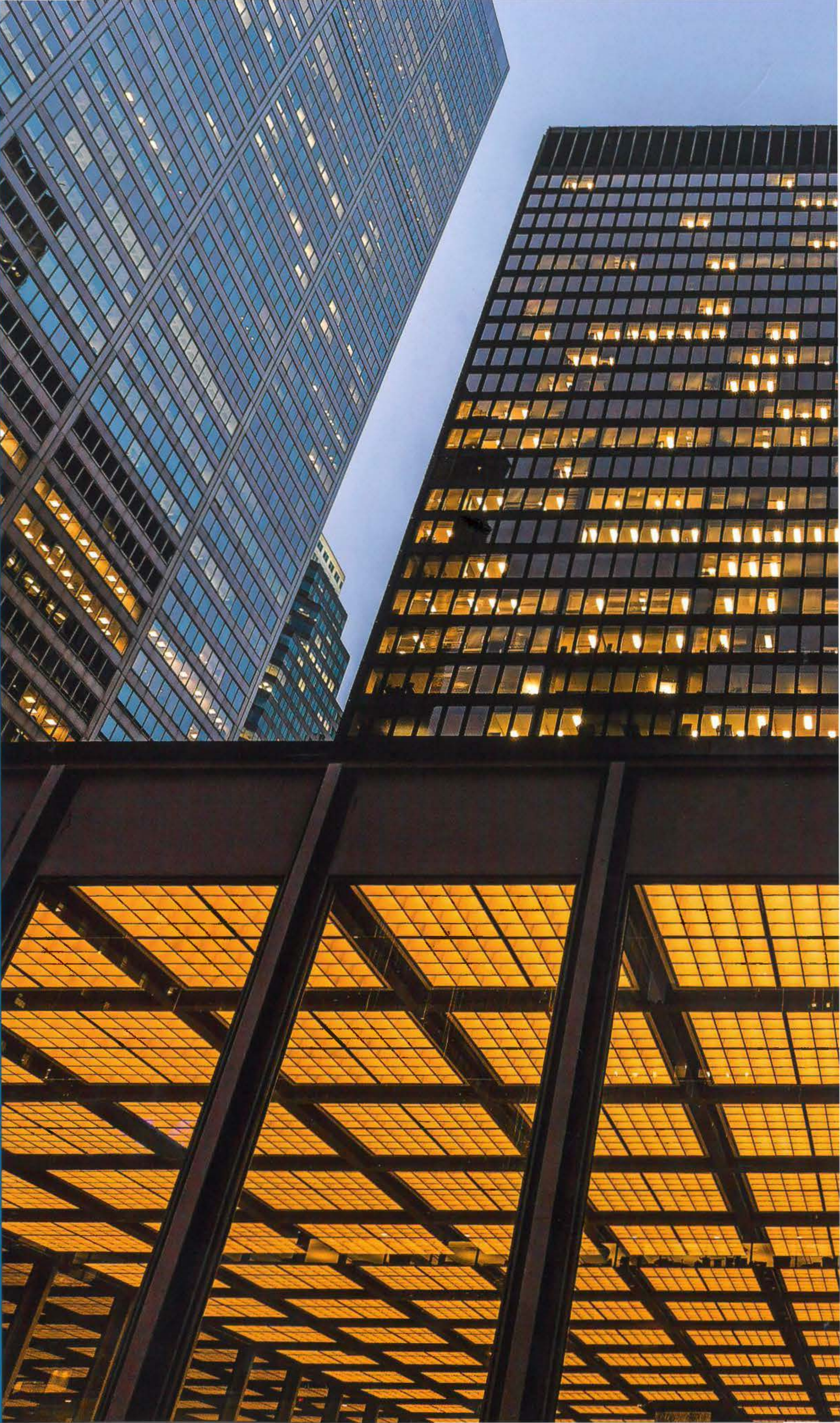
CONSERVING
MODERN
HERITAGE

Managing Energy Use in Modern Buildings

Case Studies in Conservation Practice

Edited by
Bernard Flaman and
Chandler McCoy



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Edited by Bernard Flaman and Chandler McCoy
with Gail Ostergren

Getty Conservation Institute, Los Angeles

Conserving Modern Heritage
Series Editors: Susan Macdonald and Chandler McCoy

CONSERVING MODERN ARCHITECTURE

The Conserving Modern Architecture Initiative (CMAI) is a comprehensive, long-term, and international program of the Getty Conservation Institute (GCI). The goal of the CMAI is to advance the practice of conserving twentieth-century heritage, with a focus on modern architecture, through research and investigation, the development of practical conservation solutions, and the creation and distribution of information through training programs and publications. The CMAI works with international and local partners, including professional and organizational networks focused on modern architecture conservation, to expand the existing knowledge base.

