

Introduction

AIR-CONDITIONING AND THE HISTORIOGRAPHY OF MODERN ARCHITECTURE



Modern architectural history has long been concerned with the collaboration of architects and structural engineers to create the iconic works of the nineteenth and twentieth centuries. Yet much 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. Technologies of heating, ventilating, and cooling are among the more poorly understood and neglected parts of the historiography of modernism, even though these technologies are essential for habitability and are an integral part of the development of modern construction. Only since the pioneering work of scholars like the late Reyner Banham, with his book *The Architecture of the Well-Tempered Environment* (1969), have there been efforts to study the evolution of environmental controls as part of the broad history of modern architecture. As Banham implied, 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.”¹

Since Banham wrote these words, this lacuna had, until recently, long persisted in spite of the rethinking of energy use in buildings that followed the first major oil crisis, of 1973–74, and the transformation

of contemporary architecture in pursuit of ideas of sustainability, which has accelerated since the 1990s. Emerging priorities of green, or environmental, architecture have shifted contemporary thinking about the built environment so radically that a corresponding shift in modernist historiography is now emerging. Within the last decade, attention has newly been paid to the history of environmental concerns in modern architecture of the early to mid-twentieth century.² This attention has often taken the form of either an extension or a critique of Banham’s approach, which is still much cited. A recent alternative to Banham’s emphasis on the evolution of specific environmental technologies is that of the sociologist of science Bruno Latour, who has argued that technical innovations are optimally understood as part of a collective system that includes the motivations of their users, makers, and those who maintain them.³ Both Banham’s and Latour’s analytical models are applicable to air-conditioning as a technology embedded within larger social networks of human actors who create and inhabit modern architecture. The chapters that follow seek to unearth significant parts of that history, in the course of tracing the development of air-conditioning and its integration into modern American architecture.

Among many issues of energy consumption in modern buildings, air-conditioning

has occupied a central place in American built environments since the advent of mechanical cooling and dehumidifying of air just after 1900. Historically, more energy has been used for heating buildings, but air-conditioning is a more intense use of energy to dehumidify as well as cool their interiors. For example, in 1934, in the early days of residential air-conditioning, experts estimated that to heat a house of fifteen thousand cubic feet to 70°F, with an outdoor temperature of 0°F, required about 100,000 Btu per hour. But to cool such a house only 10°F below an outside temperature of 95°F, 50,000 Btu of heat per hour must be removed. This included energy needed to remove water vapor from the air, heat generated inside the dwelling by people and other sources, and heat caused by the sun shining on the roof, walls, and windows.⁴ The widespread adoption of air-conditioning and the intensity of energy use in the conditioning process meant that by 2000, of the total energy consumed by buildings in the United States, 48 percent (the largest single component) was used for comfort cooling and refrigeration.⁵ The release of carbon dioxide and other greenhouse gases into the atmosphere from fossil fuels involved directly or indirectly in powering air-conditioning has made air-conditioning central to global warming and climate change.

Different types of historical studies related to air-conditioning have appeared in the last three decades. Prominent have been social histories of its impact as a new technology that had its origins in assisting manufacturing processes but quickly became central to environmental comfort in a wide variety of buildings. The history of the concept of comfort in the modern period now has its own literature. These histories tend to see air-conditioning as a celebrated focus of bourgeois consumption and

popular culture associated with income-based privilege, advertising, and corporate promotion. Refrigeration and industrial productivity were also long closely tied to air-conditioning.⁶ Contemporaneous but different in their aims have been recent historical studies of air-conditioning that focus on technical invention and pioneering applications through the twentieth century. Like the more socially oriented histories, these accounts of science and engineering touch on how air-conditioning became part of architectural design. But they tend to emphasize theoretical and experimental innovation in creating new devices and equipment for controlling the temperature, humidity, and movement of indoor air.⁷

