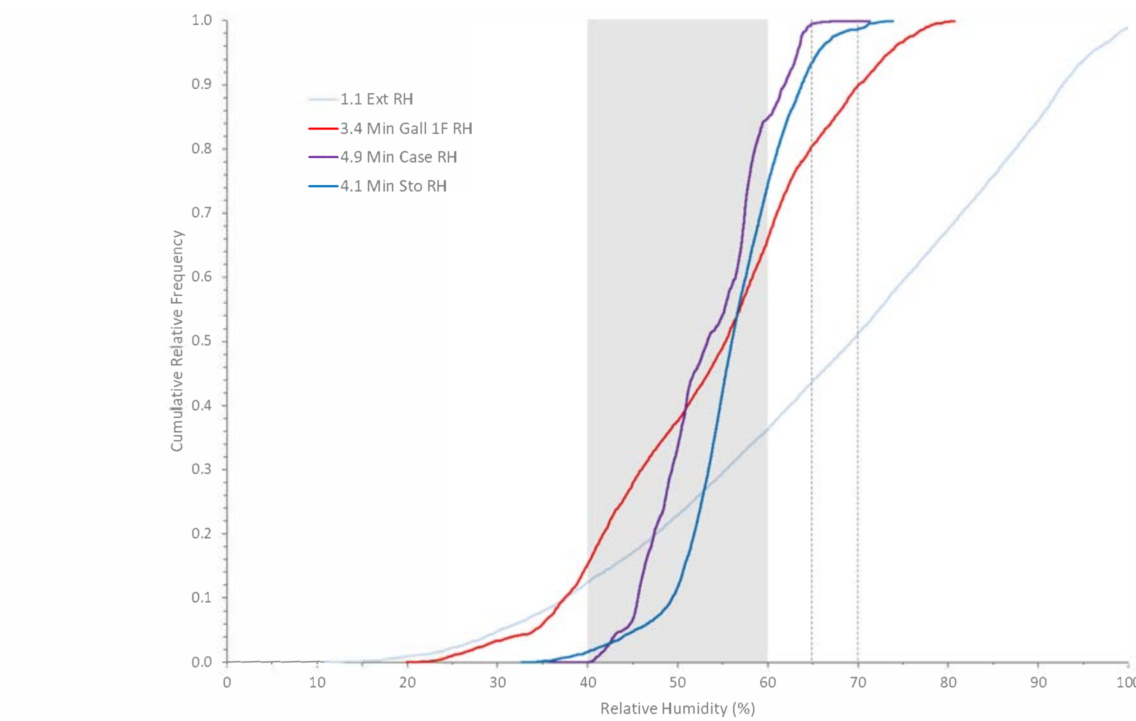


FIGURE 4.26.
Cumulative relative frequency of relative humidity for the exterior, Miniatures Gallery, miniatures case, and miniatures storage. Thresholds of 70%RH, 65%RH, 60%RH, and 40%RH are shown on the plot. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

case reflects the impact of the high thermal mass of the building. In the miniatures storage, where air temperature is controlled by HVAC, 30°C is exceeded by 3% of the data. At a threshold of 25°C, the exterior, Miniatures Gallery, miniatures case, and miniatures storage air temperature exceed this value during 49%, 59%, 58%, and 28% of the period, respectively. The overlapping lines of the air temperatures of the Miniatures Gallery and miniatures case indicate the similarity in behavior in these two spaces.

For relative humidity, values of 70%RH, 65%RH, 60%RH, and 40%RH were selected to explore the data (see fig. 4.26). The first two examine values near the mold growth threshold (~75%RH), while the remaining two roughly define a range of acceptable relative humidity levels for many mixed collections as defined by the Bizot Green Protocol (Bizot Group 2023). While the 70%RH threshold is exceeded in the exterior and Miniatures Gallery by 49% and 10% of the data, respectively, this is reduced to less than 1% for the miniatures case and 1% for miniatures storage, reflecting the ability of the case to limit moisture infiltration and operation of the storage HVAC system. A similar trend is observed for the 65%RH threshold; data for the exterior and Miniatures Gallery exceed this value during 54% and 19% of the period, while this occurs in less than 1% of the miniatures case data and 6% of the miniatures storage data. Focusing on the region between 40%RH and 60%RH, Miniatures Gallery data are within this range during 51% of the period (CRF at 60%RH = 0.66, CRF at 40%RH = 0.15, percentage between 40%RH and 60%RH = 0.66–0.15), while this occurs for 85% and 73% of the miniatures case and storage data, respectively. In contrast to the similar behavior of the air temperature in the Miniatures Gallery and miniatures case shown previously, relative humidity data for the miniatures case more closely align with that observed in miniatures storage.

Seasonal Variation

Overlaying environmental data on a psychrometric chart, as shown in figure 4.27, demonstrates the interconnectedness of air temperature (shown on the x-axis), humidity ratio (right y-axis), and relative humidity (lines of constant relative humidity curving upward and to the right, also known as isohumes). These are part of a suite of psychrometric variables (including dew point, enthalpy, wet bulb temperature, and specific volume) that describe a parcel of air. By identifying the season associated with each data point, environmental shifts can be delineated throughout a year.

During spring (March to May, yellow), air temperature ranges from 18.7°C to 37.8°C (mean: 27.9°C) and humidity ratio ranges from 6.5 g/kg to 16.7 g/kg (mean: 10.5 g/kg); this results in a relative humidity range from 20%RH to 65%RH (fig. 4.27). In the subsequent pre-monsoon (June, red), air temperature (30.8°C to 37.9°C, mean: 34.4°C) and humidity ratio (11.5 g/kg to 21.7 g/kg, mean: 16.8 g/kg) increase, and relative humidity ranges from 28%RH to 60%RH. During monsoon (July to September, orange), air temperature decreases slightly (range: 27.3°C to 36.3°C, mean: 32.2°C) and humidity ratio (range: 12.5 g/kg to 23.8 g/kg, mean: 20.2 g/kg) and relative humidity (range: 43%RH to 80%RH) increase. The following post-monsoon (October to November, green) brings decreases in air temperature (17.4°C to 31.5°C, mean: 25.1°C), humidity ratio (4.8 g/kg to 14.8 g/kg, mean: 9.3 g/kg), and relative humidity (range: 23%RH to 67%RH). Finally, winter (December to February, blue) exhibits further decreased air temperature (range: 11.8°C to 25.3°C, mean: 16.9°C) and a slightly narrower humidity ratio range (4.6 g/kg to 11.1 g/kg, mean: 7.8 g/kg). Because the cooler air temperature is approaching dew point, the relative humidity range widens from 28%RH to 81%RH. Complementing the psychrometric chart, figures 4.28 to 4.30 use box plots to assess the seasonal Miniatures Gallery environment for individual variables.

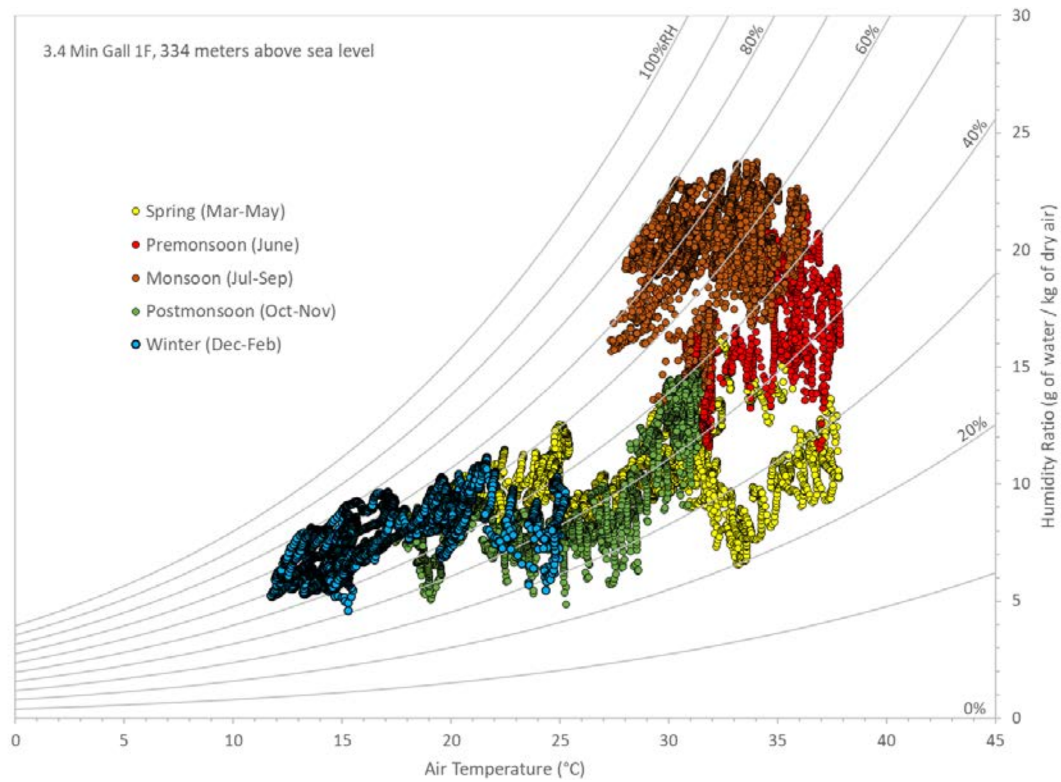


FIGURE 4.27.
Psychrometric chart showing seasonal environments in the Miniatures Gallery. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

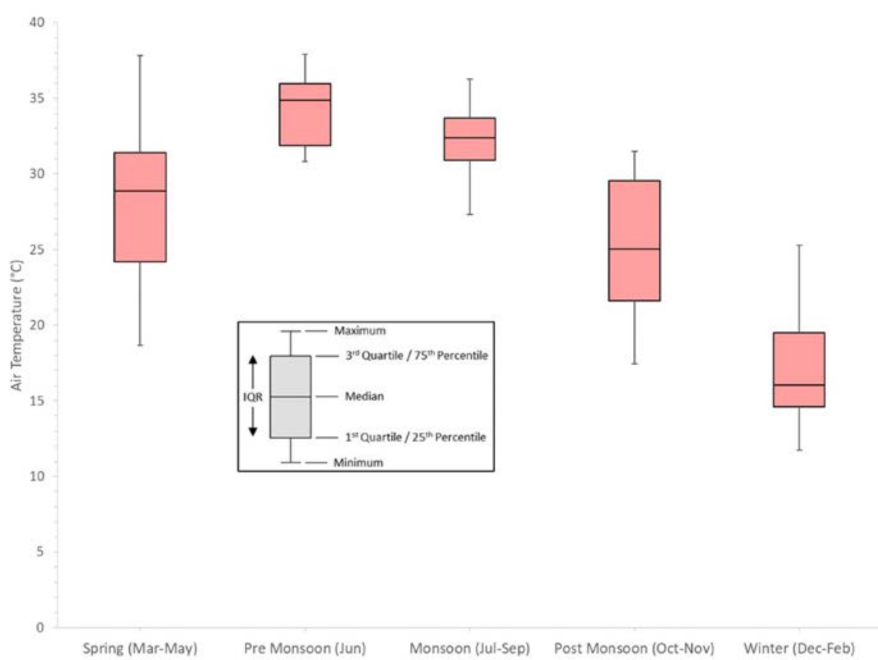


FIGURE 4.28.
Box plots showing seasonal air temperature in the Miniatures Gallery. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

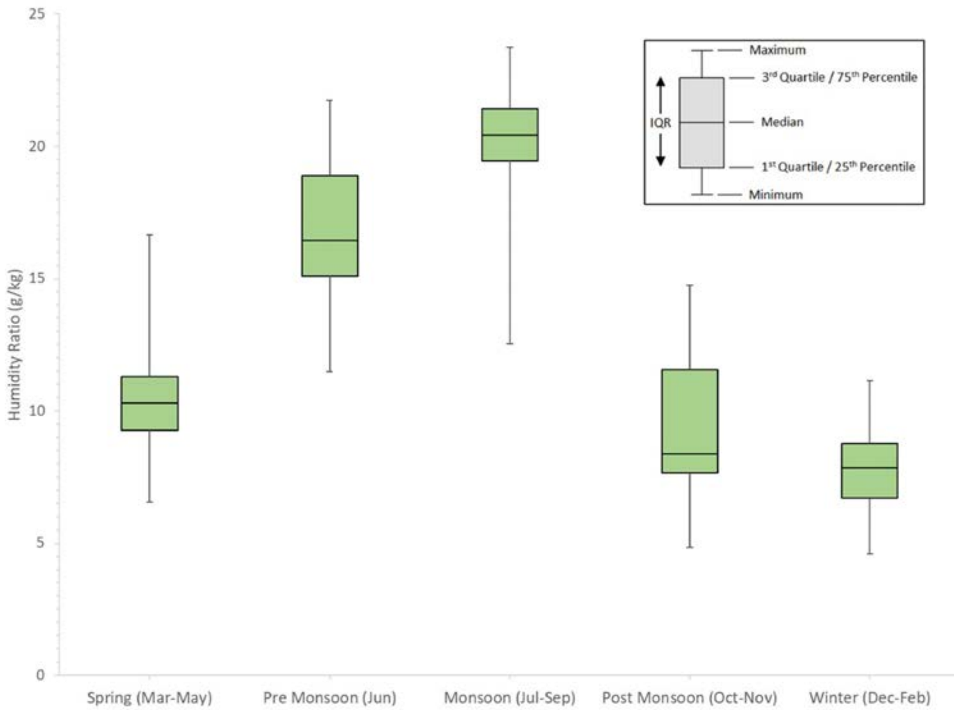


FIGURE 4.29.

Box plots showing seasonal humidity ratio in the Miniatures Gallery. Chart: Vincent Laudato Beltran and Jenny You-kyoung Kim, © J. Paul Getty Trust.

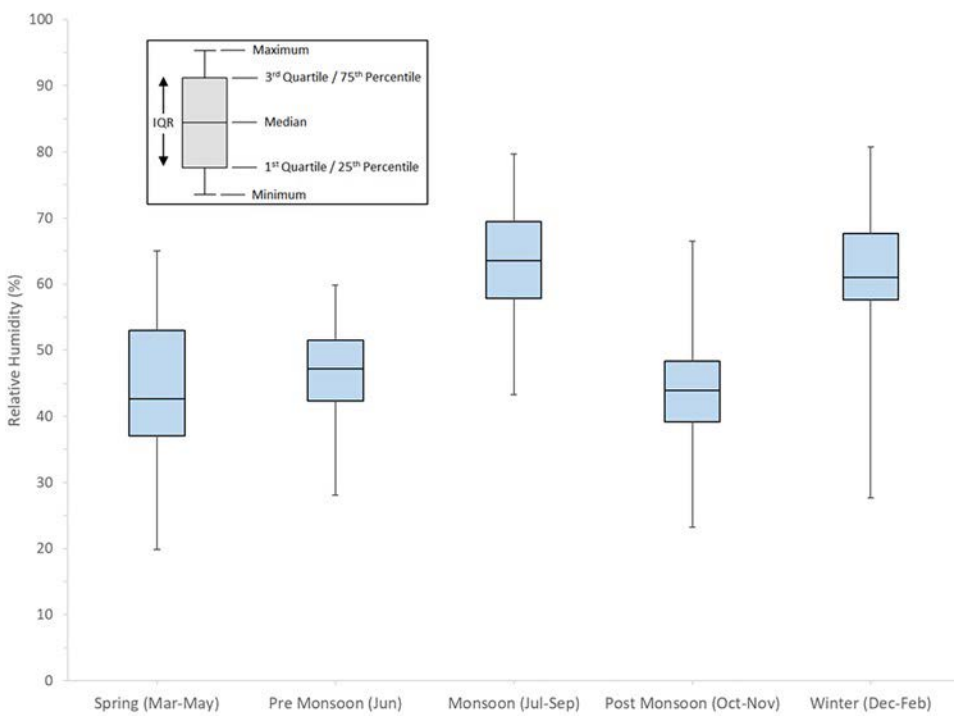


FIGURE 4.30.

Box plots showing seasonal relative humidity in the Miniatures Gallery. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

Stratification of the Great Hall

The Great Hall in the Government Museum and Art Gallery encompasses the full height of the building, and its interior environment is subject to stratification. Figures 4.31 and 4.32 examine air temperature and relative humidity, respectively, in the Great Hall, with data collected at the ground floor, first floor, and second floor. With respect to air temperature, the difference between the second floor and ground floor increases through spring, peaking at 4.8°C in May (see fig. 4.31). This air temperature difference gradually diminishes through the end of post-monsoon, when the difference is negligible (near zero). Near the end of winter, the difference between second-floor and ground-floor air temperature slowly begins to increase. Figure 4.32 shows a similar but reverse trend for relative humidity, with ground-floor relative humidity exceeding second-floor relative humidity by a maximum of 20%RH at the end of spring, to be followed by diminishing stratification through the end of post-monsoon. This indicates the impact that temperature has on relative humidity, with lower temperatures leading to higher relative humidity and vice versa (assuming relatively uniform dewpoint through the Great Hall at any given time).

Particulates and Pollution

The collection and analysis of PM_{10} data from the museum's library indicated a seasonal trend, with peak values (maximum: 975 µg/m^3, collected at one-minute intervals) occurring in winter (fig. 4.33). This trend also aligns with monthly average PM_{10} values recorded by the CPCC for sector 17-C (the closest location with data), which also peaked during winter (Chandigarh Pollution Control Committee 2023). When library PM_{10} data were recalculated as monthly averages, its values were consistently lower than those of sector 17-C.

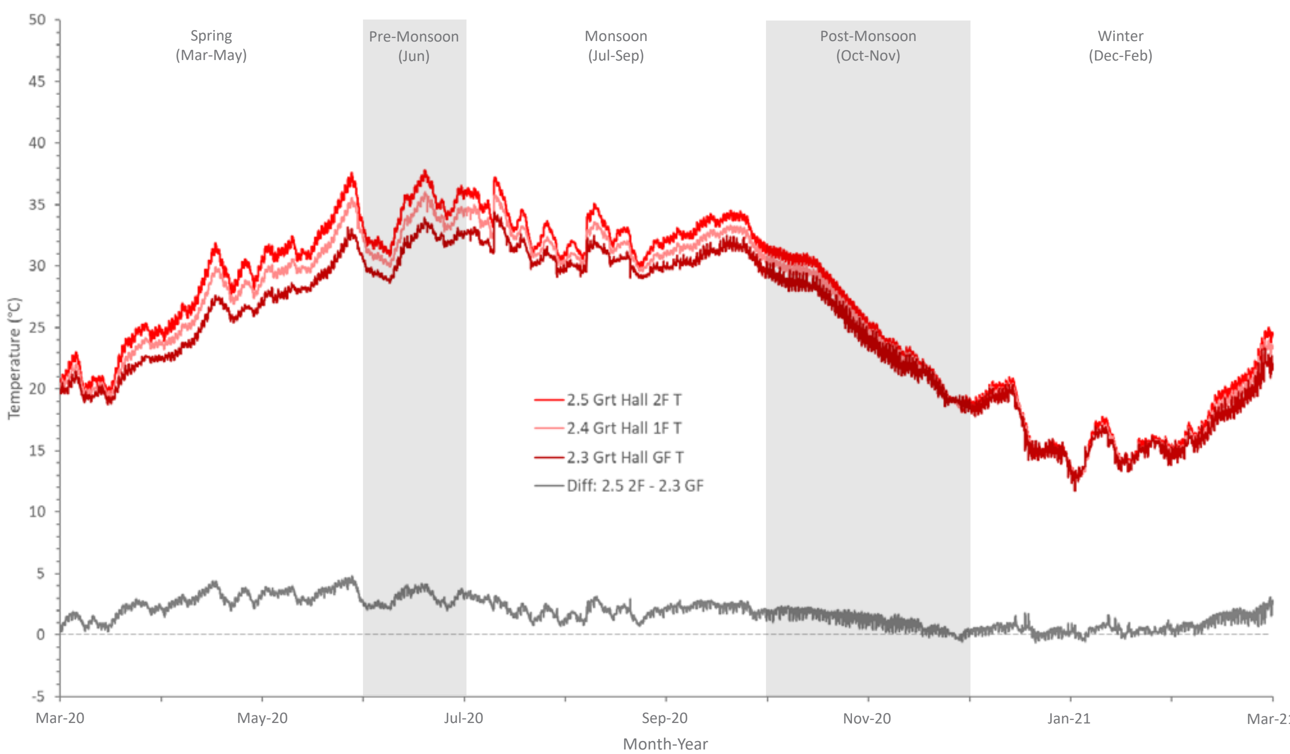


FIGURE 4.31.

Air temperature recorded on the ground floor, first floor, and second floor of the Great Hall, indicating the difference between second-floor and ground-floor values. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

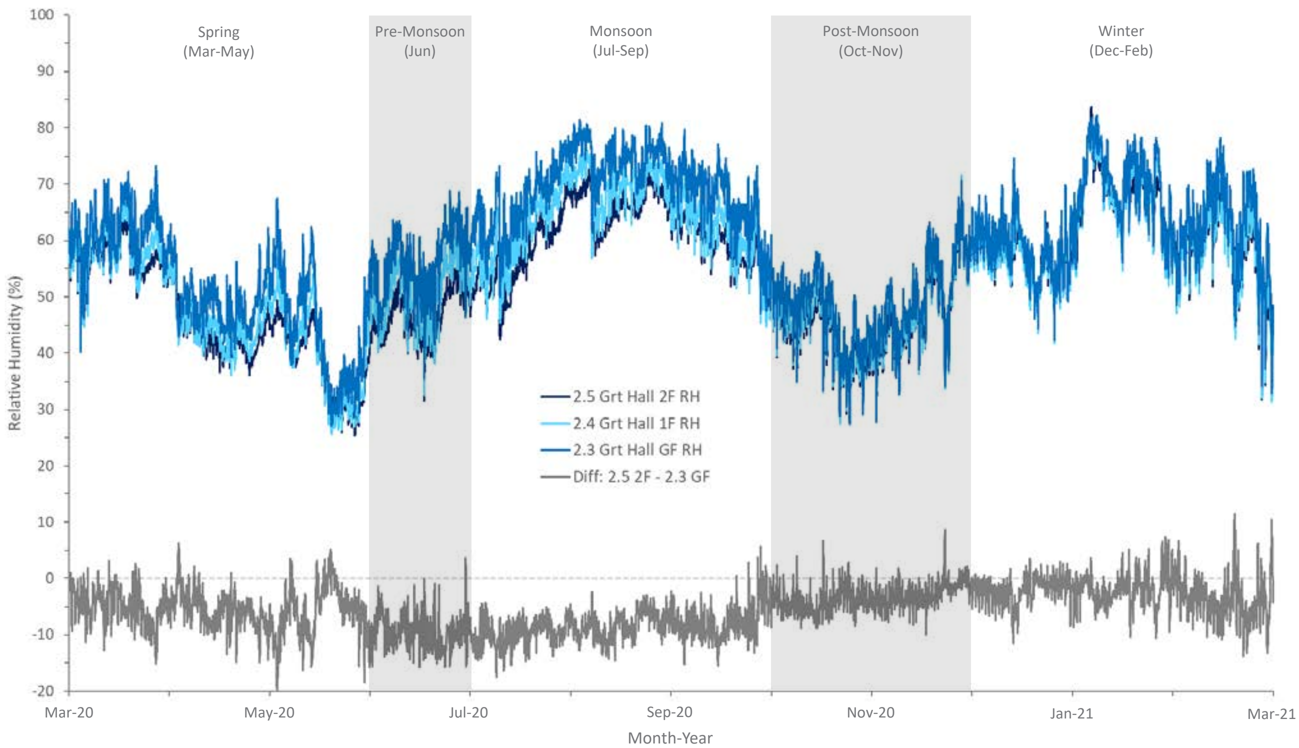


FIGURE 4.32.

Relative humidity recorded on the ground floor, first floor, and second floor of the Great Hall, indicating the difference between second-floor and ground-floor values. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

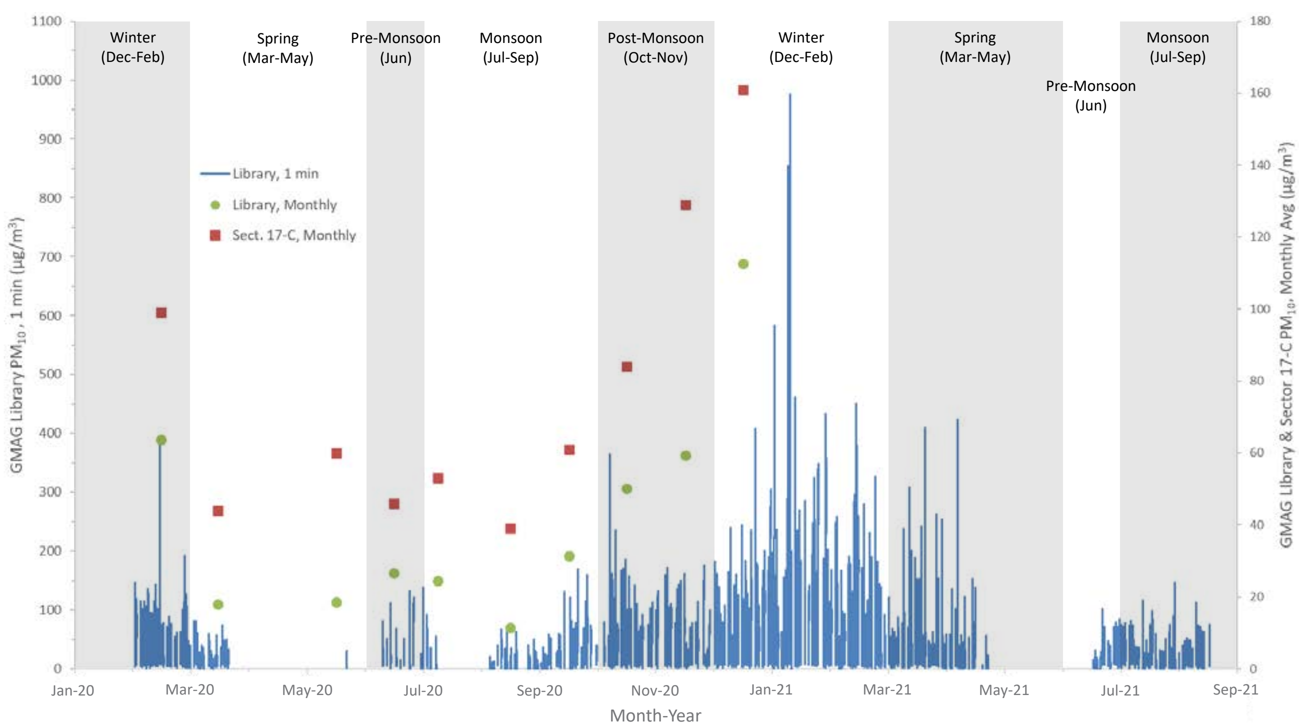


FIGURE 4.33.

PM_{10} particulate data (one-minute intervals and monthly averages) collected at the library and the exterior. Note that the sector 17-C exterior data were provided by the CPCC. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

Interior pollution was also assessed through deployment of Purafil CCCs. The results indicated that all but one location was class 4 (Contaminated) or class 5 (Polluted); the exception was Contemporary Storage Prints Shelf 5, which was assessed as class 3 (Clean) (fig. 4.34).

Light Measurements

The collection of handheld light measurements in January 2020 helped guide the selection of seventy-one locations throughout the museum for the deployment of Blue Wool cards (table 4.1). Focusing on the one-year exposure of BW1 (area A: August 2020 to August 2021), which is most sensitive to light, the highest color change was observed at two locations in the Gandhara Sculptures Gallery (8.13a: case near column E7, close to the undulatory window; 8.17e: south corner of building, near column A8) and one location in the Metal Sculptures Gallery (8.07a: case near column E5, adjacent to the Great Hall) (fig. 4.35). Within the Miniatures Gallery, the most color change was observed at locations 8.19b (case near column B5) and 8.20e (between columns A5 and B5), both of which are near the southwest terrace. Similar results were observed for BW1 in area B (December 2020 to August 2021) and area C (April 2021 to August 2021) (figs. 4.36, 4.37).

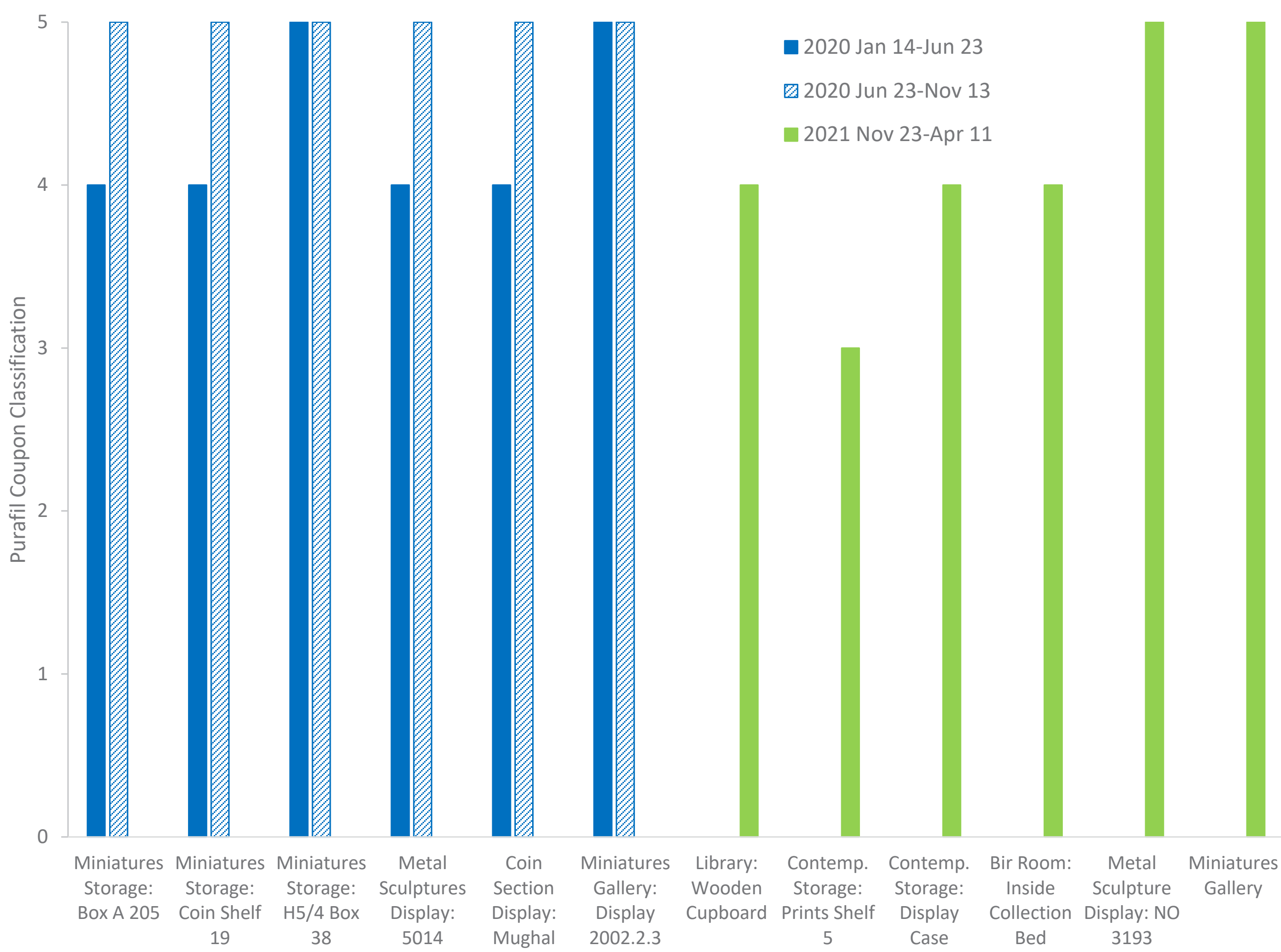


FIGURE 4.34.

Pollutant classifications for Purafil Corrosion Classification Coupons exposed to ambient air in various locations. Class 1 is Extremely Pure, class 2 is Pure, class 3 is Clean, class 4 is Contaminated, and class 5 is Polluted. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

TABLE 4.1.
Location of Blue Wool Cards

Location	No.	Column(s), Notes	Direction Facing
Great Hall	8.01e	D3	SE
	8.02b	D4	SW
	8.02c	D4	NW
	8.02d	D4	NE
	8.02e	D4	SE
	8.03b	Between F4 and F5	SW
	8.04c	Ramp, D5	NW
	8.04e	Ramp, D5	SE
	8.05b	Ramp, between E5 and E6	SW
	8.06c	Ramp, D5	NW
Metal Sculptures Gallery	8.07a	E5, in display case	Up
	8.08c	E4	NW
	8.08d	E4	NE
	8.08e	E4	SE
	8.09a	Between E3 and F3, in display case	Up
	8.09e	Between E3 and F3, in display case	SE
	8.10b	F4	SW
	8.11a	Between F4 and F5, in display case	Up
Gandhara Sculptures Gallery	8.12e	F7	SE
	8.13a	E7, in display case close to window	Up
	8.14a	E7, in display case	Up
	8.15b	D7	SW
	8.15c	D7	NW
	8.15d	D7	NE
	8.15e	D7	SE
	8.16e	A6, next to stairs	SE
	8.17c	A8	NW
	8.17d	A8	NE
	8.17e	A8	SE
	8.18a	Between A7 and A8, in display case	Up

(continued on next page)

TABLE 4.1.
(continued)

Location	No.	Column(s), Notes	Direction Facing
Miniatures Gallery	8.19a	B5, in display case	Up
	8.19b	B5	SW
	8.19c	B5	NW
	8.19d	B5	NE
	8.19e	B5	SE
	8.20e	Between A5 and B5	SE
	8.21a	B3, in display case	Up
	8.22b	B3, in display case	SW
	8.22c	B3, in display case	NW
	8.22e	A3, in display case	SE
	8.23b	A3, in display case	SW
	8.23c	A3, in display case	NW
	8.23e	A3, in display case	SE
	8.24a	B3, in display case	Up
	8.25a	B1, in display case	Up
	8.25b	B1, on staircase	SW
	8.26e	Between A1 and B1	SE
	8.27e	Between B1 and C1	SE
Pottery Gallery	8.28d	C2	NE
	8.29a	Between C1 and D1, in display case	Up
	8.30c	D3	NW
Medieval Sculptures Gallery	8.31b	E2	SW
	8.31c	E2	NW
	8.31e	E2	SE
	8.32b	Between F2 and F3	SW

(continued on next page)

TABLE 4.1.
(continued)

Location	No.	Column(s), Notes	Direction Facing
Contemporary Art Galleries I and II	8.33e	G1	SE
	8.34c	G2	NW
	8.34e	G2	SE
	8.35b	Between H2 and H3	SW
	8.36d	Between F3 and F4	NE
	8.37b	H5	SW
	8.38c	G5	NW
	8.38d	G5	NE
	8.38e	G5	SE
	8.39b	Between G6 and G7	SW
	8.39d	Between G6 and G7	NE
	8.40b	H8	SW
	8.40c	H8	NW
	8.41c	G8	NW
	8.42e	Between F6 and G6	SE
	8.43c	Between F7 and G7	NW

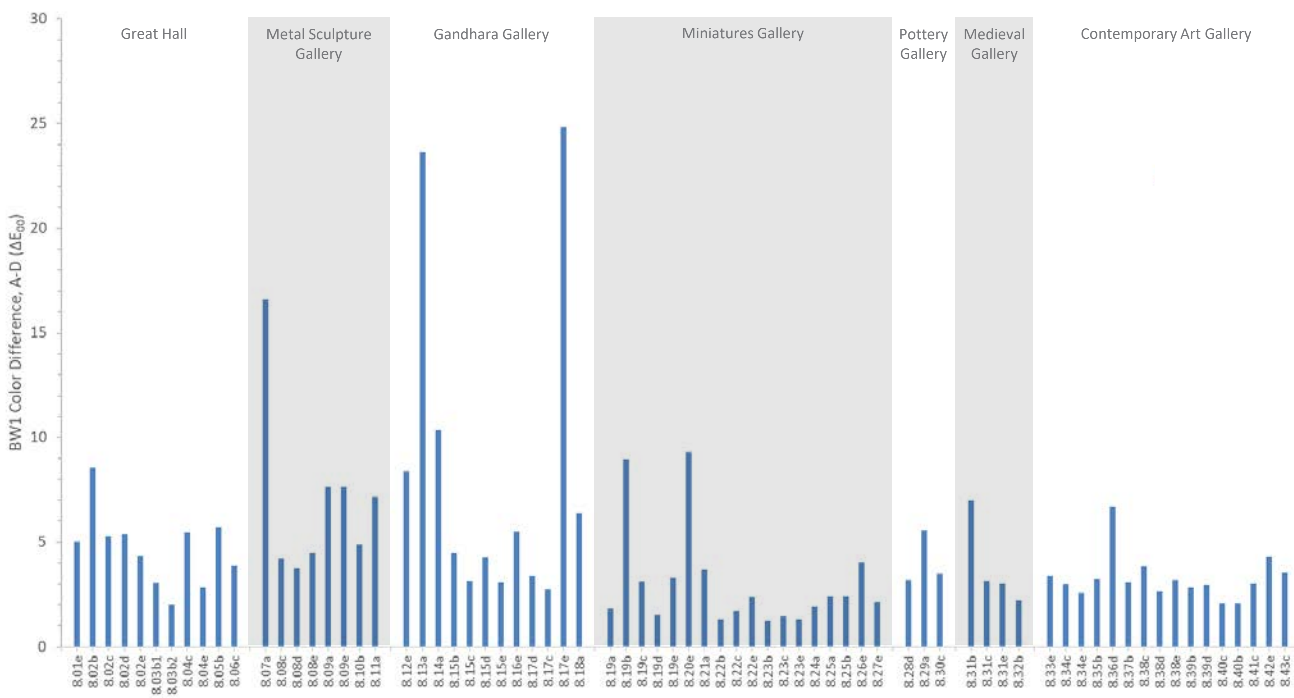


FIGURE 4.35.
Color difference for BW1, area A (exposed to light from August 2020 to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

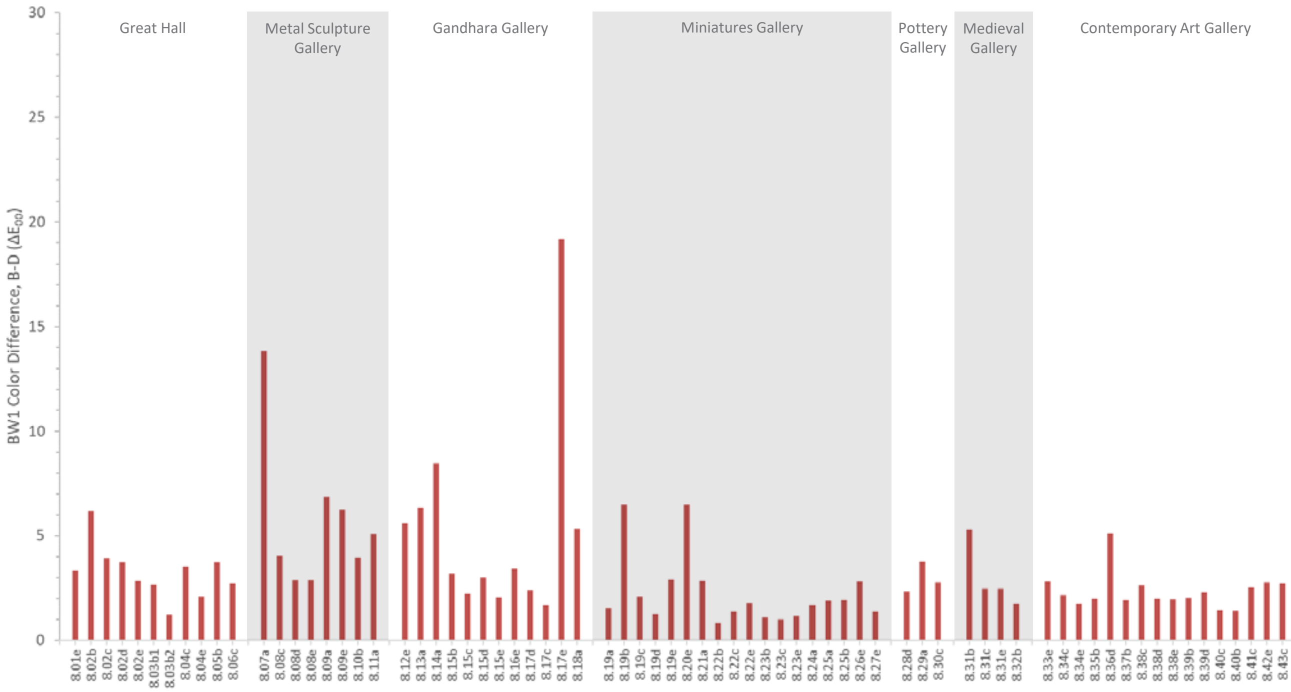


FIGURE 4.36.
Color difference for BW1, area B (exposed to light from December 2020 to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

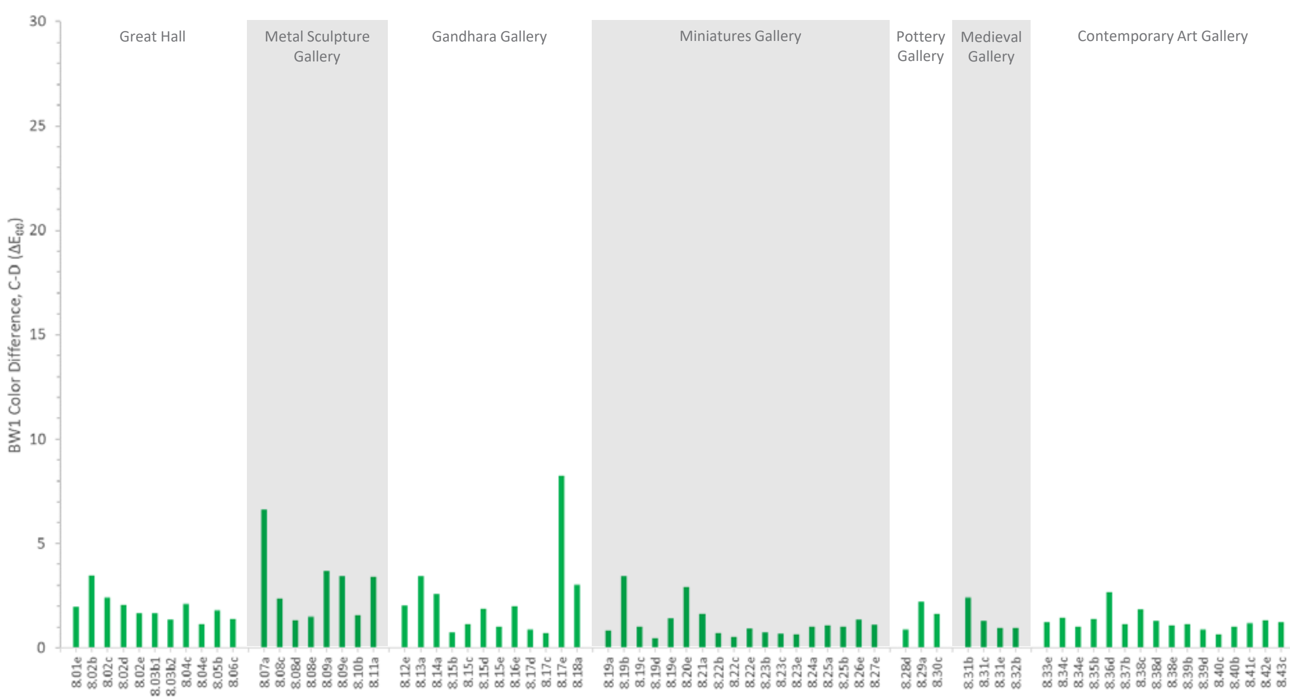


FIGURE 4.37.
Color difference for BW1, area C (exposed to light from April 2021 to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

CHAPTER 5

OBJECTIVES AND RECOMMENDED STRATEGIES

This chapter presents the objectives and the recommended strategies for improving the collection's environments at the Government Museum and Art Gallery in Chandigarh.