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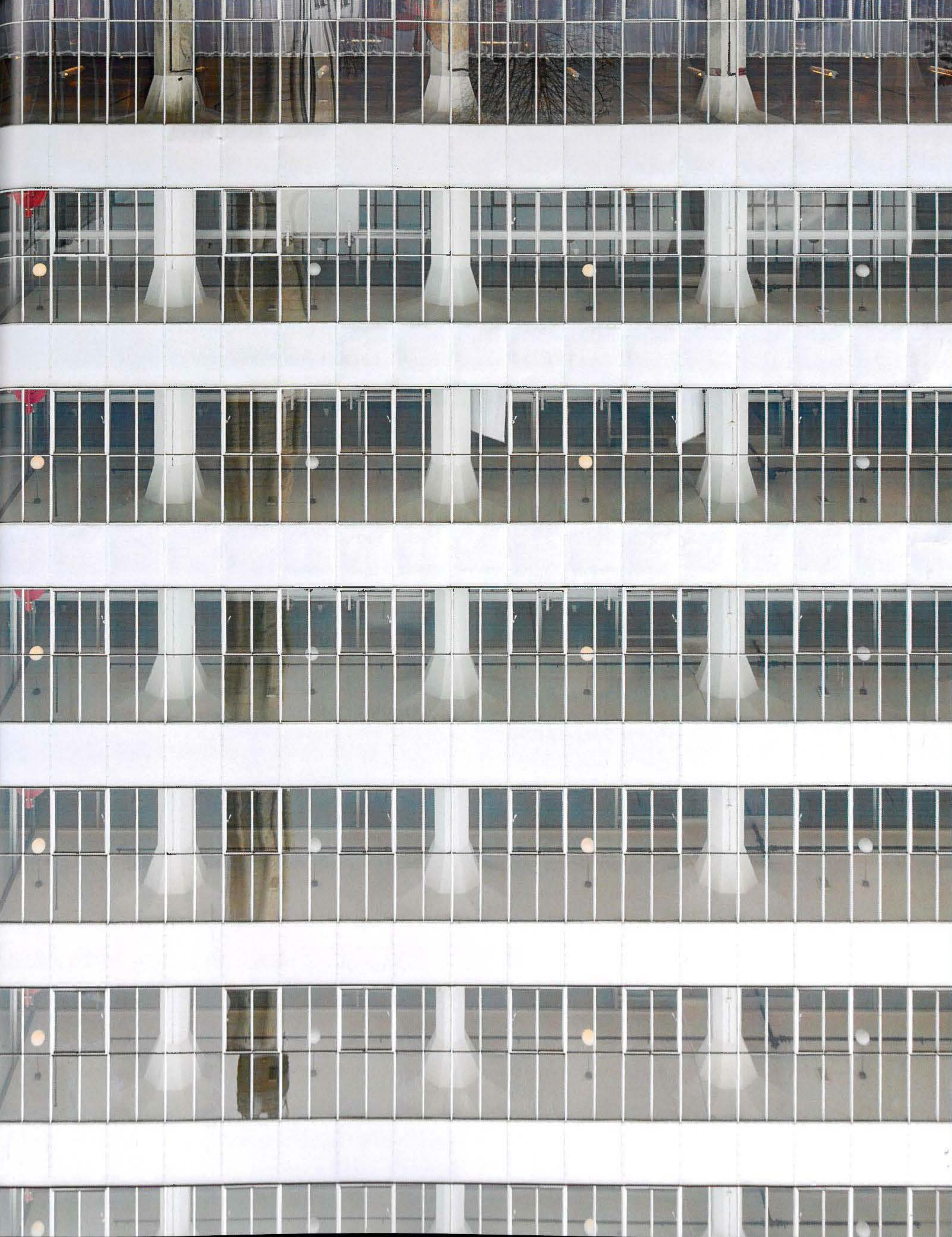


