Thermally Active Surface in Architecture

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Abstract

This body of research focuses on the new role of thermally active surfaces in architecture in the discipline's work towards low-to-no energy consumption buildings. In this transformation of energy and building practices, the thermal conditioning of a building is decoupled from the ventilation system by using the mass of the building itself as the thermal system rather than air. This method of heat transfer is physiologically and thermodynamically optimal. It also reinvests the fabric of the building itself with a more a poignant role: the structure is also the primary mechanical system. As an energy and construction strategy, it yields a cascading set of advantages for the building design and construction industry: radically lower energy consumption, more durable buildings, more healthy buildings, and more integrated building systems and design teams. As such, thermally active surfaces are central to multiple aspects of sustainability.

The Upjohn grant has significantly accelerated the production of the first book manuscript, *Thermally Active Surfaces in Architecture* (Princeton Architectural Press), that combines parallel strains of research related to thermally active surfaces: the historical and social construction of the technological momentum of air-conditioning and thermally active surfaces, the documentation and illustration of the physiological and thermodynamic basis of thermally active surfaces, the elucidation of changes and amendments to professional practice and the building industry implied with this technique, ten case studies that focus on the illustration/documentation on the systems, performance, and constructability of each project of these case studies. This report summarizes the book and its organization that documents the multi-faceted strains of research on thermally active surfaces completed, in part, through the Upjohn Research grant.

Keywords: thermally active surfaces, the history of air- conditioning, radiant transfer, de-fragmenting buildings, sustainability

1. Introduction

"In a world more humanely disposed, and more conscious of where the prime human responsibilities of architects lie, the chapters that follow would need no apology, and probably would never need to be written. It would have been apparent long ago that the art of and business of creating buildings is not divisible into two intellectually separate parts—*structures*, on the one hand, and on the other *mechanical services*. Even if industrial habit and contract law appear to impose such a division, it remains false."[1]

Given the resonance in practice today of Reyner Banham's above "Unwarranted Apology" to his volume on the conditioning of buildings written forty years ago, *The Architecture of the Well-Tempered Environment,* it is apparent that there has been little significant change in our approach to buildings and their conditioning in the last forty years. The Upjohn research developed her focused thermally active surfaces, a technique that aims to finally dissolve the fallacy of fragmented architectural design, building science, and pedagogies. Thermally active surfaces provide the integration of building systems, energy strategies, and a cascading set of effects for design practice. In what follows, this report will summarize the structure of a book published by Princeton Architectural Press that was developed in part through the Upjohn Research program.

From the first sentence of the first chapter in Vitruvius's *Ten Books on Architecture,* architecture's disciplinary expertise has been the integration of multiple, necessary bodies of knowledge. Yet, in the current context of building production and education, approaches to the topics of energy, material, sustainability, construction, history, and formalism, while intimately connected in actuality, are too often disparate realms of theory, practice, and pedagogy. Routinely they are theorized, taught, and practiced by separate entities and disciplines that in many cases operate in exclusive domains: a division of knowledge that is administratively convenient perhaps for the academy and practice but one that undermines our integrating capacity and disciplinary expertise. This approach to architectural knowledge results in buildings that are driven by autonomous formal ambitions, willful material aspirations and tectonic strategies, *or* by paying attention to the thermodynamic actuality of architecture; but one often at the expense of the other or, all too common, in isolation from each other. These habits of mind, when coupled with increasingly fragmented systems of construction and energy practices, in part lead to the energy consumptive practices of many contemporary buildings as well as the escalating complexity and spiraling cost of contemporary buildings: a fiduciary failure of our integrating capacity and a form of technological acquiescence that is a failure of our disciplinary imagination.

These habits of mind and practice developed during the twentieth-century in a context of seemingly endless material resources and energy resources. Their resultant, reckless energy practices and fragmented construction methods were largely based on an unquestioned assumption: that air is a reasonable medium to heat and cool buildings. These techniques and practices have led us astray and our judgment about buildings and their systems is awry. Air is a poor medium for transferring heat energy and it unnecessarily absorbs a disproportionate amount of a building's budget and energy use. Today, its efficacy is increasingly in doubt. In our current global context of increasing demands of diminishing resources, another approach to energy transfer is necessary based on more sound thermodynamic and physiological assumptions. Our new context demands new habits of mind, new practices, and new more thermodynamic imagination. The higher-performance, yet simple and integrated, approach of thermally active surfaces stands to transform building production and energy practices. Thus, At the core of this research and subsequent book lies the seemingly innocuous question: "Why do we heat and cool buildings with air?"

