THERMAL BUILDING PERFORMANCE OPTIMIZATION USING SPATIAL ARCHETYPES

by

Eleni Primikiri

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Architecture)
in The University of Michigan
2004

Doctoral Committee:

Professor Panos Papalambros, co-chair
Professor James Turner, co-chair
Assistant Research Scientist Michael Kokkolaras
Professor Leon Pastalan

To Athina and Kostas my mother and father for
their constant encouragement, love and support

CHAPTER 1

INTRODUCTION

1.1. Energy Consumption

Energy conscious building design has always been a goal for consultants, architects and researchers. Due to the increase in energy consumption, optimal building environmental performance has gained a more significant role in the design process. An increasing number of countries in the world are developing or updating their building energy codes to accommodate the emerged need for energy efficient buildings. This dissertation describes a methodology that facilitates thermal building performance optimization and whose successful use will allow more architects to get involved in the process even during the early design stages.

Achieving good building energy performance has been a major challenge in architecture but has intensified over the past twenty years. After the oil embargo of 1973, efforts for energy efficiency became national priorities for the first time. Today, the constant increasing cost of energy and the environmental impact of production and energy use make reduced energy use a significant objective in the design and operation of buildings. In the US, during the year 2000, about 30% more residential energy was consumed than in the year 1970 and 80% more is expected to be consumed by year 2020, see

Figure 1.1 (EIA, 2001). Almost 20% from that energy is consumed in residential buildings. About 50% of the total residential energy consumption is spent for heating and cooling systems, see Figure 1.2.

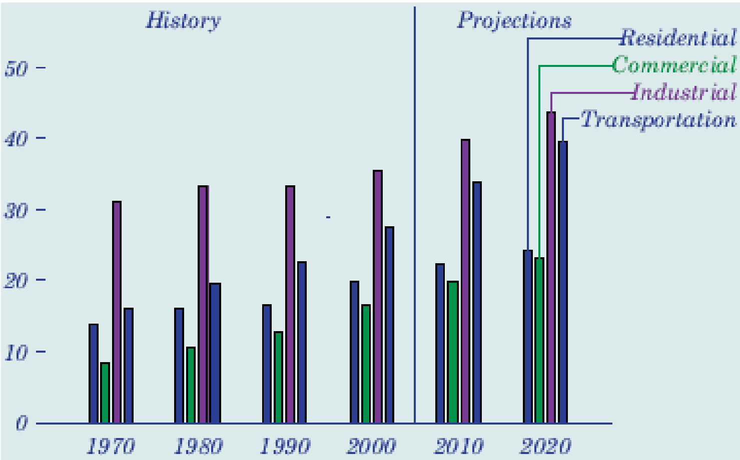

Figure 1.1 Primary energy consumption by sector, 1970-2020 in quadrillion Btu (EIA, 2001)

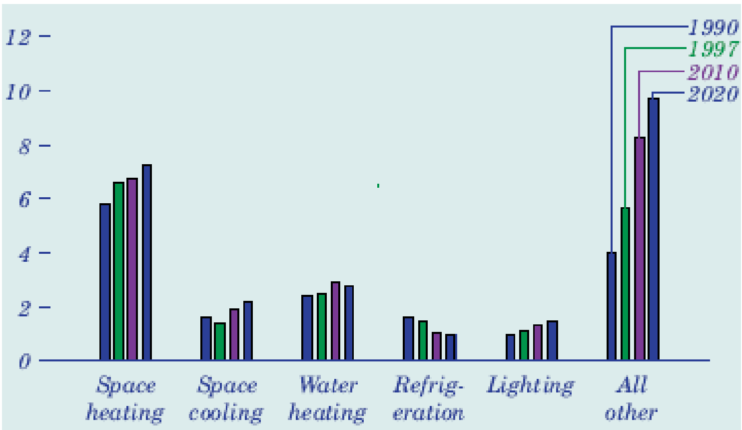

Figure 1.2 Residential Primary Energy Consumption by end use in quadrillion Btu (EIA, 2001)

Improving energy efficiency reduces greenhouse gas (GHG) emissions that contribute to climate change. With the Kyoto protocol and the increasing number of countries committing to United Nations Framework Convention on Climate Change to reduce greenhouse gas emissions on an average of 5%, it is evident that energy-conscious design has to become a necessity, Figure 1.3. A thoughtful design can improve thermal building behavior. It is often the case that such careful design may involve relatively small design changes, which, however, significantly affect overall building energy performance. As Heating, Ventilating, and Air Conditioning (HVAC) systems account for the primary energy use and operational costs in a building's life cycle, it is crucial to comprehend and optimize the performance of these systems so that energy conservation can be achieved.