While linking to both the technical history and the social history of air-conditioning, this book focuses on how architects integrated it and related technologies of heating and ventilating into their understanding of their art's total functional scope. In modernist historiography, structural engineering has long been accepted as a source of aesthetic invention and expression. This book is centrally about the ways in which mechanical engineering has been assimilated into the culture of architecture, as one facet of its broader modernist project. Thus these chapters seek to integrate the perspectives of art history, history of technology, and related social and cultural history. On one level, each chapter discusses a set of case studies that represent larger patterns of technical development. These studies explore how key modernists—Dankmar Adler and Louis Sullivan, Frank Lloyd Wright, Albert Kahn, George Howe and William Lescaze, Wallace Harrison, Ludwig Mies van der Rohe, Pietro Belluschi, Gordon Bunshaft, Eero Saarinen, Louis Kahn, and others—grappled with the need to integrate mechanical systems into

their aesthetic programs. For them, the modernist ideal of functionality was incompletely realized if it did not wholly assimilate heating, cooling, ventilating, and artificial lighting. The incorporation of mechanical systems into modernism's discourse of functionality was a gradual process, and there were inconsistencies between what architects proposed to do aesthetically and how they accommodated air-conditioning formally, spatially, and visually. But it profoundly shaped architects' work, as they and their engineering collaborators and clients well knew but as most critics and later historians of their architecture, with some notable exceptions, have left unremarked.⁸

This range of issues has made limiting the scope of this monograph a challenge. On one level, the history of air-conditioning's relationship to modern architecture is so broad that it resists the long-standing historiographic emphasis on individual master architects. The technical developments and their social origins and consequences are largely outside the intellectual space of art history, where historical studies of architecture have been rooted. At the same time, major modernist architects were outstanding in part because they took on the question of how to integrate mechanical systems into the spatial and structural forms of buildings as works of modern art. Thus, the following chapters include both necessary discussion of air-conditioning's technical and social history and case studies of buildings by master architects that brought that technology into the conceptual and formal project of modernism. This way of organizing the narrative carries an inherent tension. Indeed, one could imagine two books: one that is broadly concerned with air-conditioning's development as a relatively anonymous historical process, in the tradition of Sigfried Giedion's *Mechanization Takes*

Command (1948),⁹ and another that is about how celebrated individual architects made this technology into a part of their creative agenda, a subject that Banham incorporated into his narrative. This book seeks to do both, in an effort to show how the history of this technology intersects with the history of art. The chapters proceed chronologically from about 1890, when comfort cooling for American public buildings began, to the early 1970s, when the environmental movement accelerated rethinking of air-conditioning's climatic impact. Given the vast scope of these developments, the coherence of the monograph requires that the case studies be selective. Most of the buildings chosen here have a canonical status in the historiography of American modernism, which is based on the evolution of visual style. But reading these buildings mechanically shows that their stylistic impetus was often at odds with their climatic control, so that we see these familiar works differently.

Chapter 1 looks first at the baseline conditions of architectural practice for heating, cooling, and ventilating in the work of Dankmar Adler and Louis Sullivan in Chicago and elsewhere around 1890, before the advent of mechanically powered air-conditioning. These developments provide a context for revisiting Frank Lloyd Wright's approach to the integration of heating and cooling in his Larkin Building, in Buffalo, New York (1902–6). The beginning of air-conditioning can be traced back to 1902, when the invention of mechanical cooling for industrial and commercial buildings by engineers such as Willis Carrier and Alfred Wolff entailed study of how to manage the humidity, temperature, and movement of circulated air. In the Larkin Building, Wright assimilated certain emerging technologies for environmental comfort into his design's

interior spatial and exterior sculptural form to give these systems a monumental presence.

Chapter 2 focuses on the development of air-conditioning in industrial buildings, especially those for the Ford Motor Company, which, in modernizing its production facilities, became perhaps the largest corporate investor in the new technology. As Banham has noted, this was the building type wherein the major inventions in cooling and humidity control were first developed in the 1900s, before their application to theaters, office buildings, and other types in the 1920s and to individual houses from the 1930s on. At companies like Ford, Taylorist methods for calculating efficiency as a means to increase profits embraced air-conditioning, because it markedly increased worker productivity. At Ford, its scale of application effectively redefined the architecture of the factory as a building type, and architects such as Albert Kahn and lesser-known contributors like Ford's construction engineer, Edward Gray, were at the center of this process. They began early in the twentieth century with the daylight factory, before the advent of air-conditioning. Then, after mechanical cooling became part of the program for new facilities by the 1920s, architects and their industrial clients explored the windowless factory as a wholly sealed interior environment to facilitate production. This concept pervaded the design of buildings at the Century of Progress Exposition, in Chicago, of 1933–34, and the New York World's Fair of 1939. By the later 1930s, glass block, developed for insulating while daylighting air-conditioned factories, became a signature material of modernism, notably in the Museum of Modern Art in New York City, opened in 1939.