FOREWORD

In 2011, the Getty Conservation Institute launched its Conserving Modern Architecture Initiative as a means of advancing international practice in this emerging area of interest through research and investigation, the development of practical conservation solutions, and the creation and distribution of information through training programs and publications. Early on, the GCI identified the need for good information on appropriate approaches and methods for conserving modern heritage and more technical information on ways to address the material conservation problems typical in modern buildings. In response to this need, the GCI introduced the series Conserving Modern Heritage to bring together case studies that demonstrate suitable approaches and solutions to conservation challenges specific to modern heritage. The first volume in this series, *Concrete: Case Studies in Conservation Practice,* was published in 2018. We are pleased to now present the second volume in this series, *Managing Energy Use in Modern Buildings: Case Studies in Conservation Practice.*

This book addresses how energy use and thermal comfort can be managed in modern buildings, a subject of pressing importance today as architects and policy makers work to identify more sustainable design solutions to combat climate change. Governments and environmentalists are now looking to the design community and building managers to lower the carbon footprint of both new and existing buildings. Simultaneously, a growing awareness of the heritage value of buildings from the twentieth century means that more attention must be paid to their conservation. With its ten case studies, this book provides readers with practical examples of how to balance improvements to a building's energy efficiency with its conservation.

As always, it takes a skilled team to conceptualize and produce a volume such as this. Our thanks to the editors, Bernard Flaman, Conservation Architect, Government of Canada, and Chandler McCoy, Senior Project Specialist, GCI, who assembled these case studies and crafted the book. Gratitude is also due to each of the case study authors and to the GCI staff members who assisted with the editing and production of the publication. We hope this series continues to provide practical and useful information to those involved in the conservation of modern heritage.

Timothy P. Whalen
John E. and Louise Bryson Director, Getty Conservation Institute

Our gratitude goes to all the authors of the case studies that make up this volume for their willingness to share the successes and challenges of their projects. The case studies deal with a variety of building types in different climates and highlight the design significance of buildings from the modernist period. They demonstrate the problems that modern buildings pose, the need to understand a building deeply before solutions are developed, and the process for bringing a successful solution to fruition. Each case study presents a unique set of issues, yet they share a common aim—to conserve the significance of these structures while balancing the need to improve and upgrade their energy performance and thermal comfort.

Thanks also go to two external reviewers for their contributions to the manuscript: Michael C. Henry reviewed each case study and provided thoughtful technical guidance pertaining to descriptions of building envelopes, systems, and energy use. Janet Bridgland reviewed and provided editing assistance with early drafts of the case studies.

The editors would also like to thank series coeditor Susan Macdonald, as well as the GCI's Gail Ostergren, who undertook much of the supporting editing work to bring the book to fruition; César Bargues Ballester, for his tireless management of the book's photos, other images, and permissions; Anna Duer, for her expert assistance with the bibliography; Candace Wai, for providing logistical support; and Cynthia Godlewski, who shepherds the GCI's publications through to completion. At Getty Publications, we thank Rachel Barth, Jeffrey Cohen, Michelle Woo Deemer, Victoria Gallina, and Leslie Rollins for their hard work.

Bernard Flaman and Chandler McCoy

PREFACE AND ACKNOWLEDGMENTS

The Getty Conservation Institute's Conserving Modern Architecture Initiative (CMAI) is motivated by its intention to advance the practice of conserving twentieth-century heritage, and is fulfilling this objective in part by conducting research into material conservation issues and by publishing case studies that illustrate some of the recurring technical and material challenges specific to the conservation of modern heritage. Early on, CMAI identified the management of energy use in modern buildings as a key concern. This issue continues to grow more urgent as increasing awareness of climate change creates pressure to make buildings as energy efficient as possible.

Managing Energy Use in Modern Buildings, the second volume in the Getty Conservation Institute's Conserving Modern Heritage series, addresses the unique challenges surrounding the improvement of energy consumption and thermal comfort in modern buildings. The first volume, *Concrete: Case Studies in Conservation Practice*, was published in 2018 and tackled the question of conserving a widely used material in modern buildings. The third volume, *Conservation Planning*, is already in preparation. Future volumes in this series will address broad subjects such as urban conservation and integrated art as well as the technical challenges related to conservation of specific materials.