Methodology

Members of the project team met with Seema Gera and Megha Kulkarni of the Government Museum and Art Gallery's curatorial staff in two virtual online workshops held on 8 and 9 June 2022. The first workshop focused on the current condition of the collection and the environment, and its participants collaboratively identified realistic and achievable objectives for improving the collection's environments at the museum. The second workshop discussed environmental assumptions, findings, and possible strategies for achieving the objectives defined in the first workshop.

A third online workshop held on 13 and 14 September 2022 presented the findings of the first two workshops to stakeholders of the Government Museum and Art Gallery. This meeting included the project team from the Getty Conservation Institute (GCI); the museum's curatorial staff; one electrical engineer and one mechanical engineer from the Chandigarh city government; S. D. Sharma, one of the architects who worked on the construction of the building; and two staff members from the Development and Research Organisation for Nature, Arts and Heritage (DRONAH), who wrote the Conservation Management Plan (CMP) for the museum. Input from stakeholders on the proposed strategies was gathered and then used to refine the strategies.

Objectives for the Collection's Environments

The first workshop began with a review of the findings of the collection and environmental assessments by the GCI team, including the following:

- Distribution of the collection by material type and by value
- Risks to the collection, factored by frequency and by loss in terms of type and of value
- Environmental risks to the collection, factored by frequency and by loss in terms of type and of value
- Seasonal analysis and spatial comparison of the exterior environment and the environments of the naturally ventilated spaces and mechanically conditioned rooms

Discussions during the workshop centered on the museum staff's responses to the following questions:

- What are your concerns with respect to environmental damage to the exhibited and stored collections?

Adaptive Human Thermal Comfort

The National Building Code of India 2016 provides separate environmental criteria for buildings with natural ventilation (NV) and buildings with HVAC systems. Although these criteria apply to new buildings, they are useful guidance when considering occupant comfort in the naturally ventilated galleries of the Government Museum and Art Gallery.

The National Building Code of India states that when exterior temperatures are higher than 15°C,

> "the following equation should be used for design and operation of naturally ventilated (NV) buildings. It indicates that occupants in NV buildings thermally adapt to the outdoor temperature of their location. It is based on the 30-day outdoor running mean temperature (in °C).
>
> *Indoor operative temperature = (0.54 × outdoor temperature) + 12.83*
>
> Where indoor operative temperature (in °C) is neutral temperature, and outdoor temperature is the 30-day outdoor running mean air temperature (in °C).
>
> The 90 percent acceptability range for the India specific adaptive models for naturally ventilated buildings is ±2.38°C. (National Building Code Sectional Committee 2016, 19)"

If the National Building Code of India requirement for naturally ventilated buildings was applied to the Government Museum and Art Gallery, the desired interior temperature at the first floor on 1 July 2020 would be 27.2°C to 31.0°C, based on the prior 30-day average exterior temperature at the entrance. However, the actual temperature on 1 July in Contemporary Art Gallery I was 35°C to 35.7°C, and in the Gandhara Sculptures Gallery it was 35.3°C to 36°C. Since the air temperature at the entrance on 1 July was 31.5°C to 34.3°C, it would not be possible to lower the interior temperature by natural ventilation to within the range indicated by the National Building Code of India.

The conditions in the example above are representative of the problem of maintaining human thermal comfort in the museum with natural ventilation during conditions in late spring through pre-monsoon, monsoon, and early post-monsoon seasons (April to October). Although exterior air temperatures during this period might be lower than interior temperatures, nighttime ventilation is not recommended for the following reasons:

- Atmospheric moisture (dew point temperature) tends to increase at night, and the combination of increased dew point temperature and decreased air temperature will elevate interior relative humidity, increasing the risk of mold.
- Since the aerators must be manually operated, leaving them open at night would be problematic during rain events, which would result in increased moisture content of the interior air.
- The retained heat of the concrete structure increases from April to September, and the retained heat of this thermal mass has a strong influence on interior air temperature.

- What are your priorities for improving the interior environmental management for the Government Museum and Art Gallery's collection?
- What are your concerns for preserving the significance and condition of the museum building, especially exhibition furniture and spaces that contain collections?
- What are your concerns with respect to the Government Museum and Art Gallery's visitor experience/comfort?

Workshop attendees discussed the responses and agreed upon the following objectives for environmental management for the collection:

- The Miniatures Gallery, the temporary exhibition gallery, the library, and the collections storage area will continue to be heated, cooled, and dehumidified/humidified by HVAC systems.
- The remaining spaces will continue to be naturally ventilated rather than mechanically conditioned due to the cost and the visual and physical encroachment of HVAC systems on architecturally significant building fabric and spaces.
- High value/risk collections in mechanically conditioned and naturally ventilated spaces must have object-level protection from environmental risk factors.
- Effective environmental management by natural ventilation will require reestablishing functionality and seasonal operation to original features such as the aerators.
- Effective environmental management by natural ventilation may necessitate introduction of reversible, sensitively designed architectural interventions.
- Human thermal comfort should be improved where possible but may not meet current expectations for adaptive human thermal comfort in new, naturally ventilated buildings.

Strategies for Improving the Collection's Environments

Following the collaborative development of objectives for environmental management, the GCI team then used these objectives to identify a set of possible strategies for improving environmental conditions in the museum's collection spaces. These were presented to and discussed with museum staff in the second workshop and further refined after input was received from museum stakeholders during the third and final workshop.

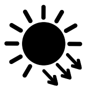
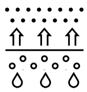
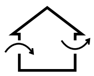
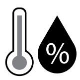
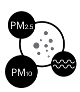
As the GCI team developed the strategies, the following issues and opportunities became apparent:

- Any attempt to control the interior environment of a large portion of the main block with an HVAC system would require unacceptable changes to the appearance of the building. In addition to introducing HVAC piping and ductwork into the main gallery spaces, it would be necessary to seal the aerators, install doors at the main entry, and apply thermal insulation and vapor control barriers in the walls and ceiling of the galleries.
- The HVAC system serving the miniatures storage room appears to perform well. Small space volume, minimal external heat and moisture loads, and a simple HVAC system are contributing factors.
- The collections storage is congested and requires additional space, separation from adjoining spaces, and improved/updated HVAC equipment.
- There is a precedence for exhaust fans in the clerestories. This is a viable opportunity for improved airflow and for destratifying hot air in the galleries and library.

- The rear gallery has the potential to be a conditioned space for temporary exhibitions if artwork is not hung directly on the exterior walls and if upgrades are made to the roof, walls, and HVAC system.
- The large expanse of high mass, nonreflective roof surface adds to interior heat load, especially in the clerestories.
- An inherent characteristic of the museum is to facilitate natural ventilation by stack-effect ventilation and cross-ventilation; it is programmed into the "design DNA" of the building. The architecture of the Government Museum and Art Gallery is consistent with Le Corbusier's design approach for interior environmental management for other buildings in Chandigarh. The natural ventilation characteristic of the building can be enhanced with minimal impact on its character-defining architectural features.
- The interior temperatures tend to stratify vertically, with the highest air temperatures in the clerestories.
- Inaccessible or inoperable aerators reduce the capacity for cross-ventilation. Stack-effect ventilation into or out of the Great Hall has been greatly reduced by inaccessible or inoperable aerators.
- Partitions on the sides of the stairways to the library block airflow from Contemporary Art Gallery II to the nearby aerators.
- During pre-monsoon/monsoon rain events, splashing discharge that travels from the roof spouts to the large gutters allows water to be blown onto the metal screens at the aerators, adding to moisture load of air that enters the building.
- Exhibit cases are effective in reducing the range of fluctuations in relative humidity within the cases.
- The absorbent facing brick of the exterior walls can have a high moisture load from rain. The potential for this moisture to dry toward the inside wall surface poses a mold risk for objects mounted directly on the exterior wall.
- The seasonal variations in exterior temperature, rainfall, and water vapor will necessitate seasonal protocols for operation of the aerators to manage natural ventilation and interior conditions. Continued environmental monitoring will be required to optimize seasonal protocols for the Building Strategies and Object-Level Strategies.
- It is important to empower museum staff to collect and interpret the data to support implementation of the various mitigation strategies.

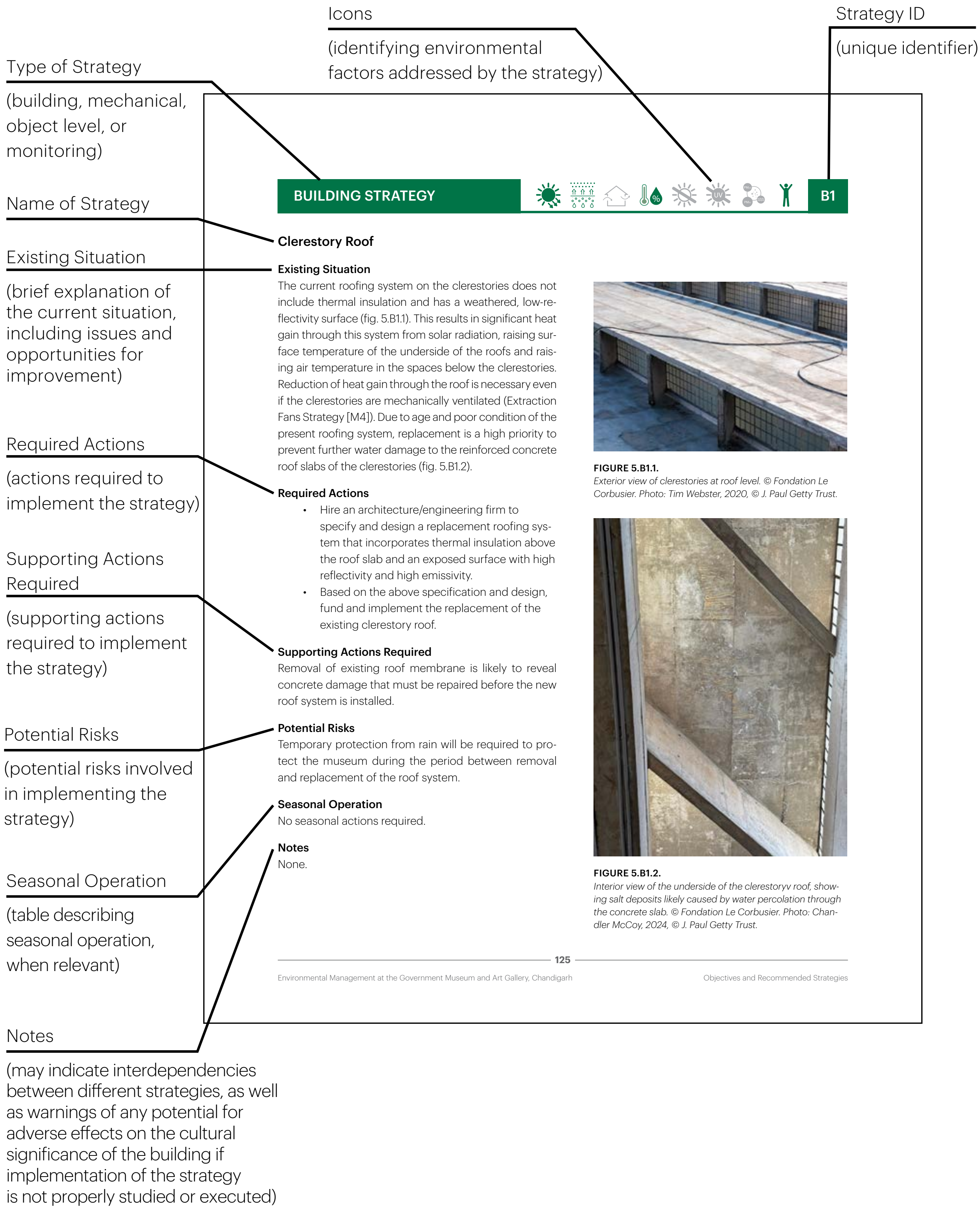
The GCI team organized the recommended strategies into four broad categories: mechanical systems, building envelope and operation, collection protection, and environmental monitoring. Each strategy addresses one or more of the environmental factors shown in table 5.1.

TABLE 5.1.
Environmental Factors

Icon	Environmental Factors
	Manage Heat Gain
	Manage Interior Moisture Vapor
	Improve Natural Ventilation
	Manage Temperature/RH Extremes
	Limit Light Damage to Collections
	Limit UV Damage to Collections
	Limit Particulate Damage to Collections
	Improve Human Thermal Comfort

Strategy Sheets

In this section, each of the seventeen recommended strategies to improve environmental management at the Government Museum and Art Gallery is presented in individual data sheets. These data sheets provide a description of each strategy, including the environmental factors addressed, the existing situation, implementation and operation, and potential risks. See figure 5.1 for a sample strategy sheet. Photographs and schematic drawings are also included. A summary of the strategies is shown in table 5.2.



BUILDING STRATEGY B1

Clerestory Roof

Existing Situation

The current roofing system on the clerestories does not include thermal insulation and has a weathered, low-reflectivity surface (fig. 5.B1.1). This results in significant heat gain through this system from solar radiation, raising surface temperature of the underside of the roofs and raising air temperature in the spaces below the clerestories. Reduction of heat gain through the roof is necessary even if the clerestories are mechanically ventilated (Extraction Fans Strategy [M4]). Due to age and poor condition of the present roofing system, replacement is a high priority to prevent further water damage to the reinforced concrete roof slabs of the clerestories (fig. 5.B1.2).

Required Actions

- Hire an architecture/engineering firm to specify and design a replacement roofing system that incorporates thermal insulation above the roof slab and an exposed surface with high reflectivity and high emissivity.
- Based on the above specification and design, fund and implement the replacement of the existing clerestory roof.

Supporting Actions Required

Removal of existing roof membrane is likely to reveal concrete damage that must be repaired before the new roof system is installed.

Potential Risks

Temporary protection from rain will be required to protect the museum during the period between removal and replacement of the roof system.

Seasonal Operation

No seasonal actions required.

Notes

None.

FIGURE 5.B1.1.
Exterior view of clerestories at roof level. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

FIGURE 5.B1.2.
Interior view of the underside of the clerestoryv roof, showing salt deposits likely caused by water percolation through the concrete slab. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

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Environmental Management at the Government Museum and Art Gallery, Chandigarh — Objectives and Recommended Strategies

FIGURE 5.1.
Sample strategy sheet, with labels explaining each element.

TABLE 5.2.

Summary of Recommended Strategies for Environmental Management

Type	ID	Strategy				%		UV	PM2.5 PM10	
Mechanical Strategies	M1	Collection Storage Enclosure and HVAC	■	■		■	■	■	■	■
	M2	HVAC – Miniatures Gallery				■			■	■
	M3	HVAC – Library				■				■
	M4	Extraction Fans		■	■	■				■
	M5	Ceiling Circulation Fans								■
Building Strategies	B1	Clerestory Roof	■	■		■				■
	B2	Terrace (Main) Roof	■	■		■				■
	B3	Clerestory Daylight and UV Management in Second-Story Spaces	■			■	■	■		■
	B4	Clerestory Daylight and UV Management above Galleries					■	■		
	B5	Natural Ventilation and Natural Conditioning with Exterior/Interior Aerators		■	■	■				■
	B6	Daylight and UV Management in Two-Story Terrace Windows	■			■				■
	B7	Baffle/Deflect Daylight through Clerestories above Contemporary Art Gallery II					■			
	B8	Artificial Lighting	■				■	■		
Object-Level Strategies	O1	Cases				■			■	
	O2	Microclimate Frames				■			■	
	O3	Seasonal Object Rotation				■	■		■	
Monitoring Strategies	Mo1	Environmental Monitoring	■	■	■	■	■	■	■	■

Collections Storage Enclosure and HVAC

Existing Situation

Environmental monitoring data suggest that the existing enclosure and HVAC system for collections storage is generally effective in protecting collections from environmental deterioration/damage. However, improvements can be made to

- increase HVAC system reliability (fig. 5.M1.1),
- minimize particulates by improving filtration (fig. 5.M1.2), and
- reduce dehumidification load/cost by reducing moisture vapor infiltration through openings in the storage space enclosure (fig. 5.M1.3).

Required Actions

- Engage a highly qualified contractor to maintain and service the collections storage HVAC system on a regular basis and provide on-call emergency service if needed. The service contract should include system controls, air-handling unit, piping, valves, filtration, condenser, and humidifier.
- Regularly service and test the emergency generator that powers the storage HVAC unit.
- Increase the frequency of filter replacement in the HVAC unit. Verify that condensate pans and drains function and are free of standing water and mold.
- Check the accuracy of the HVAC temperature and relative humidity sensors.
- Estimate the remaining service life of the HVAC unit and schedule replacement before reliability loss or failure.

Supporting Actions Required

- Engage an architect to survey the walls and ceiling of the storage room and to
  - design closures for any openings that permit entry of particulate or moisture vapor, and

FIGURE 5.M1.1.
HVAC unit serving the collections storage room. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

FIGURE 5.M1.2.
Heavily soiled air filter on HVAC unit serving the collections storage room. Photo: © Michael C. Henry, 2018.

- investigate and specify coatings for the concrete walls, ceiling, and floor that will reduce particulate shedding from the exposed concrete surface. Coatings should be low in volatile organic compounds, and floor coatings must be resistant to traffic abrasion.
- Assess space organization according to ICCROM's RE-ORG method (ICCROM, n.d.).

Potential Risks

Potential environmental risks include
- electrical power failure and emergency power failure,
- blocked or slow condensate drainage in HVAC units,
- excessively dirty air filters due to infrequent service, and
- particulate and moisture vapor entry through openings in storage room walls/ceiling.

Seasonal Operation

No seasonal actions required.

Notes

None.

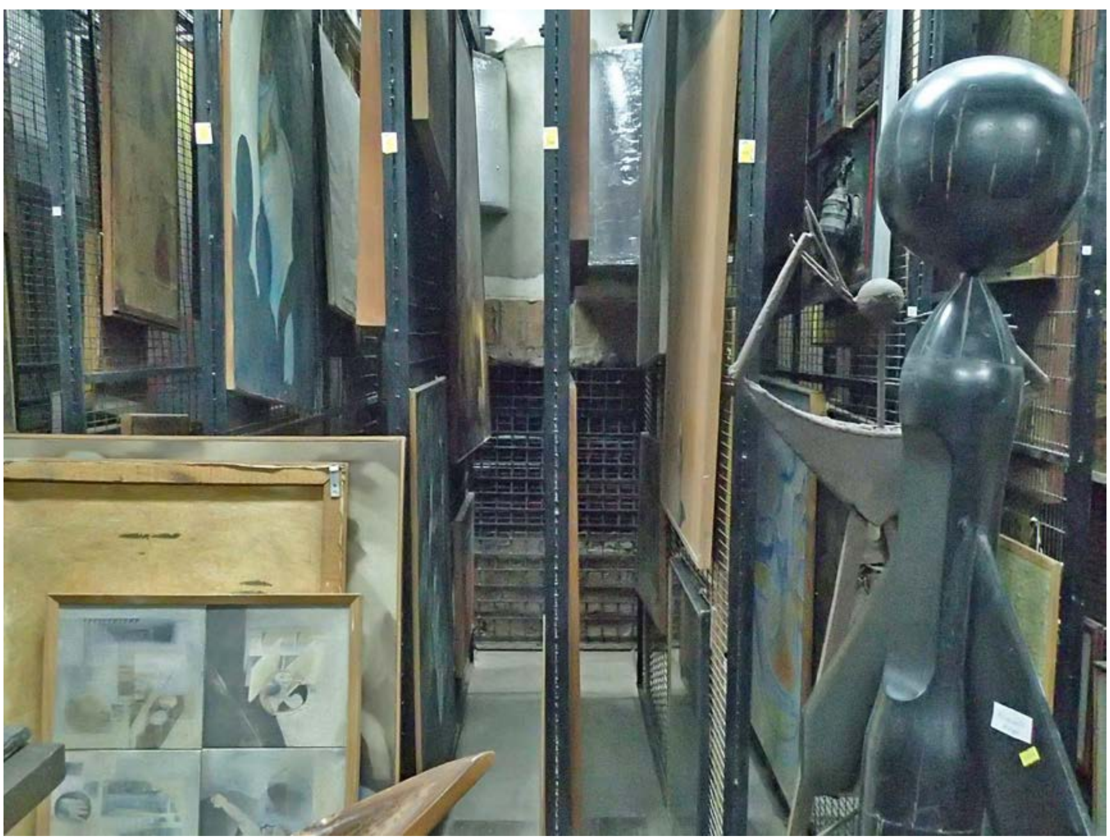


FIGURE 5.M1.3.
Opening in the storage room wall. © Fondation Le Corbusier. Photo: © Michael C. Henry, 2018.

HVAC – Miniatures Gallery

Existing Situation

The value and environmental vulnerability of the miniatures collection requires better management of relative humidity and high temperature than other collection materials. The Miniatures Gallery is cooled and dehumidified and heated and humidified by an HVAC system consisting of an air-handling unit (AHU), a chilled-water system, a hot-water system, and a humidifier (figs. 5.M2.1, 5.M2.2). There are two management approaches posed, one focused on mechanical (main M2) and the other on non-mechanical solutions (alternate M2; see Notes below). Reliability is required 24 hours/day, 7 days/week. Environmental monitoring data indicate that the chilled-water unit serving the AHU for the Miniatures Gallery HVAC did not cool or dehumidify the gallery during the monitoring period. The chilled-water unit has been replaced since the monitoring period.

Currently, the HVAC is only operated during periods when the museum is open to the public.

Required Actions

- Engage a highly qualified contractor to maintain and service the HVAC system on a regular basis and provide on-call emergency service if needed. The service contract should include system controls, chiller, AHU, piping, valves, filtration, condenser/cooling tower, and humidifier.
- Repair the HVAC system so that it is fully functional and operate it 24 hours/day, 7 days/week.
- Regularly service and test the emergency generator that powers the HVAC unit.
- Increase the frequency of filter replacement in the AHU. Verify that condensate pans and drains function and are free of standing water and mold.

FIGURE 5.M2.1.
AHU serving the Miniatures Gallery in second-floor room adjacent to southwest terrace window. © Fondation Le Corbusier. Photo: © Michael C. Henry, 2018.

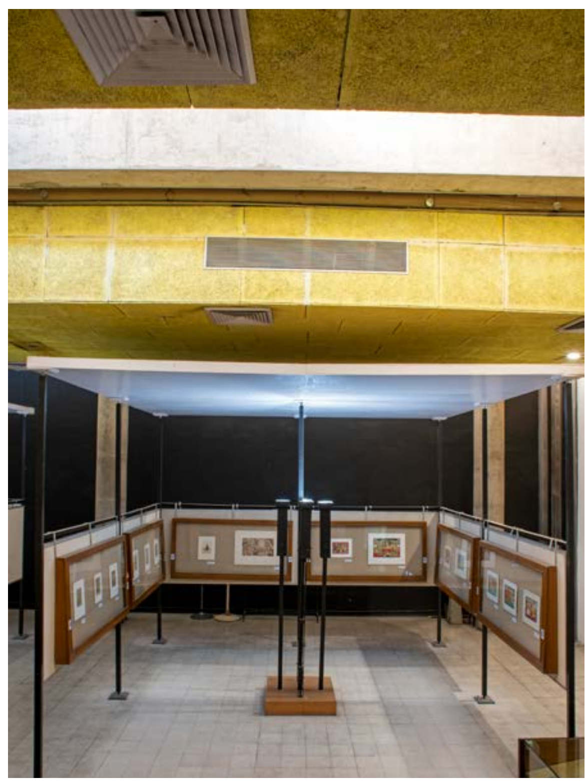


FIGURE 5.M2.2.
Supply air grilles above the Miniatures Gallery. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

- Check the accuracy of the HVAC temperature and relative humidity sensors annually.
- Estimate the remaining service life of the AHU and schedule replacement before reliability loss or failure.

Supporting Actions Required

- Engage an architect to carry out the following:
  - Survey the walls and ceiling of the Miniatures Gallery and design closures for any openings, including aerators, that permit entry of particulate or moisture vapor.
  - Prepare drawings to relocate the glass partition on the south end of the Miniatures Gallery northward by one structural bay to eliminate the thermal influence of the southwest terrace window on heat gain in the Miniatures Gallery (fig. 5.M2.3). This will also reduce the risk of damage to the collection from leaks in the overhead mechanical room.

Potential Risks

Potential environmental risks for the mechanical approach include

- electrical power failure and emergency power failure,
- failure of the chilled-water units, pumps, and piping,
- chilled-water leaks in the mechanical room above the Miniatures Gallery,
- blocked/slow condensate drainage in the AHUs in the mechanical room above the Miniatures Gallery, and
- excessively dirty air filters due to infrequent service.

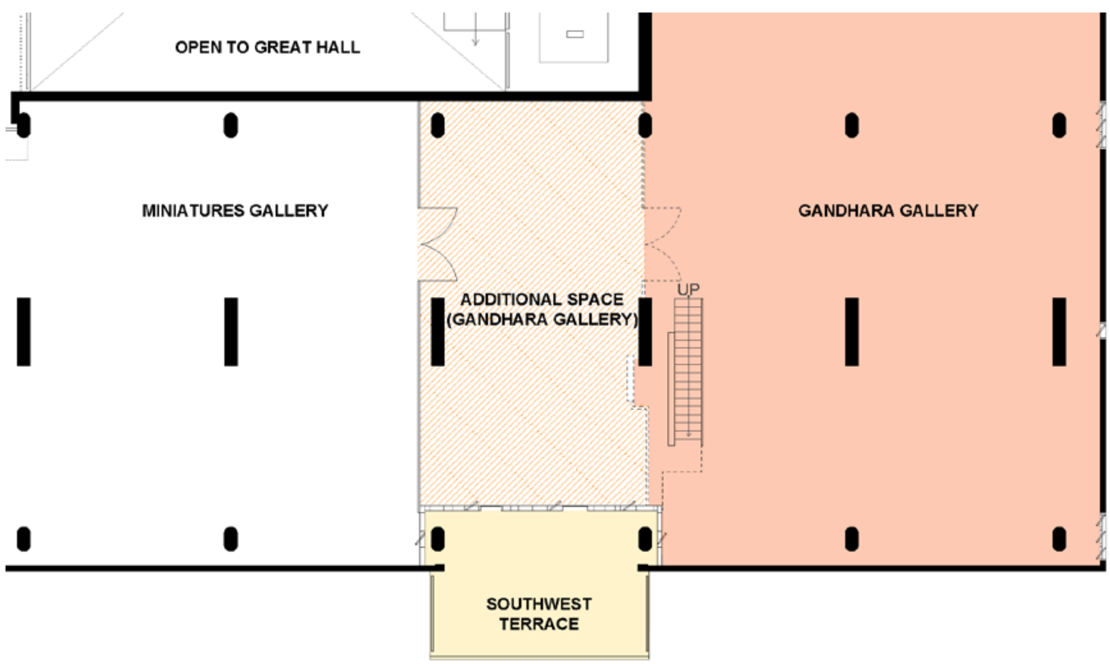


FIGURE 5.M2.3.
Plan of proposed relocation of glass partition between the Gandhara Sculptures Gallery and Miniatures Gallery.
© Fondation Le Corbusier. Image: Timothy Augustus Y. Ong, 2024, © J. Paul Getty Trust.

Seasonal Operation

No seasonal actions required.

Notes

If the above mechanical strategy is not feasible, adopt the alternate, non-mechanical strategy described below:

1. Remove the HVAC system and the glass partitions at the Miniature Gallery entries. Remove ductwork and false ceiling. Assess if removal results in direct light on collection displays.
2. Implement Natural Ventilation and Natural Conditioning with Exterior/Interior Aerators Strategy (B5).
3. Implement Cases Strategy (O1) and Microclimate Frames Strategy (O2) and place collections in rehabilitated and upgraded exhibit cases for environmental stability.
4. Implement Seasonal Object Rotation Strategy (O3).

Potential environmental risks for non-mechanical approach:

- Particulate and moisture vapor entry through openings in gallery walls/ceiling
- Failure to consistently implement non-mechanical management strategies
- Additional risks listed in Cases Strategy (O1) and Microclimate Frames Strategy (O2)

HVAC – Library

Existing Situation

The library is served by several individually controlled, wall-mounted ductless fan coil air-conditioning units (fig. 5.M3.1) with air-cooled condensers mounted on the roof of the rear gallery, or temporary exhibition gallery (fig. 5.M3.2).

At present, the air-conditioning units experience frequent failures, reportedly due to variations in the electrical power supply. Power stabilizers have not completely resolved this problem (see fig. 5.M3.1). Because the library is mechanically conditioned, the interior and exterior aerators in the library spaces are kept closed and are blocked by furniture (fig. 5.M3.3). This greatly reduces the potential effectiveness of Natural Ventilation and Natural Conditioning with Exterior/Interior Aerators Strategy (B5).

FIGURE 5.M3.1.
Fan coil air-conditioning unit and power-stabilizing units in the library. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

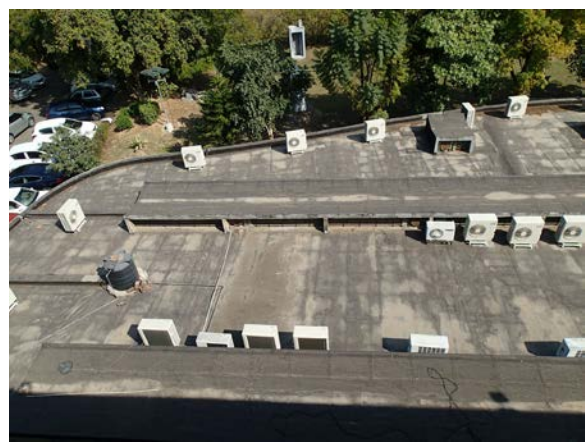


FIGURE 5.M3.2.
Roof-mounted condensers. © Fondation Le Corbusier. Photo: © Michael C. Henry, 2018.

Required Actions

- Implement Natural Ventilation and Natural Conditioning with Exterior/Interior Aerators Strategy (B5) but operate HVAC in the library when necessary for human thermal comfort during extreme conditions.
- Improve current HVAC system as follows:
  - Resolve the problem with air-conditioning unit failure.
  - Provide for removal and disposal of condensate.
  - Clean filters regularly.
  - Estimate the remaining service life of the air-conditioning units and schedule replacement before reliability loss or failure.
  - Implement Clerestory Roof Strategy (B1).
  - Implement Clerestory Daylight and UV Management in Second-Story Spaces Strategy (B3).

Supporting Actions Required

- Implement Extraction Fans Strategy (M4).
- Implement Cases Strategy (O1).
- Reposition library furniture away from aerators to allow for operation and airflow.

Potential Risks

Potential risks of the present HVAC units are

- electrical power failure,
- blocked condensate drains,
- infrequent replacement of air filters,
- potential risks for non-mechanical approach, and
- failure to consistently implement non-mechanical management strategies.

Seasonal Operation

Operate according to seasonal operation protocols of Natural Ventilation and Natural Conditioning with Exterior/Interior Aerators Strategy (B5).

Notes

None.

FIGURE 5.M3.3.
Interior aerators blocked by library furniture. © Fondation Le Corbusier. Photo: Foekje Boersma, 2017, © J. Paul Getty Trust.

Extraction Fans

Existing Situation

Two clerestories each feature an exhaust fan (fig. 5.M4.1), but neither fan is currently used. Operating and potentially adding more exhaust (extraction) fans will increase the rate of air exchange when Natural Ventilation and Natural Conditioning with Exterior/Interior Aerators Strategy (B5) is active.

Required Actions

- Engage an architect and an engineer to evaluate and design provisions for using existing extraction and adding more fans to improve the ventilation and seasonal temperature reduction of the Great Hall (fig. 5.M4.2), the first-floor galleries, and the second-floor spaces. Potential issues that must be addressed in the design process include airflow rate, physical size, security, water entry, noise, and electrical power.
- Fund and implement the installation of extraction fans.

FIGURE 5.M4.1.
Existing exhaust fan in clerestory. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

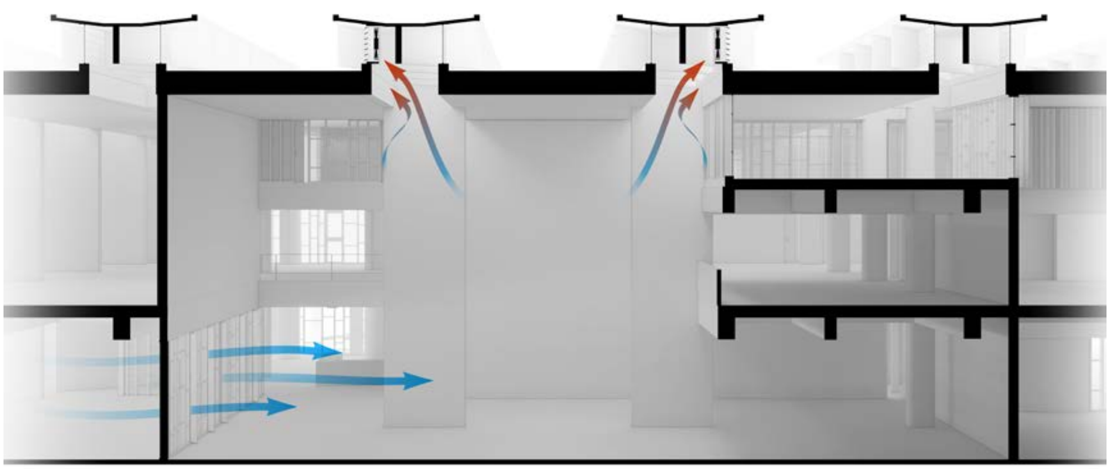


FIGURE 5.M4.2.
Longitudinal section through the Great Hall, showing proposed natural ventilation and operation of extraction fans on clerestories. © Fondation Le Corbusier. Image: Timothy Augustus Y. Ong, 2024, © J. Paul Getty Trust.

Supporting Actions Required

- Coordinate with the following:
    - HVAC – Library Strategy (M3)
    - Natural Ventilation and Natural Conditioning with Exterior/Interior Aerators Strategy (B5)

Potential Risks

No potential risks foreseen.

Seasonal Operation

Extraction fans should be operated in coordination with seasonal opening/closing of exterior/interior aerators as described in Natural Ventilation and Natural Conditioning with Exterior/Interior Aerators Strategy (B5).

Notes

None.

Ceiling Circulation Fans

Existing Situation

During periods of high temperature and high relative humidity, natural ventilation may need to be supplemented with mechanical fans to produce sufficient air movement to improve human thermal comfort for visitors and staff. From May to October, encompassing late spring, pre-monsoon, monsoon, and early post-monsoon seasons, the interior environment can become uncomfortable to users due to high temperature and relative humidity (fig. 5.M5.1).

Required Actions

- Engage an architect and an engineer to evaluate the potential for low-speed ceiling fans to destratify air and increase air movement during hot and humid conditions. The study should evaluate fan speed, air speed at the occupant level, effectiveness in improving comfort, noise, electrical power requirements, weight and mounting methods, and access for service.
- If the evaluation is positive, perform a trial installation to confirm satisfactory performance.

Supporting Actions Required

No supporting actions required.

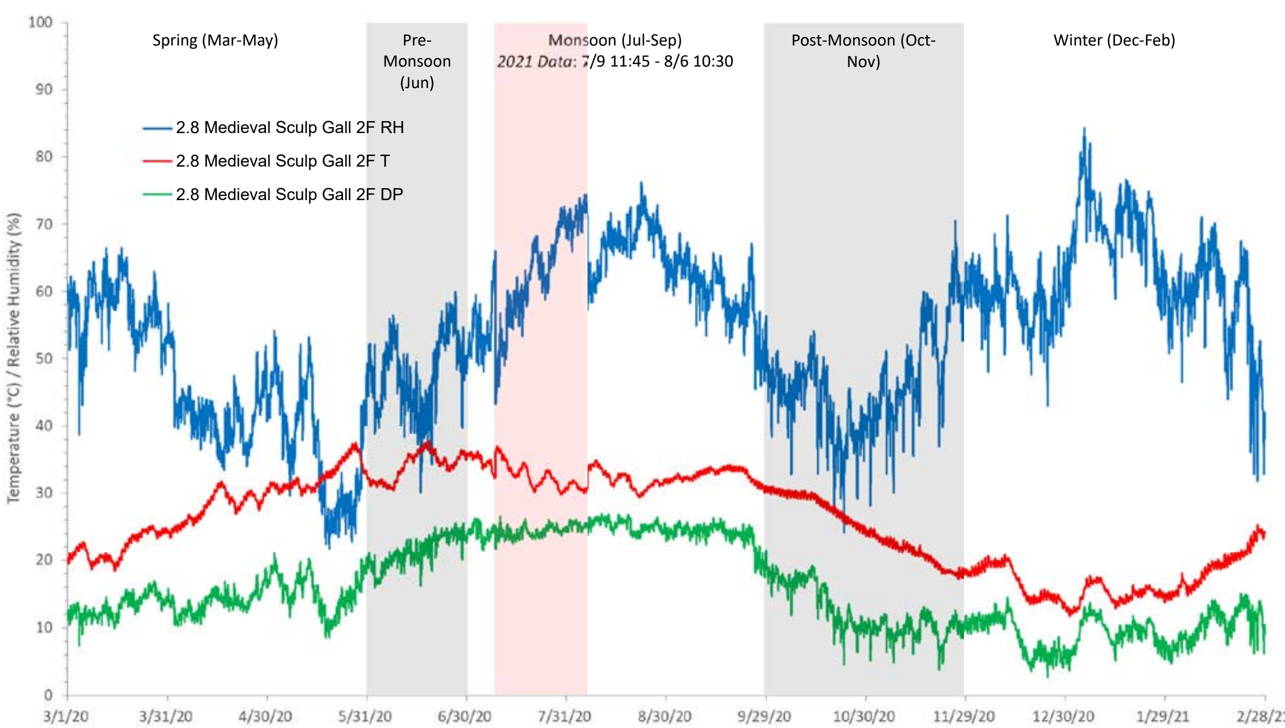


FIGURE 5.M5.1.

Time series of air temperature (red), dew point (green), and relative humidity (blue) in the Medieval Sculptures Gallery. Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

Potential Risks

No potential risks foreseen.

Seasonal Operation

TABLE 5.M5.1.

Seasonal Operational Protocols for Ceiling Circulation Fans

Spring (Mar–May)	Pre-Monsoon (Jun)	Monsoon (Jul–Sep)	Post-Monsoon (Oct–Nov)	Winter (Dec–Feb)
Operate in late spring (May).	Operate during public open hours.	Operate during public open hours.	Operate during early post-monsoon.	Do not operate.

Notes

None.

Clerestory Roof

Existing Situation

The current roofing system on the clerestories does not include thermal insulation and has a weathered, low-reflectivity surface (fig. 5.B1.1). This results in significant heat gain through this system from solar radiation, raising surface temperature of the underside of the roofs and raising air temperature in the spaces below the clerestories. Reduction of heat gain through the roof is necessary even if the clerestories are mechanically ventilated (Extraction Fans Strategy [M4]). Due to age and poor condition of the present roofing system, replacement is a high priority to prevent further water damage to the reinforced concrete roof slabs of the clerestories (fig. 5.B1.2).