Chapter 3 treats the development of heating, cooling, and air-conditioning in movie

theaters, as the most prominent building type for introducing comfort air-conditioning to a broad public. This development proceeded incrementally from the early years of the twentieth century on an ever-larger scale, with both architects and engineers debating alternative methods of supplying cooled and dehumidified air to audiences numbering in the thousands. By the mid-1920s, air-conditioning had come to movie houses in Chicago, Los Angeles, Texas, and New York, and architects had begun to consider its effects on their spatial form and the design of their surfaces. This early period of air-conditioning theaters culminated in the interiors of Rockefeller Center, including Radio City Music Hall, which opened in December 1932. Rockefeller Center collectively had the world's largest air-conditioning system. In the Music Hall, its team of architects, led by Wallace Harrison, created an auditorium that integrated lighting and air-conditioning into an Art Deco aesthetic adapted to new technology.

Chapter 4 discusses how, beginning in the 1920s, Congress, after much debate, appropriated funds for the air-conditioning of the US Capitol and nearby House and Senate office buildings. This case study represents the larger issue of retrofitting existing buildings to accommodate the new technology, which practice was then more pervasive nationally than the integration of air-conditioning into new buildings. Through the era of the New Deal in the 1930s, offices in the Federal Triangle were also air-conditioned. Air-conditioning Capitol Hill affected the annual cycle of congressional activity going into World War II. It also transformed daily bureaucratic life in buildings like the Pentagon, which had the world's largest air-conditioning plant in a single structure when it was first occupied, in 1942. Overall, Washington, DC, was arguably the first major

American city to embrace air-conditioning, setting a model for the South and the Sunbelt, whose industrial and demographic transformation depended on this new technology.

Chapter 5 focuses on the development of air-conditioning for tall office buildings from the mid-1920s to the mid-1930s, as exemplified by the Milam Building, in San Antonio, Texas, opened in 1928, designed by George Rodney Willis, a former associate of Frank Lloyd Wright, and the Philadelphia Saving Fund Society Building, in Philadelphia, opened in 1932, designed by George Howe and William Lescaze. Both were early attempts at new tall buildings whose interior environments were thoroughly heated and cooled through their full height. In these earliest examples of totally, rather than partially, air-conditioned office buildings, architects shaped interior spaces, material surfaces, and exterior masses partly in response to the novel technology. In the Milam Building, air-conditioning helped counter Texas's regional climatic disadvantages for capital investment in building and economic activity. In the Philadelphia Saving Fund Society Building, Howe and Lescaze adapted the European International Style, whose buildings often had extensive outer glass walls with operable windows and were conceived without air-conditioning. Thus the style brought the challenge of elevated cooling loads to the building's new mechanical apparatus.

Chapter 6 returns to the work of Frank Lloyd Wright, who, in his SC Johnson Company Administration Building, in Racine, Wisconsin (1936–39), combined the idea of the windowless office building, which had developed by the mid-1930s, with stylistic models of streamlining. He developed these concepts further in his adjacent SC Johnson Research Tower (1943–50). Wright's Johnson

Administration Building opened to much attention from the architectural press and has since held a canonical place in art-historical narratives of American modernism. But the building's mechanical systems, especially its air-conditioning, although essential to the architecture, have held a lesser place in its historiography. The need is clear to bridge between the traditionally separate disciplinary cultures of modernist architecture and mechanical engineering in order to recover an understanding of how the latter was a kind of silent but powerful partner in the evolution of the former. In his SC Johnson buildings, Wright engaged with the contemporaneous aesthetic ideal of streamlining, originally associated with moving air. Although Wright wrote that he did not like air-conditioning as a means of achieving comfort in houses, he consistently explored the architectural expression of mechanical systems in his series of projects for tall buildings, such as the Rogers Lacy Hotel in Dallas of 1947.