This collection of ten case studies describes projects undertaken on works of architecture built between 1931 and 1969 that are international in scope and diverse in their types, styles, and sizes. Showing ingenuity and sensitivity, these projects offer valuable lessons to others undertaking energy upgrades to modern buildings. They consider improvements to such systems as heating, cooling, lighting, ventilation, and controls, while providing examples that demonstrate best practices in conservation. They also exemplify ways to reduce a building's carbon footprint, minimize impacts to historic materials and features, introduce renewable energy sources, and comply with energy codes and green-building rating systems. There is no single, easy answer to the question of how to manage and improve energy use in modern buildings, but there is a reliable conservation methodology that can be applied, and there are many good examples of what has been done by those willing to investigate the matter with an open mind. *Managing Energy Use in Modern Buildings: Case Studies in Conservation Practice* tries to tackle the very important issue of making buildings more efficient and more comfortable, while at the same time practicing good conservation approaches.

A Note on Measurements

Metric measurements are provided throughout the case studies in this volume. In instances where authors supplied measurements in imperial or United States customary units and those measurements reflect the system in which the building or project was originally conceived and constructed, they have been retained and metric conversions added in parentheses.

INTRODUCTION

Managing Energy Use in Modern Buildings: Striking a Careful Balance

Bernard Flaman and Chandler McCoy

Modern buildings face unique challenges when it comes to managing their energy use and establishing interior comfort for occupants. Initial impressions and prevailing opinions often suggest it is almost impossible to improve energy performance and thermal comfort in modern buildings without widespread replacement of original materials. From this perspective, meeting energy-use regulations is at odds with accepted conservation practices that promote the retention of original materials, form, and appearance. Many of the very features and attributes that define buildings as modern—large amounts of single glazing, access to the outdoors, thin exterior wall and roof profiles, expressive masses of exposed concrete—provide little thermal resistance and make them inherently difficult to retrofit.

When making improvements, owners of modern buildings and the architects and engineers working with them are sometimes expected to bring them into compliance with current building codes and energy use regulations, usually developed for new construction. These regulations are becoming increasingly strict as urgency grows for buildings to reduce their greenhouse gas emissions and become carbon neutral. At the same time, expectations for what constitutes a comfortable interior environment have changed significantly since these buildings were originally designed in the early or mid-twentieth century.

The purpose of this book is to demonstrate, through successful case studies, how modern buildings can meet the challenge of managing energy use and improving thermal comfort *while also* following sound conservation practices to preserve their modern architectural significance. All of the case studies are twentieth-century buildings, modern in design, constructed between 1928 and 1969. They represent insulating a building's wall, floor, and roof cavities was rudimentary at best, and in many cases nonexistent (Dahl and Wedebrunn 2006, 69). For example, the 1927–28 *Sweet's Architectural Catalog*, a popular product resource for architects in North America, included only the most basic insulating materials such as cork, felt, hair, paper, mineral wool, cellular gypsum, and wallboard (often wood-fiber based). Indeed, one of the case studies here notes the utilization of impregnated peat as an insulation material. Fiberglass insulation was finally patented by Owens Corning in 1936, and the insulated glass unit (IGU) branded as Thermopane was first created and manufactured by Libbey-Owens-Ford in 1946 (Thomas 2015, 5). And it was not until the energy crisis of the 1970s that standards were set for insulation, such as U-values and R-values. Many modern buildings constructed prior to the 1970s are minimally insulated or uninsulated, notably those using exposed concrete. As mentioned above, many Brutalist buildings used a single wall of concrete to form both the interior and the exterior building enclosure, with no added interior or exterior finish, resulting in high levels of thermal conductivity. They rely on heating and cooling systems to compensate for uncomfortable interior environmental conditions. At the time of their construction, their energy consumption may not have caused concern because the cost of fossil fuel was low and supply was plentiful. Today, energy is expensive and its use is monitored. There is also an acute awareness of how fossil fuel use contributes to global greenhouse gas emissions.

In addition to limited means of insulating a building and inattention to providing it, modern-era designers and their clients had different expectations regarding what constitutes a comfortable and healthy interior environment than we have today. Expectations have changed dramatically since the early to mid-twentieth century, and these may drive the need to add additional equipment to supply heating, cooling, fresh air, and better light levels. This in turn increases the building's energy consumption. Fortunately, the mechanical equipment now available is superior in efficiency to its mid-twentieth-century predecessors. Designed to maximize operational performance through the use of computerized controls, sensors, and monitors, current equipment allows for separate zoning and regulation of discrete parts of a building based on use, solar exposure, and/or individual room temperatures. This gives building managers an understanding of where and how much energy is used throughout the day, and allows for real-time adjustments.