FIGURE 5.B1.1.
Exterior view of clerestories at roof level. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

Required Actions

- Hire an architecture/engineering firm to specify and design a replacement roofing system that incorporates thermal insulation above the roof slab and an exposed surface with high reflectivity and high emissivity.
- Based on the above specification and design, fund and implement the replacement of the existing clerestory roof.

Supporting Actions Required

Removal of existing roof membrane is likely to reveal concrete damage that must be repaired before the new roof system is installed.

Potential Risks

Temporary protection from rain will be required to protect the museum during the period between removal and replacement of the roof system.

Seasonal Operation

No seasonal actions required.

Notes

None.

FIGURE 5.B1.2.
Interior view of the underside of the clerestory roof, showing salt deposits likely caused by water percolation through the concrete slab. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

Terrace (Main) Roof

Existing Situation

The current roofing system on the terrace (main) roof (fig. 5.B2.1) has significant heat gain due to solar radiation, raising underside surface temperature and possibly elevating air temperature in the cavity between the roof slab and the Thermafriz ceiling panels composed of wood and wool fibers (fig. 5.B2.2). The resultant heat transmission can contribute to elevated air temperature in the building that adversely affects both collections and human comfort. Due to age and poor condition of the present roofing system, replacement is a high priority to prevent further damage to the reinforced concrete slabs of the main roof.

Required Actions

- Hire an architecture/engineering firm to specify and design a replacement roofing system with a high-reflectivity and low-emissivity surface. Replace any existing thermal insulation on the top surface of the roof but do not add thicker insulation, because this will increase the risk of water leakage at the window frame.
- Based on the specification and design developed by the architecture/engineering firm, fund and implement the replacement of the existing terrace roofing system.

Supporting Actions Required

Removal of existing roof membrane is likely to reveal concrete damage that must be repaired before the new roof system is installed.

FIGURE 5.B2.1.
Exterior view of terrace (main) roof with clerestory windows at left and right. © Fondation Le Corbusier. Photo: Ana Paula Arato Gonçalves, 2018, © J. Paul Getty Trust.

FIGURE 5.B2.2.
View of red and white Thermafriz ceiling panels. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

Potential Risks

Temporary protection from rain will be required to protect the museum during the period between removal and replacement of the roof system.

Seasonal Operation

No seasonal actions required.

Notes

The distance between the bottom of the clerestory window frame and the top of the terrace concrete slab will limit the thickness of thermal insulation between the roof membrane and the concrete roof slab (fig. 5.B2.3).

FIGURE 5.B2.3.
Exterior view of clerestory window at roof level. © Fondation Le Corbusier. Photo: © Michael C. Henry, 2018.

Clerestory Daylight and UV Management in Second-Story Spaces

Existing Situation

The clerestory windows allow unfiltered entrance of visible and infrared light and UV radiation directly above occupants/collections in second-floor spaces such as the library (figs. 5.B3.1, 5.B3.2). This contributes to high temperatures that adversely affect both collections and human comfort. In addition, the visible and infrared light and UV radiation contribute to light and UV damage to collections.

FIGURE 5.B3.1.
Exterior view of clerestory window at roof level. © Fondation Le Corbusier. Photo: © Michael C. Henry, 2018.

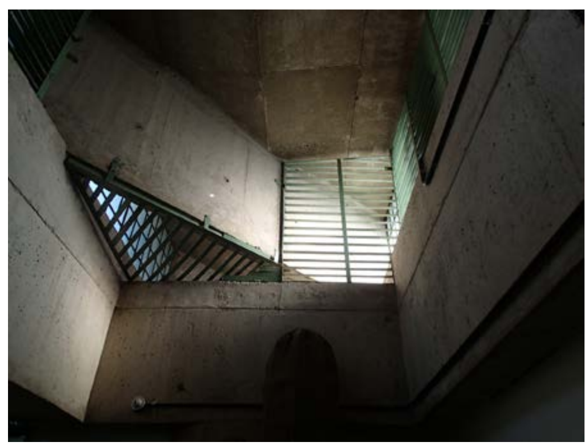


FIGURE 5.B3.2.
Interior view of clerestory window with security grilles. © Fondation Le Corbusier. Photo: © Michael C. Henry, 2018.

Required Actions

- Hire an architect to assess the exterior and interior conditions of the existing window assemblies, including glass and plastic glazing and metal frames.
  - If the conditions do not require replacement of the window glazing or frames, the architect should select a neutral tint light-reducing film with 99% UV reduction.
  - If the existing window glazing and frames must be replaced, the architect should specify replacement glazing that reduces transmitted visible light, infrared light, and UV radiation.
- Mock-ups should be evaluated to inform final selection of the film and/or replacement glazing and to confirm that the film/glazing does not cause color shifts or excessive daylight reduction.
- Fund and implement the necessary improvements for the reduction of visible light, infrared light, and UV through the clerestory glass above the library and second-floor spaces that contain collections.

Supporting Actions Required

Temporary weather protection, overhead protection, and security measures will be required during repair or replacement of glass or window frames.

Potential Risks

The effectiveness of reducing visible light, infrared light, and UV with adhered film will degrade with time and exposure and may require replacement within ten years. A program of annual measurements of visible light, infrared light, and UV should be established so that the efficacy of the adhered film can be quantified and a replacement plan can be developed.

Seasonal Operation

No seasonal actions required.

Notes

1. In some locations, access to the interior side of clerestory windows may be limited by security grilles (see fig. 5.B3.2).
2. See also Clerestory Daylight and UV Management above Galleries Strategy (B4).

Clerestory Daylight and UV Management above Galleries

Existing Situation

The clerestory windows allow visible and infrared light and UV radiation into the adjoining first- and second-floor spaces and galleries (fig. 5.B4.1). This contributes to light and UV damage to collections and to high temperatures that adversely affect both collections and human comfort.

The intensity and duration of sunlight entry through the windows varies by orientation and season.

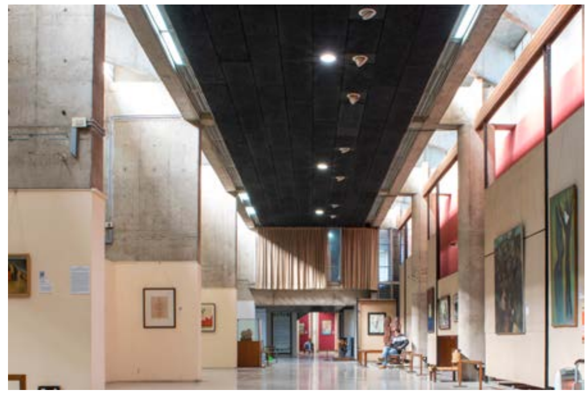


FIGURE 5.B4.1.
View of Contemporary Art Gallery II in winter, showing visible light coming through the clerestory windows. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

Required Actions

- Hire an architect to assess the exterior and interior conditions of the existing window assemblies, including glass and plastic glazing and metal frames. The architect should also perform a "daylight" analysis for the clerestory windows to determine the level of daylight reduction needed to protect the collections from damage.
  - If the observed conditions do not require replacement of the window glass or frames, the architect should select a neutral tint light-reducing film with 99% UV reduction. Mock-ups should be evaluated to inform final selection of the film and/or replacement glazing and to confirm that the film/glazing does not cause color shift or excessive daylight reduction.
  - If the existing window glazing and frames must be replaced, the architect should specify neutral tint light-reducing replacement glazing that reduces transmitted UV radiation. Mock-ups should be evaluated to inform final selection of the film and/or replacement glazing and to confirm that the film/glazing does not cause color shift or excessive daylight reduction.
- Fund and implement the necessary improvements for the reduction of visible light, infrared light, and UV through the clerestory windows above galleries.

Supporting Actions Required

No supporting actions required.

Potential Risks

The effectiveness of UV reduction with adhered film will degrade with time and exposure and may require replacement within ten years. A program of annual measurements of UV reduction by adhered film should be established so that film replacement can be planned.

Seasonal Operation

No seasonal actions required.

Notes

See related strategies:

1. Clerestory Daylight and UV Management in Second-Story Spaces (B3)
2. Daylight and UV Management in Two-Story Terrace Windows (B6)
3. Baffle/Deflect Daylight through Clerestories above Contemporary Art Gallery II (B7)

Natural Ventilation and Natural Conditioning with Exterior/Interior Aerators

Existing Situation

Le Corbusier's original concept for natural ventilation at the Government Museum and Art Gallery included airflow created by opening internal and external aerators to allow hot air to move up through and out of the building. Currently, Le Corbusier's intended airflows have been compromised by

- aerators that are no longer accessible or operable due to window shades (fig. 5.B5.1),
- grilles and exhibition furniture that block airflow between spaces (fig. 5.B5.2),
- partitions on the sides of the stairway to the library that block airflow from Contemporary Art Gallery II to the southeast aerators (fig. 5.B5.3), and
- glass doors that block airflow between the Great Hall and the reception area on the ground floor (fig. 5.B5.4).

Required Actions

For exterior and interior aerators and glass doors at Great Hall entry (fig. 5.B5.5):

- Relocate exhibition furniture that is blocking exterior and interior aerators so that airflow is not impeded.
- Operate aerators in exterior walls so that exterior air can be used to lower interior temperature in late pre-monsoon (June), monsoon (July to September), and early post-monsoon (October to November) seasons, provided that interior temperature is maintained at least 8°C higher than interior dew point temperature so that interior relative humidity does not exceed 70% (table 5.B5.1).
- Open second-floor interior aerators (for example, those between the library and the surrounding galleries) when exterior aerators are open. Open entry to Great Hall (doors, grilles, and/or operable glass panels) when

FIGURE 5.B5.1.
View of aerators in the Great Hall that are inaccessible due to window shades. © Fondation Le Corbusier. Photo: © Michael C. Henry, 2018.

FIGURE 5.B5.2.
Grilles and exhibition furniture blocking airflow between the Medieval Sculptures Gallery and Metal Sculptures Gallery. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

FIGURE 5.B5.3.
Partitions flanking the stairway from Contemporary Art Gallery II to the library. © Fondation Le Corbusier. Photo: © Michael C. Henry, 2018.

FIGURE 5.B5.4.
View of glass doors at entry to the Great Hall on the ground floor; above, opening to the Medieval Sculptures Gallery blocked by grilles and exhibition furniture on the first floor. © Fondation Le Corbusier. Photo: Ana Paula Arato Gonçalves, 2018, © J. Paul Getty Trust.

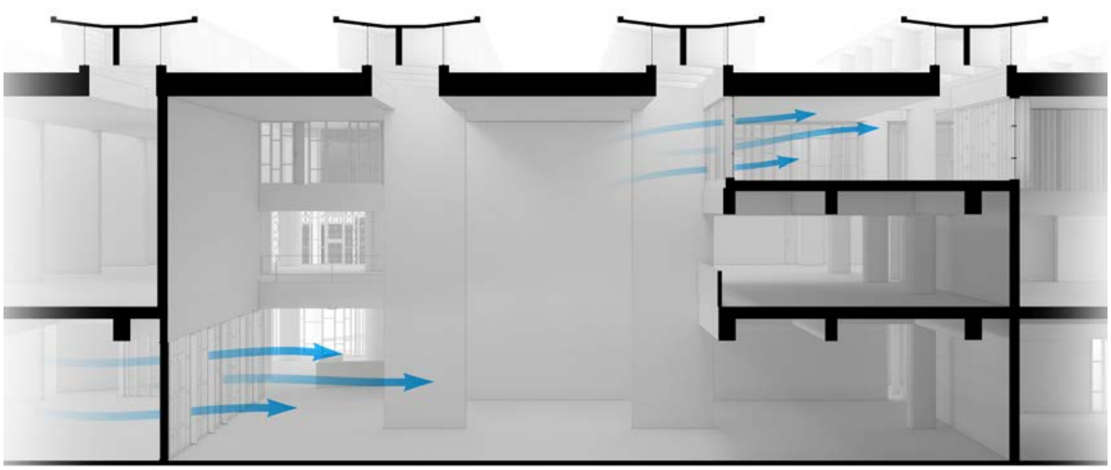


FIGURE 5.B5.5.
Longitudinal section through Great Hall, showing proposed natural ventilation. © Fondation Le Corbusier. Image: Timothy Augustus Y. Ong, 2024, © J. Paul Getty Trust.

temperature difference between second floor and ground level is 3°C to enhance natural ventilation.

- Reconfigure open grilles at Great Hall entry doors and install operable glass panels surrounding the doors.
- Reconfigure window shades so they only cover glazing.

For openings in interior walls:

- Relocate exhibition furniture and remove or open grilles that block interior openings between galleries so that airflow is not impeded.
- Remove window shades from interior openings.
- Design and install new guardrails to replace grilles in openings between the first floor and the Great Hall to prevent falls and to improve airflow.
- Remove the walls enclosing the space under the stairway between the Gandhara Sculptures Gallery and the library. Install a guardrail or similar protection to prevent impact injury with the stairway.
- Trained staff must be available to open and close aerators when seasonal conditions are appropriate (see table 5.B5.1).
- The functionality of interior and exterior aerators must be restored and aerators must be airtight and watertight when closed.
- Aerators must be maintained in operable condition.
- Limited redesign of some exhibit spaces will be necessary to reposition exhibit cases away from openings.

Supporting Actions Required

No supporting actions required.

Potential Risks

- Exterior aerators must be closed during rain and high wind events to prevent damage to collections.
- Increasing airflow through the museum will increase deposition of particulates and will require more frequent housekeeping to remove particulate deposition.
- Lack of sufficient staff or training of staff will result in failure to consistently implement non-mechanical management strategies and may increase environmental damage to collections.

Seasonal Operation

Operate exterior and interior aerators, entry hall doors, and entry hall glass panels as indicated in table 5.B5.1.

TABLE 5.B5.1.

Seasonal Operational Protocols for Ventilation

Spring (Mar–May)	Pre-Monsoon (Jun)	Monsoon (Jul–Sep)	Post-Monsoon (Oct–Nov)	Winter (Dec–Feb)
Open aerators during public open hours if exterior temperature exceeds 17°C and exterior dew point is at least 5°C less than interior temperature.	Open aerators during public open hours if exterior temperature is less than 30°C and exterior dew point is at least 5°C less than interior temperature.	Open aerators during public open hours if exterior temperature is less than 30°C and if exterior dew point is at least 5°C less than interior temperature so that interior relative humidity does not exceed 70%.	Open aerators during public open hours if exterior temperature is between 25°C and 18°C and exterior dew point is at least 5°C less than interior temperature.	Open aerators during public open hours if exterior temperature exceeds 18°C and exterior dew point is at least 5°C less than interior temperature.
During any season, close the ventilation shutters • when the above conditions do not occur, • when the museum is closed to the public, • during rain events, or • during high wind events.				

Notes

None.

Daylight and UV Management in Two-Story Terrace Windows

Existing Situation

The two-story-high banks of exterior windows (figs. 5.B6.1, 5.B6.2) allow unfiltered entrance of visible and infrared light and UV radiation into the adjoining first-floor and second-floor spaces and galleries. This contributes to light and UV damage to collections and to high temperatures that adversely affect both collections and human comfort.

The intensity and duration of sunlight entry through the windows varies by orientation and season, with the southwest-facing and southeast-facing terrace windows receiving the most direct sunlight per unit area, and the northeast-facing and northwest-facing terrace windows receiving diffuse sunlight.

The windows are fitted with vertical blinds (fig. 5.B6.3), many of which have individual blades that are missing or in disarray. The blinds do not appear to be periodically adjusted for best effect in managing sunlight entry. According to the CMP, the blinds are not original (DRONAH 2019, 100, figs. 119, 121) and should be removed (DRONAH 2019, 156).

Required Actions

- Hire an architect to do the following:
    - Select a neutral tint light-reducing film with 99% UV reduction. Mock-ups should be evaluated to inform final selection of the film and/or replacement glazing and to confirm that the film/glazing does not cause color shift or excessive daylight reduction.
    - If the non-original blinds are removed as recommended by the CMP, a new method of natural light management through the glazing will be needed. One possibility would be automatically controlled light-reducing fabric roll-up shades. The shades should not cover the aerators.
    - Perform a “daylight” analysis for each window to determine the optimal light reduction of the fabric shades and the schedule on which the shades must be lowered.

FIGURE 5.B6.1.
Southwest terrace window, similar to the window on the northeast terrace. © Fondation Le Corbusier. Photo: Ana Paula Arato Gonçalves, 2018, © J. Paul Getty Trust.

FIGURE 5.B6.2.
Northwest terrace window, similar to the window on the southeast terrace. © Fondation Le Corbusier. Photo: Ana Paula Arato Gonçalves, 2018, © J. Paul Getty Trust.

- Fund and implement the necessary improvements for reduction of visible and infrared light and UV, and replacement of the blinds with fabric roll-up shades instead of removal of the blinds as recommended by the CMP above.
- Establish monthly protocols for maintenance, operation, and positioning of the fabric shades.
- Train staff in the protocols and monitor compliance.

Optional Actions

- Hire an architect to develop a design for a floor-to-ceiling transparent enclosure parallel to and set away from the southwest terrace window (fig. 5.B6.4). The study should include a digital model and/or a physical prototype of the

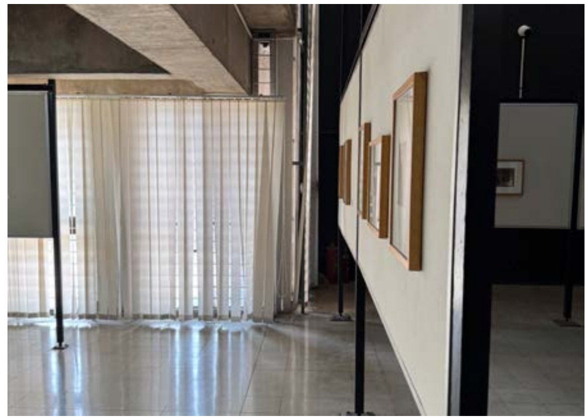


FIGURE 5.B6.3.
Vertical blinds at the southwest terrace window. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

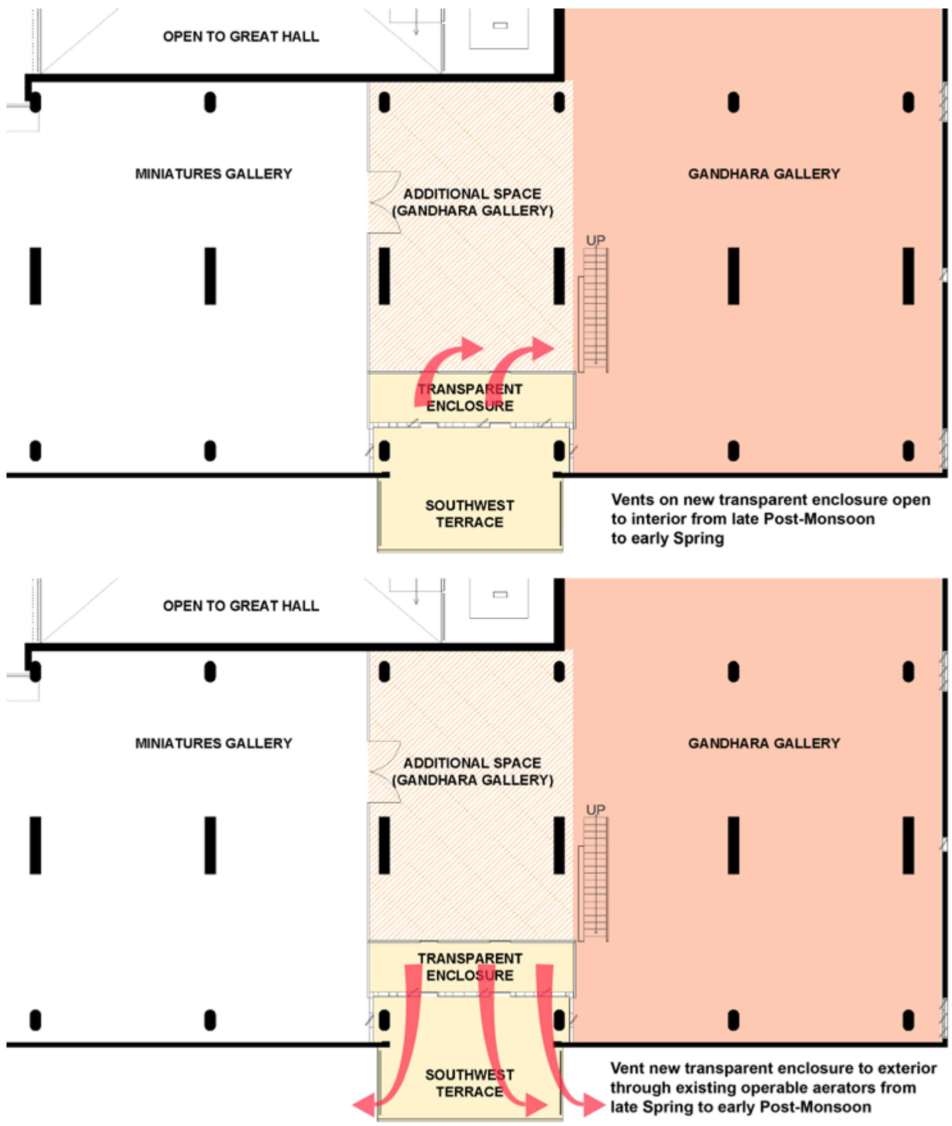


FIGURE 5.B6.4.
Plan for optional installation of passive solar heating enclosure on the southwest terrace windows, and proposed relocation of glass partition between the Gandhara Sculptures Gallery and Miniatures Gallery (see strategy sheet M2). © Fondation Le Corbusier. Image: Timothy Augustus Y. Ong, 2024, © J. Paul Getty Trust.

proposed assembly to evaluate any risks to architectural significance. This enclosure should have the capacity to be ventilated to the exterior and to the interior of the building (table 5.B6.1). The enclosed space needs to be accessible for periodic cleaning.

- Fund and implement the necessary improvements for passive solar heat collection at the southwest terrace window.
- Establish seasonal protocols for operation and positioning of the ventilators. Train staff in the protocols and monitor compliance.

TABLE 5.B6.1.

Seasonal Operational Protocols for Ventilation of Optional Enclosure at Southwest Terrace Window

Spring (Mar–May)	Pre-Monsoon (Jun)	Monsoon (Jul–Sep)	Post-Monsoon (Oct–Nov)	Winter (Dec–Feb)
Vent to interior in early spring.	Vent to exterior.	Vent to exterior.	Vent to interior in late post-monsoon.	Vent to interior.

Supporting Actions Required

Train museum staff in coordination and operation of the fabric roll-up shades and the optional passive solar heating enclosure.

Potential Risks

The effectiveness of daylight and UV reduction with adhered film will degrade with time and exposure and may require replacement within ten years. A program of annual measurements of visible and infrared light and UV by adhered film should be established so that film replacement can be planned.

The benefit to interior environment should be measured against the risk to architectural significance.

Seasonal Operation

Protocols for seasonal operation of fabric roll-up shades and the optional passive solar heating enclosure must be developed based on analysis.

Notes

Design of the passive solar heat collector and light-blocking system must minimize their potential impact on the building's architectural value as much as possible. It should only be implemented if design studies arrive at a solution that is compatible with cultural significance.

Baffle/Deflect Daylight through Clerestories above Contemporary Art Gallery II

Existing Situation

Direct sunlight enters through the clerestories in Contemporary Art Gallery II during winter, causing light damage to paintings and prints (fig. 5.B7.1).

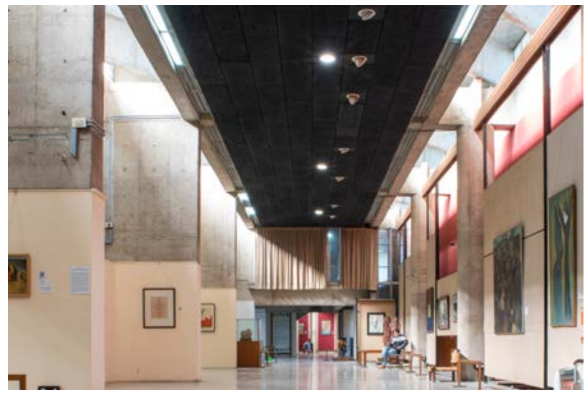


FIGURE 5.B7.1.
View of Contemporary Art Gallery II, showing visible light entering through clerestory windows during winter. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

Required Actions

- Hire an architect to develop a design for light baffles/deflectors or louvers to be installed at clerestory window level in Contemporary Art Gallery II to redirect strong winter sunlight away from collections (fig. 5.B7.2). This will require further measurements and study, such as creation of a digital model and/or a physical prototype to evaluate the visual impact of the baffle/deflector on the architectural significance of the space. The baffle/deflector may be fixed, or it may have features that require seasonal adjustment to account for sun angle and light intensity.
- Install light baffles/deflectors where needed after prototype development.

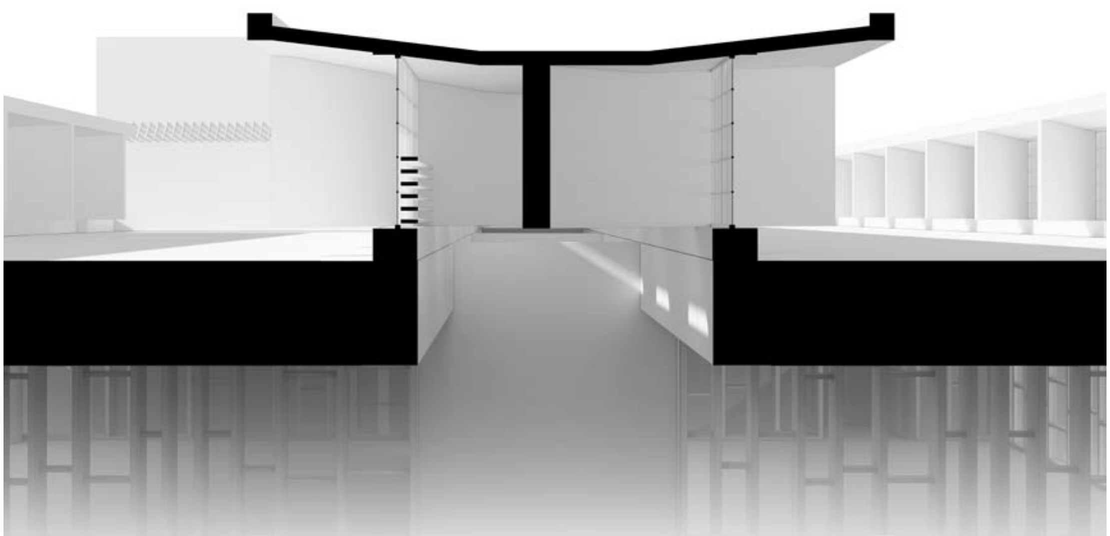


FIGURE 5.B7.2.
Detail of longitudinal section through Contemporary Art Gallery II, showing clerestory with proposed light baffle. © Fondation Le Corbusier. Image: Timothy Augustus Y. Ong, 2024, © J. Paul Getty Trust.

Supporting Actions Required

If the baffle/deflector requires seasonal adjustment, staff will need to be trained in its operation.

Potential Risks

There is a slight risk that the baffle/deflector will lower ambient natural light in seasons other than winter.

Seasonal Operation

Depending on the design of the baffle/deflector, it may be necessary to make seasonal adjustments to account for sun angle and light intensity.

Notes

The baffles/deflectors should be designed to minimize their visual impact on the building's architectural value. This building strategy should only be implemented if design studies and prototypes arrive at a solution that is compatible with cultural significance of the interior.

Artificial Lighting

Existing Situation

The current light fixtures in the gallery spaces (fig. 5.B8.1) and in the exhibit cases (fig. 5.B8.2) use a variety of lamps and light bulbs, including fluorescent lamps, halogen bulbs, and incandescent bulbs. These types of light sources present risks to collections that are sensitive to UV radiation (fluorescent lamps), radiant heat (halogen and incandescent bulbs), and excessive light levels (all types). These artificial-light sources also emit waste heat into the surrounding environment.

Almost all light fixtures that use the above listed lamps or bulbs are architecturally significant and must be retained for the architectural integrity of the museum interior and the design integrity of the architecturally significant exhibition furniture.

FIGURE 5.B8.1.
Ceiling-mounted light fixtures over exhibit cases in the Metal Sculptures Gallery. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

FIGURE 5.B8.2.
Light fixture mounted in canopy of an exhibit case. © Fondation Le Corbusier. Photo: Foekje Boersma, 2017, © J. Paul Getty Trust.

Required Actions

- Hire a museum lighting specialist to design and specify the work necessary to convert the lamps/bulbs of the existing light fixtures and lighted exhibition furniture to museum-quality light-emitting diode (LED) lamps with light levels appropriate to the collections on exhibit. The necessary work may include replacement of wiring, lamp/bulb holders, and switching. Reflectors may need modification for even light distribution, and exposed fixture surfaces may need restoration.
- If possible, the replacement LED lighting in the galleries should be equipped with dimmer controls to adjust illuminance levels according to the vulnerability of the collections.

Supporting Actions Required

- Museum staff will need to be trained in cleaning of fixtures, installation of replacement lamps, and operation of dimmer controls.
- Wiring and lamp holders for existing light fixtures should be examined for poor insulation and loose connections, which can pose a fire risk. Wiring and lamp holders should be replaced as needed.

Potential Risks

Changes in staff will require retraining in cleaning of fixtures, installation of replacement lamps, and operation of dimmer controls.

The quality of the electrical power supply will affect the service life of lamps and dimmers.

In the future, when new LED lamps are needed, it will be important to obtain high-quality lamps with performance characteristics comparable to the lamps selected by the lighting specialist. Low-quality LED lamps can have a short life, may overheat, or may have poor color-rendering.

Seasonal Operation

No seasonal actions required.

Notes

Every effort should be made to retain and use any original light fixtures. Adaptations should be made on an as-needed basis to avoid adversely impacting the building's cultural and architectural value.

Cases

Existing Situation

The original cases designed by Ratna Fabri are of exceptional cultural significance. Current cases contribute to stabilizing fluctuations in relative humidity, but their performance and operation could be improved through a careful adaptation approach that aims to conserve their cultural significance.

Cases should be used to create microclimate environments for miniatures, coins (fig. 5.O1.1), and metal sculptures (fig. 5.O1.2).

FIGURE 5.O1.1.
Coins cases on display. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

Required Actions

- Engage a designer to adapt existing cases to
  - improve airtightness of cases, especially those used for displaying metals and coins, to lower the air exchange rate;
  - improve operation;
  - replace plexiglass in the coins cases (fig. 5.O1.3) with polystyrene coin holders, for example; and
  - add silica gel trays inside cases.
- Adaptation of cases should
  - improve performance without negatively impacting cultural significance and
  - use only new materials (wood, boards, linings, and sealants) of archival quality.

Supporting Actions Required

- If Clerestory Daylight and UV Management above Galleries Strategy (B4) and Artificial Lighting Strategy (B8) are implemented, the glazing of the cases does not need a UV filter.
- If active corrosion is identified, metal pieces and coins require treatment prior to mounting inside cases.

FIGURE 5.O1.2.
Metal sculptures cases on display. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

Potential Risks

New materials used in adapting the cases can off-gas and damage the artwork, hence the importance of using archival materials.

FIGURE 5.O1.3.
Detail of current condition of plexiglass in a coins case. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Seasonal Operation

TABLE 5.O1.1.
Seasonal Operational Protocols for Cases

Spring (Mar–May)	Pre-Monsoon (Jun)	Monsoon (Jul–Sep)	Post-Monsoon (Oct–Nov)	Winter (Dec–Feb)
Consider opening cases for maintenance or repositioning when interior relative humidity is low (possibly late spring).	Add/change silica gel to lower relative humidity to 30% in metal and coins cases.	Keep cases closed due to high relative humidity conditions.	Keep cases closed due to high relative humidity conditions.	Keep cases closed due to high relative humidity conditions.

Notes

The original cases designed by Ratna Fabri are considered of exceptional value, as they are integral to the cultural significance of the Government Museum and Art Gallery and should be retained. Therefore, adaptations to these cases must minimize their potential impact on the cases' cultural value as much as possible. Adaptations should only be implemented if design studies arrive at a solution that is compatible with cultural significance.

Microclimate Frames

Existing Situation

If paintings are hung directly on the northeast wall, the high humidity in the wall poses a risk of mold growth in the space between the canvas and the wall, created by the stretcher on the back of the painting. Using the existing freestanding panels helps to avoid this risk (fig. 5.O2.1). However, if it is necessary to hang paintings directly on the northeast wall, microclimate frames should be considered.

FIGURE 5.O2.1.
Original freestanding panels on the northeast wall help avoid the risk of mold growth. © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

Required Actions

- Mount paintings in microclimate frames if hanging paintings directly on the northeast wall. A microclimate frame is designed to create a sealed enclosure around the artwork to buffer fluctuations in relative humidity and prevent the ingress of external pollutants, dust, and pests. Due to the small volume of air, there is no need to include any buffer material such as silica gel.
- The construction materials of microclimate frames (wood, boards, linings, and sealants) need to be of archival quality.

Supporting Actions Required

- If Clerestory Daylight and UV Management above Galleries Strategy (B4) and Artificial Lighting Strategy (B8) are implemented, the glazing of the microclimate frame does not need a UV filter.
- Staff trained in maintaining microclimate frames must be available.
- Maintenance is required.

Potential Risks

New materials used in microclimate frames can off-gas and damage the artwork, hence the importance of using archival materials.

Seasonal Operation

TABLE 5.O2.1.

Seasonal Operational Protocols for Microclimate Frames

Spring (Mar–May)	Pre-Monsoon (Jun)	Monsoon (Jul–Sep)	Post-Monsoon (Oct–Nov)	Winter (Dec–Feb)
No action	Maintenance of microclimate frames	No action	Maintenance of microclimate frames	No action

Notes

It is preferable to avoid hanging paintings directly on the northeast wall and use the existing freestanding panels instead.

For more information on microclimate frames, consult the following resources:

American Institute for Conservation (AIC). n.d. "Creating Well-Sealed Frames and Display Packages." AIC Wiki. Accessed 28 May 2020. https://www.conservation-wiki.com/wiki/Creating_Well-Sealed_Frames_and_Display_Packages.

Verticchio, Elena, Francesca Frasca, Fernando-Juan Garcìa-Diego, and Anna Maria Siani. 2019. "Investigation on the Use of Passive Microclimate Frames in View of the Climate Change Scenario." *Climate* 7 (8): 98.

Seasonal Object Rotation

Existing Situation

To avoid the high temperatures that accelerate chemical degradation, works on paper that are of higher value should be exhibited in cooler seasons and kept in climate-controlled storage during hot seasons (fig. 5.O3.1). Another reason for object rotation is the incidence of direct sunlight on certain walls (fig. 5.O3.2).

Required Actions

- If HVAC – Miniatures Gallery Strategy (M2) is not feasible and Non-Mechanical Management (see strategy sheet M2, Notes) is adopted for the Miniatures Gallery, exhibit the high-value miniatures during winter and until the first month of spring. Keep the high-value miniatures in climate-controlled storage during pre-monsoon, monsoon, and post-monsoon.
- For other works on paper, consider showing works of higher value in the cooler winter season.
- For contemporary paintings, relocate paintings that receive direct sunlight during winter if Baffle/Deflect Daylight through Clerestories above Contemporary Art Gallery II Strategy (B7) is not implemented.

FIGURE 5.O3.1.
Miniatures are the most valuable objects in the museum's collection and can be vulnerable to degradation from high temperatures. © Fondation Le Corbusier. Photo: Chandler McCoy, 2024, © J. Paul Getty Trust.

FIGURE 5.O3.2.
Sunlight entering through clerestories and hitting contemporary paintings during winter. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Supporting Actions Required

Implementation of seasonal object rotation demands curatorial input on the selection and positioning of objects and additional deinstallation/installation efforts.

Potential Risks

The major risks in implementing seasonal object rotation are the additional time and handling demands placed on staff.

Seasonal Operation

TABLE 5.O3.1.

Seasonal Operational Protocols for Object Rotation

Notes

None.

Spring (Mar–May)	Pre-Monsoon (Jun)	Monsoon (Jul–Sep)	Post-Monsoon (Oct–Nov)	Winter (Dec–Feb)
If M2 strategy is not feasible and Non-Mechanical Management is adopted for Miniatures Gallery, exhibit the high-value miniatures during winter and until the first month of spring.	If M2 strategy is not feasible and Non-Mechanical Management is adopted for Miniatures Gallery, keep the high-value miniatures in storage during pre-monsoon.	If M2 strategy is not feasible and Non-Mechanical Management is adopted for Miniatures Gallery, keep the high-value miniatures in storage during monsoon.	If M2 strategy is not feasible and Non-Mechanical Management is adopted for Miniatures Gallery, keep the high-value miniatures in storage during post-monsoon.	If M2 strategy is not feasible and Non-Mechanical Management is adopted for Miniatures Gallery, exhibit the high-value miniatures during winter and until the first month of spring. Other works on paper: Consider showing works of higher value in the cooler winter season. Contemporary paintings: Relocate paintings that receive direct sunlight if B7 strategy is not implemented.

Environmental Monitoring

Existing Situation

The environmental monitoring equipment installed at the Government Museum and Art Gallery by the GCI can be used for continuous monitoring of environmental conditions (figs. 5.Mo1.1, 5.Mo1.2). This is crucial for assessing the efficacy of the implemented strategies and guiding subsequent data-driven modifications. By using the same data collection system used by the GCI, museum staff will be able to make direct comparisons of past and future data that will inform future assessments of the efficacy of the implemented strategies. While the GCI has managed system maintenance and data interpretation up to this point, museum staff can be trained by the GCI to carry out these tasks independently.

Required Actions

- GCI will train Government Museum and Art Gallery staff to download and interpret environmental data.
- Museum staff will periodically download and interpret data.

Supporting Actions Required

- Identify a local technical partner to support the museum in maintaining the environmental monitoring system.
- Maintain the environmental monitoring system, including system hardware such as batteries, sensors, uninterruptible power, and wireless internet access for remote monitoring 24/7.
- Maintain data storage and integrity.

Potential Risks

Requires staff time to store, manage, and interpret data and resources for equipment maintenance.

FIGURE 5.MO1.1.
Two Onset HOBO RX3000 remote monitoring stations located in the library. © Fondation Le Corbusier. Photo: Vincent Laudato Beltran, 2020, © J. Paul Getty Trust.

FIGURE 5.MO1.2.
An Onset HOBO RX3000 remote monitoring station located in the mechanical room adjacent to the Miniatures Gallery. © Fondation Le Corbusier. Photo: Vincent Laudato Beltran, 2020, © J. Paul Getty Trust.

Seasonal Operation

No seasonal actions required for monitoring, but analysis of seasonal data will help museum staff identify appropriate adjustments needed to optimize protocols for operating the aerators.

Notes

Supports most if not all strategies.

The GCI monitoring system may be supplemented by the addition of local, standalone data loggers for environments in critical areas or near highly sensitive objects.

CHAPTER 6

DECISION-MAKING PROCESS FOR ENVIRONMENTAL MANAGEMENT

The suite of strategies presented in this report, as well as the steps informing their development, represents part of the collaborative decision-making process for environmental management at the Government Museum and Art Gallery, Chandigarh. The strategies are intended to lead toward a design stage that prepares the institution to select and design the appropriate solutions (or choose to accept the existing environment), embark on their construction, and evaluate their impact.

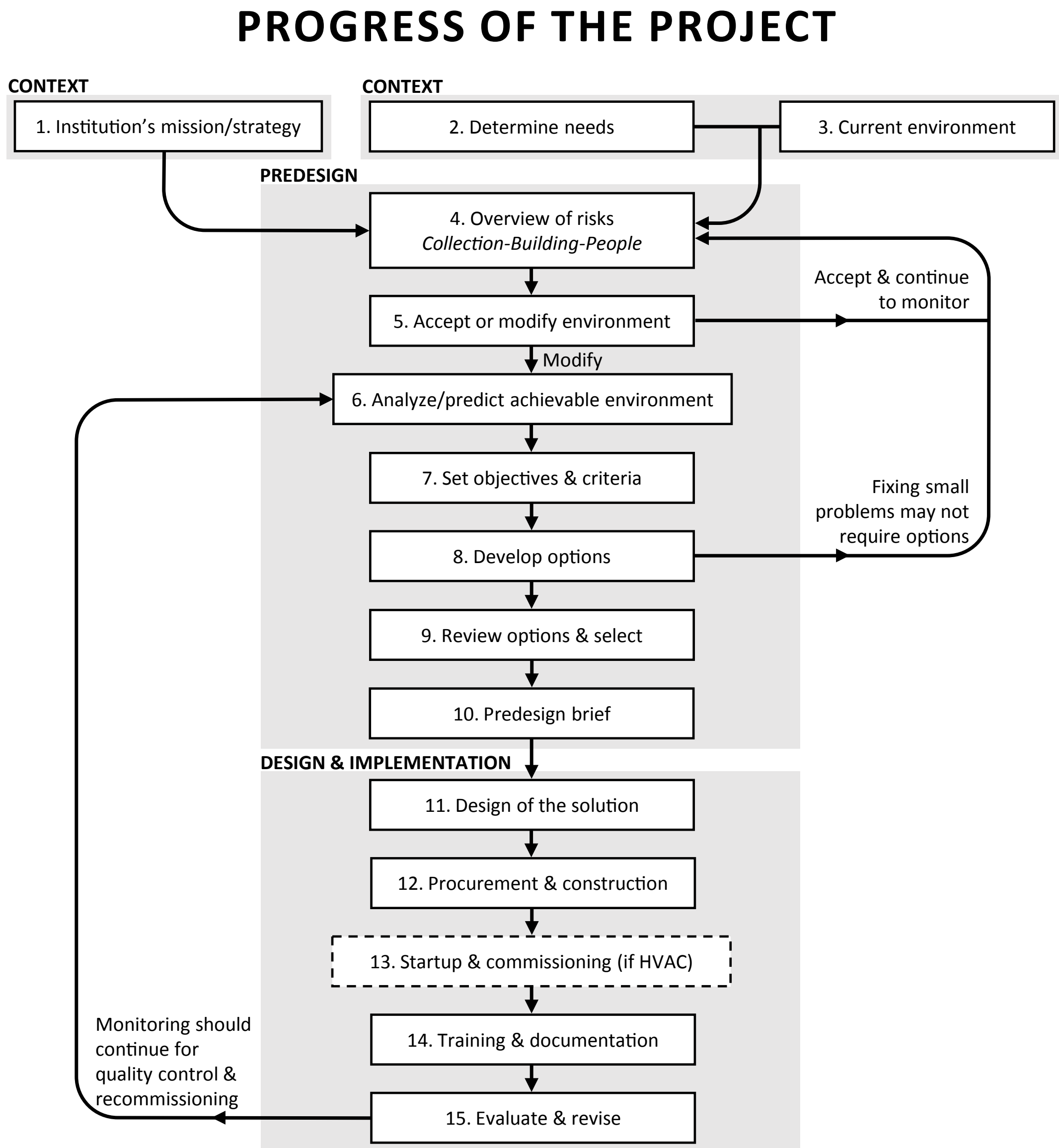
The overall decision-making process for environmental management is summarized in figure 6.1 (Taylor et al. 2023). This process aims to connect with the broader goals of a heritage institution by proposing environmental ranges and strategies that are specifically appropriate and sustainable for each institution. While institutional goals and contexts may differ, the general decision points remain similar and emphasize the links between various types of information.

