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ENERGY AND ENVIRONMENTAL CONTROLS IN THE HISTORIOGRAPHY OF MODERN ARCHITECTURE

Heating, ventilating, cooling, and lighting are often overlooked in the historiography of modernism. However, an emerging initiative in architectural history is now addressing energy use in the built environment. Recent studies have illuminated the significance of environmental technologies in nineteenth- and twentieth-century buildings across the Americas, Europe, Africa, Asia, and Australia. Numerous historic structures have now been analyzed in terms of their passive and active systems for creating optimal interior environments, as related to changing ideas on comfort, energy consumption, and environmental sustainability. There has also been a growing interest in studying the embodied energy of historic buildings going back to antiquity. This scholarship assesses how the procurement, transportation, and assembly of materials used energy before the advent of mechanically powered construction equipment. Additionally, new research into the 'constructional ecology' of architecture is closely examining energy consumption and carbon emissions associated with the fabrication of conventional modernist materials such as steel and various types of glass, as well as the mechanized production of traditional materials like stone. Collectively, these scholarly efforts are broadening the analytical scope of architectural history by bridging it to disciplines that have traditionally been separate from the primarily art historical study of architecture.

Modern architectural history has long focused on the collaboration between architects and structural engineers in creating the iconic works of the nineteenth and twentieth centuries. However, far less attention has been given to collaborations between architects and mechanical engineers in the realm of environmental controls as these developed from the mid-nineteenth century. Heating, ventilating, cooling, and lighting remain underexplored and often overlooked in the historiography of modernism, despite being essential for habitability and integral to the development of modern construction. Recently, a growing body of research in architectural history has begun to examine energy use in the built environment. Studies in this field have effectively illuminated the importance of environmental technologies for a range of nineteenth- and twentieth-century buildings across the Americas, Europe, Africa, Asia, and Australia. This emerging field has produced numerous analyses of individual historic structures, investigating both passive and active systems for creating optimal interior environments. For this subfield to develop it has had to build an interdisciplinary bridge to the history of mechanical engineering, a discipline traditionally separate from art historically rooted studies of architecture.

This potential to reframe the past from the perspective of the energy-conscious present speaks to one of the central thematic questions of this issue of *Opus Incertum*, whose editors ask: "Is the growing interest in hyper-contemporaneity a problem or an opportunity for the architectural historian? Are there chronological limits that should not be crossed to preserve the necessary critical distance or is the study of hyper-contemporaneity a stimulating challenge that could lead to methodological innovations and open new interdisciplinary horizons in the field?" Architectural history now has an opportunity to learn from contemporary design practices, particularly those associated with the concept of 'integrated design'. This term, frequently used in current literature on green building, indicates a collaborative process in which architects, engineers, fabricators, contractors, and building owners work together to combine both passive material and active mechanical systems in larger buildings that aspire to be green or energy-conserving. A notable example of such an environmentally responsible structure is the California Academy of Sciences, designed by Renzo Piano and completed in 2008, at the time the world's largest LEED Platinum building with the largest green roof (fig. 2)[1].

Histories of such recent buildings examine multilateral collaborations among utility companies, local and national governments, and foundations and consultants for energy issues. As the critic Sara Hart observed: "In architecture and engineering, coordination and collaboration are essential functions, but the terms are not interchangeable. Coordination is quantifiable and rational. Collaboration, on the other hand, is creative and often daring. Collaborators are allies, committed to a single vision. Successful collaboration can raise a building's stature to that of an icon"[2]. The consensus is that integrated design as interdisciplinary collaboration is necessary to design green buildings that combine passive and mechanical systems for energy efficiency.

This transformation of contemporary architecture has recently led historians to reconsider older buildings as products of technical and artistic collaborations that lie outside traditional art historical models of analysis[3]. In scholarship, this direction has begun to shape historical accounts for contemporary green buildings that could be fruitfully applied to architecture of earlier periods[4]. This model is an example of a direction, derived from current architectural practice focused on energy use and environmental controls, that could potentially enrich the practice of an interdisciplinary architectural history. It might be insightfully brought to different building types, such as museums, residences, office buildings, schools and universities, government buildings, and renovations of historic buildings, with attention to the connections between their programs, budgets, climates, locales, and technologies.

The need to link histories of architecture with histories of energy use and environmental technologies raises important methodological questions related to this new interdisciplinary necessity. Traditionally, art historical studies of architecture have focused on the analytical model whereby a building emerges from a dialogue between its patron or client and its architects and their artistic collaborators. However, recent scholarship examining the collaborative process behind canonical works has begun to explore in-