Chapter 7 traces the assimilation of air-conditioning in iconic glass-curtain-wall buildings of the mid-twentieth century. The glass front presented wholly new challenges to its architects and engineers. Major examples include Pietro Belluschi's Equitable Building, in Portland, Oregon (1948); Wallace Harrison and Max Abramovitz's United Nations Secretariat Building, in New York (1950); Lever House, in New York (1952), designed by Gordon Bunshaft of Skidmore, Owings, and Merrill; and Ludwig Mies van der Rohe's Seagram Building, in New York (1958). Designers had conflicting ideals, in that their formal priorities for their buildings as works of art may or may not have included the visible display of mechanical systems. Sometimes systems became sources for novel forms, and sometimes they were visually suppressed. And

certain interiors incorporated lighting and air-conditioning into a comprehensive style, wherein equipment was integrated into a modernist aesthetic that reinvented the postwar office building as a workplace. Nowhere were such problems in design given more comprehensive attention than in Eero Saarinen's General Motors Technical Center, in Warren, Michigan, dedicated in 1956.

Chapter 8 focuses on major works of Louis Kahn, who took a famously different approach to the architectural management of mechanical systems in his Yale University Art Gallery addition (1953); Richards Medical Research Building, at the University of Pennsylvania (1960); Salk Institute for Biological Studies, in La Jolla, California (1965); Kimbell Art Museum, in Fort Worth, Texas (1972); and Yale Center for British Art, completed in 1977, after Kahn's death. Perhaps he went the furthest in trying to bring the study of mechanical systems into architectural theory as well as practice, with his abiding interest in concepts like the distinction between "served" and "service" spaces. The latter included not only stairways and elevators but also rooms for air-handling equipment and spaces for ducts. The richness and difficulty of his collaboration with mechanical and electrical as well as structural engineers resulted in new forms that had lasting influence on modernist architecture. Yet, like his contemporaries' parallel efforts, Kahn's integration of building systems into his aesthetic was not always formally seamless.

In this long arc of American modernist architecture's engagement with air-conditioning from the 1890s to the 1970s, at least eight major themes recur. First, how individual modernist architects worked with heating, ventilating, and air-conditioning in each project was

tied to functional issues specific to different building types, such as tall office buildings, factories, and theaters. The discourse of modern architecture has treated the ideal of functionality most often in terms of the relationship between a program of needs and a building's spatial arrangement. But the history of air-conditioning shows that the operational life of buildings grew increasingly elaborate as a central part of their functionality. Banham advocated for a corresponding historiography that embraces this aspect of design as a way of rethinking the whole of twentieth-century architecture as its buildings' environmental systems developed. Until recently, we have had relatively little historical consciousness of how standards of comfort and utility were developed for different types of buildings. Each of these had its own demands for optimal temperature, humidity, ventilation, and regulation of air freshness and air movement, the definitions of which were painstakingly worked out by a range of collaborative specialists over the decades since air-conditioning's advent. Of particular importance was the relationship of air systems to electric lighting, which had its own history that included its gradual integration with ventilation and cooling systems.¹⁰

Second, how each architect integrated the technology into their aesthetic depended on their theoretical outlook. In each case, an important part of that outlook was the architect's approach to collaboration. To discuss individual architects reflects an art-historical habit of mind that tends to occlude appreciation of their technical collaborators. Modernist architectural culture has long stressed creative genius, when in fact even the most celebrated architects increasingly worked in teams of architects, engineers, suppliers, contractors, and clients. Air-conditioning is just one of

many systems that tested the ideal of individual control, and histories of modern buildings need to consider the multilateral collaborations they entailed. As the critic Sara Hart has written: “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.”¹¹

The case studies in this book illuminate the vital collaborative role of mechanical engineers in the process of architectural design. The history of this critically important profession has been given little attention in the literature on modern architecture. Studies that have examined the relationship of architects and engineers have typically concentrated almost solely on the contributions of structural engineers.¹² But since its origins as a distinct field in the mid-nineteenth century, mechanical engineering has gradually assimilated an ever-broader portfolio of responsibilities that came to include not only heating and ventilating but all manner of issues related to building equipment. Often key technical contributions were made by mechanical engineers working within the companies that supplied air-conditioning equipment. Of these, the Carrier Corporation is the most well known, but a number of others shaped the field. We think of electrification in modern architecture since its advent in the 1880s as mainly focused on lighting. But the integration of electricity into buildings also completely transformed their mechanical potential in relation to heating, ventilating, and eventually air-conditioning.