The structure of the book reflects a multivalent view of integrated systems in architecture. Before elaborating the techniques and technologies, the first chapter argues for a reorientation of our assumptions about technology and architecture. The first chapter of the book discusses the role of technology in architecture. It relies heavily on sources from the history and theory of technology in order to articulate a non-deterministic view of technology in architecture. This is essential to both the technique of thermally active surfaces and larger technical practices in architecture. It is critical to note that all techniques and technologies are social before they are technical. Social needs and desires underwrite technical development. Technologies ultimately offer no answers and make no demands. They determine very little in our technics. The agency of choice remains the primary determinant in our technologically saturated lives. In this respect, we will know very little about the capabilities and culpabilities of a technology if we only study a technology in terms of its technical potential and performance. In a context where economic, social, technical, and performance pressures of architecture are increasingly central to architectural production, a broader view of the techniques and technologies for building in the twenty-first century is necessary. While the book specifically aims to advance the knowledge of a more sound material and energy technique, in a more general sense, the book is demonstrative of a more reflexive view of research and technology relies as much upon social and historical factors as it does performance criteria.

2. Approaches to Technology and Human Comfort

Closely related, the second and third chapters describe the history of two parallel building conditioning techniques: one considering air and one considering water. These chapters identify the technical and social formation of these thermal conditioning techniques and articulate what

Lewis Mumford described as the “cultural preparation” of each technique. As these thermal conditioning techniques developed during the twentieth century, they simultaneously conditioned air, people, design practices, and building practices. Any technique, such as a building system or design practice, is a product of a range of engenderment pressures and drives. Some of these pressures are rational and some are irrational. By looking closely at the histories of air and water-based conditioning systems, certain problems and opportunities emerge for the construction and conditioning of buildings in the current and future contexts of architectural production. As opposed to increasing the efficiency of inherently inefficient systems based on out-moded premises, there is great efficacy in re-evaluating existing technical systems and a few overlooked principles in their historical development. This engenders a more strategic reorientation building systems and building science for low-consumption material and energy systems for buildings.

3. Principles and Practices of Thermally Active Surfaces

The fourth chapter elaborates the physiological and thermodynamic milieu of bodies in buildings, thereby articulating the fitness of thermally active surfaces in this milieu. A few basic physiological and thermodynamic principles form the core of the embodied and operational efficiencies of thermally active surfaces.

For instance, it is essential to begin with the physiology of the human body as the basis for sound energy systems in buildings. To maintain thermal comfort within these modes of heat transfer, the body constantly modifies its internal temperature through its own heat production and by absorbing the temperature of the surrounding milieu. At typical room temperatures, the sedentary body produces roughly 400 btuh per hour from its metabolic processes. The proportions of radiant, convective, and evaporative heat transfer vary with the body’s activity level and milieu. As the surrounding room temperatures increase, the rate of evaporative loss (sweat) increases. In most building occupancy conditions, however, 90 btuh of the basal 400 btuh are used to maintain life functioning. In most situations, the body transfers about 190 btuh through radiant transfer and about 110 btuh by convection. The remainder is transferred via respiration and other physiological processes.

Conduction becomes the primary mode of heat transfer when bodies come into direct contact with an architectural surface. This is the case with a bare foot on a warm or cold floor. While an efficient mode of heat transfer, bodies are rarely in direct contact with thermally active surfaces and objects. Thermally active surface systems, based primarily upon radiant transfer, target the next most significant physiological heat transfer mode and in doing so, modulate human comfort more directly and more efficiently. The body itself is a thermally active, hydronic heating and cooling system that transfers heat energy to and from its core to its skin. This establishes an integrated relationship between thermal comfort and energy efficiency. In this way, the body is neither a metaphor for design nor a source of biomimicry. Rather, the comfort and energy efficiencies inherent in thermally active surfaces arise because bodies and hydronic thermally active surfaces share the same thermo-dynamic system.