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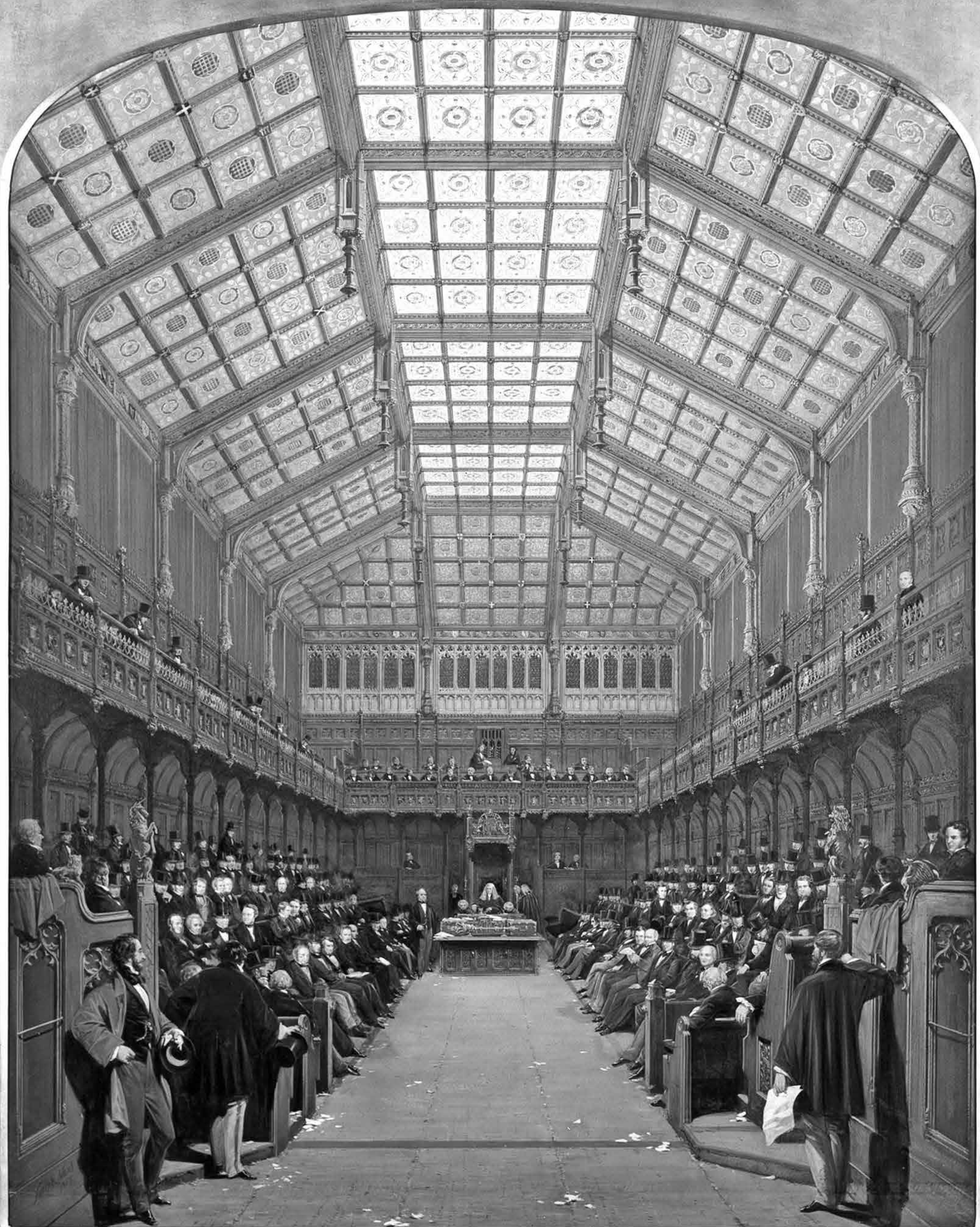

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Fig. 1 *J. Nash, Interior of the House of Commons During a Debate, 1858 (© Heritage Collections at UK Parliament, WOA 2934).*

Fig. 2 *R. Piano with Stantec Architecture (formerly Chong Partners Architecture), California Academy of Sciences, Golden Gate Park, San Francisco, 2000-2008 (© California Academy of Sciences).*

teractions between clients, architects, and engineers in ways previously less considered. To understand buildings historically in terms of energy use, scholars need to not only engage with technical expertise as the traditional model of a mechanical engineering firm designing a heating, ventilating, and air-conditioning (HVAC) system either with or alongside architects and structural engineers. Instead, they need to examine the importance of multilateral collaboration involving many actors. This approach would transcend an art historical focus on individual architects that may occlude appreciation of how they worked in teams with engineers, suppliers, contractors, and clients. Art history has long sustained interdisciplinary aspirations. In architectural history, could these extend beyond social, cultural, material, and structural analyses to fully engage the mechanical realm?

Historiography of environmental controls

Most historical studies of modern architecture and energy have focused on operational energy consumed for heating, ventilating, lighting, and air conditioning. Among the first scholars to take this approach was Reyner Banham who, with his 1969 book *The Architecture of the Well-tempered Environment*, integrated study of the evolution of environmental controls into the broader history of modern architecture. As Banham wrote, what is needed is "a bridge between the history of modern architecture as commonly written – the progress of structure and external form – and a history of modern architecture understood as the progress of creating human environments"[5]. Coinciding with the environmental movement, James Marston Fitch's 1972 book *American Building: The Environmental Forces That Shape It* proposed a historiography for American architecture that engaged the whole human experience of the built environment, taking into account how buildings are heated and cooled, how they are ventilated and how their air is filtered, their artificial and natural lighting, their acoustics, and the integration of environmental control systems to create interior microclimates[6].