As to this second theme, it is often assumed that architects develop their designs for

buildings and then consult engineers. What the following case studies illuminate is the essential role of their collaboration with both mechanical and structural engineers from the early phases of the design process. What is more, and what is largely unrecognized, is that the input of mechanical engineers can help architects to develop their designs not only technically but conceptually. In this regard, analogies of modern buildings to organisms or machines have repeatedly been invoked to convey how integral technical, spatial, and formal systems had become. As architects worked to gain conceptual and formal control over air-conditioning and related technologies, those systems were reciprocally redefining architecture’s disciplinary boundaries and professional concerns. Shared visions of a project’s potential brought together teams of collaborators to create iconic modernist buildings, such as the mechanical engineer Alfred Jaros in his work with both Gordon Bunshaft on Lever House and Mies van der Rohe on the Seagram Building. Also, Samuel R. Lewis of Chicago, a prolific author on air-conditioning and a president of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, helped Frank Lloyd Wright design the systems of the SC Johnson Research Tower.

Third, with a few exceptions, like Wright and Louis Kahn, modernist architects did not speak or write professionally or publicly on what they were doing mechanically. Their dialogues with engineers, suppliers, clients, and contractors about air-conditioning could be intense but usually were not included in architectural discourse or journalism. Architecture, after all, did not develop a theorization of its mechanical systems analogous to its long disciplinary history of theorizing structure. Engineers’ theoretical discourse of

air-conditioning, meanwhile, was almost purely scientific. In case after case, the key accounts of environmental systems for buildings were to be found largely in engineering literature, whose editorial program and audiences were less architectural. This book is the first among architectural histories to make extensive use of these primary sources. These articles also contained key explanatory drawings and photographs of mechanical equipment in place and discussions of economy in the uses of energy and its supporting utilities. Such images were notably absent from architectural journalism, so that the same building would often be documented and published differently for different professional readerships, almost as if it were two different buildings. Unpublished, archival sources about the architecture, such as correspondence, preliminary drawings, and specifications, can be helpful for deciphering a building's mechanical life, but these are usually less clarifying than the published explanations by the engineers involved. However, these published accounts prepared by engineers, clients, and architects tend to be uncritically descriptive, so other evidence is needed to shape a fully analytical picture.

A fourth recurrent theme in the adaptation of air-conditioning to modern building types is the ideal of productivity. From this perspective, air-conditioning is subject to analysis from a Marxist viewpoint as a technology that enabled increased returns on capital investment in buildings. The decision to develop and employ air-conditioning almost always related to larger concerns about the environmental definition of people's well-being inside buildings and how that related to the financial return on their activities. A factory owner would decide to air-condition if they perceived that the system would measurably benefit productivity and/or

product quality and thereby provide a demonstrable and rapid return on the initial investment. A movie-theater owner would similarly decide to air-condition if the enhanced comfort to audiences would increase attendance in warm weather, which it almost invariably did. Owners of hotels, department stores, and other public facilities of all kinds, including art museums, had analogous concerns to ponder. An office-building owner would calculate the efficacy of air-conditioning for attracting and holding desirable tenants, in competition with nearby owners. Congress weighed the question of expenditures for air-conditioning in terms of its value for members' comfort as a means to efficiency in transacting legislative business. Scientific laboratories were among the most complex environments to manage in terms of air-conditioning, which was essential to their productivity as sites for research and development. The emergence of this technology in buildings was related to the performance of the buildings' occupants as economic actors, whether they were producers or consumers. It quickly redefined how modern society might function. Thus the more specifically architectural issues discussed in the following chapters relate to broader questions of how productivity is measured and how environments are regulated in capitalist economies.