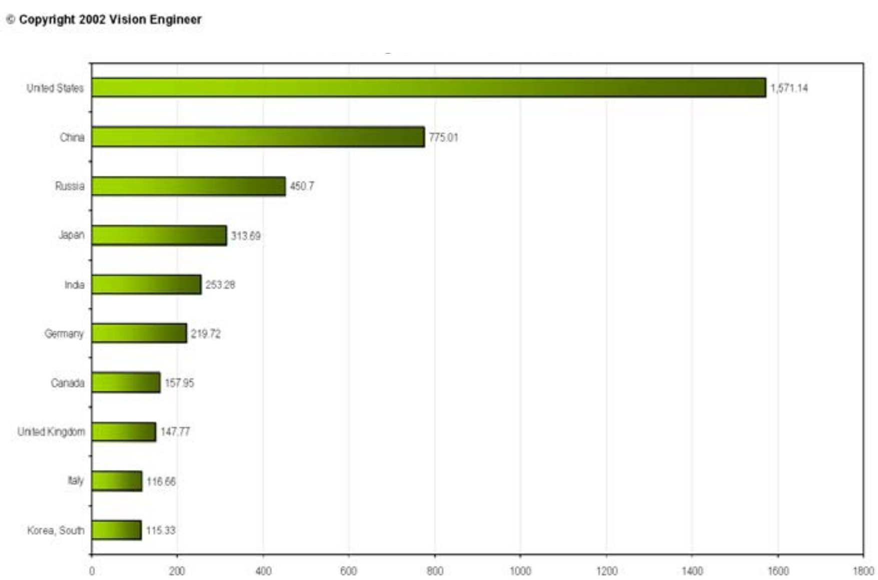

Figure 1.3 Year 2000 CO2 Emissions- Top 10 Countries
Million Metric Tons of Carbon Equivalent
Source: US Department of Energy

1.2. Building Simulation and Optimization

This dissertation addresses the general problem of minimizing building energy consumption and the associated operational costs of HVAC systems. Over the past years, building performance simulation has been used for energy analysis. A literature review of those tools, their capabilities and problems will be presented in Chapter 2. Availability of such tools enables realistic use of mathematical optimization, the approach followed in this dissertation.

Towards this end, it addresses also some of the current issues with building simulation tools, namely, the lack of data visualization and the need for specialized knowledge to use them; knowledge that may be not easily accessible to many architects. A methodology is developed that supports design decision-making and creates opportunities for optimization as part of the design process, for example, presenting building performance data to the user for an evolving design with a relatively modest effort.

1.3. Spatial Archetypes

More specifically, this dissertation aims at the development of a methodology that enables the categorization of building spaces with similar thermal behavior, namely "spatial archetypes." Such archetypes of architectural design spaces for optimal thermal performance and visualization allows concurrent optimization of several space variants, which together can be used to build a complex design. Conversely, a highly complex building can be decomposed and optimized by optimizing its components.

1.4. Outline of Dissertation

The proposed methodology is developed in three stages. In the literature review of building simulation tools in Chapter 2, the issue of visualization means for building performance data is brought forth. A proposed visualization methodology is discussed in Chapter 3. As the tools for visualization are established, the methodology is extended towards generating complex analysis data in an efficient manner. This methodology is described in detail in Chapter 4.

Following these methodologies, the main body of the research focuses on formulating building archetype spaces based on their thermal performance and using such archetypes to perform design optimization. This is presented in detail in Chapter 5. A major design study conducted to test the applicability of this methodology on an actual complex building (a University dormitory) is described in Chapter 6. Guidelines and a roadmap for the systematic use of this methodology in practical problems are given in Chapter 7. Finally, conclusions and contributions of this dissertation are presented in Chapter 8.

.