Several scholars have pursued the agenda that Banham and Fitch envisioned, offering new insights into buildings considered canonical for the histories of modern architecture. One such historian is Henrik Schoenefeldt, who has rigorously reexamined key sites such as Joseph Paxton's Crystal Palace (1850-1851) in London, which relied largely on passive means of cooling and ventilating, and the New Palace of Westminster (Houses of Parliament), also in London (1836-1868). Designed by Sir Charles Barry and Augustus W. N. Pugin, the latter building had traditionally been understood as central to the history of the Gothic Revival as the major stylistic and ideological movement in English architecture of its time. Schoenefeldt has explored the mechanically innovative heating and ventilating systems developed by David Boswell Reid, especially for the chambers of both the House of Lords and the House of Commons (fig. 1). These systems we-

[1] See, for example, K. Moe, *Integrated Design in Contemporary Architecture*, New York 2008.
[2] S. Hart, *An Icon Is Completed After 80 Years: Part I*, "Architectural Record Innovation", 193, 2005, 11, pp. 20-23.
[3] See, for example, D. Hawkes, W. Forster, *Energy Efficient Buildings: Architecture, Engineering, Environment*, New York 2002, which explores architect-engineer collaborations for environmental controls from the eighteenth century to the present.
[4] *Integrated Design: GSA/Morphosis/Arup; San Francisco Federal Building*, edited by B. Carter, Buffalo 2008; S. Wels, *California Academy of Sciences: Architecture in Harmony with Nature*, San Francisco 2008; M.A. Thomas, *The Greenest Building: How the Bullitt Center Changes the Urban Landscape*, Portland 2016.
[5] R. Banham, *The Architecture of the Well-tempered Environment*, Chicago 1984[2] (first ed. London 1969), p. 92. N. Whiteley, *Reyner Banham: Historian of the Immediate Future*, Cambridge 2002, esp. ch. 4.
[6] J.M. Fitch, W. Bobenhausen, *American Building: The Environmental Forces That Shape It*, Boston 1972.

Fig. 3 *W. Harrison, E. Durell Stone, D. Deskey, Radio City Music Hall, New York City, 1929-1932 (Wurts Bros. X2010.7.1.7534; © Museum of the City of New York).*

re groundbreaking in their scale and complexity, and in the integration of technical experimentation with the building's complex programmatic concerns. Schoenefeldt's work reveals such buildings as climatic machines in a way that complements earlier assessments of them in histories of modern architectural styles. Specifically, his studies highlight the importance of interstitial space within a modern building's overall volume for housing equipment, piping, ducts, and ancillary devices[7].

This body of work exemplifies a rich new direction for studies of nineteenth-century buildings that necessarily bridges between the history of art and the history of mechanical engineering. A comparably fruitful focus for such studies has been large theater buildings of the nineteenth and twentieth centuries for which heating, ventilating, and cooling were critical. These were among the first public buildings wherein energy consumption on a large scale had enabled functionality as habitability, especially since the advent of electrification in the 1880s for powering air systems as well as lighting. Given the need to move large quantities of air to adequately ventilate auditoriums seating 2,000 to over 6,000 people, these spaces became central to both theoretical speculation and practical experimentation in controlling humidity to aid cooling in environments of heat- and fume-producing gaslights, and, after 1890, the heat load created by electric lighting, in addition to the heat generated by the audience (fig. 3). To account for these developments, architectural history needs to move beyond its conventional narratives of visual style and spatial form to bridge to the histories of technology and medicine[8].

Another building type central to the history of modern architecture has been the tall office building and eventually the skyscraper as its supertall (300-meters or higher) variant. Its historiography, theory, and criticism have traditionally focused on formal or aesthetic issues, considering the building's exterior as an artistic object. Parallelling this tradition there has been an ongoing interest in tall buildings from the standpoint of structural engineering, from foundations to wind-bracing. However, distinct from studies of the skyscraper's form and structure, more recent has been the effort to chart its evolution as a mechanically serviced interior system which is ever more energy dependent in its operations. Indeed, there was an evolution of tall office buildings through several stages of energy systems that paralleled the type's stylistic and structural development. Yet, the connections between all these aspects of tall buildings' history have been less explored, largely due to a lack of interdisciplinary awareness. This is now changing, in part because these buildings are enormous consumers of energy; reducing their energy profiles has prompted the development of a new parallel historiography[9].