A fifth important theme concerns the methods by which air-conditioning was inserted into buildings, what might be called the search for interstitial space, meaning those volumes in a building that were planned as places for necessary equipment such as refrigeration machines, air handlers, fans, pipes, and ductwork of different kinds. As these elements grew dramatically in their spatial demands, architects from George Howe to Frank Lloyd Wright to Eero Saarinen to Louis Kahn, among others,

all embraced the need to think anew about the three-dimensional volume of a building not just in terms of habitable rooms but their ceiling depths, wall cavities, mechanical floors and penthouses, and often multiple basements that made up a new realm of interstitial space. Over time, this concept became part of the theory as well as the practice of modern architecture, especially in terms of the integration of its mechanical and structural systems.¹³

A sixth recurring theme is the major shift in thinking about built form attendant to air-conditioning that had to do with the concept of the building envelope as a layered system of materials and openings that manages the relationship of interior conditions and exterior climate, especially in terms of heat gain. Earlier ideas of cladding in architecture, which had been a preoccupation of nineteenth-century theory, now expanded to include ever more sophisticated analyses of wall assemblies, including evolving types of glass, as thermal barriers that had to be considered in relationship to the capacities of air-conditioning. These concerns brought together mechanical and material issues in a new way that began before 1900 and remains central to contemporary architecture.

A seventh theme, most prominent in the first decades of air-conditioning's development and proliferation, is the apparent lack of concern for the issues of sustainability that have become central to architectural culture worldwide since the 1990s. Perceived not as a technology that consumed inordinate quantities of energy, air-conditioning was instead seen as an engine of economic development, especially during the Great Depression. Yet while there was, through the mid-twentieth century, less reference to the broader ideal of sustainability or ecological (or green) architecture,

there was a continuous and ever more sophisticated search for economy in the use of fuels and efficiency in the operation of systems. The term "energy conservation" was not broadly used until the 1970s, but the concept was a central aim of mechanical engineers, since air-conditioning began to make a new order of demands on buildings' electrical and water systems. The conservation ideal was there, even if it was framed in financial, rather than environmental, terms. Thus the historical study of attempted efficiencies in air-conditioning up to the energy crises of the 1970s reveals what might be termed the prehistory of sustainability.

An eighth issue in air-conditioning's history is most visible in larger-scaled developments beyond individual buildings. Sites like Rockefeller Center and the US Capitol's district highlight how architectural solutions to air-conditioning relate to urban utility systems—notably water supplies but also electrical power and steam-tunnel district networks. While focused on individual architects and buildings, these chapters show how designers' choices were rooted in larger urban issues of energy production and distribution and in questions of private appropriation of collective resources, such as ground water in San Antonio, Texas, whose climate made water a precious commodity. At first, condenser water, which is necessary to remove heat from many large air-conditioning systems, was thrown away into rivers or elsewhere, until cooling towers were developed to recycle it. The heating, ventilating, and cooling systems for buildings were related to the local urban infrastructure that they tied into, such as municipal steam supplies. Air-conditioning for larger buildings caused clients, architects, engineers, and local governments to reassess architecture's

relationship to the utility systems that supported this new technology, including electricity and water for cooling equipment.

In addition to the thematic issues that appear in the following chapters are other noteworthy concerns that lie beyond the scope of this study. As Gail Cooper and other historians of technology have revealed, air-conditioning had its own discourse among heating, ventilating, and cooling engineers, and their collaborations with architects were presented in their professional periodicals. Yet equally compelling, if more elusive, is the social history of how air-conditioning effected changes in the lives of those who experienced it in a variety of settings, from factories, offices, laboratories, and other workplaces, to theaters, department stores, art museums, and other public or commercial buildings, not to mention domestic environs from apartment towers to tract houses. Air cooling's capacity to shape behaviors, create expectations, and alter perceptions of the built environment has been an important facet of modernity. Its differential availability based on class, gender, race, locale, and conditions of production and consumption was often a telling measure of spatial privilege or deprivation. Air-conditioning's adaptation to houses, both with central systems and window units, which evolved rapidly after World War II, is its own monographic topic. At its advent for domestic use in the 1930s, in New York City, air-conditioning appeared in high-income apartment buildings on the Upper East Side of Manhattan, whose mechanical systems were quite different from those of the first large low-income housing projects of the era, such as Parkchester, in the Bronx.¹⁴ Thus, in addition to the voices of architects, engineers, and clients, we need to recover not only popular embrace

of the technology but also ambivalence about and occasionally resistance to the inequalities it represented.