These decision points involve multidisciplinary stakeholders whose level of participation—which includes taking a leading role ("lead"), contributing to decision-making ("consult"), and being impacted by the decision ("inform")—will shift during the course of the project (table 6.1). Note that the specific titles described in this table refer to general roles that will vary among different institutions and different countries; smaller institutions may have staff that assume multiple responsibilities.

The initial "Context" stage (steps 1–3) of the decision-making process gathers information on the roles and needs of the collection, building, and institution, as well as on the current environment, including the interior environment and professional culture. This focus on context helps reveal what might be considered "problems" and for whom. For many institutions, it is helpful if this stage is guided by an external professional facilitator. This stage may precede the involvement of external technical consultants such as a conservator or engineer, and it is imperative that this contextual information is shared so it can be used as a valuable resource during the process.

Subsequently, the "Predesign" stage (steps 4–10) provides an opportunity to synthesize this information to identify connections, allowing other risks and strategic priorities to be considered alongside the environment. If considering changes to the environment, one will need to specify environmental ranges and management options and develop a predesign brief that succinctly conveys the priorities, requirements, and criteria of the design solutions. This stage also provides an opportunity to accept the existing environment and continue monitoring as the situation poses low risks to the collection, building, and occupants.

The final "Design" stage (steps 11–15) is the realization of the selected strategies through design, implementation, and evaluation, and will vary considerably between institutions depending on the choices made in the previous steps.



Step 1. Institution’s mission/strategy: Institutional background (introduction)

Step 2. Determine needs: Architectural significance/guidance (introduction), environmental guidance (introduction), collection vulnerabilities to the environment (chapter 3)

Step 3. Current environment: Institutional background (introduction), external climate (chapter 1), building envelopes (chapter 2), existing environmental management systems (chapter 2), collections (chapter 3), interior environment (chapter 4)

Step 4. Overview of risks: Environmental guidance for human comfort (introduction), environmental risks to collections (chapter 3), environmental risks to the building envelope (chapter 5)

Step 5. Accept or modify environment: Interior environment (chapter 4), environmental guidance for human comfort (introduction), environmental risks to collections (chapter 3), environmental risks to the building envelope (chapter 5)

Step 6. Analyze/predict achievable environment: Environmental data analysis (chapter 4)

Step 7. Set objectives & criteria: Mechanical objectives (chapter 5), building (non-mechanical) objectives (chapter 5), collection objectives (chapter 5)

Step 8. Develop options: Mechanical strategies (chapter 5), building (non-mechanical) strategies (chapter 5), collection strategies (chapter 5)

Steps 9–15: Steps to be discussed by staff and stakeholders of the Government Museum and Art Gallery

FIGURE 6.1.

Top: diagram of the decision-making process delineating the points or steps for the design of a plan for implementing environmental management strategies. Bottom: description of the progress made thus far in the project, as discussed in this report. Diagram: Joel Taylor, rendering by Annelies Cosaert, © J. Paul Getty Trust.

TABLE 6.1.

Stakeholder Involvement in the Design of Environmental Management Strategies

Stage	Step	Lead	Consult	Inform
Context	1	Directorial/Curatorial	Collections, Internal Facilities	Architect, Engineer, External Consultant
	2	Collections, Internal Facilities	Curatorial	Engineer
	3	Collections/External Consultant, Internal Facilities	Curatorial, External Consultant, Security	Architect, Engineer
Predesign	4	Collections/External Consultant, Internal Facilities	Architect, Curatorial, Engineer, External Consultant, Security	Directorial
	5	Directorial/Curatorial/ Collections	Architect, Engineer, Internal Facilities	Directorial
	6	Architect, Engineer, Internal Facilities	Architect, Collections, Curatorial, Engineer	Directorial
	7	Collections, Engineer, Internal Facilities	Architect, Curatorial, External Consultant	External Consultant
	8	Architect/Engineer/External Consultant	Collections, Curatorial, Internal Facilities, Security	All Staff
	9	All Staff	All Staff, External Consultant	All Staff
	10	Curatorial/Directorial, Collections, Internal Facilities	Chief Financial Officer, External Consultant, Security	Architect, Commissioning Agent, Engineer
Design and Implementation	11	Architect/Engineer	Collections, External Consultant, Internal Facilities, Security	Commissioning Agent, Curatorial/Directorial
	12	Architect/Engineer, Chief Financial Officer, Internal Facilities	Collections, Commissioning Agent, Security	Curatorial/Directorial
	13	Commissioning Agent, Engineer	Chief Financial Officer, External Consultant	Collections
	14	Engineer, Internal Facilities	Collections, Commissioning Agent, Security	All Staff
	15	Engineer/External Consultant, Internal Facilities	Collections, Security	Curatorial/Directorial

Notes: This list is not exhaustive, and the specific nature of the decision will vary with the context of the situation. It is intended to be broad enough for many situations.
The titles refer to general roles rather than specific jobs, because of the variation among institutions and countries. Their position may also vary from this general guide.
In general, informing and involving people early is best; deeper collaboration is also more challenging and time-consuming in the short term.
A "/" indicates "either/or."
Source: Taylor et al. 2023, 146

All three stages must be informed by an uninterrupted program of monitoring of the interior and exterior environment of the museum. Continued environmental monitoring is crucial for quality control and recommissioning and provides a feedback loop to compare the predicted achievable environment to the actual response of the museum environment as a "system."

Regarding the Government Museum and Art Gallery case study, this report completes the "Context" stage (steps 1–3) and much of the "Predesign" stage (up to step 8) of the decision-making process shown in figure 6.1. Immediate "Predesign" steps include the review of the suggested strategies and the selection of key strategies for implementation by museum staff and its stakeholders; the Government Museum and Art Gallery team includes the director, curators and collection care staff, maintenance staff, and an external facilities team responsible for the museum and other nearby buildings. The following "Design" stage requires considerations of cost and timing of implementation, including obtaining the necessary approvals to move forward from the museum directorate, Chandigarh heritage authorities, and municipal building permit officials; coordinating with museum operations and other initiatives; and managing the resulting construction and/or repair projects.

ACKNOWLEDGMENTS

This project would not have been possible without the contributions of many people and, most importantly, without the solid partnership between the Government Museum and Art Gallery, Chandigarh, and the Getty Conservation Institute, with Michael C. Henry as consultant in environmental management.

Government Museum and Art Gallery, Chandigarh

Seema Gera and Megha Kulkarni have been involved throughout the entire project. Their contributions were key in the assessment of the collection, identifying needs and defining goals for the strategies, and they provided essential feedback on proposed strategies. They also supported local data gathering and served as liaisons with museum stakeholders. We acknowledge the interest and involvement of the various directors who held office during the course of this project, especially Naveen Danics, the museum's current director, who reviewed the findings and provided helpful comments in May 2024.

Getty Conservation Institute

Vincent Laudato Beltran, scientist, led the installation of the environmental monitoring system and made key contributions to data analysis and the development of environmental management strategies.

Chandler McCoy, principal project specialist, led the project from the start and provided architectural conservation perspective to the development of environmental management strategies.

Cecília Winter, senior project specialist (2022–2025), complemented and finalized the collection assessment, contributed to data analysis, and provided object conservation perspective to the development of environmental management strategies.

Ana Paula Arato Gonçalves, associate project specialist, assisted with project management from the end of data collection to the publication of this report, developed the layout for the draft report, and contributed to the development of the strategy sheets.

Annelies Cosaert, professional fellow (2018–21), managed the project during development of the monitoring strategy and up to the start of data gathering. She assisted with the installation of the environmental monitoring system and conducted data gathering on-site and during the initial collection assessment.

Jenny Youkyoung Kim, assistant scientist, made key contributions to environmental data analysis. She also assisted in the collection assessment and development of strategies.

Timothy Augustus Y. Ong, graduate intern (2023–24), developed architectural plans and 3D models based on files provided by the Development and Research Organisation for Nature, Arts and Heritage (DRONAH), which were used in the analysis of sunlight incidence and to illustrate this report.

Tahmida Afroze, graduate intern (2023–24), developed an architectural section based on files provided by DRONAH, which was used to illustrate this report.

Hongye Wang, graduate intern (2024–25) with the Conserving Modern Architecture Initiative team, contributed to finalizing the layout of the draft report and architectural drawings.

Martin Coleman, publications manager, guided the publication process for this report.

Reem Baroody, former project associate, provided administrative support for this project until 2024.

Kathleen Dardes, former head of the Collections Department, guided the initial project definition.

Foekje Boersma, former senior project specialist, contributed to the initial project definition.

Consultants

Michael C. Henry led the development of the environmental monitoring system and made key contributions to data analysis and understanding of the environmental behavior of the museum and the development of environmental management strategies.

Dianne Woo copyedited the manuscript.

Anthony Paular typeset the material.

Further Thanks

We would like to thank the Getty Conservation Institute department heads Stavroula Golfomitsou, Tom Learner, and Susan Macdonald for their steadfast support for this project and the publication of this report. We are especially grateful for Stavroula Golfomitsou's review and guidance on chapter 3.

We are grateful to architect S. D. Sharma and representatives from Chandigarh Administration's Engineering Department and from the Development and Research Organisation for Nature, Arts and Heritage, who attended a virtual workshop in August 2022 to learn about the results of the environmental monitoring of the Government Museum and Art Gallery and to provide feedback on the proposed strategies.

The authors would like to thank Fondation Le Corbusier for permission to publish images from its archive in figures 2.15 and 2.17 and images of Le Corbusier's work.

APPENDIX A

Architectural Drawings

The set of architectural drawings in this appendix was adapted from a set developed by the Development and Research Organisation for Nature, Arts and Heritage for the Government Museum and Art Gallery's Conservation Management Plan. It illustrates the current configuration and use of building spaces at the time of the project.

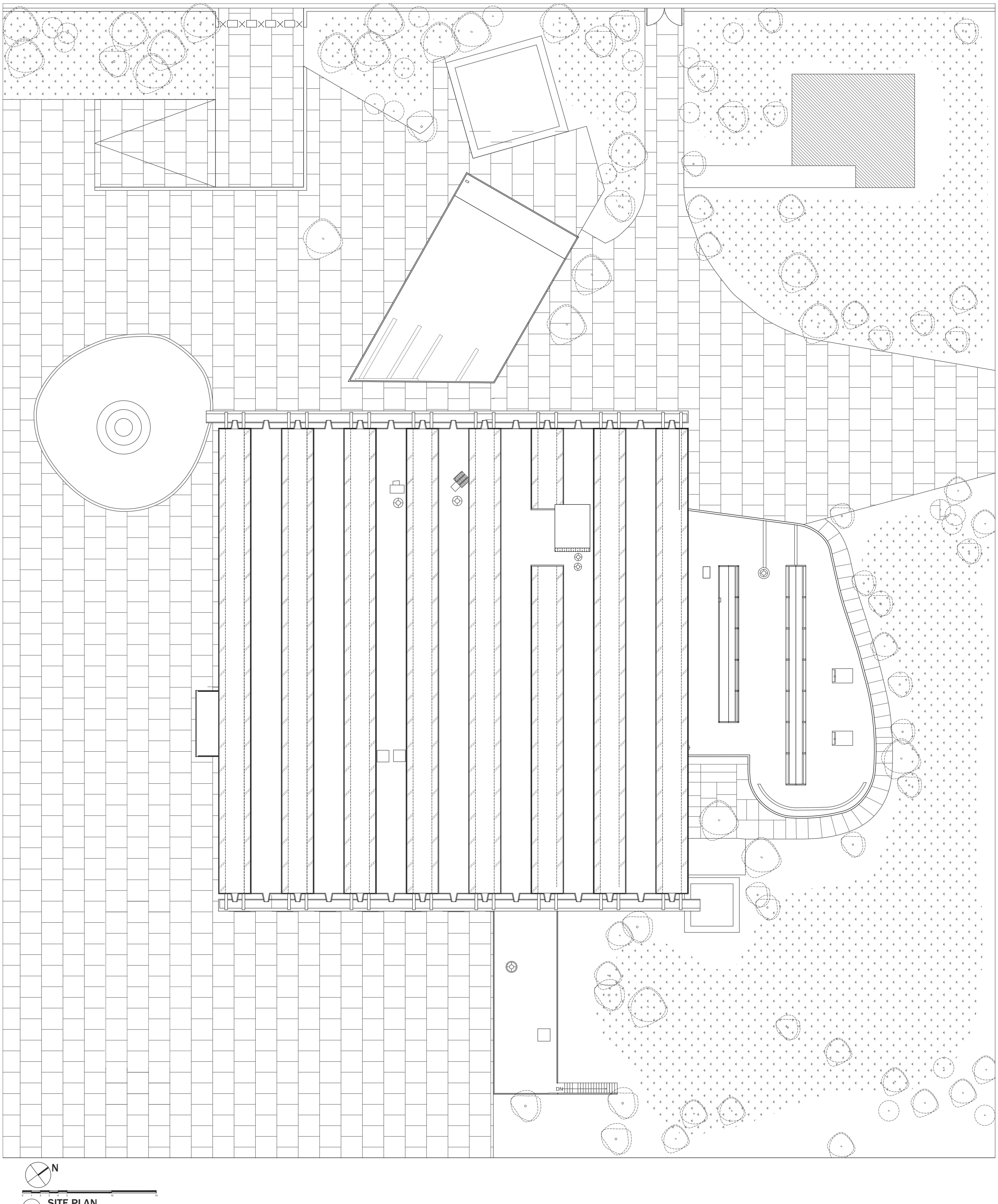


FIGURE A.1.

Site plan of the Government Museum and Art Gallery. © Fondation Le Corbusier. Drawing: DRONAH, modified by Timothy Augustus Y. Ong and Hongye Wang. Image © J. Paul Getty Trust.

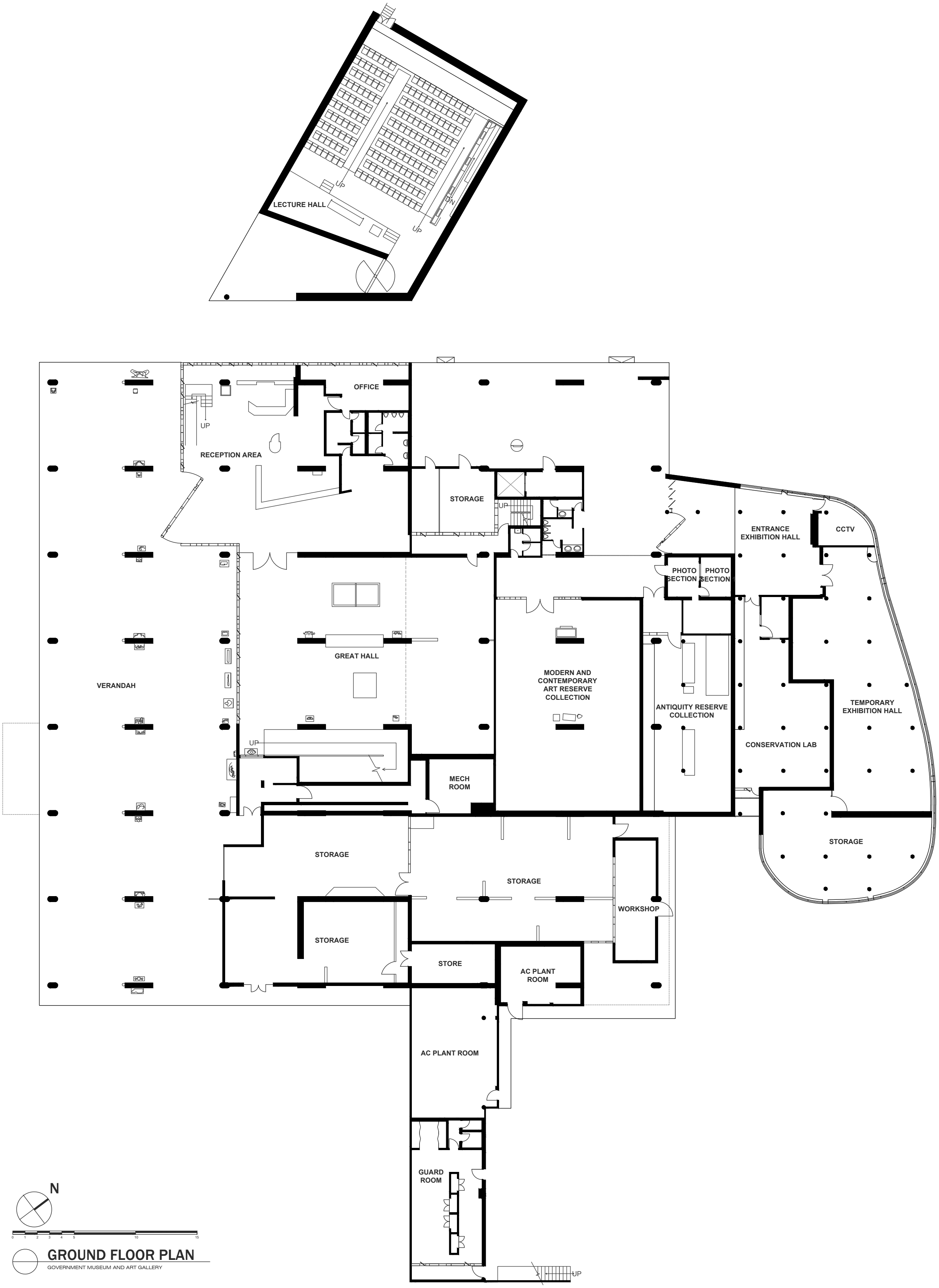


FIGURE A.2.

Ground-floor plan of the Government Museum and Art Gallery. © Fondation Le Corbusier. Drawing: DRONAH, modified by Timothy Augustus Y. Ong and Hongye Wang. Image © J. Paul Getty Trust.

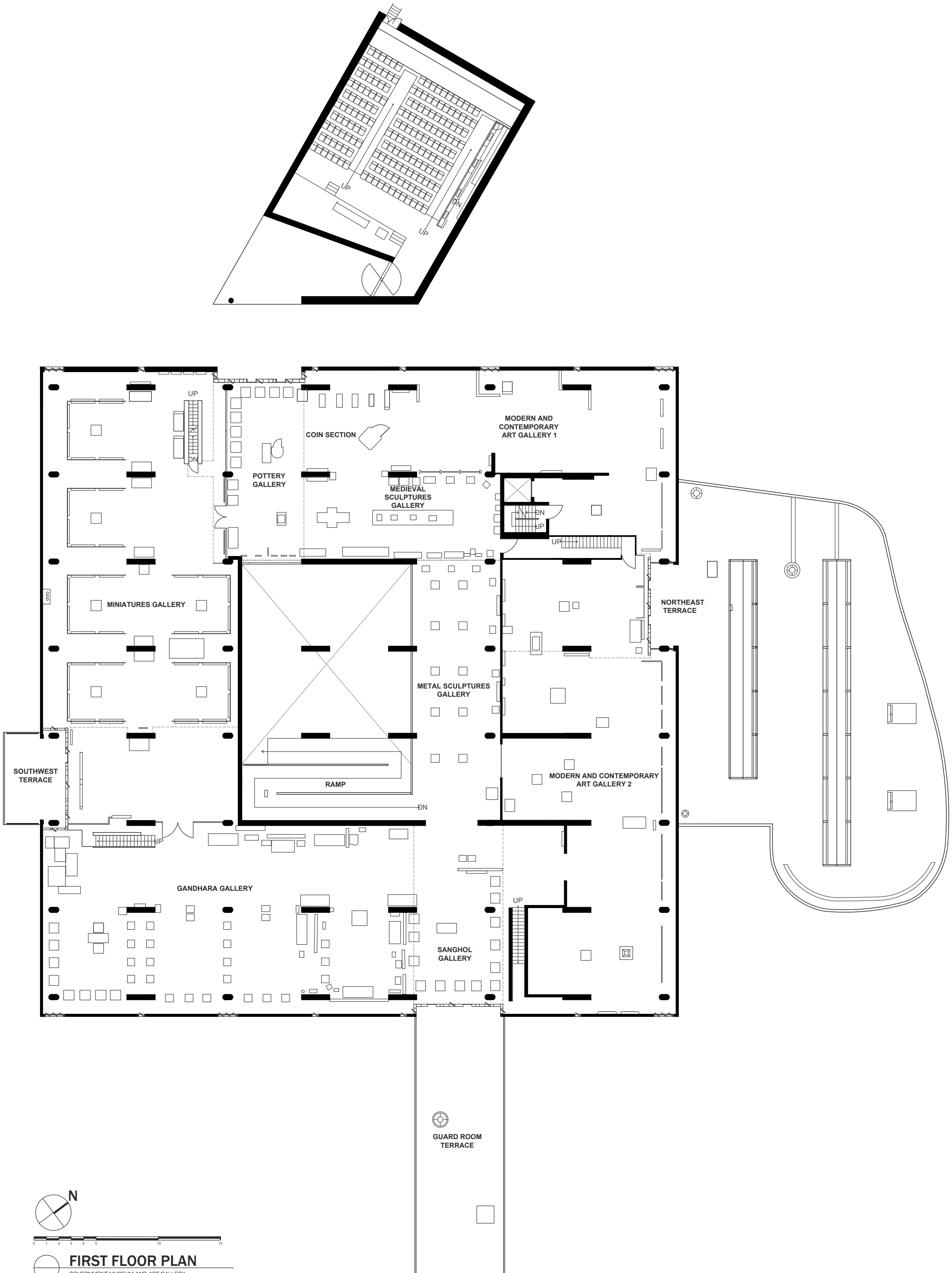


FIGURE A.3.

First-floor plan of the Government Museum and Art Gallery. © Fondation Le Corbusier. Drawing: DRONAH, modified by Timothy Augustus Y. Ong and Hongye Wang. Image © J. Paul Getty Trust.

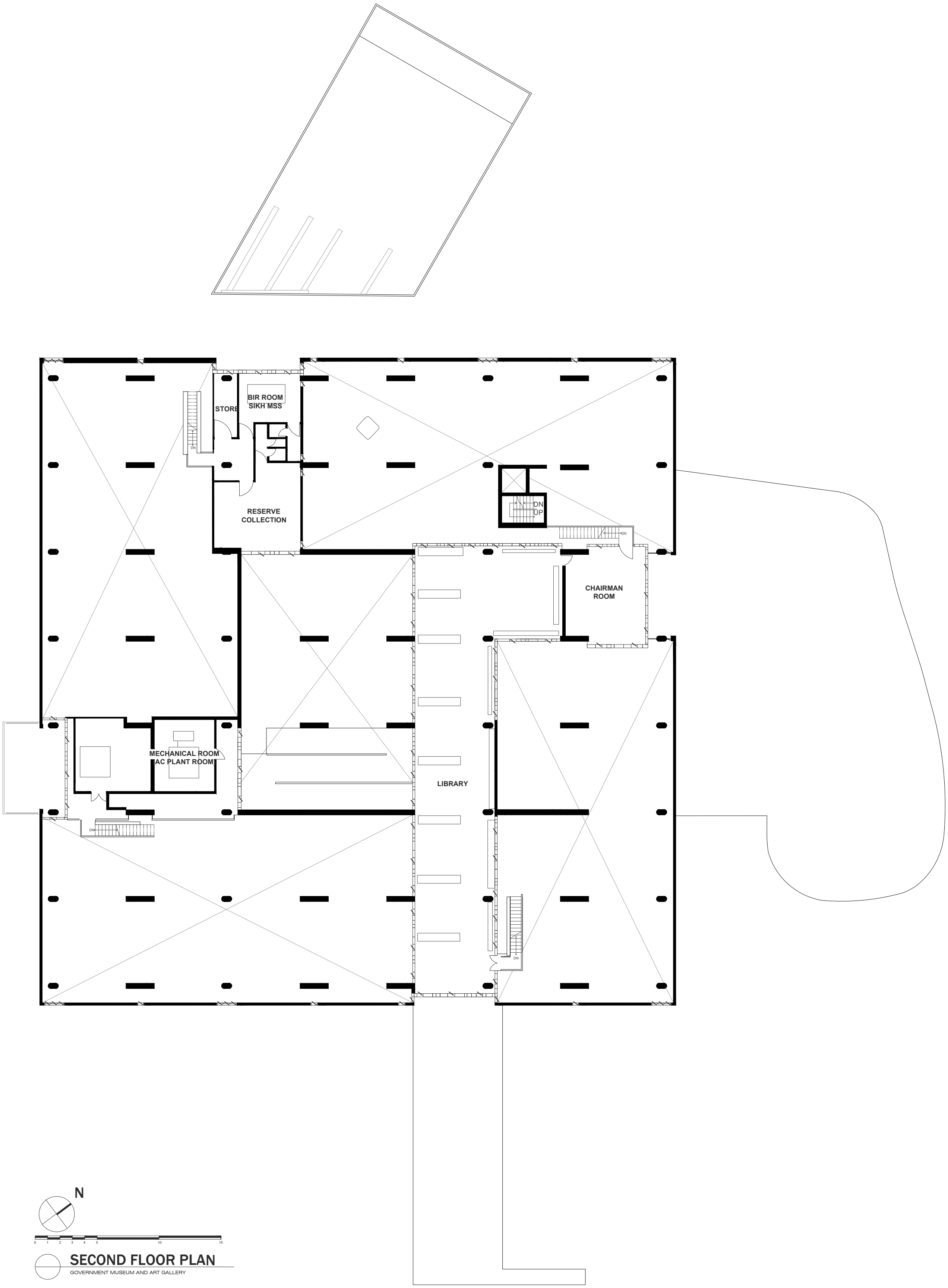


FIGURE A.4.

Second-floor plan of the Government Museum and Art Gallery. © Fondation Le Corbusier. Drawing: DRONAH, modified by Timothy Augustus Y. Ong and Hongye Wang. Image © J. Paul Getty Trust.

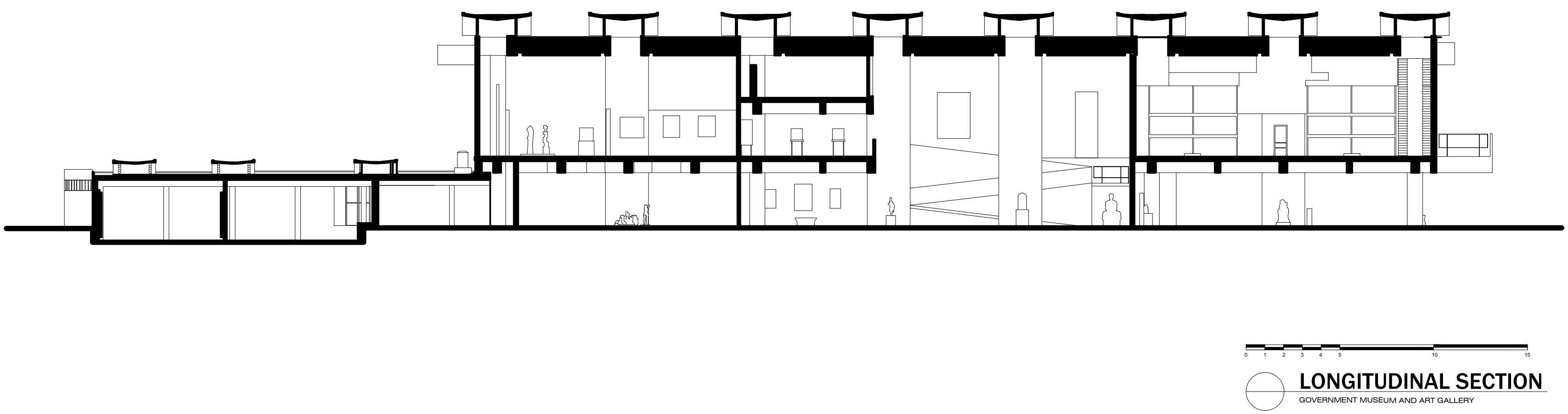


FIGURE A.5.
Sectional drawing of the Government Museum and Art Gallery. © Fondation Le Corbusier. Drawing: DRONAH, modified by Tahmida Afroze. Image © J. Paul Getty Trust.

APPENDIX B

Report on Installation of Monitoring Equipment

Annelies Cosaert, Chandler McCoy, and Kathleen Dardes

Scope

This report, which was compiled in May 2020, covers the installation of monitoring equipment that took place from 2 to 24 January 2020 at the Government Museum and Art Gallery. The installation was carried out according to instructions provided by Michael C. Henry.

Monitoring Campaign

Types of Measurements

Light
Method: light sensors, spot readings of visible light and UV light (fig. B.1), and Blue Wool cards (see fig. 4.4).

Temperature and Relative Humidity Monitoring
Method: sensors placed throughout the exhibition rooms and library, physically connected to the remote monitoring station (HOBO RX3000) and standalone loggers that are battery operated.

FIGURE B.1.
An ELSEC 765 environmental monitor for spot reading of UV (lumen) and visible light (lux) of the natural light. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Pollution

Method: remote dust monitor (fig. B.2) and Corrosion Classification Coupons (see fig. 4.2).

FIGURE B.2.
A Met One ES-642 remote dust monitor, connected to the HOBO RX3000 monitoring station. © Fondation Le Corbusier. Photo: Annelies Cosaert, 2020, © J. Paul Getty Trust.

Installation of the Equipment

The equipment listed by Michael C. Henry in the plan he developed for environmental monitoring of the museum was shipped to India about two months in advance of installation. The museum installed this equipment based on the instructions he provided.

Table B.1 lists all monitoring devices, passive and active, present at the museum during the monitoring campaign. Also indicated is the location of current and planned measurements on 25 February 2020.

TABLE B.1.
Sensor Directory

ID/Tag No.	Type	Description	Location
Data Loggers			
CGMAG1	Data Logger RX3000	Data collection from sensors measuring exterior condition on the roof, and interior conditions at Contemporary Art Gallery I	Library, 2nd floor
CGMAG2	Data Logger RX3000	Data collection from sensors measuring interior conditions at the clerestory level, library, Great Hall, and entrance	Library, 2nd floor
CGMAG3	Data Logger RX3000	Data collection from sensors measuring conditions at Miniatures Gallery and Gandhara Sculptures Gallery	Mechanical room, 2nd floor
Sensors Connected to CGMAG1			
1.01	T/RH (S-THB-M002) and Shield (RS-3-B)	Sensor measuring temperature and relative humidity of exterior air	Roof level
1.02	Rainfall (RGB-M002)	Sensor measuring rainfall	Roof level
1.03	Solar (S-LIB-M003)	Sensor measuring solar radiation NE direction	Roof level
1.04		Sensor measuring solar radiation SE direction	Roof level
1.05		Sensor measuring solar radiation SW direction	Roof level
1.06		Sensor measuring solar radiation vertical direction	Roof level
1.07	WS/WD (S-WSET-B)	Sensor measuring wind speed	Roof level
1.08		Sensor measuring wind direction	Roof level
2.07	T/RH (S-THB-M008)	Sensor measuring temperature and relative humidity of interior air	Contemporary Art Gallery I, 1st floor
2.08	T/RH (S-THB-M002)	Sensor measuring temperature and relative humidity of interior air	Medieval Sculptures Gallery, 2nd floor
Sensors Connected to CGMAG2			
2.01	T/RH (S-THB-M002) and Shield (RS-3-B)	Sensor measuring temperature and relative humidity of interior air	Entrance
2.02	Surf T (S-TMB-M006)	Sensor measuring surface temperature	Entrance
2.03	T/RH (S-THB-M008)	Sensor measuring temperature and relative humidity of interior air	Great Hall, ground floor

ID/Tag No.	Type	Description	Location
2.04	T/RH (S-THB-M002)	Sensor measuring temperature and relative humidity of interior air	Great Hall, 1st floor
2.05		Sensor measuring temperature and relative humidity of interior air	Great Hall, 2nd floor
2.06		Sensor measuring temperature and relative humidity of interior air	Library, 2nd floor
1.09	Surf T (S-TMB-M006)	Sensor measuring surface temperature	Clerestory
1.10	T/RH (S-THB-M002) and Shield (RS-3-B)	Sensor measuring temperature and relative humidity of interior air	Clerestory
1.11	Solar (S-LIB-M003)	Sensor measuring solar radiation	Clerestory
6.01	Met One ES-642 (Analog Sensor)	Sensor measuring pollution PM_{10}	Library, 2nd floor
Sensors Connected to CGMAG3			
3.01	T/RH (S-THB-M008)	Sensor measuring temperature and relative humidity of interior air	Gandhara Sculptures Gallery, 1st floor, low
3.02	T/RH (S-THB-M002)	Sensor measuring temperature and relative humidity of interior air	Gandhara Sculptures Gallery, 1st floor, high
3.03	Surf T (S-TMB-M006)	Sensor measuring surface temperature	SW wall
3.04	T/RH (S-THB-M008)	Sensor measuring temperature and relative humidity of interior air	Miniatures Gallery, 1st floor, low
3.05	T/RH (S-THB-M002)	Sensor measuring temperature and relative humidity of interior air	Miniatures Gallery, 1st floor, high
3.06		Sensor measuring temperature and relative humidity of supply air (HVAC)	Miniatures Gallery
3.07		Sensor measuring temperature and relative humidity of return air (HVAC)	Miniatures Gallery
Standalone Data Loggers – yearlong monitoring			
4.01	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Miniatures storage, on compact shelving
4.02	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Contemporary art storage, on screen 21
4.03	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Temporary exhibition gallery, next to light fixture, between columns I4 and I5
4.04	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Storage (former Child Art Gallery), on the ceiling near column F7
4.05	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Bir room, Sikh manuscripts, on bed, sensor facing up, near column D1
4.06	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Contemporary Art Gallery I, behind painting, acc. nr. 3311

ID/Tag No.	Type	Description	Location
4.07	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Metal Sculptures Gallery, display case, acc. nr. 5014
4.08	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Coins Section, display case nr. X
4.09	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Miniatures Gallery, low display case, acc. nr. 2002.2.3
Corrosion Classification Coupons			
5.01	Corrosion Classification Coupon (CCC)	Corrosion Classification Coupons (CCC) by Purafil are reactivity monitors that passively assess the quality of ambient air	Miniatures storage, compact shelving in box 205
5.02	Corrosion Classification Coupon (CCC)	Corrosion Classification Coupons (CCC) by Purafil are reactivity monitors that passively assess the quality of ambient air	Miniatures storage, with coins on slide 19
5.03	Corrosion Classification Coupon (CCC)	Corrosion Classification Coupons (CCC) by Purafil are reactivity monitors that passively assess the quality of ambient air	Miniatures storage, wood box nr. 38
5.04	Corrosion Classification Coupon (CCC)	Corrosion Classification Coupons (CCC) by Purafil are reactivity monitors that passively assess the quality of ambient air	Metal Sculptures Gallery, display case, acc. nr. 5014
5.05	Corrosion Classification Coupon (CCC)	Corrosion Classification Coupons (CCC) by Purafil are reactivity monitors that passively assess the quality of ambient air	Coins Section, display case "Mughal Coins"
5.06	Corrosion Classification Coupon (CCC)	Corrosion Classification Coupons (CCC) by Purafil are reactivity monitors that passively assess the quality of ambient air	Miniatures Gallery, low display case, acc. nr. 2002.2.3
5.07	Corrosion Classification Coupon (CCC)	Corrosion Classification Coupons (CCC) by Purafil are reactivity monitors that passively assess the quality of ambient air	Library, in wooden cup-boards with Chandigarh-related correspondence
5.08	Corrosion Classification Coupon (CCC)	Corrosion Classification Coupons (CCC) by Purafil are reactivity monitors that passively assess the quality of ambient air	Contemporary art storage, prints collection, metal flat file cabinet
5.09	Corrosion Classification Coupon (CCC)	Corrosion Classification Coupons (CCC) by Purafil are reactivity monitors that passively assess the quality of ambient air	Contemporary art storage, prints collection, display case
5.10	Corrosion Classification Coupon (CCC)	Corrosion Classification Coupons (CCC) by Purafil are reactivity monitors that passively assess the quality of ambient air	Bir room, on manuscripts collection bed
5.11	Corrosion Classification Coupon (CCC)	Corrosion Classification Coupons (CCC) by Purafil are reactivity monitors that passively assess the quality of ambient air	Metal Sculptures Gallery, display case against wall with brown spots
5.12	Corrosion Classification Coupon (CCC)	Corrosion Classification Coupons (CCC) by Purafil are reactivity monitors that passively assess the quality of ambient air	Outside of display case
Standalone Data Loggers – short-term monitoring			
7.01	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Close to door, on screen
7.02	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Back of storage in front of screen

ID/Tag No.	Type	Description	Location
7.03	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Back of storage on back of screen, next to mechanical room
7.04	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Inside box in wooden shelving
7.05	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	Inside box in compact shelving
7.06	T/RH (UX100-011)	Sensor measuring temperature and relative humidity	In compact shelving
Blue Wool Cards			
8.01e	Blue Wool Card	Used to gauge the level of light exposure	Great Hall, column D3, facing SE
8.02b	Blue Wool Card	Used to gauge the level of light exposure	Great Hall, column D4, facing SW
8.02c	Blue Wool Card	Used to gauge the level of light exposure	Great Hall, column D4, facing NW
8.02d	Blue Wool Card	Used to gauge the level of light exposure	Great Hall, column D4, facing NE
8.02e	Blue Wool Card	Used to gauge the level of light exposure	Great Hall, column D4, facing SE
8.03b	Blue Wool Card	Used to gauge the level of light exposure	Great Hall, between columns F4 and F5, facing SW
8.04c	Blue Wool Card	Used to gauge the level of light exposure	Great Hall (ramp), column D5, facing NW
8.04e	Blue Wool Card	Used to gauge the level of light exposure	Great Hall (ramp), column D5, facing SE
8.05b	Blue Wool Card	Used to gauge the level of light exposure	Ramp, between columns E5 and E6, facing SW
8.06c	Blue Wool Card	Used to gauge the level of light exposure	Ramp, column D5, facing NW
8.07a	Blue Wool Card	Used to gauge the level of light exposure	Metal Sculptures Gallery, column E5, in display case, facing up
8.08c	Blue Wool Card	Used to gauge the level of light exposure	Metal Sculptures Gallery, column E4, facing NW
8.08d	Blue Wool Card	Used to gauge the level of light exposure	Metal Sculptures Gallery, column E4, facing NE
8.08e	Blue Wool Card	Used to gauge the level of light exposure	Metal Sculptures Gallery, column E4, facing SE
8.09a	Blue Wool Card	Used to gauge the level of light exposure	Metal Sculptures Gallery, between columns E3 and F3, in display case, facing up
8.09e	Blue Wool Card	Used to gauge the level of light exposure	Metal Sculptures Gallery, between columns E3 and F3, in display case, facing SE
8.10b	Blue Wool Card	Used to gauge the level of light exposure	Metal Sculptures Gallery, column F4, facing SW

ID/Tag No.	Type	Description	Location
8.11a	Blue Wool Card	Used to gauge the level of light exposure	Metal Sculptures Gallery, between columns F4 and F5, in display case, facing up
8.12e	Blue Wool Card	Used to gauge the level of light exposure	Gandhara Sculptures Gallery, column F7, facing SE
8.13a	Blue Wool Card	Used to gauge the level of light exposure	Gandhara Sculptures Gallery, column E7, in display case close to window, facing up
8.14a	Blue Wool Card	Used to gauge the level of light exposure	Gandhara Sculptures Gallery, column E7, in display case, facing up
8.15b	Blue Wool Card	Used to gauge the level of light exposure	Gandhara Sculptures Gallery, column D7, facing SW
8.15c	Blue Wool Card	Used to gauge the level of light exposure	Gandhara Sculptures Gallery, column D7, facing NW
8.15d	Blue Wool Card	Used to gauge the level of light exposure	Gandhara Sculptures Gallery, column D7, facing NE
8.15e	Blue Wool Card	Used to gauge the level of light exposure	Gandhara Sculptures Gallery, column D7, facing SE
8.16e	Blue Wool Card	Used to gauge the level of light exposure	Gandhara Sculptures Gallery, column A6, against stairs, facing SE
8.17d	Blue Wool Card	Used to gauge the level of light exposure	Gandhara Sculptures Gallery, column A8, facing NE
8.17c	Blue Wool Card	Used to gauge the level of light exposure	Gandhara Sculptures Gallery, column A8, facing NW
8.17e	Blue Wool Card	Used to gauge the level of light exposure	Gandhara Sculptures Gallery, column A8, facing SE
8.18a	Blue Wool Card	Used to gauge the level of light exposure	Gandhara Sculptures Gallery, between columns A7 and A8, in display case, facing up
8.19a	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column B5, in display case, facing up
8.19b	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column B5, facing SW
8.19c	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column B5, facing NW
8.19d	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column B5, facing NE
8.19e	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column B5, facing SE
8.20e	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, between columns A5 and B5, facing SE
8.21a	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column B3, in display case, facing up

ID/Tag No.	Type	Description	Location
8.22b	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column B3, in display case, facing SW
8.22c	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column B3, in display case, facing NW
8.22e	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column A3, in display case, facing SE
8.23b	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column A3, in display case, facing SW
8.23c	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column A3, in display case, facing NW
8.24a	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column B3, in display case, facing up
8.25a	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column B1, in display case, facing up
8.25b	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, column B1, on staircase, facing SW
8.26e	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, between columns A1 and B1, facing SE
8.27e	Blue Wool Card	Used to gauge the level of light exposure	Miniatures Gallery, between columns B1 and C1, facing SE
8.28d	Blue Wool Card	Used to gauge the level of light exposure	Pottery Gallery, column C2, facing NE
8.29a	Blue Wool Card	Used to gauge the level of light exposure	Pottery Gallery, between columns C1 and D1, in display case, facing up
8.30c	Blue Wool Card	Used to gauge the level of light exposure	Pottery Gallery, column D3, facing NW
8.31b	Blue Wool Card	Used to gauge the level of light exposure	Medieval Sculptures Gallery, column E2, facing SW
8.31c	Blue Wool Card	Used to gauge the level of light exposure	Medieval Sculptures Gallery, column E2, facing NW
8.31e	Blue Wool Card	Used to gauge the level of light exposure	Medieval Sculptures Gallery, column E2, facing SE
8.32b	Blue Wool Card	Used to gauge the level of light exposure	Medieval Sculptures Gallery, between columns F2 and F3, facing SW
8.33e	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery I, column G1, facing SE
8.34c	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery I, column G2, facing NW
8.34e	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery I, column G2, facing SE

ID/Tag No.	Type	Description	Location
8.35b	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery I, between columns H2 and H3, facing SW
8.36d	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery II, between columns F3 and F4, facing NE
8.37b	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery II, column H5, facing SW
8.38c	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery II, column G5, facing NW
8.38d	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery II, column G5, facing NE
8.38e	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery II, column G5, facing SE
8.39b	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery II, between columns G6 and G7, facing SW
8.39d	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery II, between columns G6 and G7, facing NE
8.40c	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery II, column H8 facing NW
8.40b	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery II, column H8, facing SW
8.41c	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery II, column G8, facing NW
8.42e	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery II, between columns F6 and G6, facing SE
8.43c	Blue Wool Card	Used to gauge the level of light exposure	Contemporary Art Gallery II, between columns F7 and G7, facing NW

During the January 2020 visit, the following actions were completed by museum personnel with help from Vincent Laudato Beltran of the Getty Conservation Institute (GCI). Sensor ID/tag numbers are indicated in parentheses; see the complete sensor directory in table B.1 for more information.

