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RAVI SRINIVASAN  
AND KIEL MOE

THE  
HIERARCHY  
OF ENERGY IN  
ARCHITECTURE  
ENERGY ANALYSIS

ROUTLEDGE



**PocketArchitecture:**  
**Technical Design Series**

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# **The Hierarchy of Energy in Architecture**

**Emergy analysis**

**Ravi Srinivasan and  
Kiel Moe**

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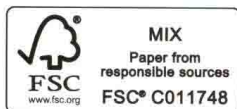
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## **The Hierarchy of Energy in Architecture**

The laws of thermodynamics – and their implications for architecture – have not been fully integrated into architectural design. Architecture and building science too often remain constrained by linear concepts and methodologies regarding energy that occlude significant quantities and qualities of energy.

*The Hierarchy of Energy in Architecture* addresses this situation by providing a clear overview of what energy is and what architects can do with it. Building on the emergy method pioneered by systems ecologist Howard T. Odum, the authors situate the energy practices of architecture within the hierarchies of energy and the thermodynamics of the large, non-equilibrium, non-linear energy systems that drive buildings, cities, the planet, and the universe.

Part of the *PocketArchitecture* series, the book is divided into a fundamentals section, which introduces key topics and the emergy methodology, and an applications section, which features case studies applying emergy to various architectural systems. The book provides a concise but rigorous exposure to the system boundaries of the energy systems related to buildings and thus will appeal to professional architects and architecture students.

**Ravi Srinivasan** is Assistant Professor of Low / Net Zero Energy Buildings at the College of Design, Construction and Planning at the University of Florida, USA. He develops and teaches new courses related to low and net zero energy buildings in both the undergraduate and graduate programs, enhancing the School's internationally recognized sustainable construction management program, researching and establishing net zero and low energy building frameworks, and organizing student competitions. He has more than 50 technical publications in peer-reviewed journals, refereed conference papers, and research reports.

**Kiel Moe** is Associate Professor of Architecture and Energy at the Graduate School of Design at Harvard University, USA, where he is Co-Director of the MDes program, Co-Coordinator of the Energy & Environments MDes concentration, and Co-Director of the Energy, Environments, and Design Research Unit. He is author of *Insulating Modernism: Isolated and non-isolated thermodynamics in architecture* (2014), *Convergence: An architectural agenda for energy* (2013), *Thermally Active Surfaces in Architecture* (2010), and *Integrated Design in Contemporary Architecture* (2008). He was co-editor, with Ryan Smith, of *Building Systems: Design technology & society* (2012).

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**The Hierarchy of Energy in Architecture**

*Ravi Srinivasan and Kiel Moe*



“The full transition to a renewable economy will only become possible when architects understand the different qualities of the materials, power sources, and settlement patterns with which they work. In *The Hierarchy of Energy*, Srinivasan and Moe explain the concepts and tools needed for environmental building design, and situate architecture within the self-organization of human and natural ecosystems.”

– Dr. William W. Braham, FAIA, Director,  
Master of Environmental Building Design,  
University of Pennsylvania, USA

## Series editor's preface

Although architects and building professionals come into contact with, specify, design, and build technical practices every day, they actually know relatively little about them. They are “abstract systems” construed and constructed upon industry norms passed through generations of professionals. Most of them are correct, but many, when disassociated from their cultural underpinnings of building vernacular and, more importantly, their scientific basis and practice contexts, present challenges that cause buildings not to perform as intended or, worse, lead to physical, economic, or social catastrophe.

*PocketArchitecture: Technical Design Series* fills this void. The series comprises succinct, easy-to-use, topic-based volumes that collate in one place unbiased, need-to-know technical information about specific subject areas by expert authors. This series demystifies technical design criteria and solutions. It presents information without overlaid theory or anecdotal information. *PocketArchitecture* is on point.

As the name would suggest, the volumes in this series are pocket sized and collectively serve as a knowledge base on technical subjects in architecture, creating a value-added information base for building novices and masters alike. In addition to architects, engineers, and contractors who deliver building projects, the series is appropriate for students and academics interested in accessible technical information as it relates to building design and construction.

Despite their size, the series volumes are highly illustrated. Furthermore, the volumes use easily accessible language to succinctly explain the fundamental concepts and then apply these basic ideas to cases of common issues encountered in the built environment. *PocketArchitecture* is essential, accessible, and authoritative. This makes it important reading for architectural technologists, architects, building surveyors, building commissioners, building engineers, other construction professionals, and even owners and clients.

This volume, *The Hierarchy of Energy in Architecture: Emergy analysis*, is concerned with holistic energy considerations in the built environment. As opposed to linear and reductivist thinking concerning energy, this volume, building on the work of ecologist Howard T. Odum on emergy, presents a systems-based approach to energy in architecture. It is a non-linear, complex, and more inclusive perspective on energy hierarchies in buildings. However, it is accessible, practical, and applied. As part of the *PocketArchitecture Series* the book includes both fundamentals and advanced topics. It is appropriate for the novice and expert practitioner as its content is fresh and well considered in the field of texts on energy architecture.

## Preface

The energy systems related to human life, buildings, cities, and civilization are not adequately incorporated into architecture. In the prevailing forms of analysis in architecture, such as energy analysis or life cycle assessment, important forms of energy and essential energetic processes are methodologically externalized. As a result, architecture and engineering routinely construe curious system boundaries for the energy systems associated with buildings and often focus on the wrong magnitudes of energy. They routinely treat buildings as small scale, steady-state, isolated thermodynamic systems when in fact buildings are large scale, transient, and open thermodynamic systems. Buildings are lodged in a nested hierarchy of energy exchange, and, without understanding a building's dynamic in these hierarchies, we will not ever devise ways for buildings to maximize their impact on the environment and develop the maximum power systems that drive all forms of life and all processes on this planet. Currently designers operate without understanding the hierarchy of energy in buildings and the relative order of magnitudes associated with these hierarchies. Understanding the relative power of these magnitudes of energy is essential for design in the twenty-first century.

In short, designers need to ask critical questions about the system boundaries of every project in order to identify the maximal intake, transformation, use, storage, and feedback of the energy required of buildings. What is, what should be, the system boundary of a particular building project? These most basic thermodynamic questions about system boundaries must address the full spatial and temporal flux of energy that presupposes a building. The most rigorous and totalizing forms of energy accounting originated in ecological systems analysis: The thermodynamic analysis of large scale systems. Buildings and cities are large scale energy systems and so these ecosystem analysis methodologies offer great insight regarding the energy systems of buildings. In view of this, in this book we situate building in the context of these comprehensive forms of analysis.

To understand this method, we must present key concepts that help articulate the system boundaries of a building and, in doing so, articulate how this methodology differs in scope from other, more familiar forms of analysis. We then present a couple of examples of thorough energy analysis. The first is a simplified system – a mobile information kiosk. This simplified system will allow the reader to grasp the method. The second example focuses on a large institutional building and thus provides insight on the relative magnitudes of energy involved in buildings and their hierarchies of energy. We then also provide key citations and resources on this important emerging aspect of building science and design.

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*All images by the authors, except where noted.*

## Part 1

# Fundamentals

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