The body's largest organ—about 15% of its mass— is its skin. Skin regulates surface and deeper body temperatures through exchanges in the hydronic circulatory and the integumentary systems. The integrated integumentary and circulatory systems hydronically capture and channel heat energy: skin is the heat transfer sink and source for the body. The hypothalamus regulates the flow of blood in the body, based upon sensations of heat flow in the skin. As skin surface conditions change, the flow of blood also changes. The skin is a capillary mat of blood vessels (one square inch of skin contains up to 4.5m of blood vessels). The capillary system in the skin maximizes the heat transfer surface area. If a body is cold, blood flow to the skin surface is reduced. This is known as the vasoconstriction of blood flow. If a body is hot, blood flow from the core to the skin increases through the dilation of blood vessels and increased heat loss. If the body remains hot, water secretes through sweat glands to allow surface evaporative cooling. While the surface temperature of the body varies depending on the density of blood vessels, clothing, and activity, the average surface body temperature is about 79ºF to 84ºF. A building's mass comprises an even greater percentage of its mass; a untapped thermodynamic opportunity.

It is significant to note that the body decouples its thermally conditioning system from its ventilation system. The body evolved this way for a simple reason: water is 832 times denser than air and thus has a higher energy density. Energy density is the amount of energy that can be stored in a unit of mass. Due to the density of water, more energy can be captured and channeled with water than air. It is difficult to imagine how or why the body would use air to move heat energy; the size of the respiratory system, the diameter of veins and arteries, and the caloric intake require to thermal condition would be as absurd as it would be inefficient. It is hard, then, to imagine why we design and condition buildings in this way.

These basic principles build an argument for some equally basic transformations in the material and energy strategies of a building. Since the thermal conditioning of a building is decoupled from the ventilation with thermally active surfaces by using water in the mass of the building itself as the thermal system, rather than air, this method of heat transfer reinvests the fabric of the building with a more poignant role: the structure is the primary mechanical system. The efficiencies of thermally active surfaces emerge by responding more directly to the physiological and thermodynamic behavior of the body as a context for design decisions. These thermodynamic and physiological principles have significant implications for energy consumption, design, construction, and practice. This trajectory leads to the fifth chapter; a step-by-step design guide for thermally active surface systems written by Geoff McDonnell, P.Eng. This chapter elaborates the design process and some of the systems of thermally active surfaces.

The sixth chapter discusses some of the practice implications of thermally active surfaces for design practices. The bulk of this chapter addresses the decreasing efficacy of fragmented layers and systems of construction and their corresponding fragmentation in design profession and building industry that developed in the second half of the twentieth century. Thermally active surfaces amend this situation by merging building systems in fewer, more integrated, and more durable systems (figure 1). While thermally active surfaces are certainly a significant strategy for a low-energy and sustainable building, this chapter also aims to move architecture and the building industry towards less complicated and convoluted design practices. While integrated practice models and building information modeling software help manage the escalating complexity of practice and building production, they do not amend the unwarranted complexity of the buildings and systems themselves. Thermally active surfaces can redirect physical and intellectual capital away from unwarranted complexity and towards more sound and rich buildings.