- Sensors (1.01–3.07) were connected to the HOBO RX3000 data loggers (fig. B.3).
- HOBO RX3000 data loggers (CGMAG1, CGMAG 2, and CGMAG 3) were programmed and connected to wireless internet routers.
- Individual battery-operated loggers were used for some short-term monitoring in the storage spaces in locations 7.01–7.06 and were then moved to locations 4.01–4.09 for yearlong monitoring.
- Corrosion Classification Coupons (5.01–5.12) were put in place and future locations for placement were selected.
- Light and UV spot readings were taken from five directions: upward, northwest, southwest, southeast, and northeast, as well as at every column and in between for all exhibition spaces.

FIGURE B.3.
GCI staff members working to connect sensors to a remote logging station (HOBO RX3000, CGMAG1, and CGMAG 2). © Fondation Le Corbusier. Photo: Tim Webster, 2020, © J. Paul Getty Trust.

- Stabilizers (fig. B.4) were put in place and connected to all electrical equipment, including HOBO RX3000 data loggers (CGMAG1, CGMAG 2, and CGMAG 3) and a pollution monitor (6.01).
- A remote dust monitor equipped with a PM_{10} sharp-cut cyclone inlet (6.01) was installed and connected to the HOBO RX3000 data logger (CGMAG3).
- Sensor height was adjusted if within visitors' reach (from 1.6 m to 3.2 m [5 ft 3 in. to 10 ft 6 in.]), and rubber was trimmed off surface temperature sensors (1.09, 2.02, and 3.03).
- Weather station adjustments were made as recommended by Henry and Laudato Beltran.
- Two wireless internet routers were installed (one in the library and the other in the mechanical room).

Although there were problems with the establishment of wireless internet connection, data collected since 24 January 2020 are considered complete and reliable.

FIGURE B.4.
A stabilizer used to control input current to electrical equipment (HOBO RX3000 and dust monitor). © Fondation Le Corbusier. Photo: Vincent Laudato Beltran, 2020, © J. Paul Getty Trust.

However, the COVID-19 pandemic caused most of the equipment to come offline for a long period of time after electricity was cut off from the museum to mitigate risk of short-circuiting. Sporadic and rare visits by the staff are being logged, and as of 24 May 2020 no loss of data has been registered. Monitoring protocols have been adjusted.

Protocol

HOBO RX3000 Data Loggers

- Reconnect to wireless internet.
- For other problems, contact GCI or consult manual.

Standalone Data Loggers

- Schedule readouts.
- Download, save, and send data (in place).
- Relaunch loggers.

Corrosion Classification Coupons

- Schedule replacement and removal.
- Pack and send back.
- Reposition coupons.

Blue Wool Cards

- Placing coupons.
- Pack and send back.

Aerators

- Follow protocol for opening and closing aerators.
- Log data on conditions of aerators.

Logbook

- Introduce logbook.
- Give examples of data logging.

COVID-19

During the pandemic, museum personnel were asked to communicate their presence to the GCI so that real-time measurements could be monitored.

- Data loggers (HOBO RX3000) can compensate for loss of real-time measurements with their internal memory and long battery life. Being powered up monthly seems sufficient to avoid loss of data.
- Dust monitor (ES-642) will experience loss of all data throughout the entire closure.
- Standalone data loggers may experience loss of data because data are not read out frequently enough.
- Corrosion Classification Coupons should be sent as soon as visits to the museum allow.

Outstanding Issues

Some outstanding actions have not been completed, partially due to the pandemic and stay-at-home orders in India as well as in Los Angeles.

On 5 March 2020, the GCI asked museum staff to complete the following actions and provided the materials needed:

- Installation of additional guide wires, attached to the roof using wooden blocks to divide the weight
- Possibility of connecting the dust monitor to the 24-hour CCTV power was discussed with museum staff. Based on the advantages of seeing how the building performs during the day and night, Henry and Annelies Cosaert decided that a 24-hour real-time data collection would be beneficial.
- Collection of data on aerators and undulatory windows:
  - Location of aerators and undulatory windows
  - Total number of aerators and undulatory windows
  - Whether the aerators are operable or not operable
  - Whether the aerators are used on a regular basis by the personnel

Additional Passive Monitoring Devices

Blue Wool cards and additional Corrosion Classification Coupons were ordered but arrived at the GCI after the pandemic closure. They will be sent to the Government Museum and Art Gallery with instructions once the stay-at-home order is lifted and staff are allowed to enter the Collection Department offices again.

APPENDIX C

Location of Sensors

The set of architectural drawings in this appendix shows the location of sensors installed throughout the Government Museum and Art Gallery to collect environmental data. It complements data presented in table B.1.

FIGURE C.1.

Ground-floor plan of the Government Museum and Art Gallery, showing location of sensors. © Fondation Le Corbusier. Drawing: DRONAH, modified by Timothy Augustus Y. Ong and Hongye Wang. Image © J. Paul Getty Trust.

FIGURE C.2.

First-floor plan of the Government Museum and Art Gallery, showing location of sensors. © Fondation Le Corbusier. Drawing: DRONAH, modified by Timothy Augustus Y. Ong and Hongye Wang. Image © J. Paul Getty Trust.

FIGURE C.3.

Second-floor plan of the Government Museum and Art Gallery, showing location of sensors. © Fondation Le Corbusier. Drawing: DRO-NAH, modified by Timothy Augustus Y. Ong and Hongye Wang. Image © J. Paul Getty Trust.

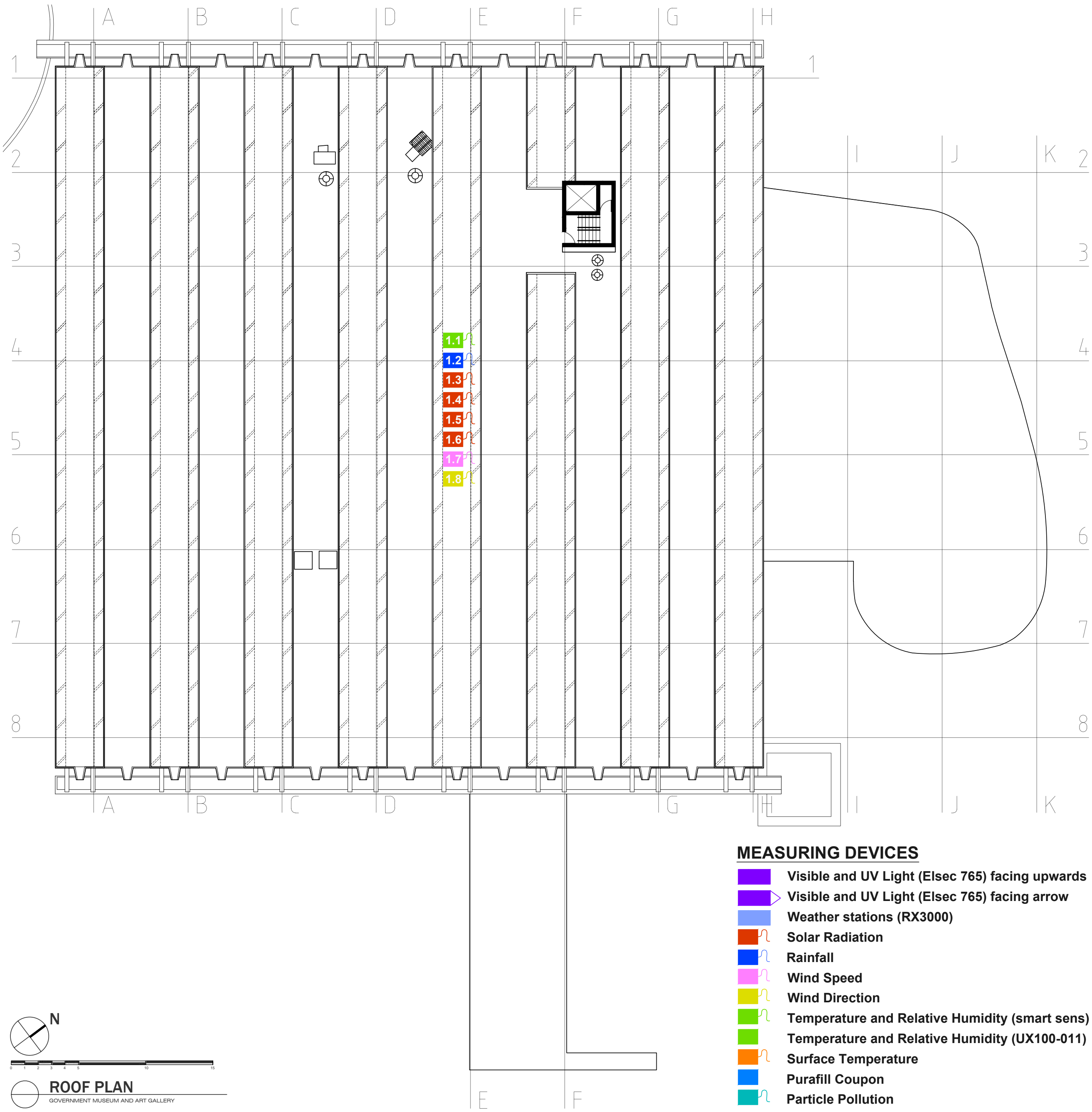


FIGURE C.4.

Roof plan of the Government Museum and Art Gallery, showing location of sensors. © Fondation Le Corbusier. Drawing: DRONAH, modified by Timothy Augustus Y. Ong and Hongye Wang. Image © J. Paul Getty Trust.

APPENDIX D

Environmental Data

The figures in appendix D show graphs of the full suite of environmental variables collected at the Government Museum and Art Gallery, including exterior climate data from the roof-level weather station and interior environmental data from various galleries and display cases. The data span a full calendar year, encompassing the five climatic seasons. There was a gap in data collection for two of the three HOBO RX3000 data loggers (CGMAG2 and CGMAG3) from July to August 2020; data from July to August 2021 were used to fill this gap. For consistency, this data replacement was also done for data collected by the third HOBO RX3000 (CGMAG1) and the standalone HOBO UX100-011 data loggers.

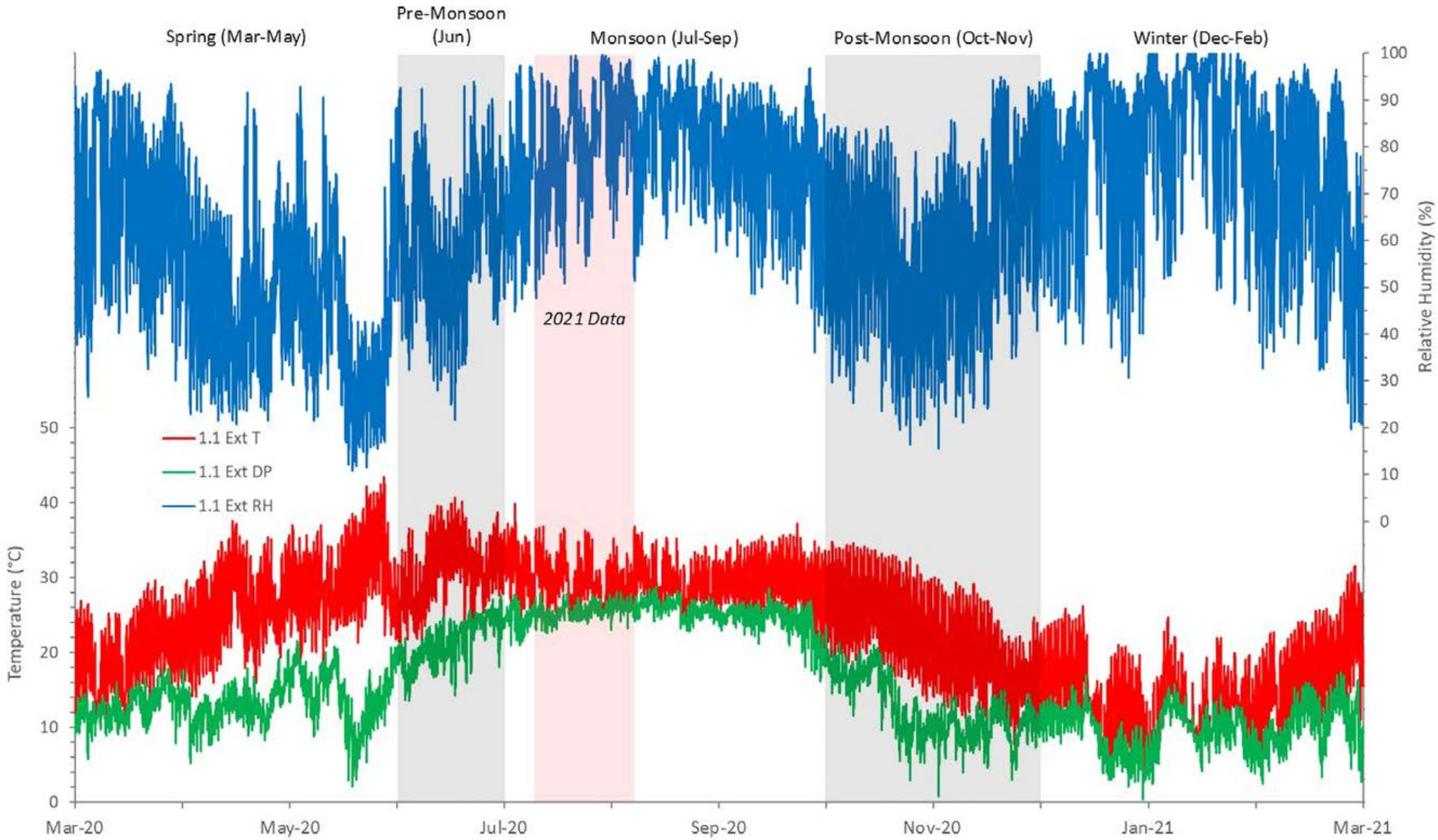


FIGURE D.1.

Exterior air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

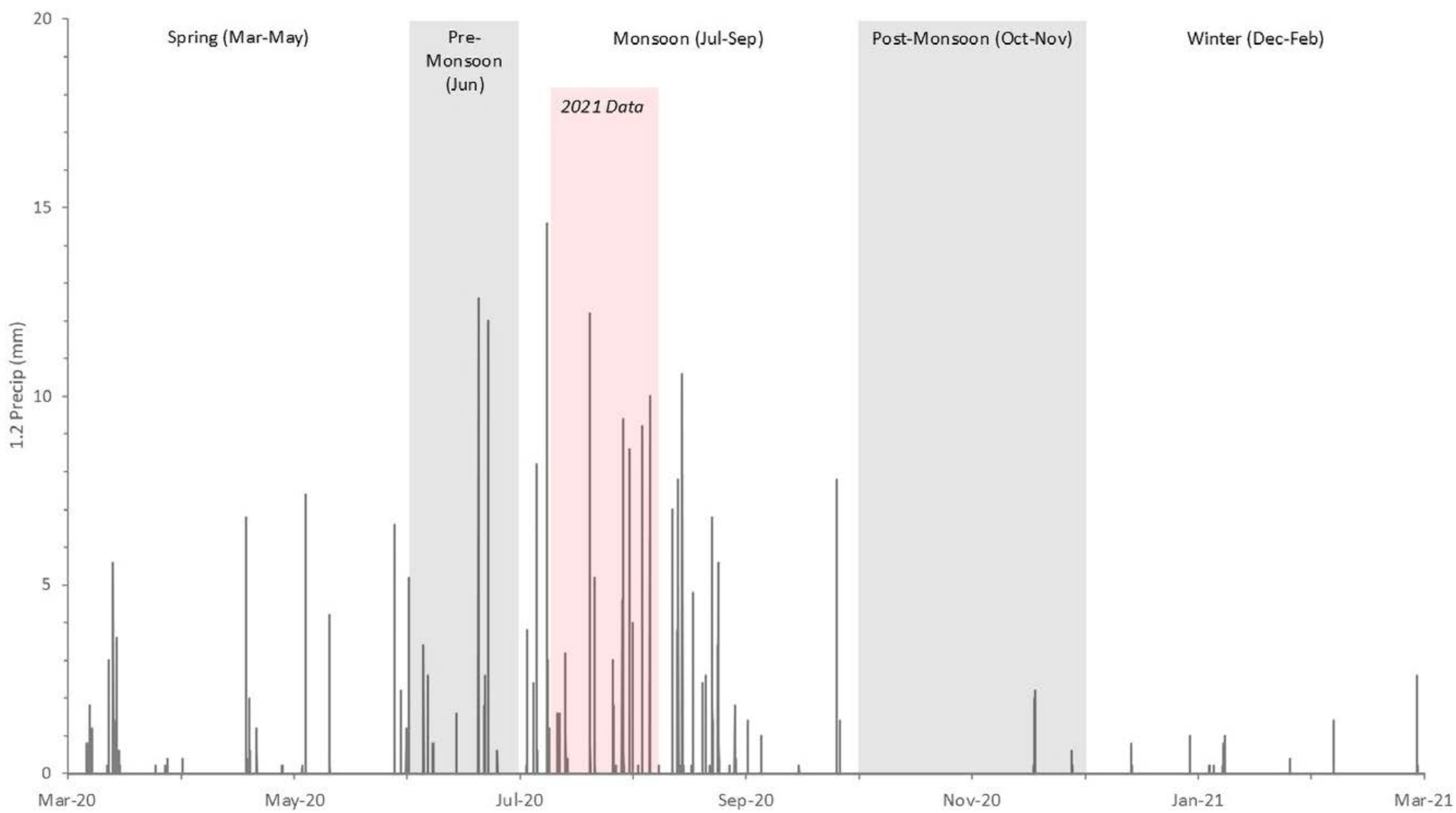


FIGURE D.2.
Precipitation from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

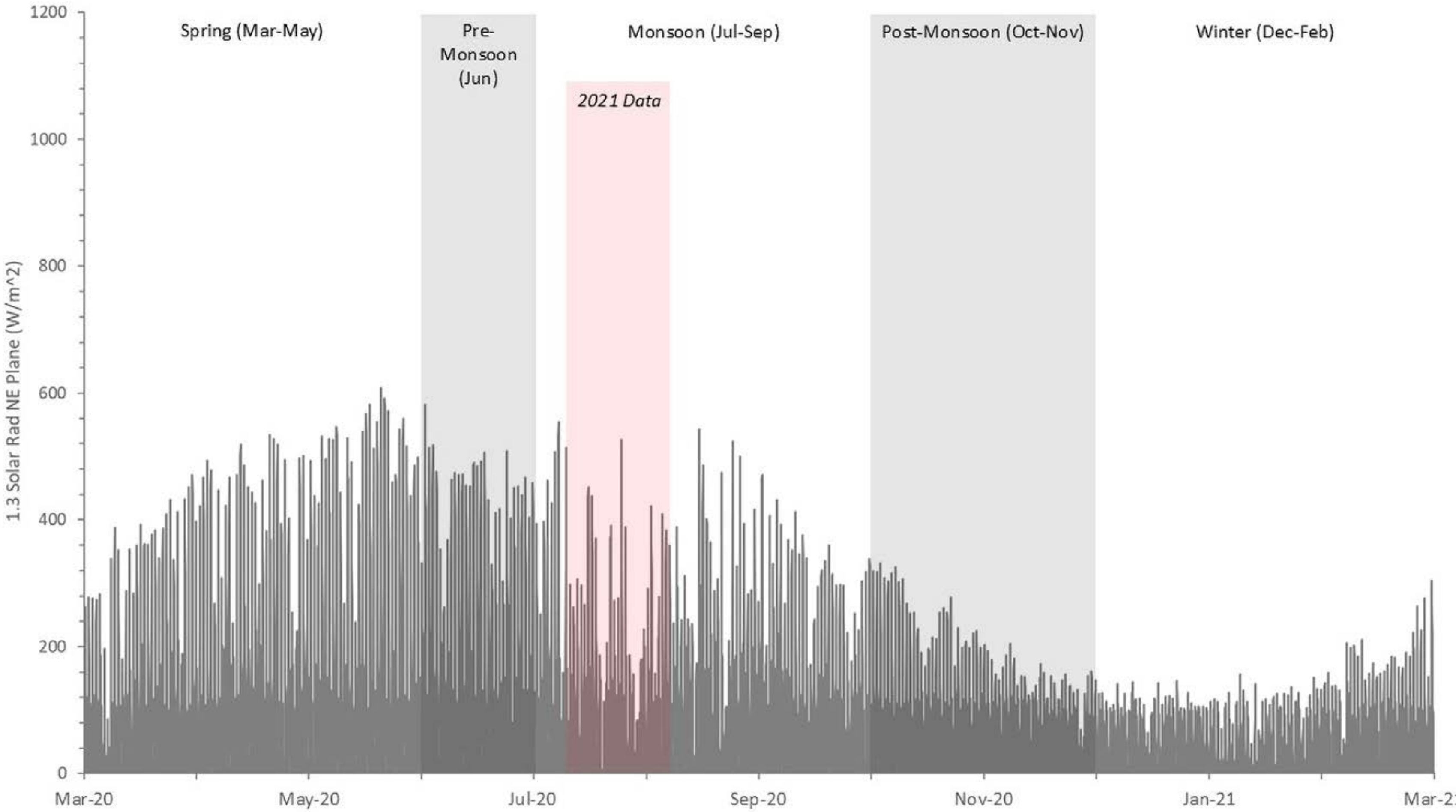


FIGURE D.3.

Solar radiation NE plane from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

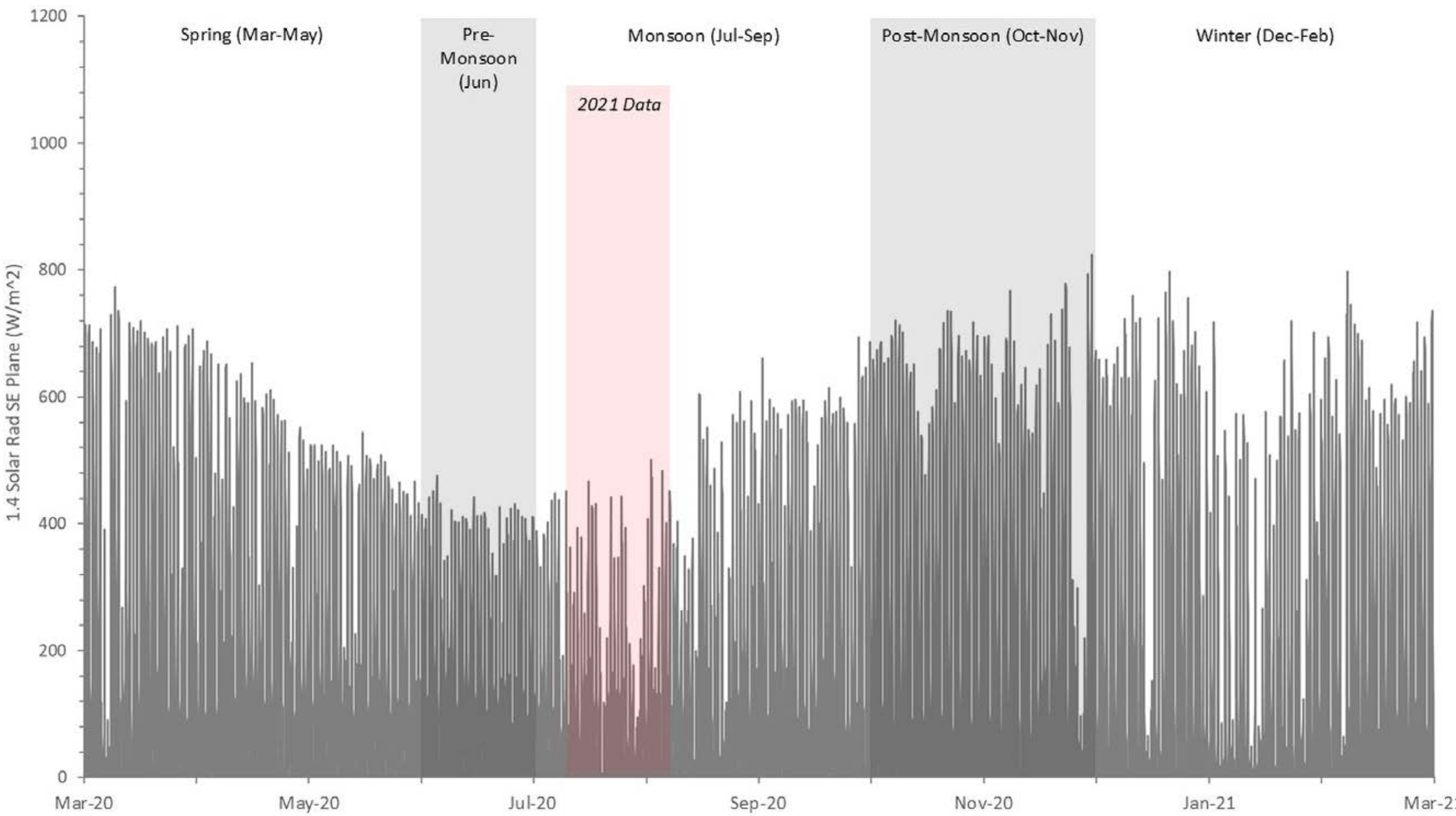


FIGURE D.4.
Solar radiation SE plane from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

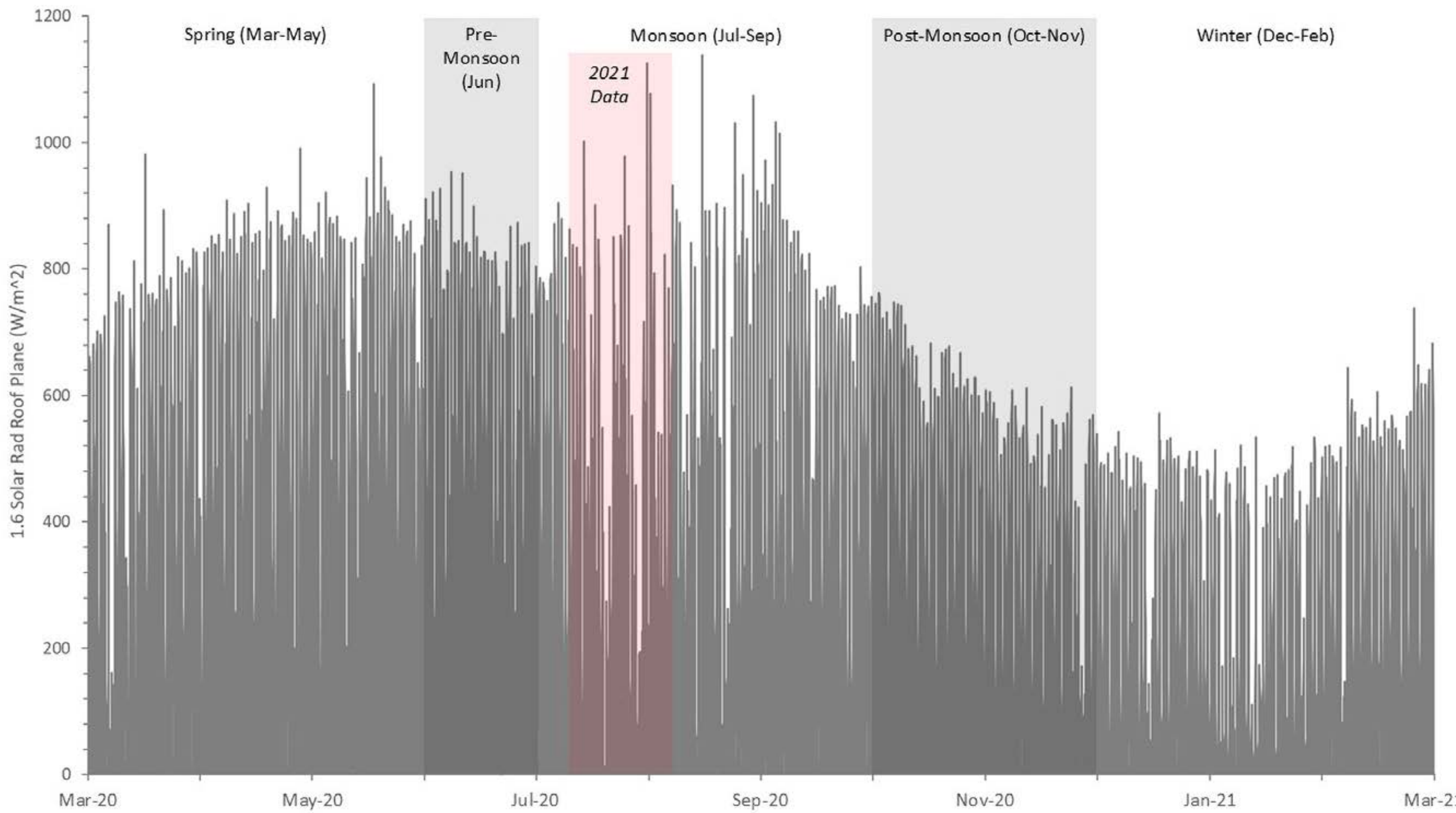


FIGURE D.5.
Solar radiation roof plane from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

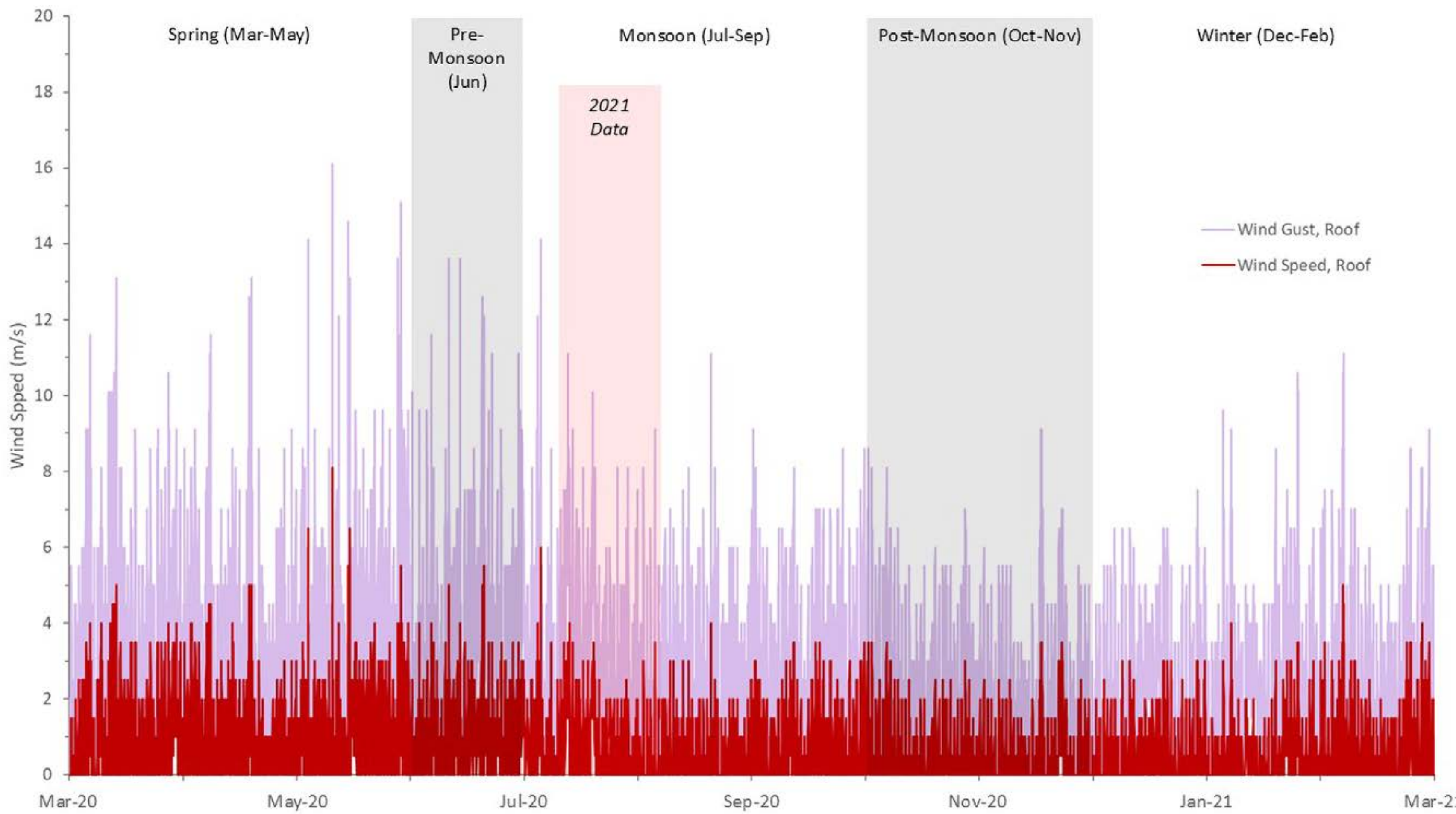


FIGURE D.6.
Wind speed and gust from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

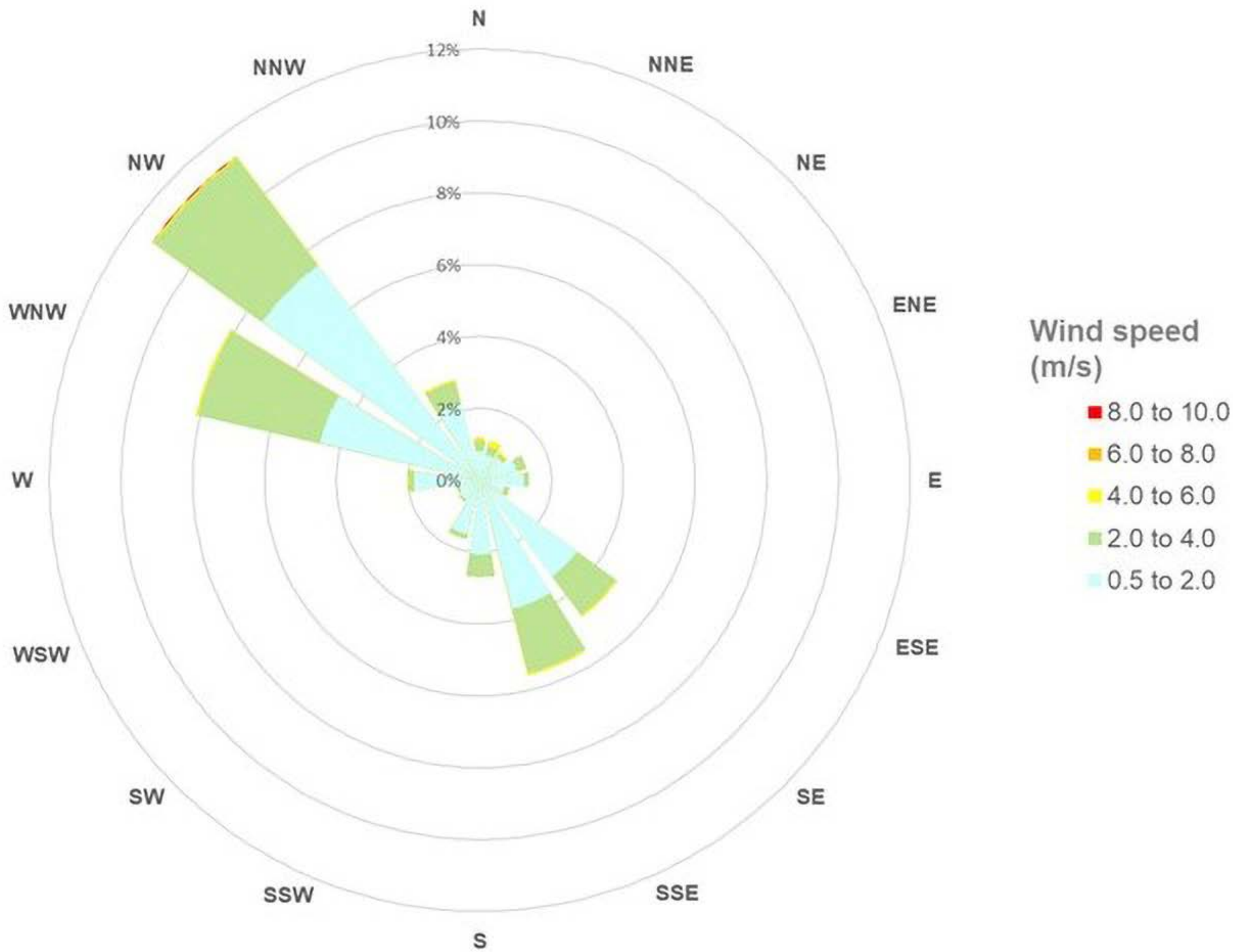


FIGURE D.7.
Wind rose during spring (March to May 2020). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