The impact of energy consciousness on historical studies of modern architecture is well illustrated by comparing three successive generations of

[7] H. Schoenefeldt, *Rebuilding the Houses of Parliament: David Boswell Reid and Disruptive Environmentalism*, Abingdon 2021; Id., *The Temporary Houses of Parliament and David Boswell Reid's Architecture of Experimentation*, "Architectural History", 57, 2014, pp. 175-215. Schoenefeldt acknowledges R. Bruegmann, *Central Heating and Forced Ventilation: Origins and Effects on Architectural Design*, "Journal of the Society of Architectural Historians", 37, 1978, 3, pp. 143-160. See also H. Schoenefeldt, *The Crystal Palace Environmental Considered*, "Arq: Architectural Research Quarterly", 12, 2008, 3-4, pp. 283-294; Id., *Adapting Glasshouses for Human Use: Environmental Experimentation in Paxton's Designs for the 1851 Great Exhibition Building and the Crystal Palace, Sydenham*, "Architectural History", 54, 2011, pp. 233-273.

[8] C. Mead, *Charles Garnier's Paris Opéra: Architectural Empathy and the Renaissance of French Classicism*, New York-Cambridge 1991; J. Siry, *The Chicago Auditorium Building: Adler and Sullivan's Architecture and the City*, Chicago 2002; Id., *Air-Conditioning in Modern American Architecture, 1890-1970*, University Park 2021.

[9] P. Oldfield, D. Trabucco, A. Wood, *Five Energy Generations of Tall Buildings: An Historical Analysis of Energy-Consumption in High-Rise Buildings*, "Journal of Architecture", 14, 2009, 5, pp. 591-613.

Fig. 4 *H. Labrouste, Bibliothèque Sainte-Geneviève, Paris, designed 1838-1839, built 1843-1851 (from E. Edwards, Memoirs of Libraries: Including a Handbook of Library Economy, London 1859, p. 674; © Library of Congress, Washington, DC, Prints and Photographs Division, LC-DIG-ppmsca-15552).*

interpretation of Henri Labrouste's Bibliothèque Sainte-Geneviève in Paris, designed from 1838-1839 and built 1843-1851. Traditionally, this building had been celebrated for innovative use of exposed iron columns and arches as the structural framework for its vast 85-meter-long reading room on the second floor (fig. 4). This interior fit beautifully into a narrative of modern architecture as a progressive development of innovative construction in iron, and then in steel and reinforced concrete[10]. Such a reading prevailed from the 1940s to the 1970s. But with the rise of post-modernism in European and American architecture in the latter decade, there was new interest in modern architecture's retrospective involvement with earlier historical styles, and the related problem of architecture's capacity to convey publicly comprehensible meaning through the reworking of known stylistic conventions. In this second moment, the historian Neil Levine powerfully revised our understanding of the Bibliothèque Sainte-Geneviève as its architect Labrouste's reinterpretation of ancient Greek and medieval Gothic architecture that expressed the French July Monarchy's commitment to public accessibility of its collections, especially for students at the University of Paris, and the monarchy's dynastic relationship to the earlier Bourbon kings who had built the adjacent Church of Sainte-Geneviève, later renamed Le Panthéon in the French Revolution[11]. In the 2010s, the library was revisited once again for its innovative system of gas lighting and central heating that enabled it to remain open after nightfall to serve students. According to this third reading, Labrouste had created a building with 'healing' properties that derived neither from its structure nor its symbolism but rather from its energy-consuming mechanical systems. In a time before electrification, these functioned with careful attention to solar control through the room's great windows and with a system of stack ventilation from the basement up above the vaults through the attic[12]. As outlined above, the historiography of this building illustrates how each successive era perceived its architecture anew.

The integration of mechanical systems into the architectural design of interiors, which Banham had identified as an historiographic lacuna, has been addressed in several works that study examples from the late eighteenth through the early twenty-first centuries. This scholarship bridges between narratives of technical innovation and architectural style, arguing for a historiography

[10] S. Giedion, *Space, Time and Architecture*, Cambridge 1967[5] (first ed. Cambridge 1941), pp. 212-226.
[11] N. Levine, *The Romantic Idea of Architectural Legibility: Henri Labrouste and the Neo-Grec*, in *The Architecture of the Ecole des Beaux Arts*, exhibition catalogue (New York, Museum of Modern Art, 29 October 1975-4 January 1976), edited by A. Drexler, New York-Cambridge 1977, pp. 325-416; Id., *The Book and the Building*, in *The Beaux-Arts and 19th-Century French Architecture*, edited by R. Middleton, Cambridge 1982, pp. 138-174.
[12] M. Bressani, M. Grignon, *The Bibliothèque Sainte-Geneviève and 'Healing' Architecture*, in *Henri Labrouste: Structure Brought to Light*, edited by C. Bélier, B. Bergdoll, M. Le Coeur, New York-Paris 2013, pp. 94-123; V. Lerum, *Sustainable Building Design: Learning from Nineteenth-Century Innovations*, London 2016, pp. 46-53.

Fig. 5 *Times Square at Night*, 30 November 1932 (*photo S.H. Gottscho, 88.11.2541; © Museum of the City of New York*).

that accounts for the experience of interiors as both aesthetic conceptions and controlled environments. This perspective has been brought to such architects as Charles Rennie Mackintosh, Le Corbusier, Mies van der Rohe, Erik Gunnar Asplund, Arne Jacobsen, Alvar Aalto, Louis I. Kahn, Carlo Scarpa, Sigurd Lewerentz, Luis Barragán, and Peter Zumthor[13]. Related studies explore how architects and environmental engineers creatively approach the design and expression of both active and passive thermal environmental control systems as innovative responses to client, site, and user requirements. These analyses focus on integration of mechanical equipment into overall building structural and spatial form, as well as designed details, and reconstruct the dialogue between architects and engineers to illuminate how their processes advanced technically and aesthetically to achieve a synthesis of their concerns[14].