Histories of refrigeration and air-conditioning as transformative technologies for architecture could systematically consider the effects of air-conditioning on the US South and Southwest during the decisive decades from its adoption in the 1930s through the 1970s. Good initial work has been done in this area, as discussed toward the end of chapter 4, on Washington, DC. But changes wrought by air-conditioning throughout the southern states and the Sunbelt were so central to the economic, social, and political development of these regions that a study of them would be worthy of a monograph in itself. The technology's adoption was essential for the South and Southwest to become preferred locations for many types of industries and their collateral urban residential and commercial development. Each of the larger cities adapted air-conditioning to its particular climate and way of life, from Miami and Atlanta to New Orleans and Houston, Phoenix and Los Angeles, to name a few major centers, apart from more-rural areas.

Since the mid-twentieth century, air-conditioning has transformed many parts of the world outside the United States, which was the main producer of air-conditioning machinery before World War II, although the science of mechanical cooling was also developing in Germany, Switzerland, and England. In 1936 Argentina was by far the largest importer of American equipment, purchasing more than twice as much as England and France combined.¹⁵ The technology was appropriated at different times and rates, but by 1939, installations could be found in 115 countries and colonies, with applications across seventy-five

different fields.¹⁶ Today air-conditioning is still much less widespread in Europe than it is in the United States, but it continues to grow, especially in Greece, Italy, Spain, the Netherlands, and the United Kingdom. Japan adopted air-conditioning in commercial buildings in Tokyo in the 1930s, and the technology made a rapid advance in that country, including in homes, from 1960 to 1990. Yet in southern India there was very little air-conditioning of any kind until the mid-1990s. In China in 1999, air-conditioning units could be found in about 20 percent of individual urban households, whereas by 2007 that figure had risen to 80 percent.¹⁷ For an equatorial nation like Singapore, air-conditioning has been crucial for economic development. Total energy consumption of buildings there takes up about a third of total electricity production. Singapore's first and longtime prime minister, Lee Kwon Yew (in office 1959–90), regarded air-conditioning as the most important invention of the twentieth century.¹⁸ The growth of regions like the Persian Gulf is similarly unthinkable without air-conditioning.¹⁹ It would take an enormous amount of energy to cool the indoor environments of the world's fifty largest metropolitan areas to levels comparable to those in the United States. For metropolitan Mumbai, an estimate of 2009 is that the potential energy demand for cooling in that city alone would be about one quarter of the current demand for the entire United States.²⁰ Thus the technology's adoption worldwide would be a valuable focus for multiple studies.

But this book is about both the broad development of air-conditioning as it emerged in nonresidential building types and the ways in which US architects and mechanical engineers collaborated to integrate air-conditioning into buildings that are canonical in histories of twentieth-century modernism. What follows is the story of the cooling systems central to modern architecture and of the integration of these new technologies into architects' concepts of their art. The thematic argument is that air-conditioning and related mechanical systems of heating and ventilating were sufficiently transformative as new technologies that they compelled architects to rethink their approach to modern functionality as a basis for the holistic design of their buildings. To the abiding issues of structure, space, and form, they had to add moving air into the logic of their solutions. The evolving relationship between air-conditioning and architectural forms was neither linear nor consistent. Over the span of the decades treated in the following chapters, there was a broad spectrum of responses. But regardless of how architects chose to align, or not to align, the mechanical and the aesthetic, air-conditioning impressed itself on their vision for their art. The building as an air-cooling and air-moving machine became a modern fact, but the architectural interpretation of that condition was open to imagination. In notable cases, this mechanical novelty went from being an alien importation into designers' thinking to being an expressive resource for expanding the possibilities of twentieth-century architecture.