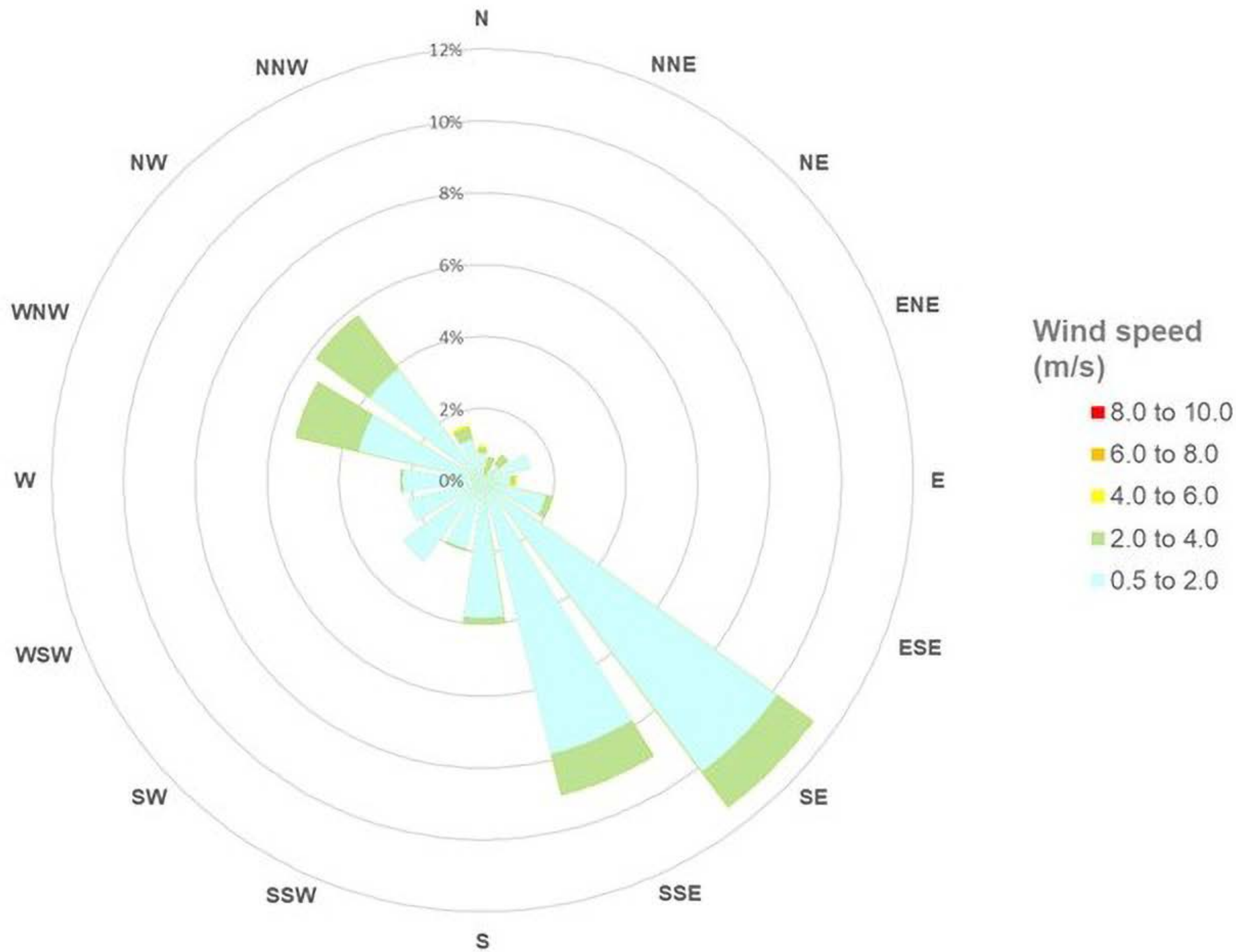


FIGURE D.8.
Wind rose during pre-monsoon season (June 2020). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

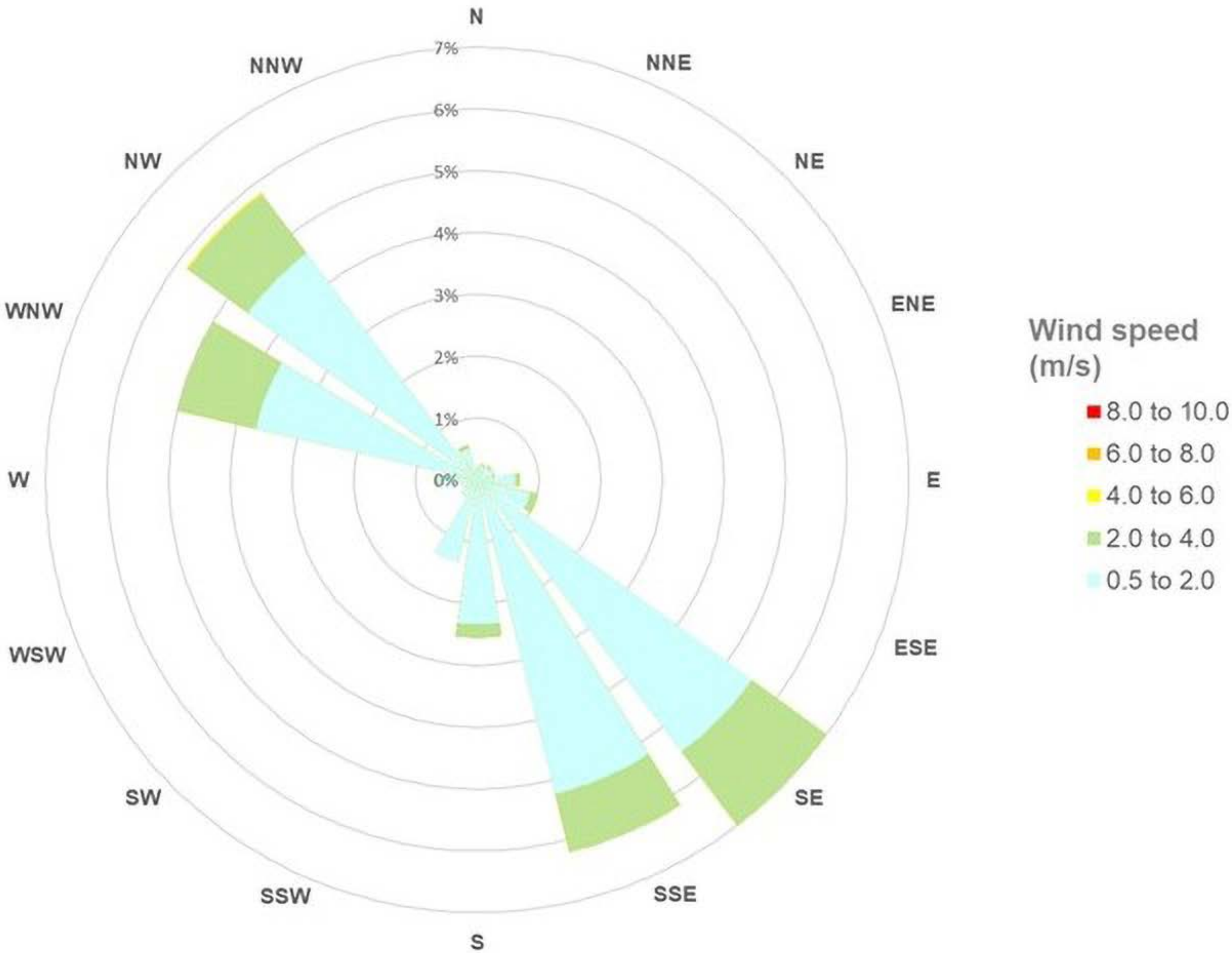


FIGURE D.9.
Wind rose during monsoon season (July to September 2020). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

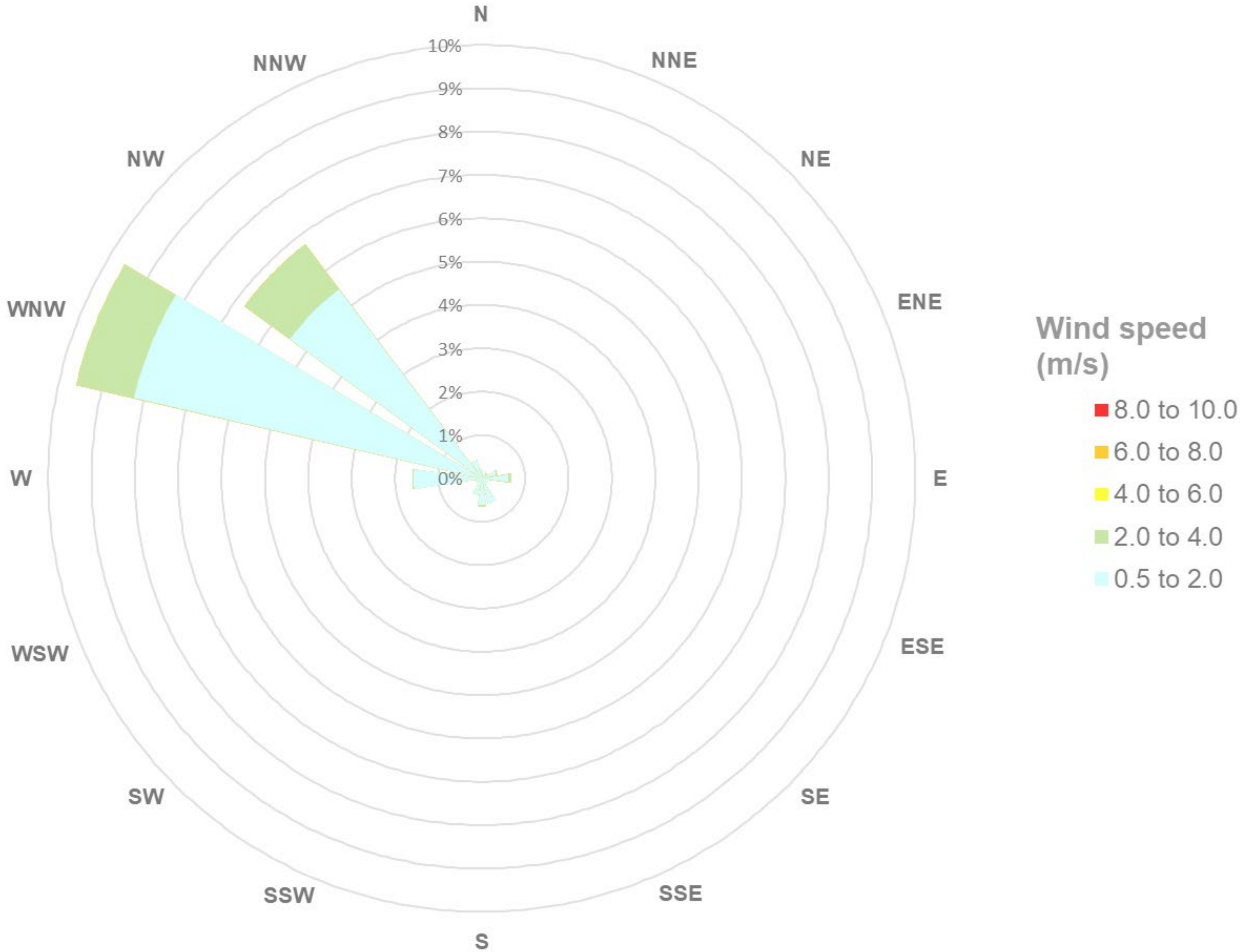


FIGURE D.10.
Wind rose during post-monsoon season (October to November 2020). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

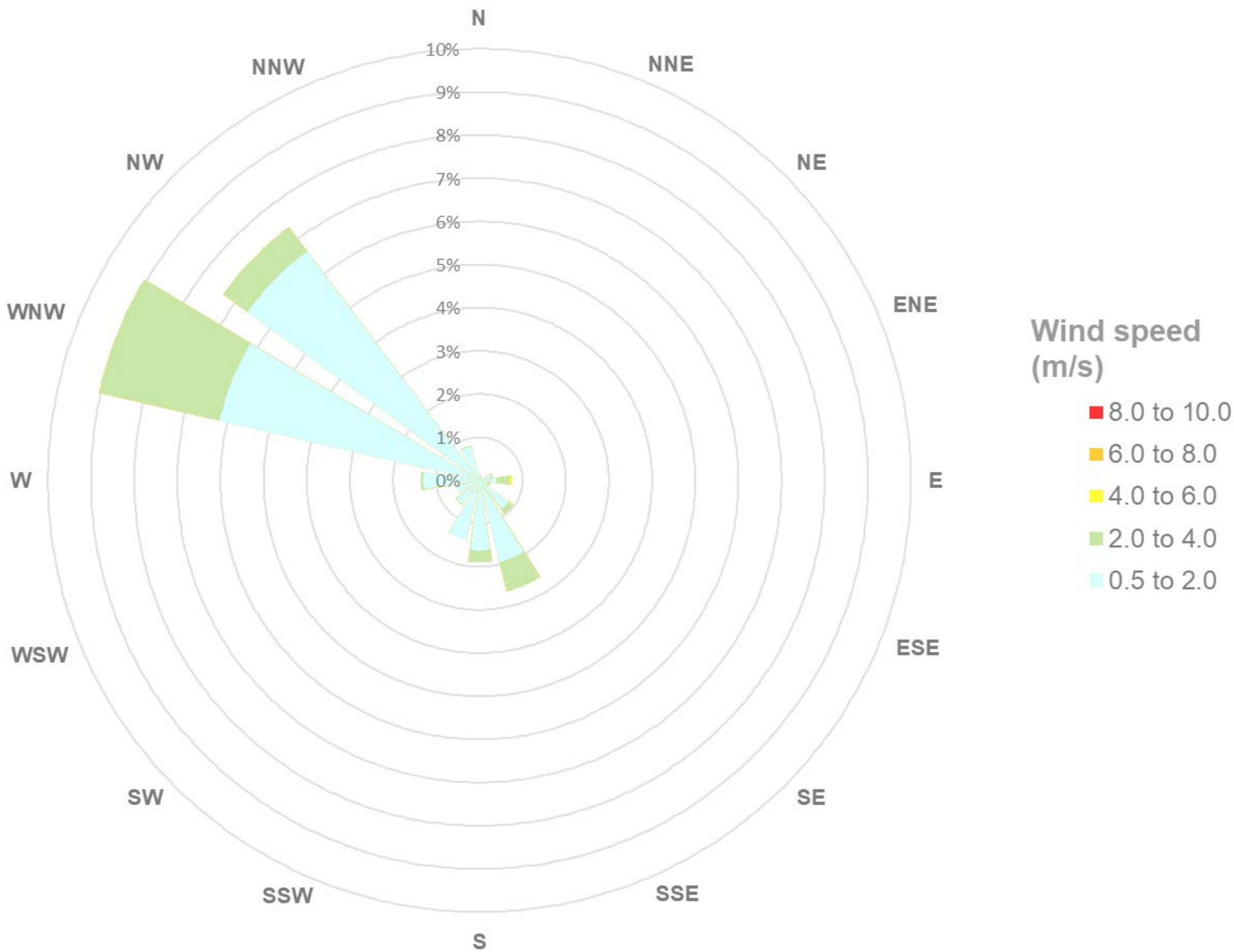


FIGURE D.11.
Wind rose during winter (December 2020 to February 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

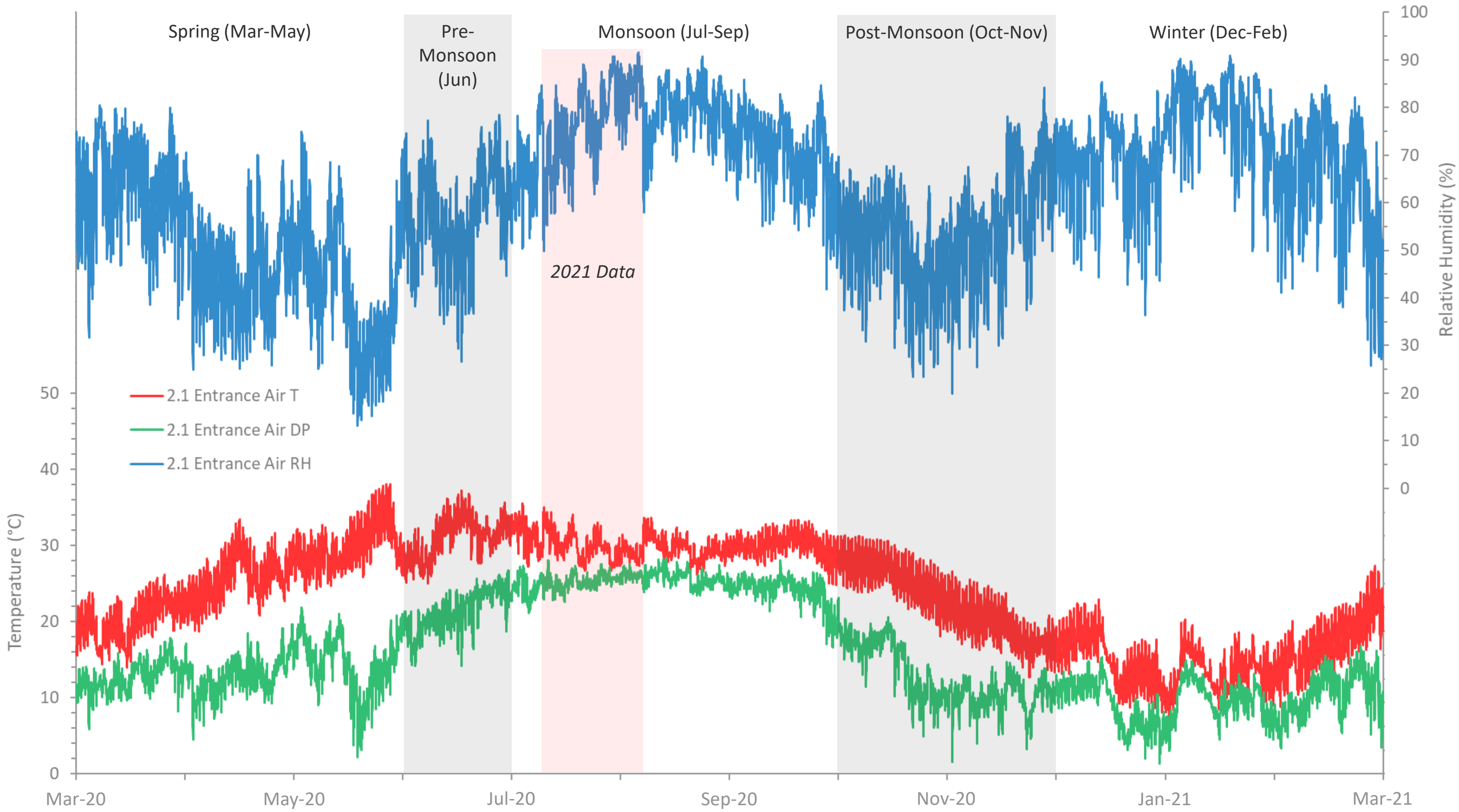


FIGURE D.12.
Entrance air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

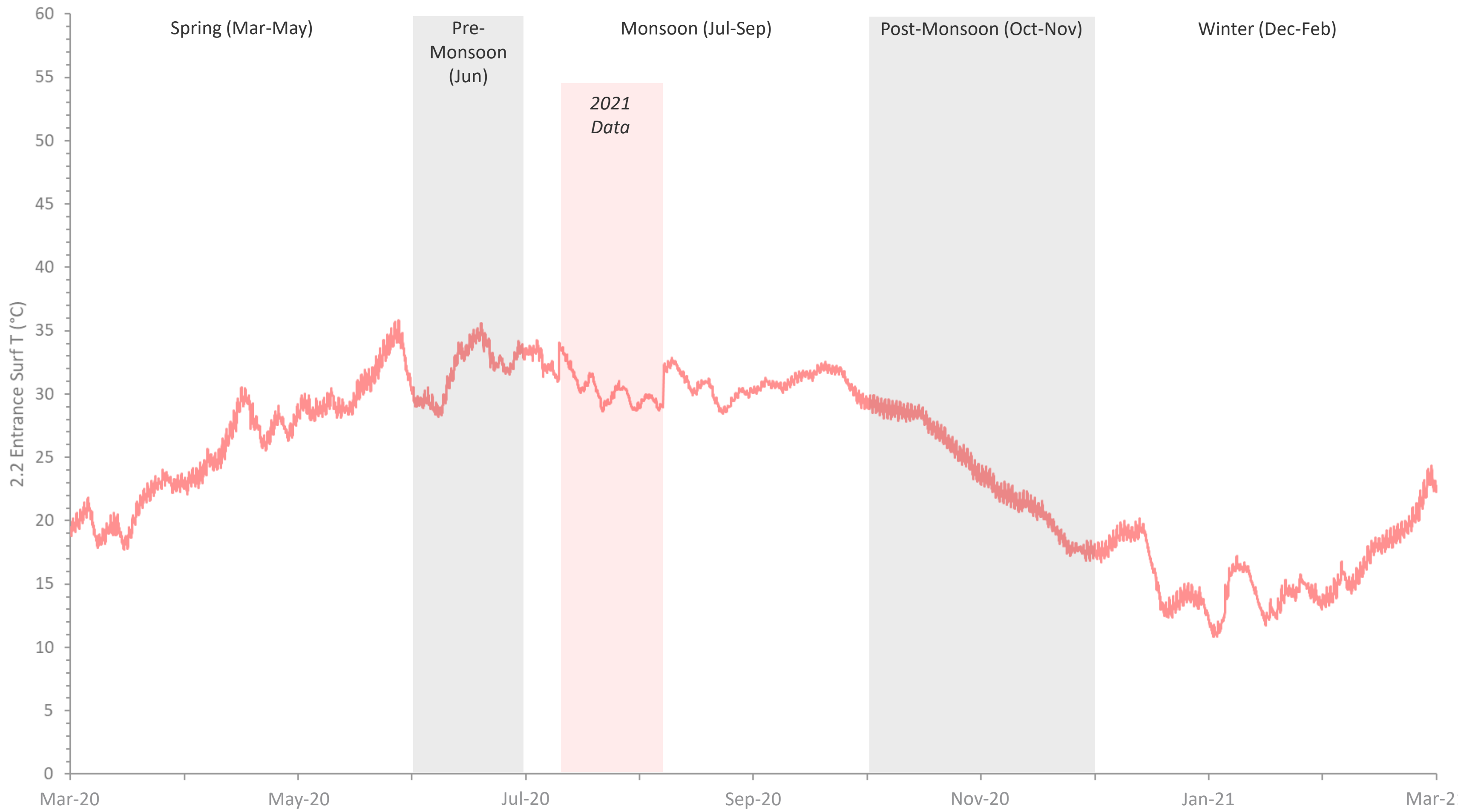


FIGURE D.13.

Entrance surface temperature from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

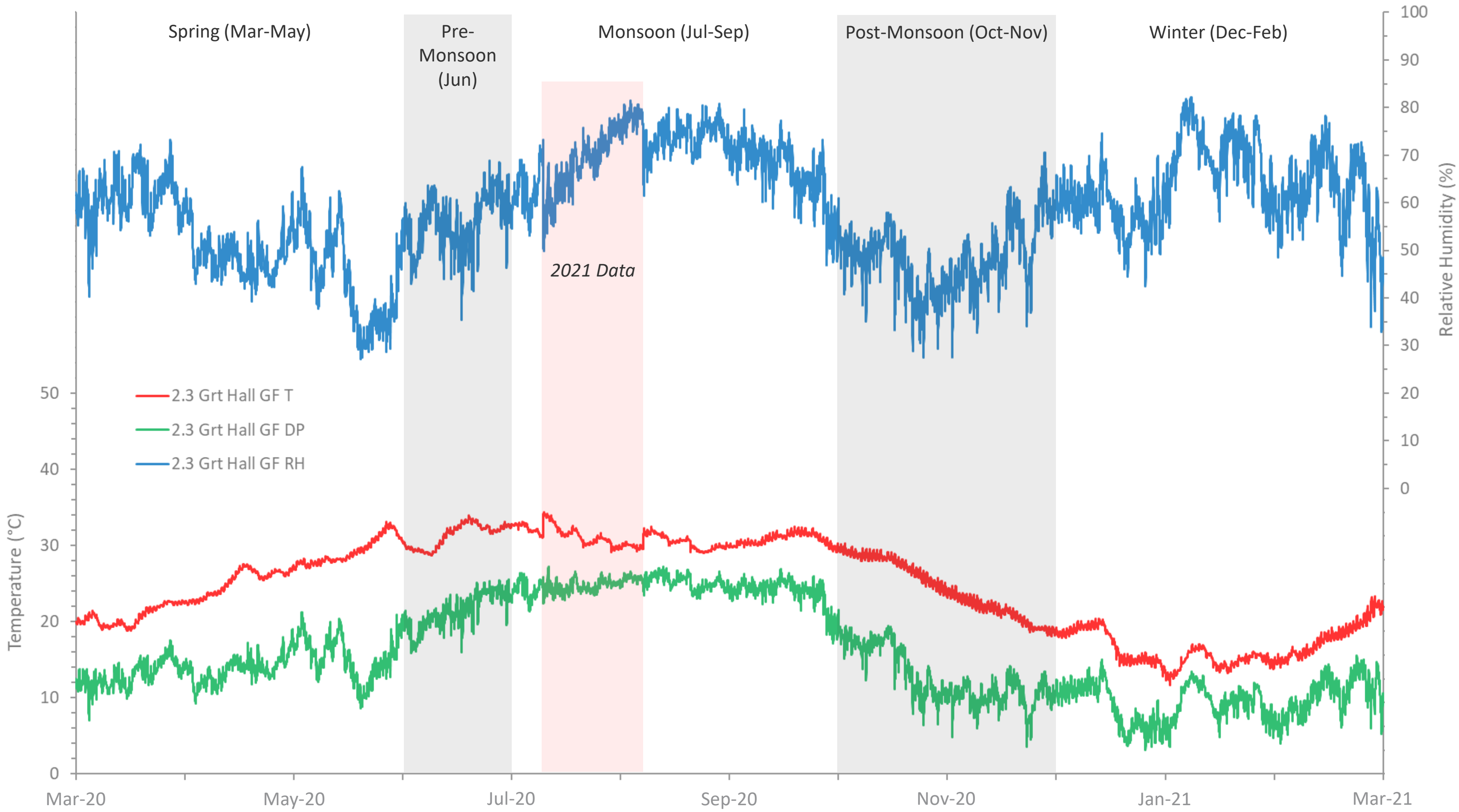


FIGURE D.14.
Great Hall ground-floor air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

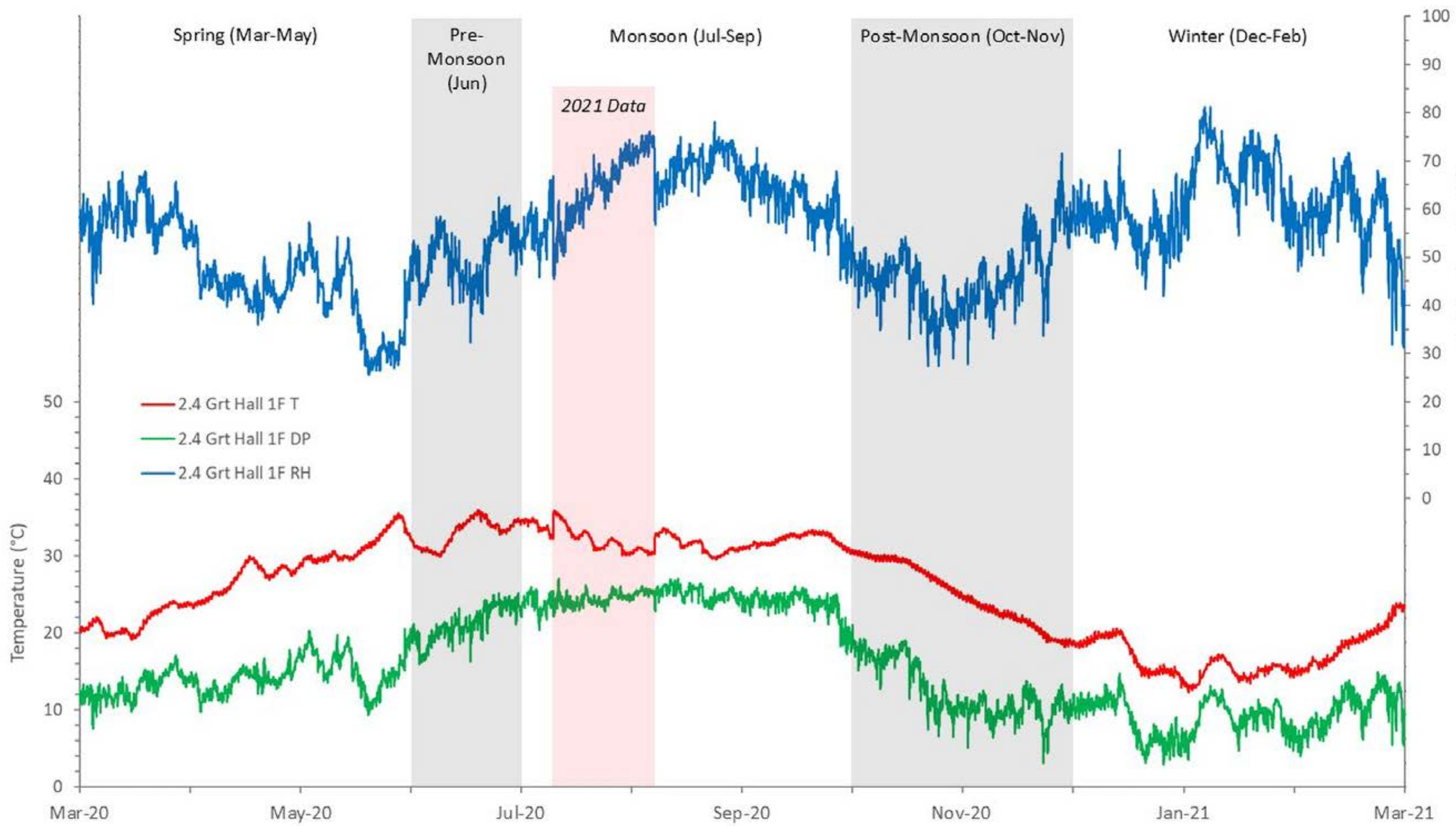


FIGURE D.15.

Great Hall first-floor air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

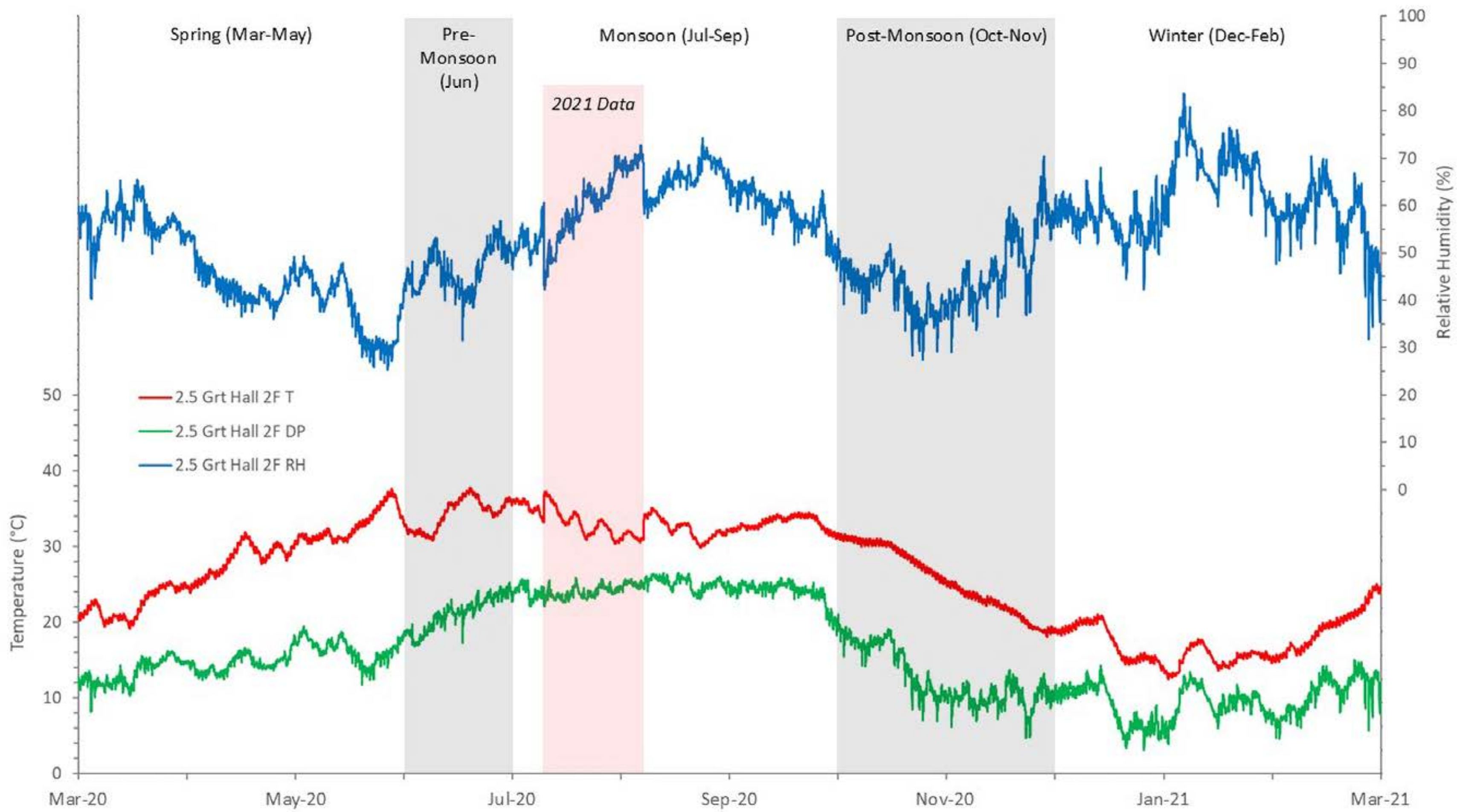


FIGURE D.16.

Great Hall second-floor air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

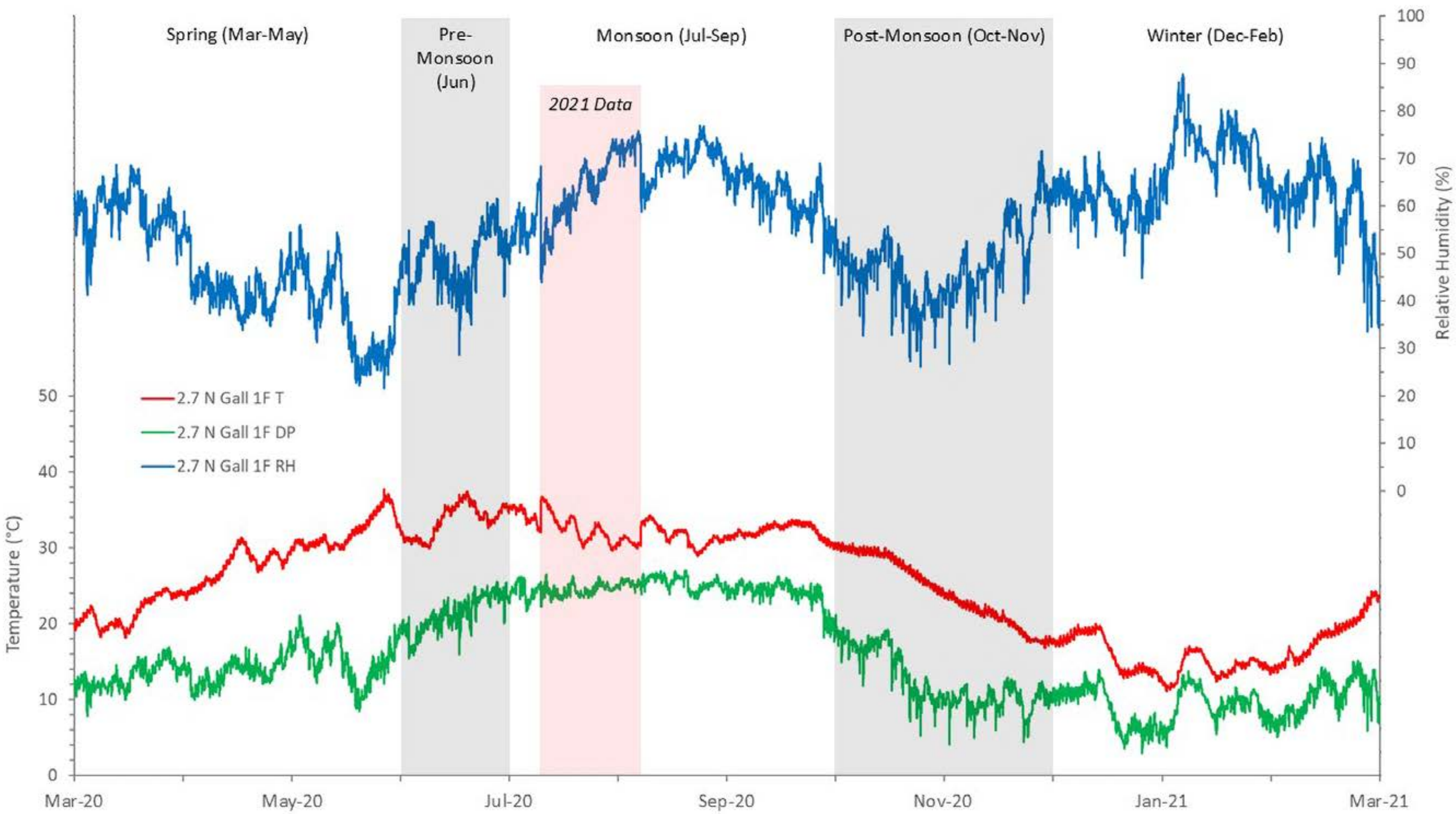


FIGURE D.17.

Contemporary Art Gallery I first-floor air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

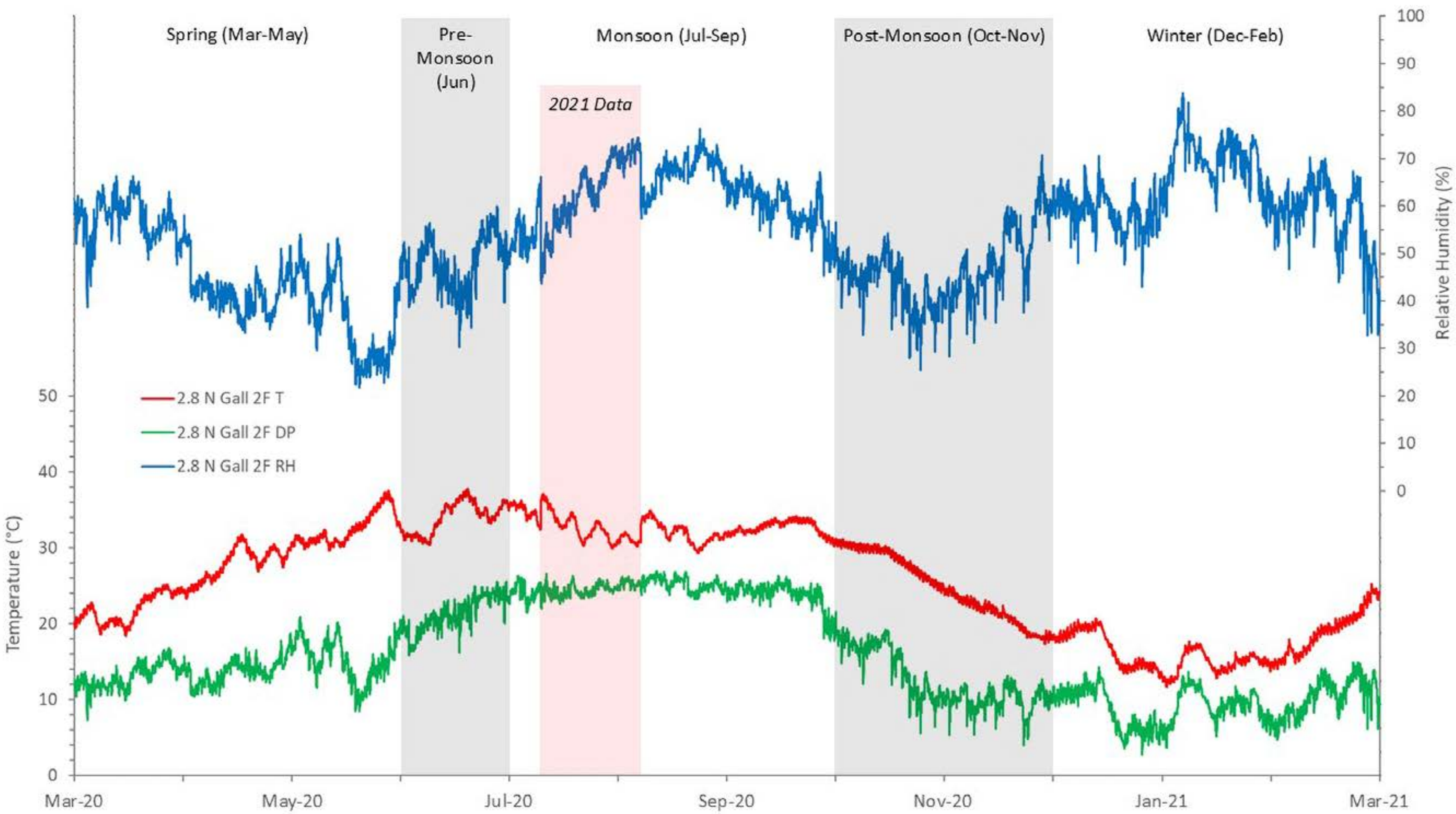


FIGURE D.18.