Furthermore, energy standards continue to evolve, such that even modern buildings from the 1970s that do have insulation do not meet current codes and expectations for thermal resistance. Adding new insulation or improving what is already there can be problematic for heritage buildings, regardless of whether they are from the modern era or are much older. Installing new or replacing existing insulation can be both physically and visually intrusive, requiring the removal or covering of existing finishes. It can also have unintended consequences; for instance, changing the temperature of the exterior walls can lead to condensation forming within exterior wall assemblies.

Lessons from the Case Studies

The principle of minimal intervention guides the practice of architectural conservation. The approach is based on doing as little as possible and only whatever is needed to solve the problem. When architectural conservation is not a factor in an energy upgrade project, the first step toward reducing the building's energy load is simply to upgrade its exterior envelope by removing conductive materials, improving insulation, eliminating thermal bridges, controlling solar gain, and making other changes that reduce demand on the building's heating and cooling systems. In such a scenario, one would remove the existing building's exterior envelope and replace it with a super-insulated one that controls seasonal solar gain. However, the ten cases presented here were designed with great concern for architectural conservation and therefore follow the principle of minimal intervention. They follow a design process that balances multiple concerns and criteria to achieve both energy improvement and conservation of heritage value.

The case studies demonstrate four main strategies for effectively managing energy use and thermal comfort in modern buildings. The four strategies are listed below, arranged from a conservation perspective in ascending levels of intervention, beginning with minimal intervention. The last two strategies, glazing and insulation, focus on the building's envelope and therefore involve higher levels of intervention.

Enhancing original features: Understanding how the building was originally designed to perform, and, through analysis and investigation, reinstating and operating its existing features.

Systems: Upgrading or replacing mechanical systems, including outfitting original equipment with new controls, sensors, and energy-efficient features to give new life to outdated systems. Major revisions to systems afford the opportunity to introduce renewable energy.

Glazing: Improving performance of glazing, either by replacing single glazing with insulated glass or by adding new layers of glazing to the single glass to enhance the performance of the building envelope.

Insulation and air barrier: Adding or improving insulation, at either the exterior or interior walls, to add thermal resistance and limit the conduction of heat and cold, and adding or enhancing air barriers to prevent drafts and limit convection, thereby improving thermal performance of the building's solid wall and roof structures.

Each of the case studies in this volume focuses primarily on one of these four strategies, but all employ additional strategies, as illustrated in table 1. In fact, the primary lesson drawn from the case studies is that efficiency is achieved through a skillful combination of strategies—realizing improvements by developing options, then testing those options to discover the right balance that improves energy efficiency and thermal comfort and also maintains the building's historic character and attributes.

The case studies are organized according to these four broad categories and represent a range of building typologies, building uses, and project sizes, as well as

		Geschwister-Scholl Grammar School	Shulman House and Studio	Calouste Gulbenkian Foundation Complex	Toronto-Dominion Centre	Hayward Gallery, Purcell Room, and Queen Elizabeth Hall at Southbank Centre	Richards Medical Research Laboratories	Catalina American Baptist Church	Van Nelle Factory	Boston University School of Law	Workers Compensation Board of Manitoba
	Climate Zone (as defined by ASHRAE)	5A (Cool-Humid)	3B (Warm-Dry)	3A (Warm-Humid)	5A (Cool-Humid)	4A (Mixed-Humid)	4A (Mixed-Humid)	2B (Hot-Dry)	5A (Cool-Humid)	5A (Cool-Humid)	7 (Very Cold)
Enhancing Original Features	Added to or improved original shading devices		■	■					■		
	Retained or reinstated original features or functions	●		●					■		■
	Enhanced existing passive features	■	●						■	■	
Systems	Focused on new or improved air conditioning		■	■	■	●		■		■	
	Replaced existing ducted AC with chilled beams or active chilled beams						■			■	
	Heat recovery	■		■					■		
	Used renewable energy from a provider or on-site photovoltaics	■		■	●						
	Added energy-efficient lighting, improved/increased natural daylighting				■	■					
	Implemented interior zoning to manage different environmental or comfort needs	■	■	■					■	■	
	Used energy-efficient equipment and controls	■	■	■	■	■	■	■	■	■	
Glazing	Retained original single-glazed windows	■	■	■		■			●		
	Replaced original (or previously replaced) glazing with improved-performance glazing			■	■	■	●	●		■	■
Insulation and Air Barrier	Insulated uninsulated walls, improved existing insulation, and/or established a continuous air/vapor barrier									●	●