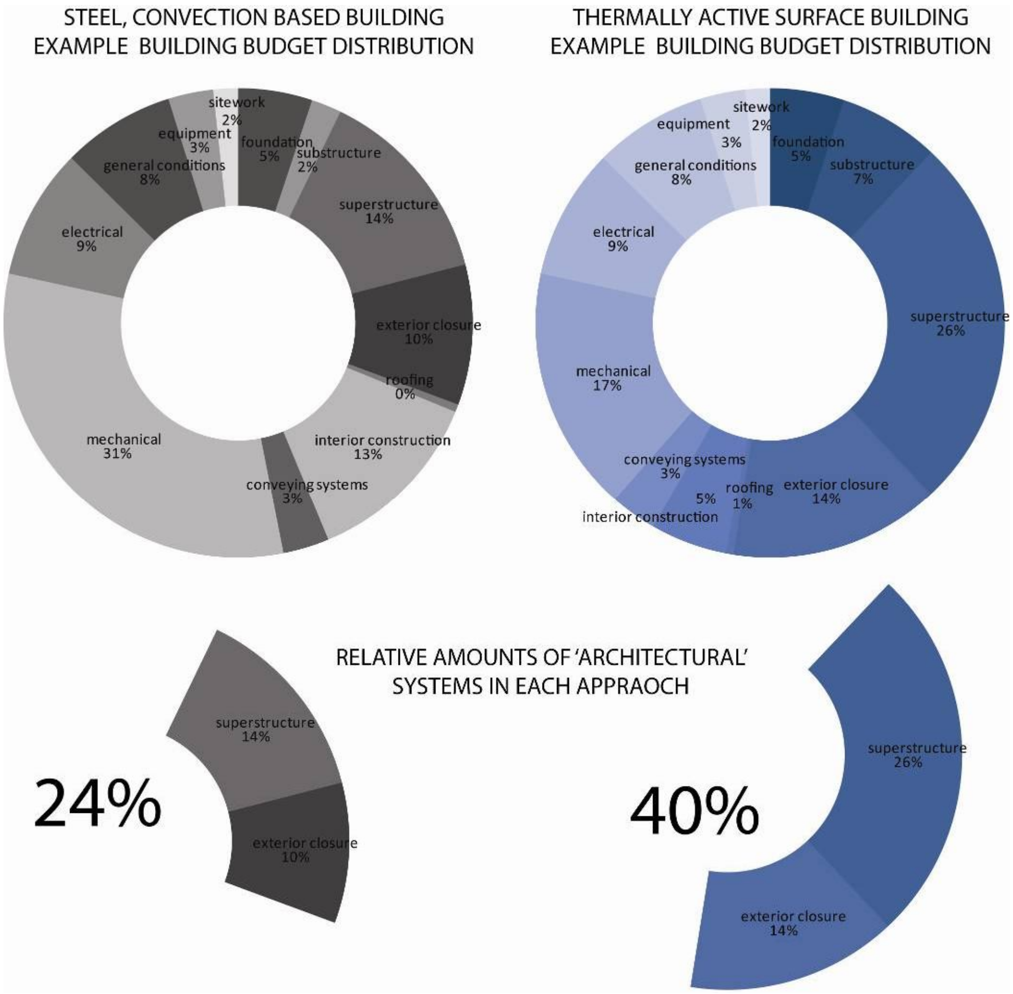

Figure 1: De-fragmented Buildings and Building Budgets

While contemporary heating and cooling systems may absorb a third or even half of a building budget, the active architectural surfaces of a thermally active surfaces system inherently redirects budget, material, labor, design time, coordination, and maintenance away from conventional heating and cooling systems and towards the fabric of the building, imbuing it with a more active role. By obviating the need for drop ceilings and increasingly complex, multi-layered wall assemblies, thermally active surfaces collapse the physical and organizational layers of contemporary construction systems and structure into one robust and integrated layer of architecture. This can catalyze a series of productive transformations in the design of buildings. One outcome is more durable and resilient building stock. Durability remains the most significant barrier to sustainability in America given our current building practices. The end of this chapter presents an analysis of building envelopes during the last century that highlights these principles and transformations in the building industry.

The final text chapter describes how the integration of building systems can engender new formal potential for architecture. Thermally active surfaces create tighter correspondences between bodies, building systems, energy systems, comfort, and sustained use. This chapter discusses compositional sensibilities that configure the tangible aspects of architecture in new ways based on one of its more intangible systems: energy. While related to familiar social, ecological, and economic imperatives, this sensibility yields provocative compositional implications for architecture that advances its enduring preoccupation with form. These new configurations of the immaterial and the material, produce novel *thermodynamic figures* in architecture that are characterized as much by their immaterial performance as by their material presence. More than a technocratic or moral response to our current technics, thermodynamic figures stand to advance formal architectural strategies by placing the increasingly non-trivial material and energy practices of the twenty-first century— along with the underwriting logics of contemporary technics—at the center of architectural formation. In doing so, they create new relationships between design, the material, and the immaterial.

4. Thermally Active Surfaces Case Studies

The final section offer ten case-study examples of contemporary thermally active surface buildings. The examples offer a range of building, climate, and budget types. The projects demonstrate the role thermally active surfaces play in current and future design practices, explains how there are built, and evaluates their performance. The book will include ten case studies that further articulate the chapters:

1. Kunsthaus Bregenz: Peter Zumthor
2. Zollverein School of Management and Design: SANAA
3. Südwestemettal Office Building: Domink Dreiner Architekten
4. Linked Hybrid: Steven Holl Architects
5. Charles Hostler Student Recreation Center, American University, Beirut: VJAA
6. Kripalu Housing Tower: The Rose + Guggenheimer Studio
7. Fred Kaiser Building, University of British Columbia: Omicron/Architects Alliance
8. The Terrence Donnelly Centre for Cellular and Biomolecular Research, University of Toronto: architectsAlliance and Behnisch Architekten
9. Klarchek Information Commons, Loyola University: Solomon Cordwell Buenz
10. The Graham Resource Center, Crown Hall, Illinois Institute of Technology: Tom Brock

4.1 Example Case Study: Fred Kaiser Building, University of British Columbia: Omicron/Architects Alliance

Figure 2: The Fred Kaiser Building

The Fred Kaiser Building at the University of British Columbia is a five story, 94,000 square foot building for the Electrical and Computer Engineering faculty. The program includes classrooms, offices, and laboratories. The new building is on the edge of the campus's Main Mall. It was built over two existing laboratory and machine shop buildings that house the university's civil, electrical, and mechanical engineering programs. This challenging site condition, along with a limited budget and a fast-track schedule, were major constraints for the design of the building. The new construction consists of a concrete structure with thermally active slabs for heating and cooling.