Beyond histories of specific mechanical innovations, there is now an intellectually rich investigation of the transformative effects of environmental technologies on human interactions with, and perceptions of, buildings and cities. Central to contemporary concerns about energy use is electric lighting. Sandy Isenstadt's studies discuss the ways this modern technology has affected the built environment and our interactions with it, focusing on the period from the late nineteenth century through the 1940s. Isenstadt's is not a straightforward history of electric lighting or its effects on architecture, but rather an investigation of how it fundamentally altered domestic experience, revolutionized perceptions of both the natural and built landscape through innovations like the electric automobile headlight, transformed manufacturing workspaces, and illuminated outdoor commercial environments, as epitomized by New York's Broadway (fig. 5). He shows that, like other environmental technologies, electric lighting depended on a new national infrastructure of power production, and underscores that lighting created

[13] D. Hawkes, *The Environmental Imagination: Technics and Poetics of the Architectural Environment*, Abingdon 2020^{2}.
[14] G. Baird, *The Architectural Expression of Environmental Control Systems*, London 2001.

Fig. 6 *L.A. Reinhard and H. Hofmeister; Corbett, Harrison, and MacMurray; and Hood, Godley, and Fouilhoux (architects); O.B. Hanson (chief engineer, NBC); A.W. Canney (air-conditioning engineer), RCA Building West, Rockefeller Center, NBC Broadcasting Studio 8H, New York City, 1933 (Wurts Bros. X2010.7.2.5847; © Museum of the City of New York).*

professional and advocacy groups like the American Illuminating Engineering Society, whose views differed from those of architects[15]. Methodologically, studies such as Isenstadt's evoke the work of the sociologist of science Bruno Latour, who argued that technical innovations are best understood as part of a collective system that includes the motivations of their users, makers, and those who maintain them[16].

Equally rich as innovative historiography have been recent studies of buildings as acoustic environments. As Sabine von Fischer and Olga Touloumi have written:

> Despite its ubiquity, sound is largely missing from histories of architecture and the built environment. Historians and scholars often rely on their critical gaze to unlock the interpretative potential of objects, buildings and sites. These ocularcentric architectural histories, following the tools and mannerisms of Western art-historical methods, look at the built environment through various scales (from object to territory) and media (from bricks to master plans). They do so with an asymmetrical focus on visuality, both as the method and resource of writing about space, ultimately, displacing the multi-sensorial spatial experience outside the purview of architectural analysis[17].

Architectural historians have engaged with the acoustic histories of building types such as churches and concert halls[18]. But an awareness of the history of energy use has recently broadened this sub-field to include interiors whose acoustic functionality depends on the integration of electronic amplification, air-conditioning, insulation, and lighting (fig. 6). These include broadcast and film production studios, as well as auditoriums designed as settings not only for live in-person meetings but as rooms whose proceedings would project to a world audience. One canonical example is the United Nations General Assembly in New York City. For architectural history to account for mechanically powered acoustic environments, there needs to be interdisciplinary expertise from the physics of sound to the political role of broadcast media[19].

Historiography of sustainability in historic buildings

Since the 1990s, sustainability's centrality as an agenda for contemporary architecture has inspired another approach to architectural history of the modern period that focuses not on mechanical innovations for controlling interior environments, but on historic buildings as repositories of ideas for passive strategies for heating, cooling, and ventilating, in alignment with the current goal of reducing energy consumption as a key component of sustainability. Various studies have traced this term's evolving uses and meanings, from its historical roots to its recent ascendancy and ever-widening scope. The concept of 'sustai-

[15] S. Isenstadt, *Electric Light: An Architectural History*, Cambridge 2018. A comparably wide-ranging cultural exploration of a technology's impact is W. Schivelbusch, *Geschichte der Eisenbahnreise: Zur Industrialisierung von Raum und Zeit im 19. Jahrhundert*, München 1977, English trans. *The Railway Journey: Trains and Travel in the Nineteenth Century*, New York 1979.
[16] B. Latour, *Reassembling the Social: An Introduction to Actor-Network Theory*, Oxford 2005.
[17] S. von Fischer, O. Touloumi, *Sound Modernities: Histories of Media and Modern Architecture*, "Journal of Architecture", 23, 2018, 6, pp. 837-880: 873.
[18] D. Howard, *Sound and Space in Renaissance Venice: Architecture, Music, Acoustics*, New Haven-London 2009; B.V. Pentcheva, *Hagia Sophia: Sound, Space, and Spirit in Byzantium*, University Park 2017.
[19] O. Touloumi, *Assembly by Design: The United Nations and Its Global Interior*, Minneapolis 2024.

nability' emerged with planned yield forestry in seventeenth- and eighteenth-century England, North America, and Germany. It resurfaced during the Industrial Revolution in the nineteenth century, and later with the environmental movement in the 1960s, before becoming widely used today to convey a utopian vision of a stable, prosperous, and ecologically minded society[20]. There are also efforts to trace the history of ecological consciousness in the modernist movement in architecture through the twentieth century, particularly since the oil crisis of the 1970s. The result is that the once-fixed canon, such as that of the Bauhaus, is now seen through a new lens that highlights modernism's tradition of environmental awareness[21].