Table 1. Comparison of case studies by topic. ● principal topic. ■ secondary topic.

several climate zones. All follow a standard organizational template that mirrors an ideal conservation methodology, starting with discussions of investigations, research, and diagnosis, followed by testing and modeling, and finally a description of the project's implementation. The climate zones referred to in this volume are based on *ANSI/ASHRAE Standard 169-2013, Climatic Data for Building Design Standards* (ASHRAE 2013, 5–6), a comprehensive source for worldwide climate data for designing, planning, and sizing building energy systems and equipment. This standard provides a system for classifying climates based on heating and cooling loads and precipitation. The classification consists of two components: the thermal zone (0 through 8) and the moisture zone (humid, dry, or marine).

The primary focus of the Geschwister-Scholl Grammar School, the Shulman House and Studio, and the Calouste Gulbenkian Foundation complex case studies is the *enhancement of original features* (interpreting and enhancing original climate-responsive features). These three are very different buildings in terms of size, use, and construction type, but all have original features—designed to be responsive to the climate or to provide interior thermal comfort—that continue to be relevant. In the case of Geschwister-Scholl, an ingenious forced-air heating system designed by the architect, Hans Scharoun, was abandoned after about twenty years of use, forgotten, then successfully reinstated once it was determined it was the best way to heat the building while providing fresh air. The fact that it was combined with contemporary heat recovery and a connection to renewable biomass electricity generation illustrates the potential of this strategy.

The Shulman House and Studio was designed to be shaded by trees and plantings, with broad, overhanging roofs and floor-to-ceiling curtains to protect from excessive summer heat gain, and operable windows and sliding doors for natural cooling. It included three screened porches, allowing the owners to easily enjoy the outdoors. When the house underwent a renovation, the porch screen material and curtains were replaced with materials that provided better protection from heat and UV light.

Geschwister-Scholl Grammar School
Lünen, Germany | 1962

Shulman House and Studio
Los Angeles | 1950

that involves upgrading to renewable energy sources, as demonstrated by the Toronto-Dominion Centre. This project removed all of the original cooling equipment, including massive cooling towers, and now uses cold water drawn from the depths of nearby Lake Ontario, supplied through a district system, to meet its cooling needs.

At Hayward Gallery, Purcell Room, and Queen Elizabeth Hall, building services, housed in large duct banks and plant rooms, were clearly and intentionally expressed as they wrapped the buildings' exteriors; since they were cast in concrete, they could not be easily moved. For the designers of this project, the challenge was to change and update the systems while using the original service paths, duct chases, and plant rooms. In the case of Queen Elizabeth Hall, they reversed the original flow of supply and return air to the auditorium while maintaining the original cast-aluminum supply registers, which are one of the room's most significant architectural features.

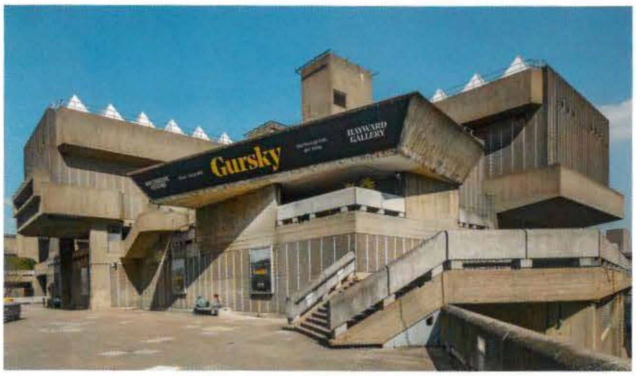
The issue of replacement *glazing* is a universal challenge for heritage buildings, whether they are traditional double-hung windows or modern plate glass supported in metal frames. Some of the case studies here preserved original glazing, while others replaced earlier replacement glazing. While there is a visual impact, replacing single glazing with insulated glass units (IGUs) undoubtedly improves the performance of the exterior wall assembly and resists condensation, and also improves thermal comfort for occupants who may be sitting near the windows. Glazing is the principal topic of three of the case studies in this volume: Richards Medical Research Laboratories, Catalina American Baptist Church, and the Van Nelle Factory.