Figure 3: The Fred Kaiser Building

The slabs contain 12.5 miles of hydronic tubing and a 25% high fly ash mix that uses roughly 40% less Portland cement than the typical concrete mix, lowering its embodied energy. A nighttime operated cooling tower generates cold water for the absorption, or cooling, cycle of the slabs. Each room below a slab is zoned separately. An interstitial space, created by the steel truss depth required to span over the existing buildings, is part of a hybrid natural ventilation system; it is essentially an air-to-air exchange plenum where warm exhaust ducts from the labs below warms fresh intake air for the labs above. Fresh air for the interior rooms and laboratories in the new construction is drawn through the interstitial space and up to low-level diffusers for displacement ventilation. The exhaust air is channeled either into an atrium or an adjacent corridor. The building uses a demand-based ventilation system. Each classroom is equipped with a carbon dioxide sensor that actuates exhaust air extract fans. This minimizes ventilation load energy use.

An atrium circulates people, air, and light through the building. The top of the atrium is equipped with building management system-controlled operable vents for exhaust air. In adverse weather conditions, the vents close and roof mounted extract fans vent the atrium. Photovoltaic cells are mounted on the south sloping roofs of the atrium. The atrium also provides indirect daylight into interior loaded seminar rooms and administrative suites. Since the building does not have the typical sheet-metal ducts with their respective plenums, the distribution logic of electrical and other wired services became a primary concern. To resolve this issue, the design team developed a cable tray that runs along the corridor above door height that provides access to a cable tray and to the office and classrooms. This millwork also incorporates the grille for high level exhaust air. The limited number of ducts, piping for waterless urinals, single temperature faucets, and localized on-demand water heating significantly reduces the bulk and cost of services.

Building envelope performance is critical to thermally active slab strategies. The envelope was designed to maximize transparency while controlling solar heat gains and minimizing heat loss. The higher cost of the building envelope was offset by the reduced heating and cooling system, as well as the reuse of exiting chillers and boilers. The floor to ceiling glass envelope has a low-emissivity coated clear glass on the ground floor and a 70% ceramic frit pattern on upper floors that partially shades the interior, while referencing the adjacent oaks that also help shade the building. Each of the perimeter loaded offices has individually controlled operable windows and electrical illumination.