Contemporary Art Gallery I second-floor air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

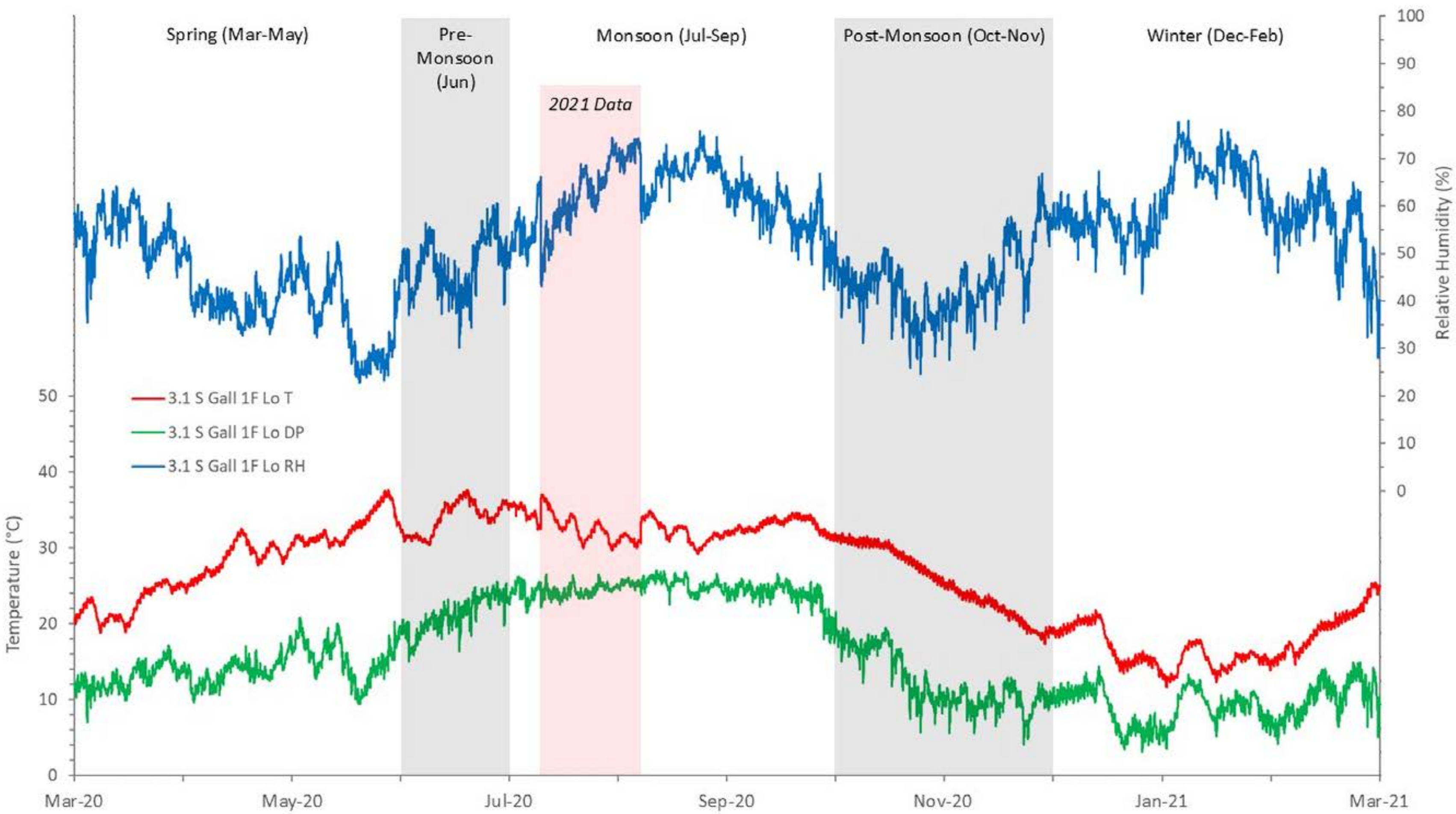


FIGURE D.19.

Gandhara Sculptures Gallery first-floor air temperature, dew point, and relative humidity taken from a low position from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

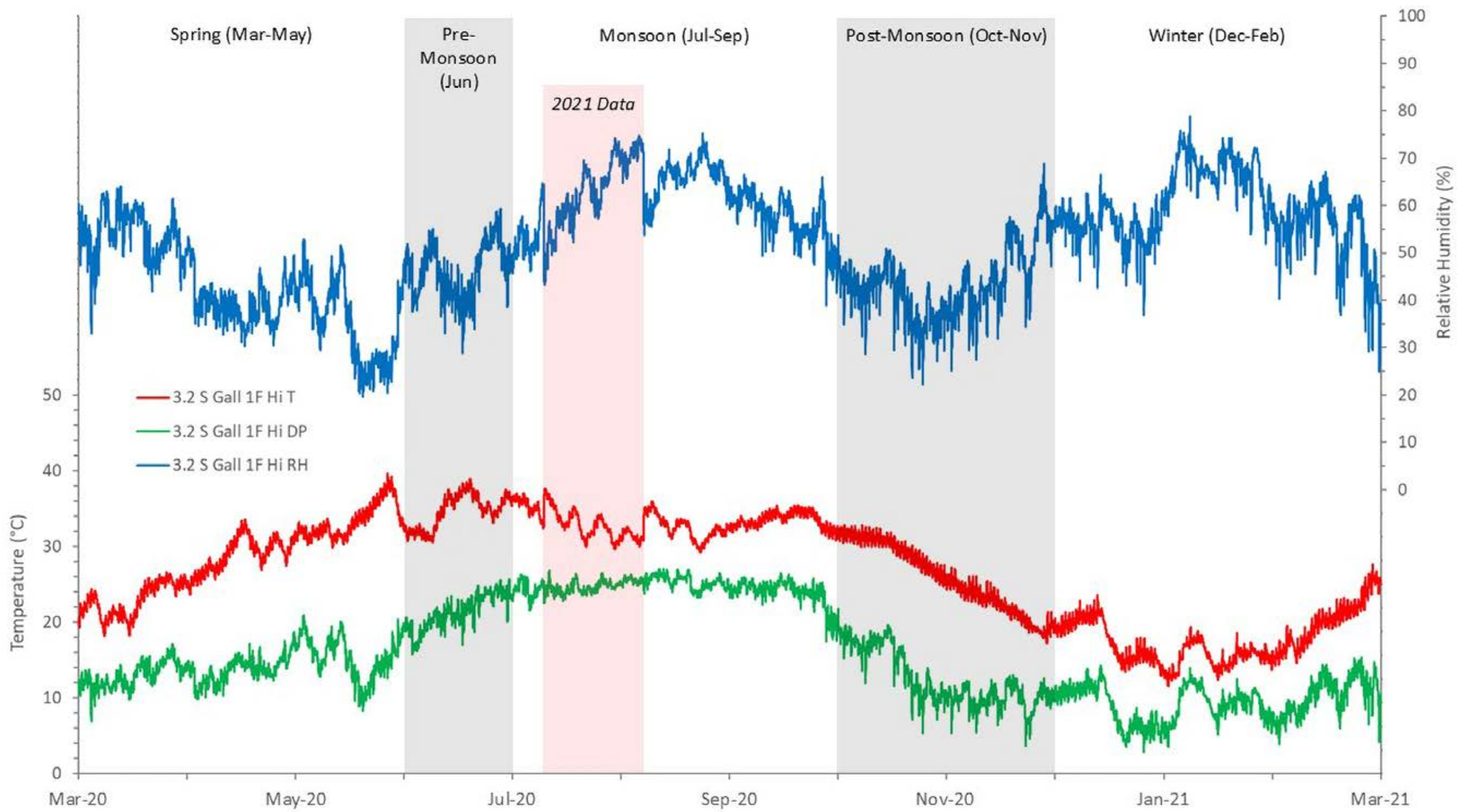


FIGURE D.20.

Gandhara Sculptures Gallery first-floor air temperature, dew point, and relative humidity taken from an elevated position from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

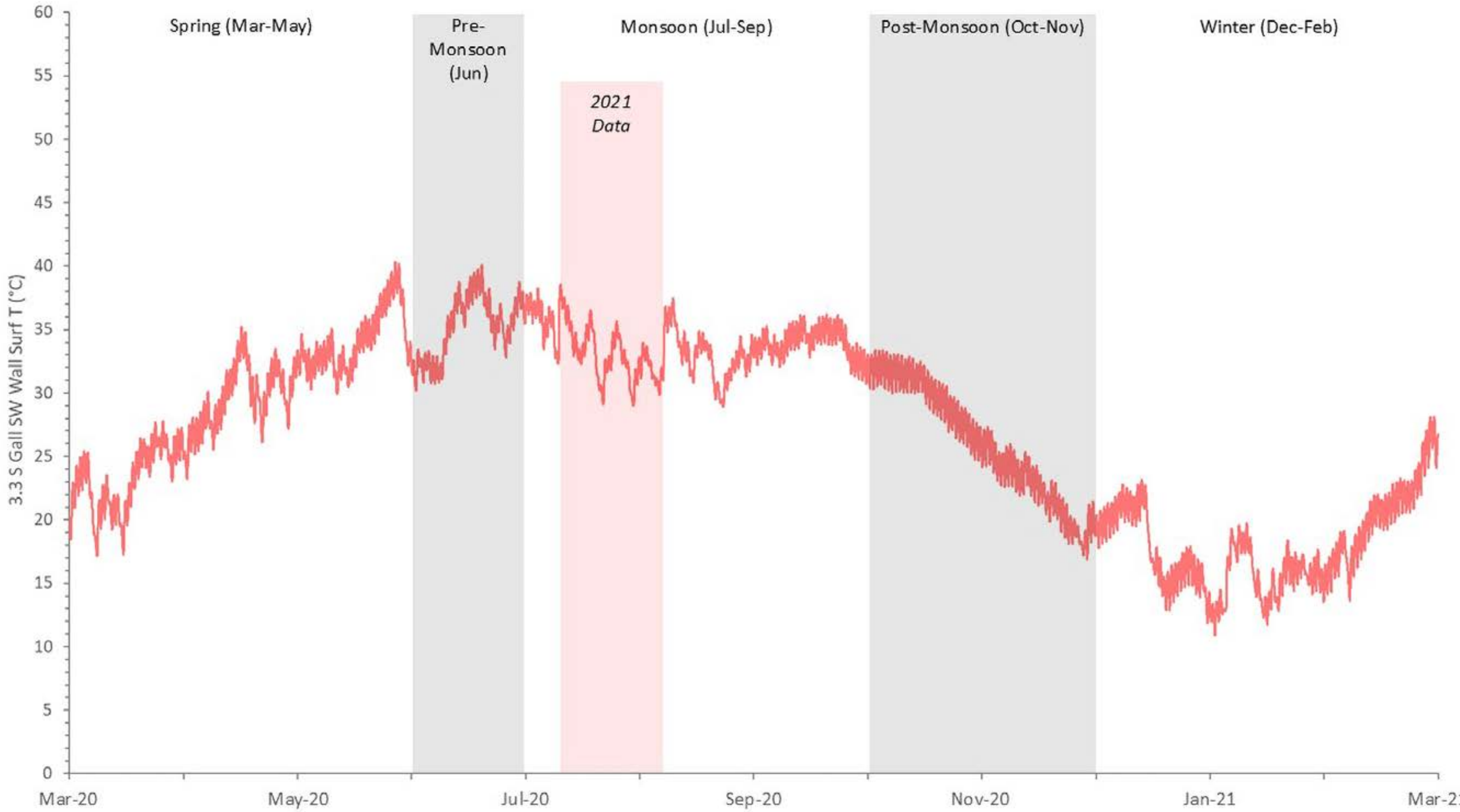


FIGURE D.21.

Gandhara Sculptures Gallery SW wall surface temperature from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

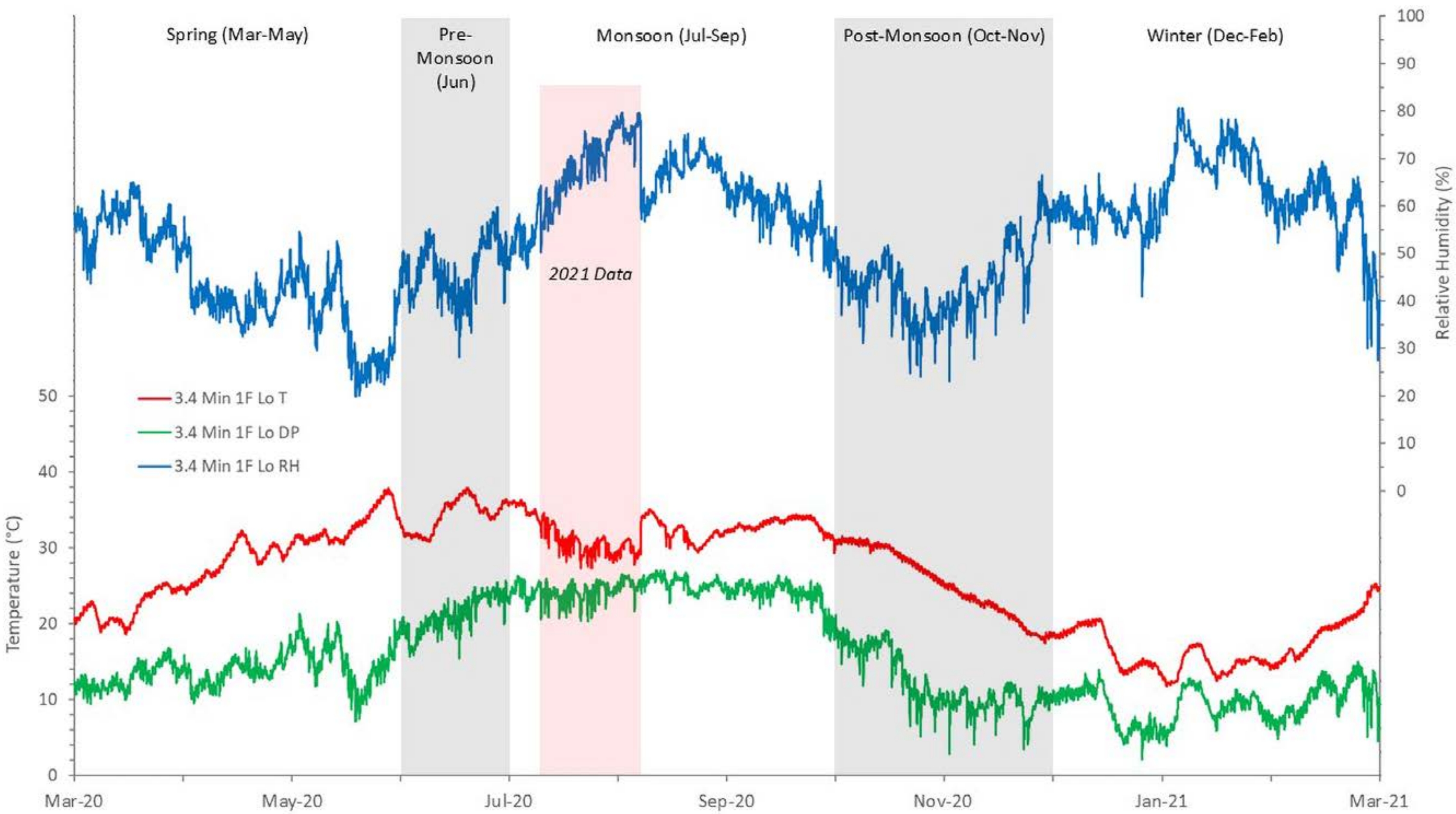


FIGURE D.22.
Miniatures Gallery first-floor air temperature, dew point, and relative humidity taken from a low position from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

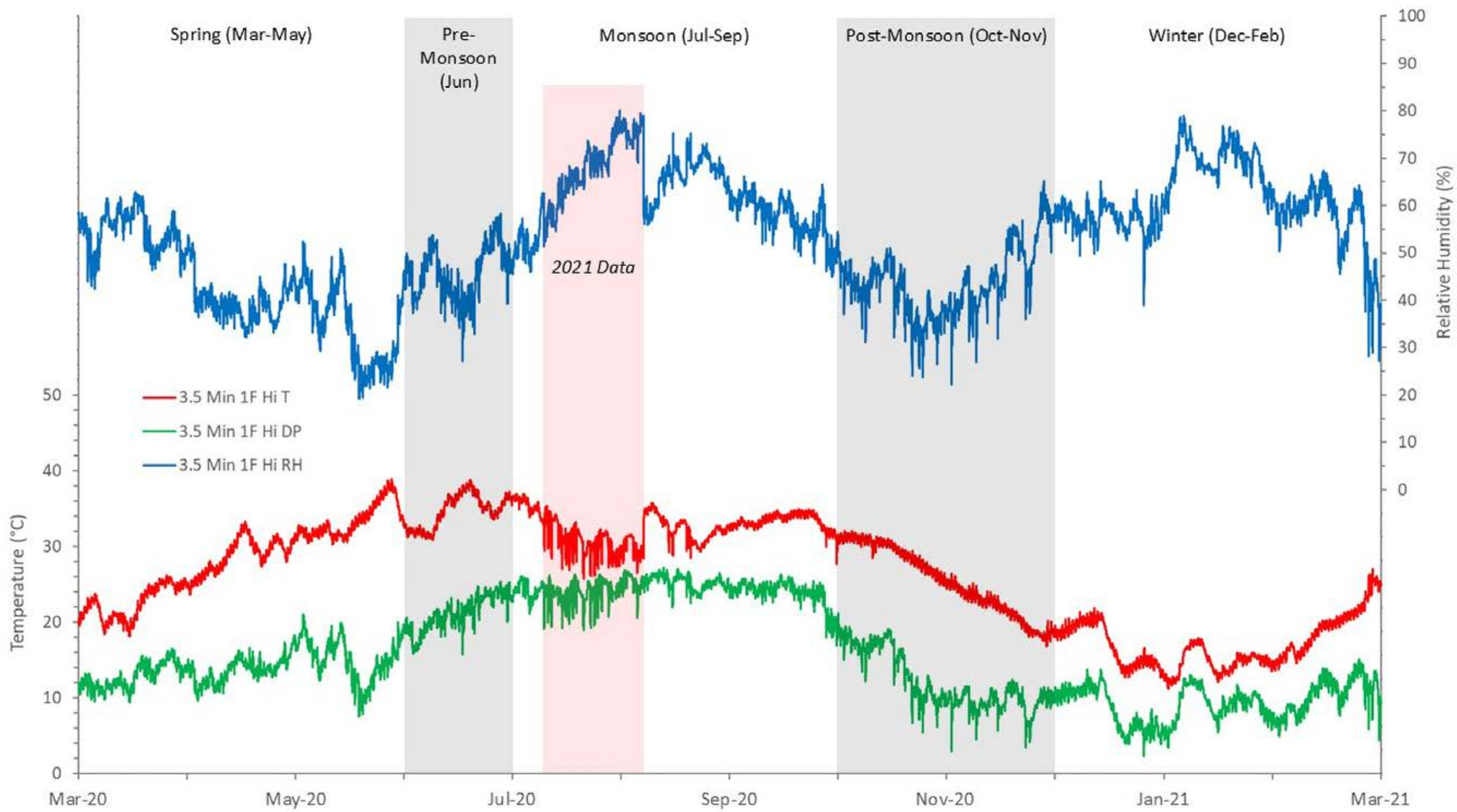


FIGURE D.23.

Miniatures Gallery first-floor air temperature, dew point, and relative humidity taken from an elevated position from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

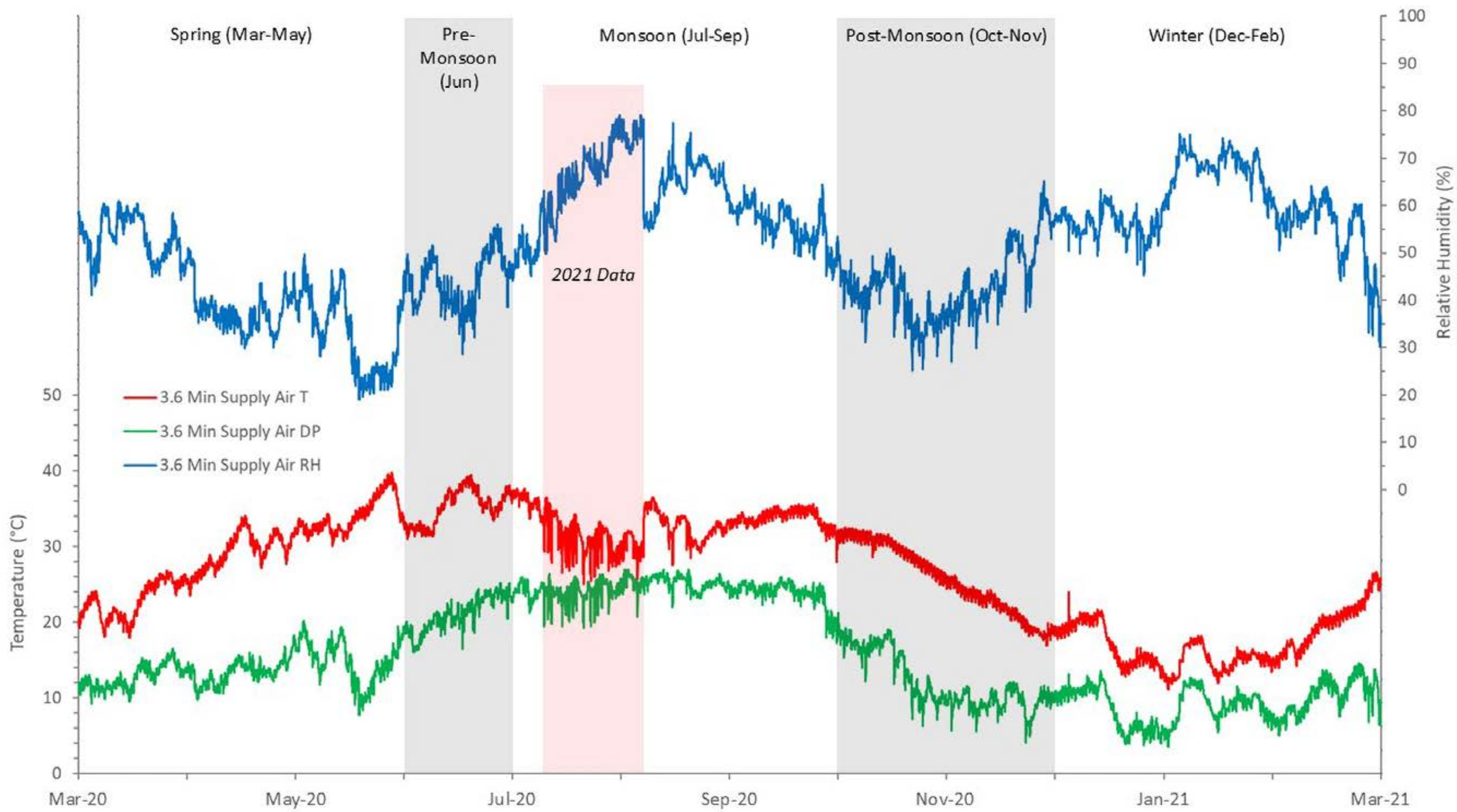


FIGURE D.24.

Miniatures Gallery supply air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

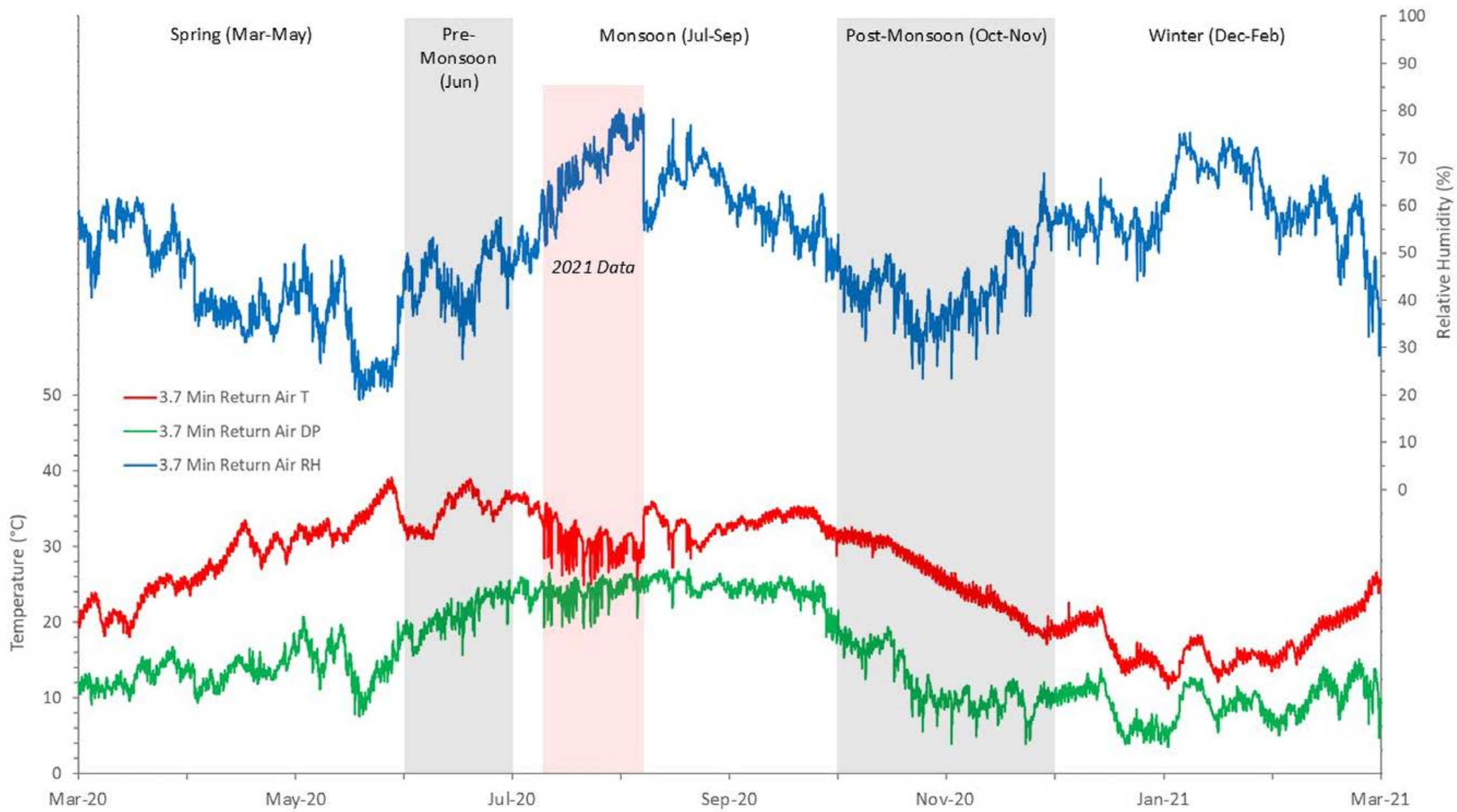


FIGURE D.25.

Miniatures Gallery return air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

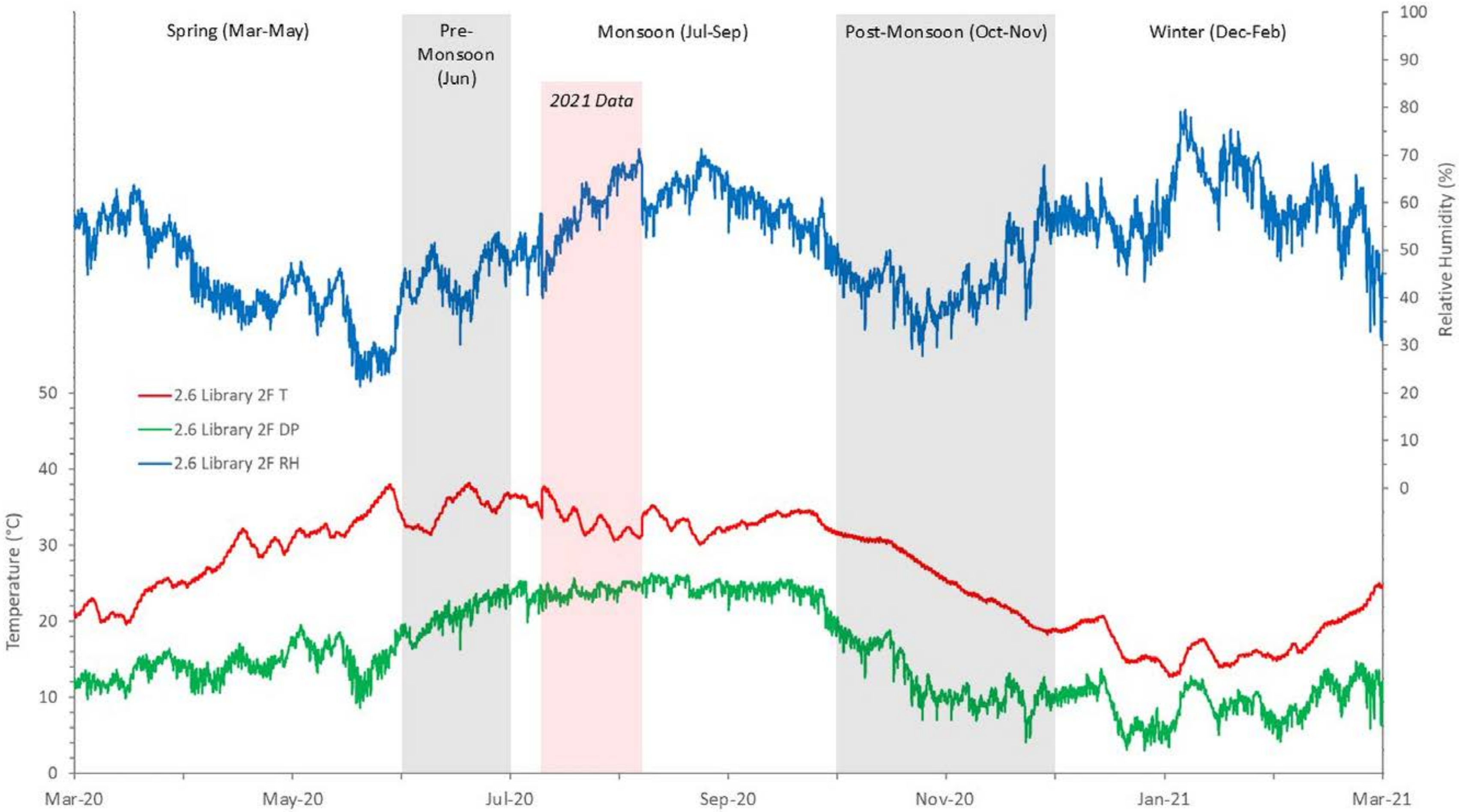


FIGURE D.26.
Library second-floor air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

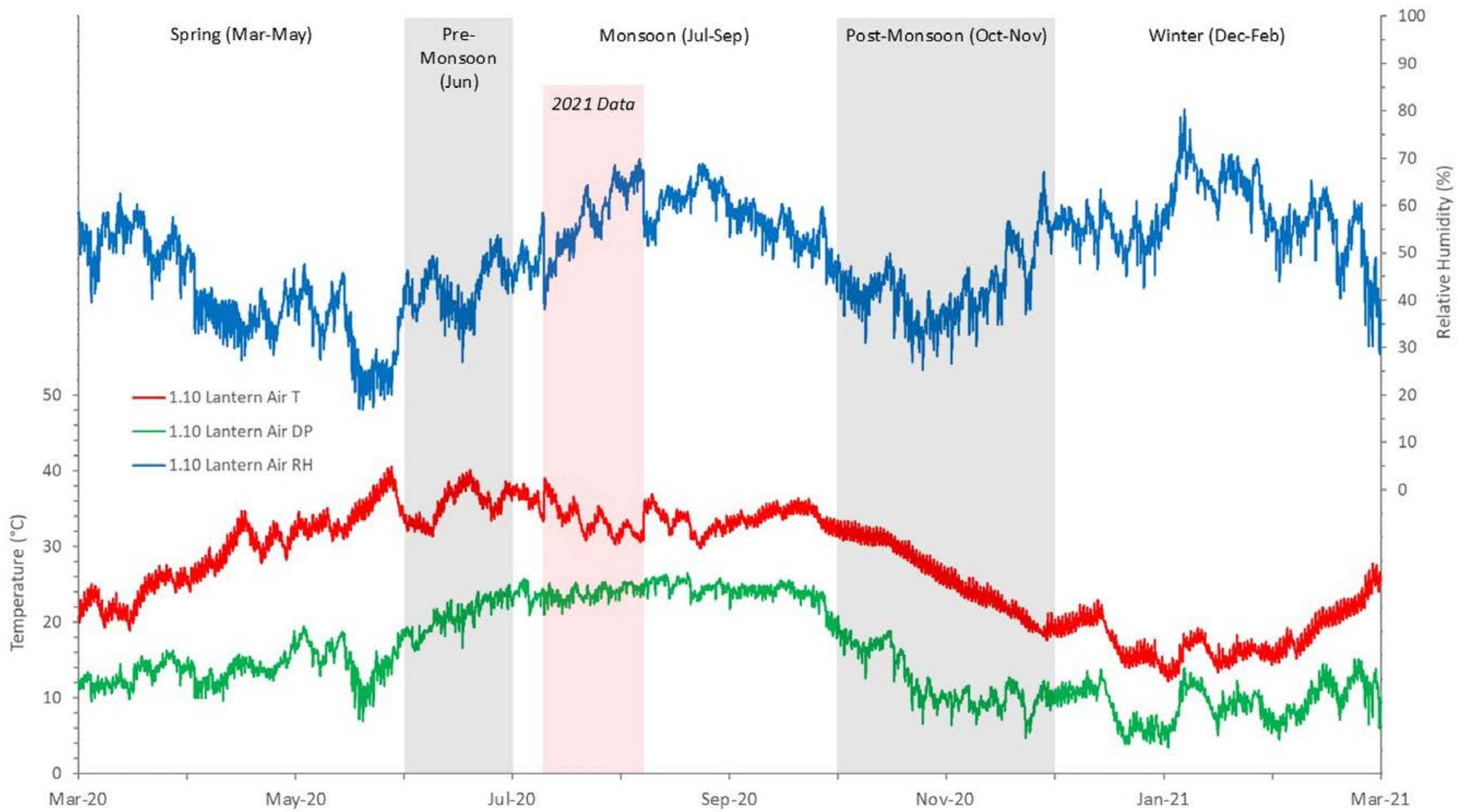


FIGURE D.27.

Lantern air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

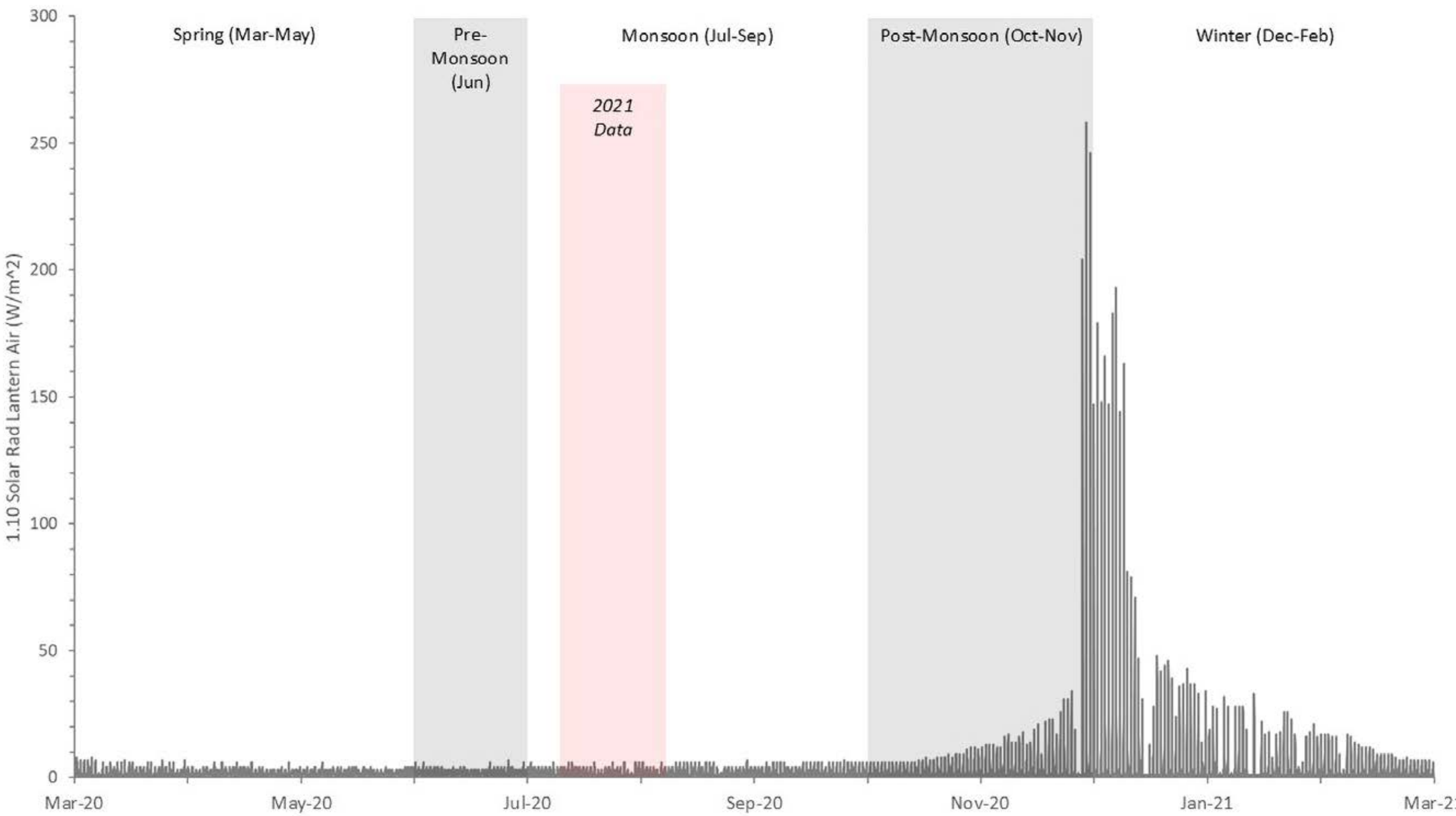


FIGURE D.28.
Lantern solar radiation from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

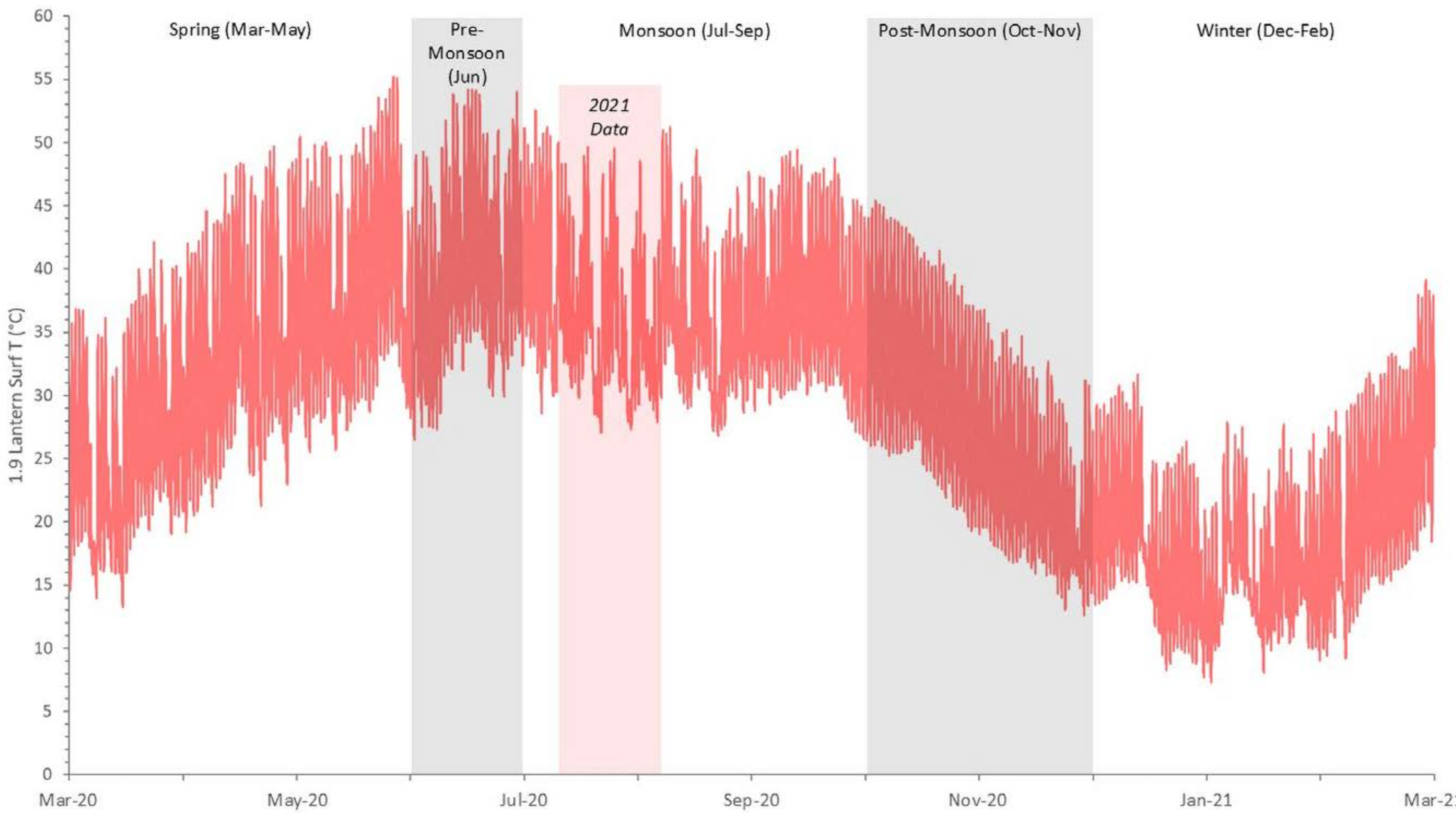


FIGURE D.29.