The ecological ideal for today's built environment has inspired historical studies that comparatively analyze major public buildings of the nineteenth and twenty-first centuries, arguing that the best-performing contemporary architecture, while innovative in materials and monitoring systems, reflects an awareness of scientific principles present in great eighteenth- and nineteenth-century buildings. These principles include the energy efficiency of buoyancy-driven ventilation and the importance of thermal mass in moderating interior temperature and humidity changes, among other consideration. Such analysis emphasizes how both historic and contemporary buildings sought to create comfortable interior environments while maintaining a sustainable relationship with the natural world. From this perspective, valuable lessons can be drawn from sites such as the eighteenth-century Winter Palace in St. Petersburg, Russia, which, after a devastating fire in 1837, was equipped with a warm air heating and ventilation system. Also noteworthy in this regard are Sir John Soane's Museum, the British Museum Reading Room, and the Natural History Museum in London[22].

Since the advent of the environmental movement in the 1960s, a tradition of studies has developed to understand architecture's relationship to climate. Fundamental to this discourse is the work of the Olgyay brothers, which has been widely cited[23]. While this conversation has largely unfolded within the design community, it has also inspired a recent tradition of historical scholarship that revisits art historically canonical architecture from the perspective of how designers addressed the response of their buildings to local climate. This historiography focuses not so much on climate-modifying equipment, but rather on how architects integrated concerns for daylighting, ventilation, heating, and cooling into the forms of their buildings and the character of their interiors. Exemplary of this approach is the work of Dean Hawkes, who has applied it to the study of English architecture from the sixteenth through the twentieth centuries. Hawkes examines how the rise of meteorology and its quantitative assessment of the English climate interacted with literary and painterly representations, shaping the scientific and cultural context in which climatically responsive architecture emerged. This insightful analysis has provided new perspectives on Robert Smythson's Elizabethan country houses of the sixteenth century, Sir Christopher Wren's church and collegiate buildings of the seventeenth century, English Palladian architecture of the eighteenth century, Sir John Soane's early nineteenth-century buildings in London's urban climate, Arts and Crafts houses of the early twentieth century, and English modernist houses of the mid-twentieth century[24].

Since the 1990s, the growing emphasis on sustainability in architecture has prompted a broad reconsideration of the modernist movement, shifting the focus from stylistic concerns to environmental ones. One of the liveliest new fields of investigation in this area has been to revisit canonical and less canonical form-givers to understand how these architects thought through their buil-

[20] J.L. Caradonna, *Sustainability: A History*, New York 2014.
[21] P. Anker, *From Bauhaus to Ecohouse: A History of Ecological Design*, Baton Rouge 2010; *Sorry, Out of Gas: Architecture's Response to the 1973 Oil Crisis*, edited by G. Borsari, M. Zardini, Montreal 2007.
[22] Lerum, *Sustainable Building Design*… cit.
[23] V. Olgyay, *Design with Climate: Bioclimatic Approach to Architectural Regionalism*, Princeton 1963; B. Givoni, *Man, Climate, and Architecture*, Amsterdam-London-New York 1969; *Climate and Architecture*, edited by T. Dahl, London 2010.
[24] D. Hawkes, *Architecture and Climate: An Environmental History of British Architecture 1600-2000*, London 2012.

Fig. 7 *U.S. Capitol, House of Representatives, Washington, D.C. Attic viewed along its center line, showing air conditioning ducts (installed in 1928) between iron trusses (installed in 1857), with diffusers along the base of the ducts at the edges of glass ceiling panels (from "Heating, Piping, and Air Conditioning", 1, 1929, 8, p. 66; © Carrier Corporation Archives, Iron Mountain).*

dings as modulating climate, seeing the modernist tradition through the lens of sustainability as an integral component of its avant-garde character – an aspect previously overlooked. The revisionary approach has shed new light on such figures as Le Corbusier, Oscar Niemeyer, Johannes Duiker, Alvar Aalto, Frank Lloyd Wright, Jean Prouvé, Arne Jacobsen, Marcel Breuer, Lina Bo Bardi, Iannis Xenakis, and others. Reassessing how these architects considered factors like the solar path in relation to the orientation of houses and designed their building envelopes as climate-modifying systems has expanded our understanding of modernism's vision of functionality to include buildings' biological habitability[25].