The design team and building owner for Richards Medical Research Laboratories determined that the large corner windows in the four lab towers were a major architectural element, the appearance of which had to be retained. They carefully studied several options for glass replacement and decided on laminated glass, which improves thermal properties and blocks UV light, but is also thin enough to fit into the original (non-thermally broken) steel window frames. They offset what might be considered the window's lower energy performance by developing a highly efficient heating and

Richards Medical Research Laboratories
Philadelphia | 1961

Calouste Gulbenkian Foundation Complex
Lisbon | 1969

Toronto-Dominion Centre
Toronto | 1967–69

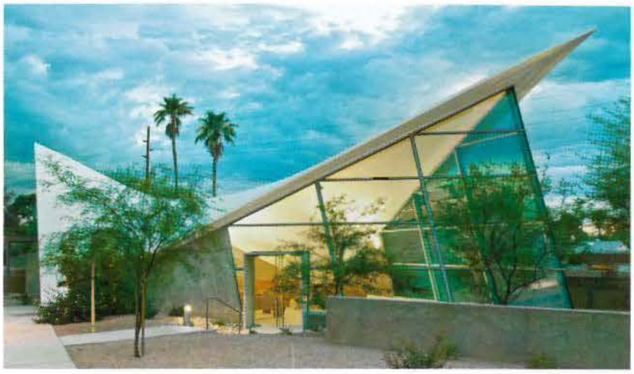


Hayward Gallery, Purcell Room, and Queen Elizabeth Hall at Southbank Centre
London | 1967 and 1968

The owners decided to add a zoned air conditioning system to address increasingly hot summer weather in Los Angeles, but because the house's passive cooling features work so well, they rarely need to use it.

The Calouste Gulbenkian Foundation complex was designed in the late 1960s with many environmentally friendly features, such as deep overhangs to shade windows, green roofs to reduce heat gain, ample natural daylight entering the buildings through windows, doors, and internal courtyards, and spacious pathways for services and air distribution that made reconfiguring existing heating and cooling systems and installing new components easy. The original features, which are character-defining, were retained and complemented with an upgraded heating and cooling system that enhances the buildings' inherent efficiency and climate responsiveness.

The case studies where the primary focus is *systems* include the Toronto-Dominion Centre and the Hayward Gallery, Purcell Room, and Queen Elizabeth Hall at Southbank Centre, London. That said, all the case studies in this volume include improvements and/or replacements to existing systems because this can be one of the best ways to decrease energy use. The ultimate energy-saving systems replacement is one



Catalina American Baptist Church
Tucson, Arizona | 1961

Van Nelle Factory
Rotterdam | 1931

cooling system that also fit with the building's exposed concrete truss structure, and achieved significant overall reduction in energy use.

The Catalina American Baptist Church's striking hyperbolic paraboloid concrete roof soars dramatically upward but does nothing to shade its large expanses of fixed glass from the unrelenting Arizona desert sun. The original single glazing had previously been replaced with smaller panes and additional mullions, and had been covered with tinted film and metal screens to reduce solar gain and glare, but its air conditioning system still strained to keep churchgoers comfortable. Any consideration of adding insulation was rejected in favor of maintaining the profile of the exposed thin-shell concrete structure that is the building's most significant architectural feature. Instead, the design team chose to maximize the window performance and chose new tinted, insulated glazing that allowed them to reinstate the original glass size and mullion pattern. At the same time, they upgraded the HVAC system and planted trees to help shade the glass.

In the case of the Van Nelle Factory, its original transparency—one of its principal character-defining elements—was retained by keeping the single glazing and non-thermally broken window sash, but compartmentalizing the building and accepting differing levels of comfort depending on the occupants' level of activity. The designers essentially created double glazing by adding new secondary interior glazing inside the building, parallel to the original window walls but without touching them. One of these interior glazing partitions defines the circulation corridor along the north facade, which is only briefly occupied, allowing it to have a more varied temperature range than the office areas where people sit and work during the day.