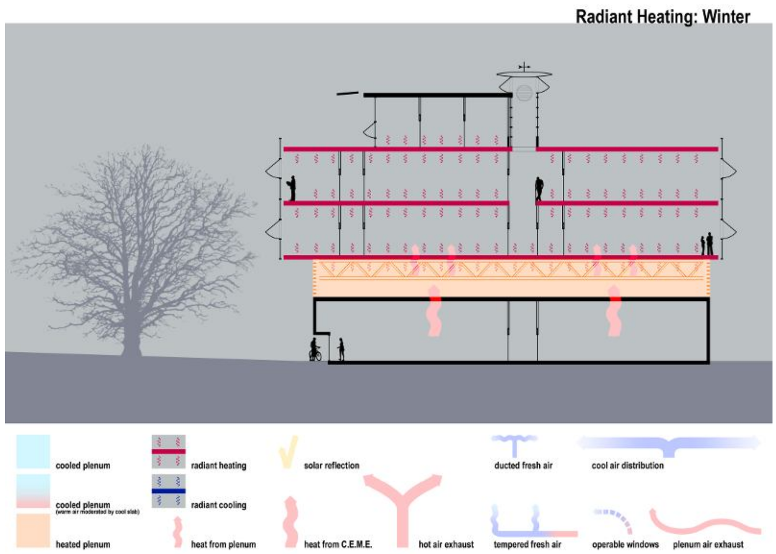

Figure 4: Thermally Active Surface Heating Strategy

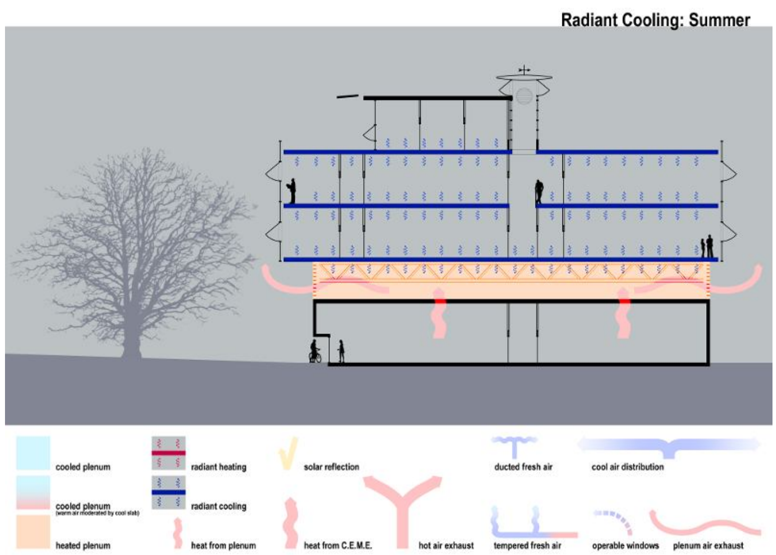

Figure 5: Thermally Active Surface Cooling Strategy

The building performs 31% below the model energy code. The thermally active portions of the building operate at 55% below the model building code for buildings in Canada. To meet performance expectations, the building required both integrated building systems and an integrated design team. Throughout the building, there is an emphasis on durable, low maintenance, and low energy systems; all of this on a tight budget and fast-track schedule. As such, it is a model for integrated building design in the twenty-first century.

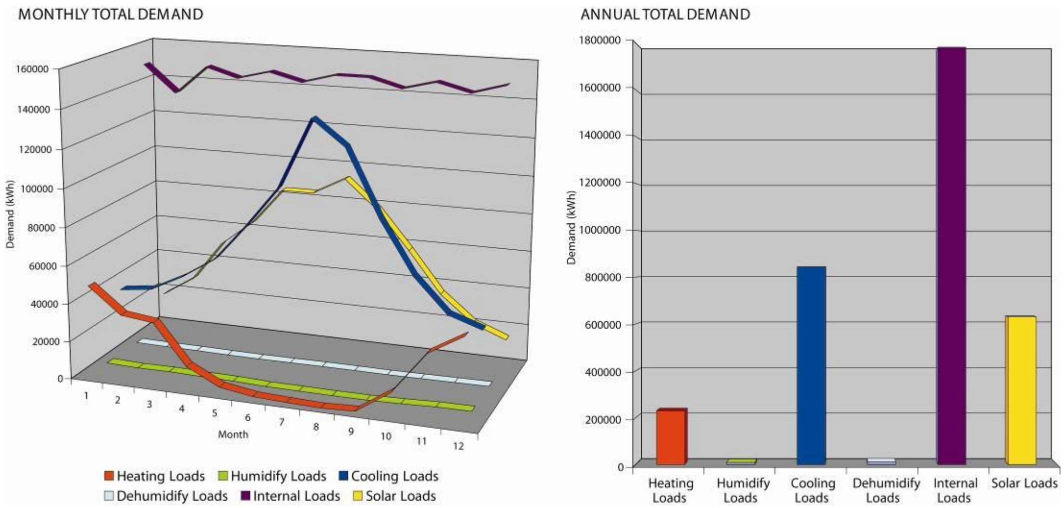

Figure 6: Relative Loads for the Kaiser Building

5. Conclusion

Building design in this century will be increasingly legitimated through an integration of ecological, economic, social, cultural, technical, and formal parameters. In this book, I attempt to integrate these systemic parameters because they are inevitably integrated in the actual performance of a building; perhaps ending the fallacious divisions and dubious efficacy of fragmented technics that Banham attacked forty years ago. The aim of this book is not only to help devise more ecologically, economically, and technically sane building systems for our current context, but in doing so, amend aspects of architectural practice as well, making it more sane. I view this aim as a fundamentally formal proposition and this research remains committed to the achievement of the ecological, economic, social, cultural, technical, and formal performances that can make architecture so rich.

6. Citations

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7. Illustrations

Figure 1: By Author
Figure 2: photo by Terry Guscott

Figure 3: construction photos courtesy Omnicron
Figure 4: drawings courtesy architectsAlliance
Figure 5: drawings courtesy architectsAlliance
Figure 6: drawings courtesy Omnicron

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[1] Banham, Reyner (1969), "An Unwarranted Apology" in *The Architecture of the Well-Tempered Environment*, London: The Architectural Press.