Along these lines, one fruitful focus for recent historical studies has been the solar house, especially as it evolved from the 1930s through the 1970s. Throughout this period, a succession of architects and researchers explored how 'natural conditioning' – heating and cooling with passive solar techniques – could offer a viable alternative to fossil fuels. Studies of this movement emphasize the myriad ways in which architects collaborated not only with clients, engineers, and builders on individual projects, but also within networks that included research scientists in universities and national and international organizations that sought to develop collective expertise. During the Cold War of the 1950s and 1960s, and later during the Arab oil embargo of 1973, when energy security became a pressing global concern, the passive solar house emerged as a politically charged architectural type[26].

Historiography of interior comfort

Among many issues of energy consumption in modern buildings, air-conditioning holds a central place in twentieth-century architecture since the advent of mechanical cooling and dehumidification just after 1900. Historically, more energy was used for heating, but air-conditioning demands greater energy intensity to both dehumidify and cool interiors. By 2000, the intensity of energy use for comfort cooling and refrigeration accounted for 48 percent of the total energy consumed by buildings in the United States, making it the largest single component[27]. Since fossil fuels and natural gas are typically burned to generate the electricity that powers air-conditioning – releasing carbon dioxide and other greenhouse gases into the atmosphere – air-conditioning plays a central role in accelerating global warming and climate change. The profound impact of air-conditioning on energy consumption in buildings has, in part, inspired a new historiography that examines its role in the development of modern architecture. These studies bridge the traditionally separate disciplines of art history – focused on such issues as style, form, patrona-

[25] *Lessons from Modernism: Environmental Design Strategies in Architecture, 1925-1970*, edited by K. Bone, S. Hillyer, S. Joh, New York 2014.
[26] A. Denzer, *The Solar House: Pioneering Sustainable Design*, New York 2013; D.A. Barber, *A House in the Sun: Modern Architecture and Solar Energy in the Cold War*, Oxford 2016.
[27] S. Hayter *et al.*, *Designing for Sustainability*, ASHRAE conference paper (Dublin, 20-22 September 2000), NREL/CP-550-27797, pp. 1-2.

Fig. 8 *Skidmore, Owings, and Merrill (architects); G. Bunshaft (chief designer); Jaros, Baum, and Bolles (mechanical engineers); R. Loewy (interior designer), Lever House, New York City, 1950-1952. Office interior, showing central air diffusers in the acoustic ceiling (© Ezra Stoller/ Esto).*

ge, and functionality – and the history of mechanical engineering within the broader history of technology. By integrating these fields, they demonstrate how the latter became integral to the discourse on architecture as a new element of its functionality (fig. 7)[28].

Related but distinct is an emerging field of study that focuses on the history of ideas about comfort in the built environment and the social history of climatic control of interiors. Rooted in literature on light and warmth in domestic spaces from the seventeenth through the nineteenth centuries, particularly in English and American traditions of country houses and cottages, histories of comfort address the material culture of heating and illumination before physical comfort became an explicit concern. By the eighteenth century, comfort had become a central value in material culture as a legitimated form of popular consumption[29]. Also related are studies of the interior environments shaped by modern technologies, which extend historiographical discussions to offices and workplaces as well as domestic interiors. Engaging with the sociology of consumption and technology, these studies trace how, over the past few generations, expectations of comfort, cleanliness, and convenience have altered radically. They investigate the evolution of these changes associated with energy-consuming technologies – including showers, heating, air-conditioning, and clothes washing – as well as their social meaning as prevalent practices and daily rituals linked with homes, offices, domestic appliances, and clothing. Formative scholars like Elizabeth Shove highlight how conceptions of normality and cultural and economic forces control routine consumption, with a tendency toward escalating and standardizing patterns

[28] Siry, *Air-Conditioning in Modern American Architecture…* cit. See also G. Cooper, *Air-Conditioning America: Engineers and the Controlled Environment, 1900-1960*, Baltimore 1998.
[29] J.E. Crowley, *The Invention of Comfort: Sensibilities and Design in Early Modern Britain and Early America*, Baltimore 2001; F.M. Butera, *Dalla caverna alla casa ecologica. Storia del comfort e dell'energia*, Milano 2004; *Addressing the Climate in Modern Age's Construction History: Between Architecture and Building Services Engineering*, edited by C. Manfredi, Cham 2019.

of energy use (fig. 8)[30]. Recently, historians have started thinking about how to define comfort in a future society that prioritizes lower energy consumption and reduced carbon emissions to mitigate climate change[31].

The artificially cooled and mechanically ventilated environment of the mid-twentieth century also created new opportunities for indoor public spaces that integrated passive material envelopes with energy-consuming active systems. These interiors became environmental refuges, designed to counter the deterioration of postwar, postindustrial cities[32]. Important work by Michelle Murphy examines the history and science of what became known as 'sick building syndrome', meaning contaminated environments associated with sealed, mechanically ventilated and cooled interiors. Her research, along with other studies, explores how this issue was perceived by a range of actors, including feminist activists, protesting workers, ventilation engineers, toxicologists, epidemiologists, corporate scientists, and ecologists. 'Sick building syndrome' represents an environmental politics of the indoors, where habitability is enabled by buildings' high operational energy use[33].