Lantern surface temperature from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

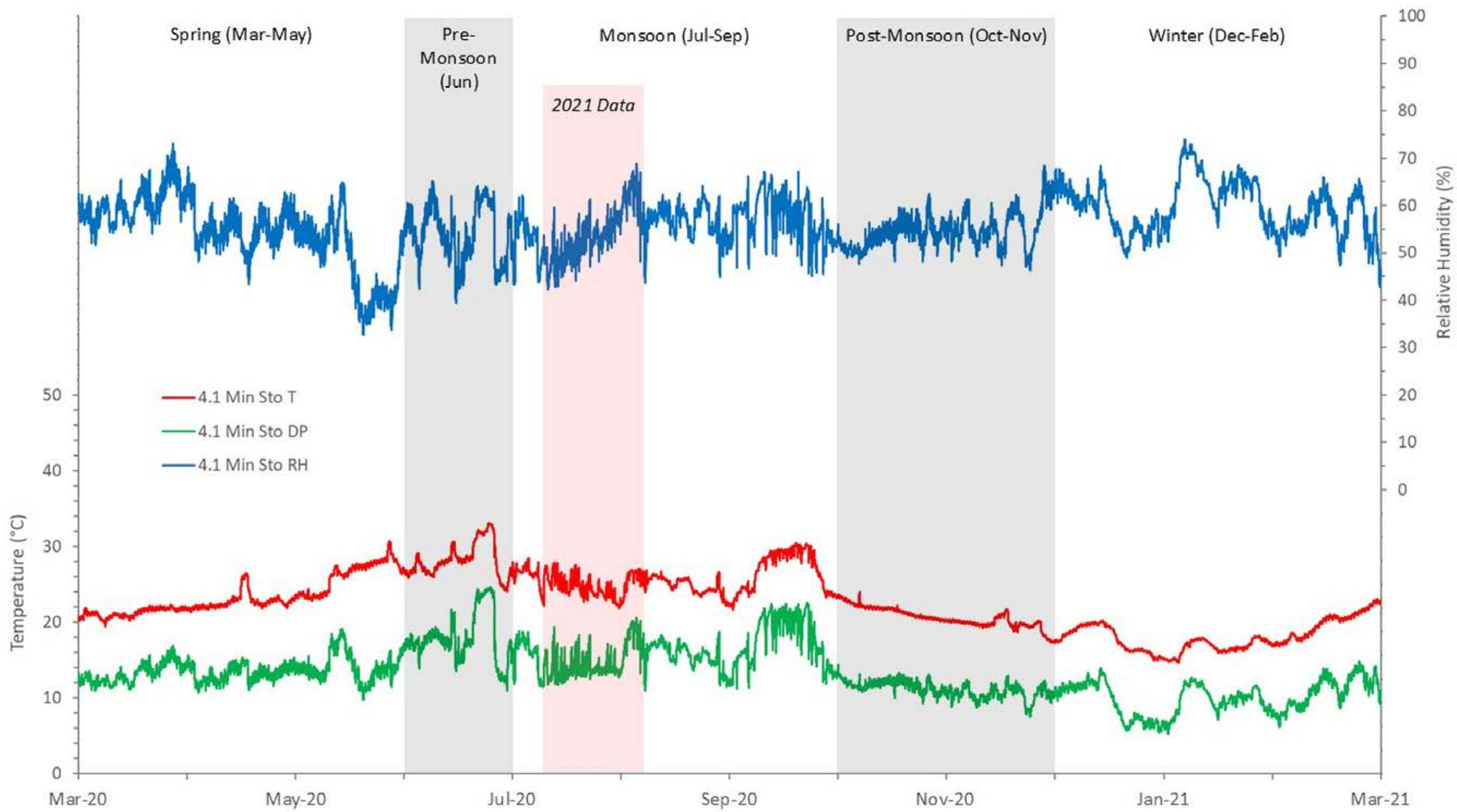


FIGURE D.30.
Miniatures storage air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

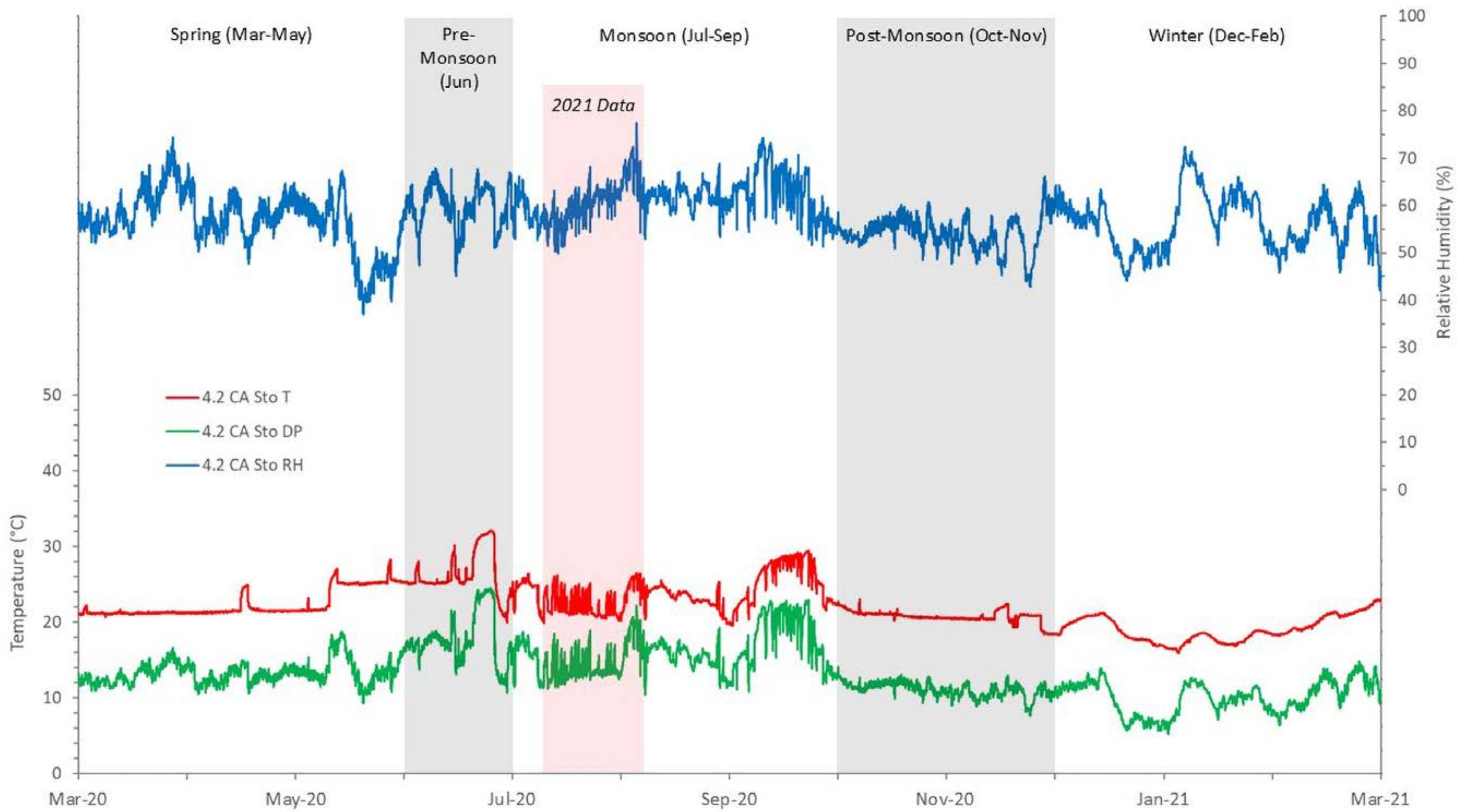


FIGURE D.31.

Contemporary art storage air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

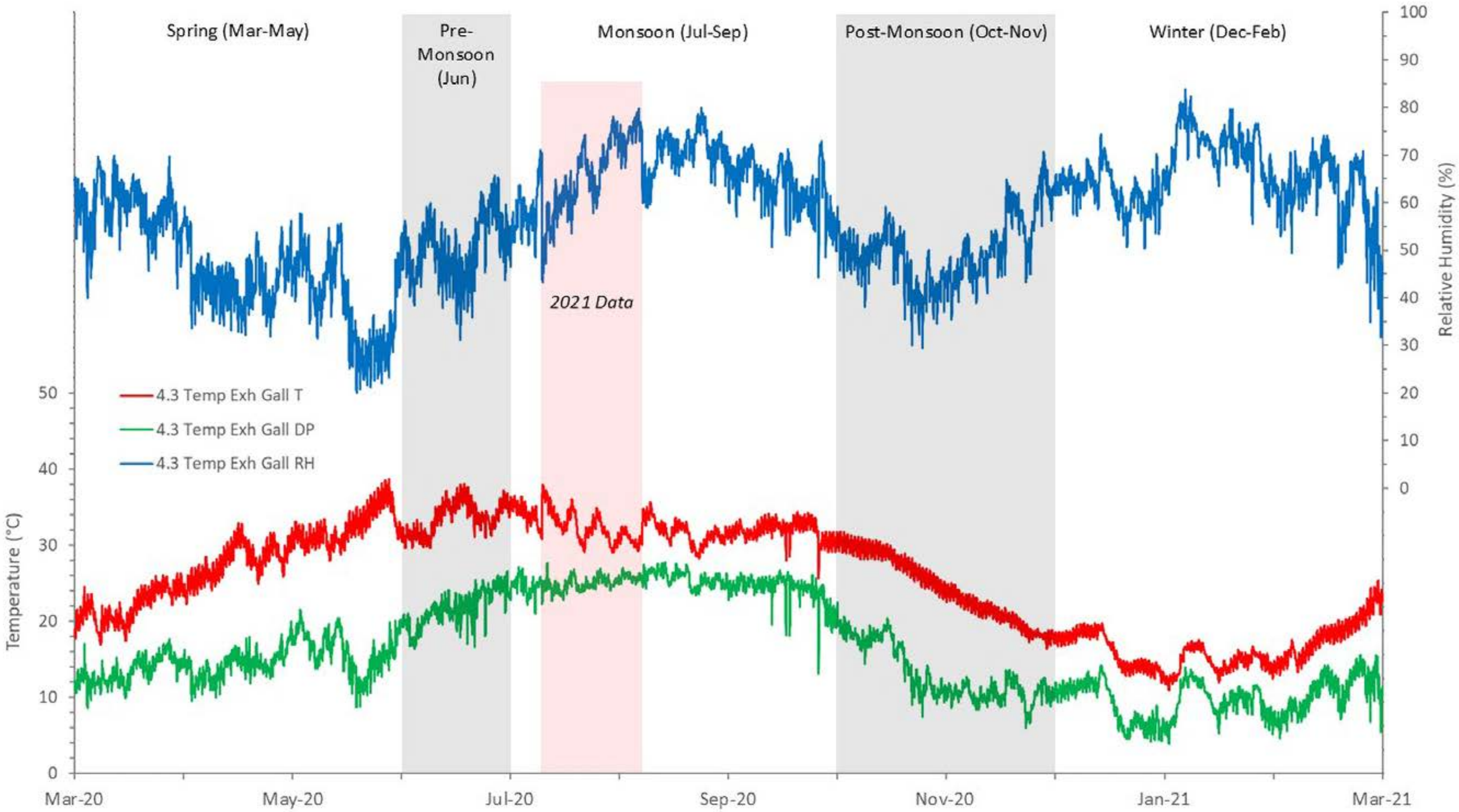


FIGURE D.32.

Temporary exhibition gallery air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

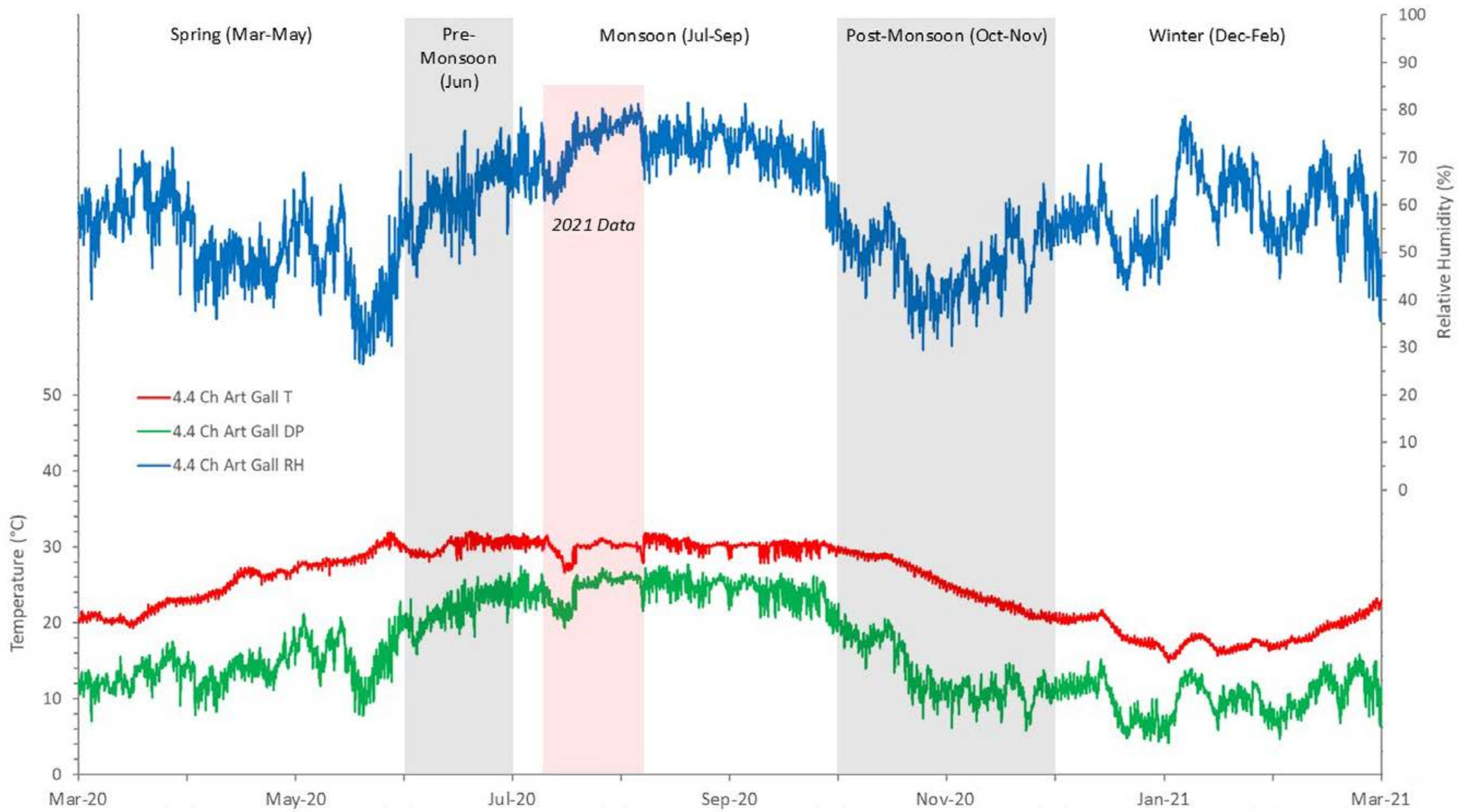


FIGURE D.33.
Child Art Gallery air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

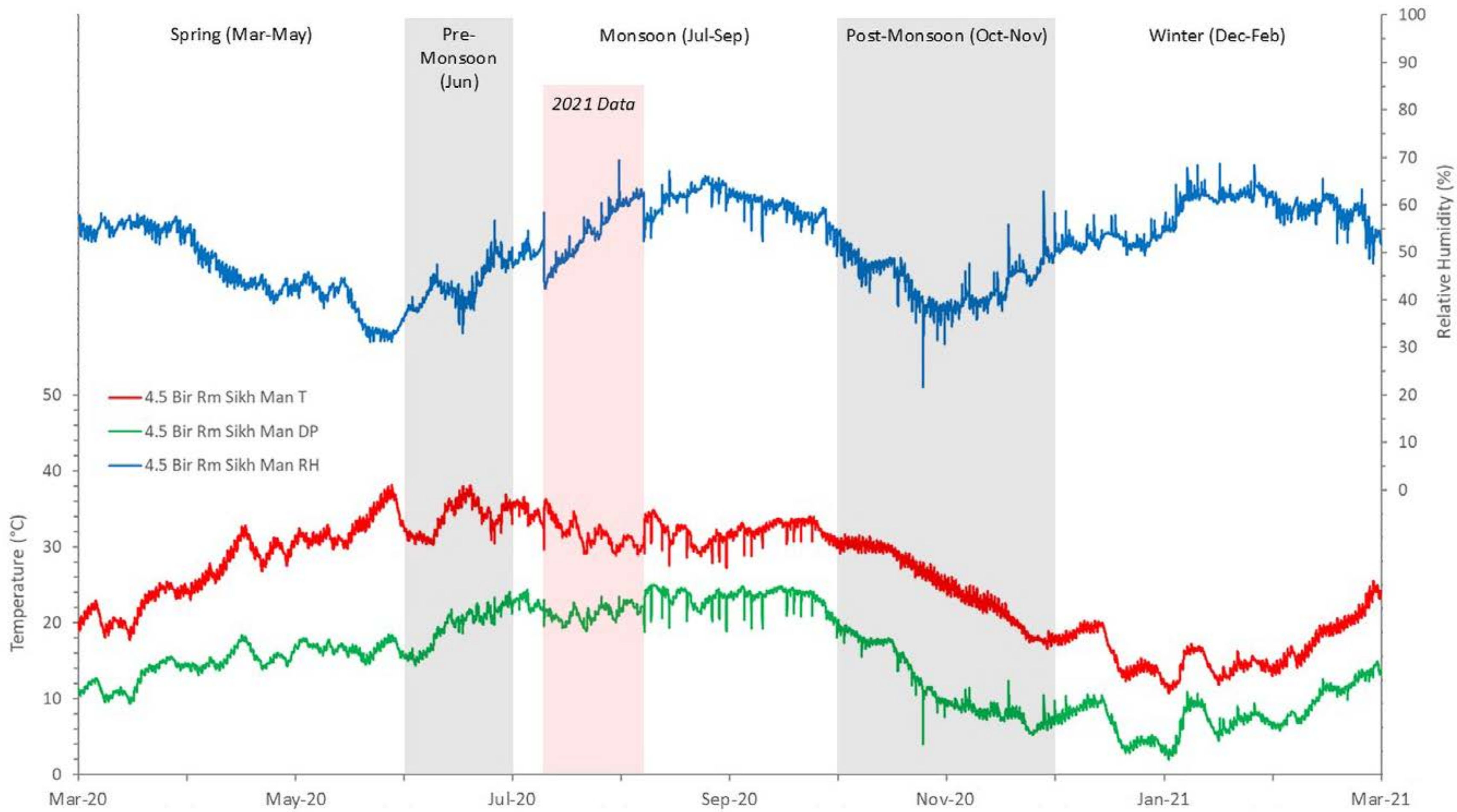


FIGURE D.34.

Bir room, Sikh manuscripts air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

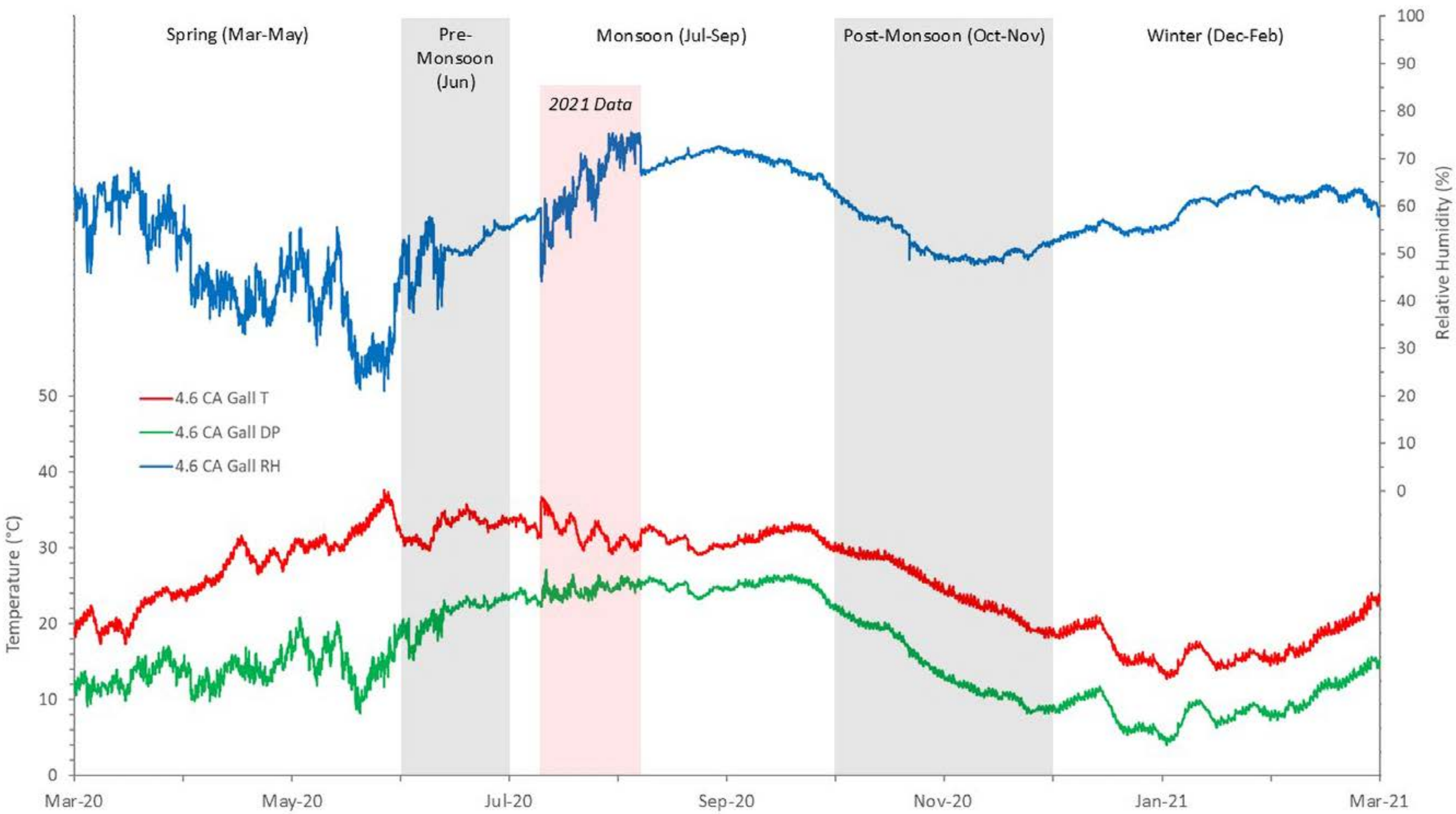


FIGURE D.35.
Contemporary Art Gallery I air temperature, dew point, and relative humidity behind paintings from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

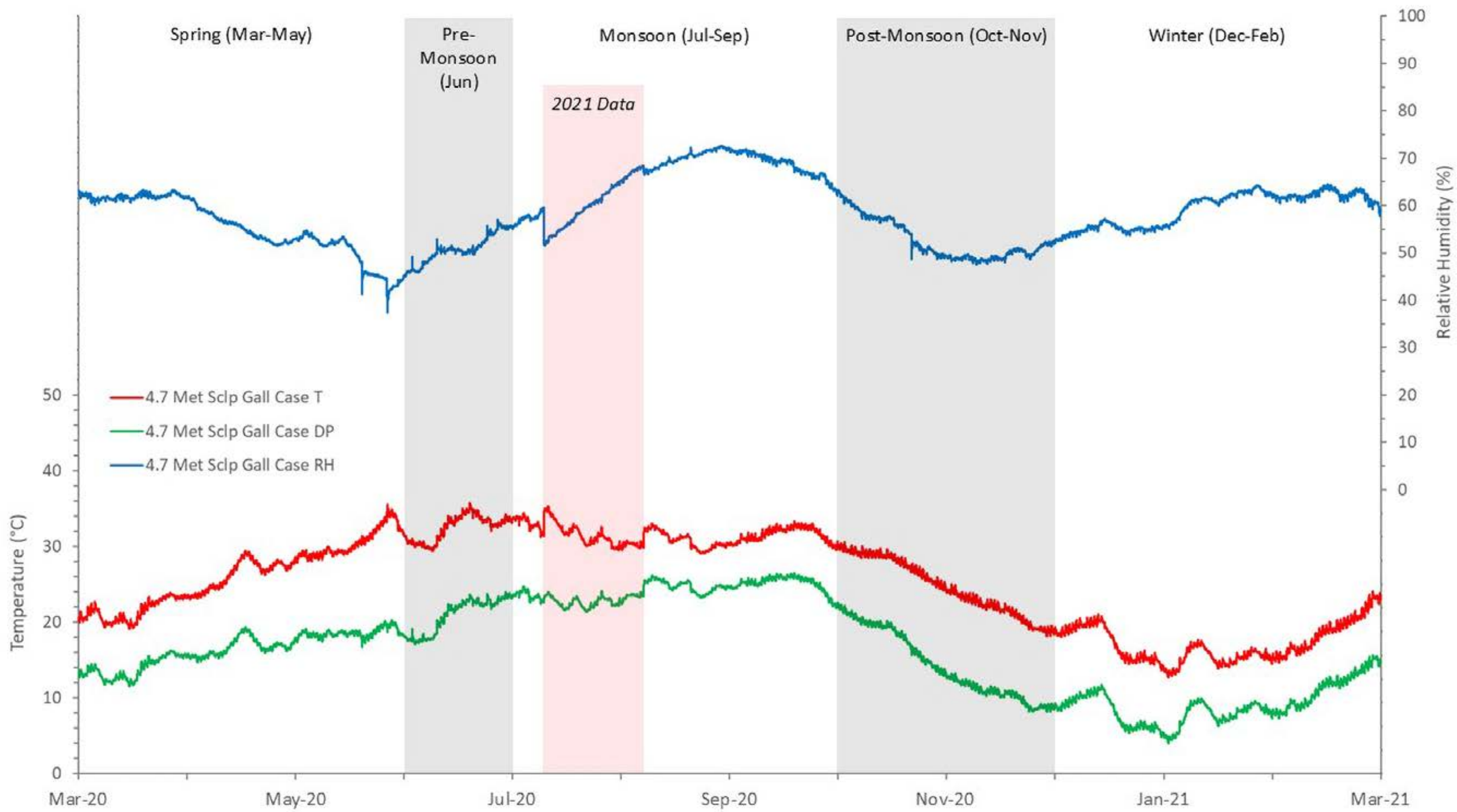


FIGURE D.36.
Metal Sculptures Gallery display case air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

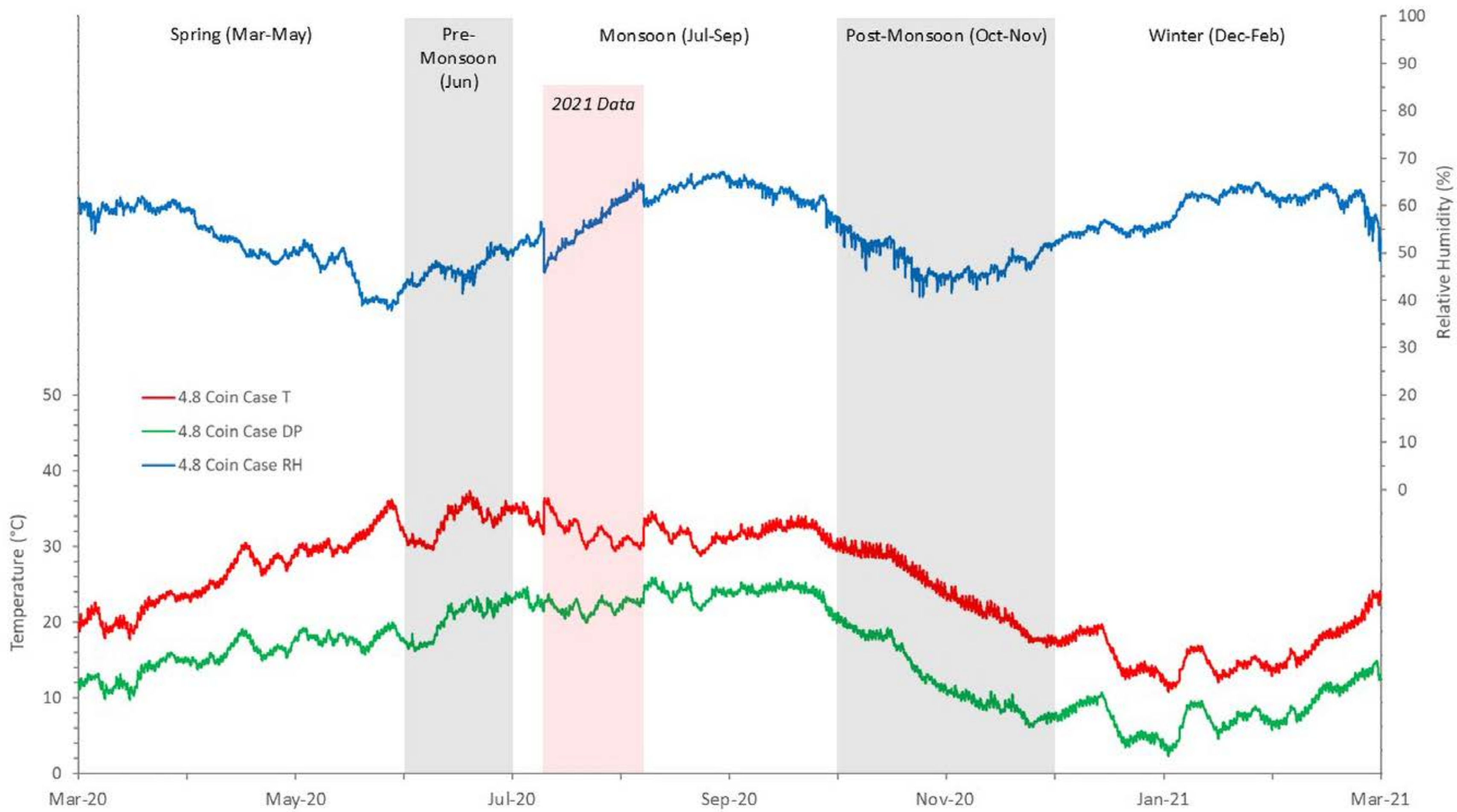


FIGURE D.37.
Coins Section display case air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

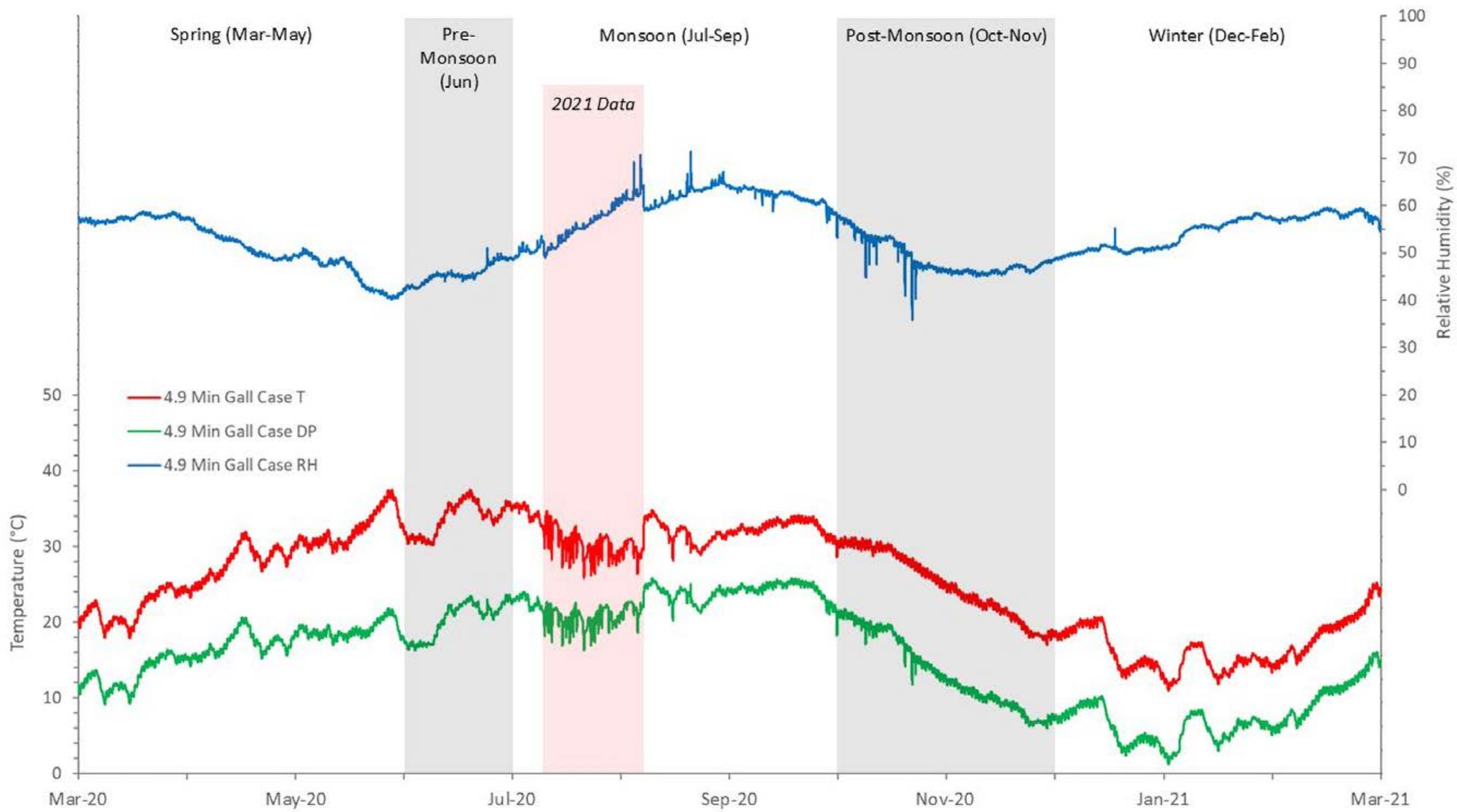


FIGURE D.38.
Miniatures Gallery display case air temperature, dew point, and relative humidity from March 2020 to March 2021 (vertical pink box indicates data taken from July to August 2021). Chart: Vincent Laudato Beltran and Jenny Youkyoung Kim, © J. Paul Getty Trust.

GLOSSARY

Aerator
Refers to Le Corbusier's *aerateur*, an opaque hinged door or casement inserted into a section of solid wall or into a window wall system whose purpose was to provide controllable ventilation. The design of this element later evolved to be fabricated from aluminum with a more aerodynamic shape and to pivot on its center vertical axis. Also called ventilator shutters in the Conservation Management Plan for the Government Museum and Art Gallery in DRONAH (2019).

Agents of deterioration
"A conceptual framework to categorize the main causes of change, loss, or damage to collections. The most common format is the Canadian Conservation Institute's (fire; incorrect relative humidity; incorrect temperature; light, ultraviolet & infrared; pests; pollutants; physical forces; thieves and vandals; water), first published by Stefan Michalski in 1990 and later expanded to include custodial neglect (now dissociation) by Robert Waller in 1994. This framework is a major influence on the applied practice of preventive conservation and collection management, especially risk management for cultural heritage collections." (Taylor et al. 2023, 239)

Box plot
"A method for graphically depicting probability for a numerical dataset. The box always encompasses data within the 25th and 75th percentile (also known as the interquartile range, or IQR) and an intermediate line is used to denote the median. The lines or whiskers extending from the top and bottom of the box can have variable definitions (e.g., maximum and minimum, 95th and 5th percentile). The x-axis identifies the classification of each box (e.g., individual spaces, seasons, years), while the y-axis shows the variable of interest." Also called box and whisker plot. (Taylor et al. 2023, 239)

Clerestory
An architectural feature commonly found in buildings, especially churches or large halls. It is the upper part of a wall that contains windows, located above eye level, usually just below the roofline. The purpose of a clerestory is to let natural light into the building's interior, often creating a bright and airy atmosphere. Also referred to as monitors.

Cross-ventilation or **wind-driven ventilation**
Occurs when outside air can pass through inlets in the windward wall and interior air can exit through outlets in the leeward wall. This air movement is caused by a pressure difference between opposing sides of a building.

Cumulative relative frequency (CRF) plot
"A graphical description of the distribution of data for an individual variable by which each data point is paired with its CRF, which is the proportion of observations that are less than or equal to that specific value. CRF plots display the variable of interest on the horizontal axis and its CRF (from 0 to 1) on the vertical axis. Note that the interquartile range (IQR) is denoted by values corresponding to CRFs of 0.75 (75th percentile) and 0.25 (25th percentile). If the dataset is relatively complete, a CRF plot can determine the percentage of time that the data reside within a target zone." (Taylor et al. 2023, 240)

Gandhara sculpture
The term *Gandhara* refers to an ancient region located in what is now northwestern Pakistan and eastern Afghanistan. In the context of Indian sculpture, Gandhara is renowned for its unique art style, often called Gandhara art, which flourished between the first century BCE and the seventh century CE. This style is particularly significant for its fusion of Greco-Roman artistic elements with Indian Buddhist themes.

Human thermal comfort
"The condition of the mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation. Factors directly affecting thermal comfort can be separated into personal (metabolic rate, clothing level) and environmental (air temperature, mean radiant temperature, air speed, and humidity)." (Taylor et al. 2023, 242)

Humidity ratio
"The ratio of the mass of water vapor in a given air parcel to its mass of dry air, expressed as gram/kilogram, pound/pound, or grains/pound. Humidity ratio is depicted on the right y-axis of a psychrometric chart. It is also known as mixing ratio." See also *moisture content*. (Taylor et al. 2023, 242)

Interquartile range (IQR)
See *box plot*.

Mechanical conditioning
Involves the use of mechanical means to heat, cool, dehumidify, or humidify the air to achieve the desired interior environmental conditions for occupants or museum collections.

Mechanical ventilation
Introduction of outside air into a building through the use of fans or other mechanical means to force air movement in order to improve the quality of the interior air.

Moisture content
"The mass of water in the material divided by the mass of dry material." See also *humidity ratio*. (Taylor et al. 2023, 243)

Natural conditioning
Results from natural ventilation when the temperature and relative humidity of the replacement (outside) air can improve the thermal comfort of the building occupants. (Simmonds and McConahey 2021, chap. 2)

Natural ventilation
Introduction of outside air into a building driven by buoyancy and wind, and with no mechanical means to force air movement, in order to improve the quality of the interior air.

Pilotis
In architecture, the term *pilotis* refers to slender supports, often in the form of columns or piers, that elevate a building above the ground or water. These elements are commonly used to create open spaces underneath structures, promoting better airflow, access, and even aesthetic appeal.

Psychrometric chart
"A graphic depiction of the suite of thermodynamic parameters of an air parcel at a constant barometric pressure (or elevation). The x- and y-axes show dry bulb temperature and humidity ratio, respectively, while relative humidity is defined by isohumes (lines of constant relative humidity) that curve to the upper right. Also commonly depicted are dew point temperature, enthalpy, wet bulb temperature, and specific volume. Preferred in Europe, the Mollier diagram is identical in content with the psychrometric chart but differs in appearance." (Taylor et al. 2023, 244)

Relative humidity (RH)
"The ratio of the amount of water vapor in the air and the total amount of water vapor the air can potentially contain at a given temperature. Expressed as a percentage (%), RH will vary with temperature, as its water vapor holding capacity will lessen at lower temperatures and vice-versa. At 100% RH, air is saturated and will result in condensation." (Taylor et al. 2023, 244)

Significance
"Encompasses all of the qualities, values, and meanings that people and communities bestow on heritage and endows the heritage with the importance of being preserved." See also *value*. (Taylor et al. 2023, 245)

Spot reading
"A measurement that has been taken at a specific location for a brief duration (as little as one data point). Examples include the use of handheld instruments without data logging capability to measure parameters such as light, temperature, relative humidity, and particulates. The portability of such instruments allows for flexibility of location, but the data represents a snapshot in time that may be difficult to interpret without more context." (Taylor et al. 2023, 245)

Stack-effect ventilation
"The movement of air in a building due to differences in temperature. Warm air rises and cool air falls." Also called buoyancy-driven ventilation. (Taylor et al. 2023, 245)

Temperature, dew point
"The temperature to which air must be cooled to become saturated with water vapor, and below which dew (liquid condensation) or frost (solid deposition) first forms. An elevated dew point value indicates the presence of more moisture in an air parcel." See also *humidity ratio*. (Taylor et al. 2023, 241)

Temperature, dry bulb
"Dry bulb temperature (°C or °F) is the temperature measured by a thermometer freely exposed to air, but shielded from radiation and moisture. DBT is what is commonly implied when discussing air temperature. Note that DBT is shown on the x-axis of a psychrometric chart." (Taylor et al. 2023, 246)

Temperature, wet bulb
"Wet bulb temperature (°C or °F) is measured by passing air over a thermometer wrapped in wet muslin. Wet bulb temperature is the same as dry bulb temperature at 100% RH; at lower humidity values, wet bulb temperature is always lower than dry bulb temperature, reflecting the conversion of liquid water into vapor using thermal energy in the air." (Taylor et al. 2023, 246)

Time-series plot
"A common data visualization that depicts time on the x-axis and a variable(s) of interest on the y-axis. The utility of time series plots is increased as multiple types of data are compared, including variables recorded at separate locations (e.g., interiors, exteriors), different statistical data treatments (e.g., moving average, moving range), related variables (e.g., air temperature, relative humidity, dew point temperature), and target conditions." (Taylor et al. 2023, 246)

Undulatory window or **undulatory window wall**
Refers to Le Corbusier's *pan de verre undulatoire*, an enclosure wall consisting of vertical, irregularly spaced members (usually concrete) with narrow panes of floor-to-ceiling fixed glass in between, often used in combination with aerators. Also called undulatory glazing or undulatory fenestration in the Conservation Management Plan for the Government Museum and Art Gallery (DRONAH 2019).

Value
"Refers to the meanings, positive characteristics, or qualities perceived by certain individuals or groups in objects, collections, buildings, sites, landscapes, and intangible expressions of culture that transform them into heritage. There are many classifications of values, such as historical, aesthetic, artistic, economic, social, scientific, and spiritual. They are sometimes divergent, vary for different individuals or groups, and are not immutable over time." See also *significance*. (Taylor et al. 2023, 246)

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