Insulation and air barrier strategies usually involve a high level of intervention that can significantly alter or effectively destroy the heritage value of a building if not implemented carefully. The two case studies where the primary topic is insulation are Boston University School of Law and the Workers Compensation Board of Manitoba. The tower at Boston University School of Law is a prominent campus landmark. Its exposed concrete exterior was carefully articulated with colorful metal vent panels that opened to allow fresh air into the faculty offices in the summer. Both interior and

Boston University School of Law
Boston | 1964

Workers Compensation Board of Manitoba
Winnipeg, Canada | 1961

exterior faces of the concrete walls were uninsulated. From the beginning this building was uncomfortable and ill-suited to Boston's cold winters and hot, humid summers. To improve its poor energy performance and provide year-round comfort to its occupants, insulation was added to the inside faces of the concrete walls, maintaining the original exposed concrete expression on the facade. The vent panels were fixed shut and insulation was added to their interior sides. Its exterior appearance remains basically the same, but now the building provides a comfortable interior environment year-round.

The Workers Compensation Board of Manitoba undertook conservation of the failing original stone cladding in combination with improvements to its existing insulation and provision of a continuous air and vapor barrier to meet contemporary standards. In this case, the stone cladding was removed, the building was wrapped in a new layer of insulation, and the original stone cladding was reattached. This strategy incrementally increased the overall width of the building due to the new insulation layer, but this had only a minimal impact on its sleek modern form. This case study also includes a thorough discussion of a possible unintended consequence of adding insulation; namely, it can lead to condensation on the walls' surfaces or interior, which was determined through computer analysis.

Developing a single metric for measuring the success of these case studies has proven difficult. Ideally, the building's EUI (energy use intensity) would be calculated before and after the project to quantify how it changed. EUI is a way of expressing the building's annual energy use or calculated use per unit of gross floor area. It is expressed in MBtu/ft^2·yr or watts-hours/m^2·yr. In practice, only three case studies—Richards Medical Research Laboratories, Boston University School of Law, and the Calouste Gulbenkian Foundation Complex—model the building's EUI resulting from the project. Many of the case studies calculated changes to electrical consumption related to reduction in summer cooling or winter heating needs, but many of them did not have sufficient information about past energy use to calculate "before and after" savings comparisons. In some cases the information about energy savings was not specified at all. In any case, while a consistent metric is desirable, it would be of limited value for the purposes of this publication because the case studies are so diverse in use, type, and climate zone that their energy use cannot be meaningfully compared.

Finally, all of the case studies demonstrate the importance of thoroughly understanding the building before deciding on appropriate actions. Many of the case studies include computer modeling, which allows different options or a combination of options to be tested during the design phase of the improvement project. Many benefited from building physical mock-ups of their proposed solutions in situ, allowing for adjustments and changes before they were installed in the full building. If building owners can be convinced of their value, preliminary historic and archival research, testing multiple options through computer modeling, and trials and mock-ups can strengthen and improve the design and implementation of energy efficiency and thermal comfort measures.

WORKS CITED

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 2013. "Climatic Data for Building Design Standards Section A3." In *ANSI/ASHRAE Standard 169-2013, Climatic Data for Building Design Standards.* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 2017. "Chapter 4: Heat Transfer." In *2017 ASHRAE Handbook: Fundamentals*, 4:1–36. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Dahl, Torben, and Ola Wedebrunn. 2006. "Thermal Strategies: Towards a Modern Insulation." In *Climate and Building Physics in the Modern Movement*, edited by Jos Tomlow and Ola Wedebrunn, 69–76. Docomomo Preservation Technology Dossier 9. Paris: Docomomo International.

Fernandez, Vanessa, and Emmanuelle Gallo. 2014. "The Glass Facade and the Heating System of the Salvation Army 'City of Refuge': From Conception to Restoration." In *Perceived Technologies in the Modern Movement 1918–1975*, edited by Jos Tomlow, Alex Dill, and Uta Pottgiesser, 45–55. Docomomo Preservation Technology Dossier 13. Lisbon: Docomomo International.

Thomas, Kisora, ed. 2015. "Finding Aid: Libbey-Owens-Ford Glass Company Records, 1851–1991." Toledo, OH: University of Toledo, Ward M. Canaday Center for Special Collections. https://www.utoledo.edu/library/canaday/findingaids1/MSS-066.pdf.

US Department of Energy. 2015. "History of Air Conditioning." July 20, 2015. https://www.energy.gov/articles/history-air-conditioning.