Partly prompted by contemporary concerns for sustainability, the past decade has seen the emergence of a historiography of modern architecture in the nineteenth and twentieth centuries that traces a long line of alternative experiments in cooling without air-conditioning. The global search for less energy-intensive, and hence less costly, means of moderating climate to enable habitability, especially in equatorial or tropical regions, has inspired a kind of alternative history of modernism outside the prevailing art historical canon. A key center for such studies has been Singapore, where Jiat-Hwee Chang has traced the origins of the concept of tropical architecture to nineteenth-century British colonial architectural knowledge and practices in the tropics, as these were linked to military technologies, medical theories, and sanitary practices, and were manifested in colonial building types such as military barracks, hospitals, and housing. This scholarship also explores the ways in which colonial knowledge and practices shaped postwar and postcolonial technoscientific research in climatic design and tropical architecture through the early 1970s[34].

Other recent scholarship along these lines has taken a more global, comparative approach, exploring how leading architects of the twentieth century brought regional approaches to climate adaptability into the design process. Focusing on the period surrounding World War II – before fossil-fuel-powered air-conditioning became internationally prevalent – Daniel Barber has investigated architectural discussions of design, materials, and shading systems, including variations on *brise-soleil*, as a means of interior climate control (fig. 9). While emphasis has partly been on the work of major architects such as Richard Neutra, Le Corbusier, Lúcio Costa, and Skidmore, Owings, and Merrill, as well as climate designers like Victor and Aladar Olgyay, also important for historical study of energy and architecture has been the collective contribution of large professional and scientific organizations such as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, which traditionally lie outside an art historical frame of reference[35].

Historiography of embodied energy and the built environment's role in climate change

Over the past decade, growing concerns about climate change and carbon emissions have led architects to consider the substantial levels of energy consumption and their attendant environmental consequences associated with the manufacture and transport of building materials. This relatively recent focus on embodied ener-

30 E. Shove, *Comfort, Cleanliness, and Convenience: The Social Organization of Normality*, Oxford 2004.
31 *Comfort in a Lower Carbon Society*, edited by E. Shove, H. Chappelles, L. Lutzenhiser, London 2013.
32 D. Gissen, *Manhattan Atmospheres: Architecture, the Interior Environment, and Urban Crisis*, Minneapolis 2014.
33 M. Murphy, *Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Technoscience, and Women Workers*, Durham 2006.
34 J.H. Chang, *A Genealogy of Tropical Architecture: Colonial Networks, Nature and Technoscience*, New York 2016.
35 D.A. Barber, *Modern Architecture and Climate: Design Before Air Conditioning*, Princeton 2020.
36 B. Calder, *Architecture from Prehistory to Climate Emergency*, London 2021; Id., G.A. Bremner, *Buildings and Energy: Architectural History in the Climate Emergency*, "Journal of Architecture", 26, 2021, 2, pp. 79-115.
37 K. Moe, *Unless: The Seagram Building Construction Ecology*, New York 2021.
38 See essays on "Accumulation", a project by e-flux Architecture and Daniel A. Barber, produced in cooperation with the Princeton Environmental Institute at Princeton University, the Ph.D. Program in Architecture at the University of Pennsylvania Weitzman School of Design, and other university entities: https://www.e-flux.com/architecture/accumulation/ (last accessed 10 November 2024).
39 See the "Toxicities" series by Aggregate Architecture: https://we-aggregate.org/piece/toxics (last accessed 10 November 2024).

gy in new buildings has, in turn, inspired scholars like Barnabas Calder to investigate the embodied energy of historic structures going back to antiquity[36]. This scholarship assesses how the procurement, transportation, and assembly of materials used energy in the era before mechanically powered construction equipment. Currently, a variant of this historiography has emerged that focuses on what has been called the 'constructional ecology' of architecture. Scholars such as Kiel Moe analyze the energy consumption and carbon emissions tied to the fabrication of such conventional modernist materials as steel and other metals, and different types of glass, as well as the mechanized production of traditional materials like stone (fig. 10). Studies of operational and embodied energy link the historiography of architecture to the field of environmental history[37]. Contemporary concerns about the role of the built environment in climate change are also driving a range of interdisciplinary initiatives in architectural history. These include investigations into material accumulation – from plastics in the oceans to carbon in the atmosphere – and their connections to people, buildings, and cities[38]. Related studies explore the history of toxic substances and toxicity in the built environment from the nineteenth century to the present[39]. Collectively, these efforts broaden the analytical scope of architectural history by connecting it to other disciplines such as environmental studies, material science, and public health.

Fig. 9 *Le Corbusier, L'Unité d'Habitation, south of Marseilles, 1947-1952. West façade featuring brise-soleil (photo Archivision, 1A1-LC-UHM-1-D1; © F.L.C./ ADAGP, Paris/Artists Rights Society [ARS], New York 2024).*

Fig. 10 *L. Mies Van der Rohe, P. Johnson, Seagram Building, New York City, 1954-1958 (photo A. Jemolo / Scala /Art Resource, NY. ART432445; © 2024 Artists Rights Society [ARS], New York/VG Bild-Kunst, Bonn).*