Building Science
Concepts and Application

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with website

The book's companion website at www.wiley.com/go/pohlbuildingscience contains freely downloadable resources to support both students and lecturers:

Multiple choice questions and answers have been set for Chapters 2 to 11 and are designed to allow students to test their understanding of the concepts and principles of climate, heat, light, and sound, as well as their application in the design and construction of buildings.

PowerPoint slides have been prepared for lecturers to accompany Chapters 2 to 12 and are designed to highlight the underlying fundamental principles pertaining to the environmental aspects of building science, with some practical examples from the natural and built environment.

Please feel free to use any of these resources with appropriate attribution.

Foreword

The design of buildings and the broader field of environmental design are often described as an art and a science. Design is an art because of both the complexity of the problem-solving and decision-making processes involved, and the innate desire of the designer to produce a solution that is unique and at the same time pleasing to our human senses. In the first instance, the complexity of the design process itself is not necessarily due to the complexity of any single issue or factor that must be considered – although some of these certainly demand in-depth subject-matter knowledge – but rather the many interrelationships among those factors.

For example, placing a window into the external wall of a building for the primary purpose of providing daylight may well have far-reaching implications on other areas of the overall design solution. The same window will also allow heat to either enter or escape from the building and in this way impact the thermal balance of the building interior. If located near an external noise source such as a freeway, the presence of the window may adversely affect speech communication within the space that is served by the window. In addition, the existence of the window may impact the building structure and it may also have privacy and security implications.

Clearly, the designer is faced with a very complex situation where a change in any one factor of the overall solution can impact a host of other factors and possibly unravel the current solution altogether. But why is dealing with such complexity considered an art rather than a science? The answer is perhaps surprising to the reader. While true and tried methods exist for solving most of these factors in isolation, there are really no such methods available for producing an optimum overall solution that satisfies all of the individual factors. Instead, the designer typically utilizes a rather time-consuming, iterative process that commences with the solution of the individual design factors more or less in isolation. These individual solutions are then tested in terms of their impact on each other, usually requiring major adjustments to be made based on progressively more clearly defined constraints. This is a cyclic process that has so far defied rigorous scientific explanation. However, we do have knowledge of at least some of the characteristics of this human design activity (Pohl, 2008).

- Even though the designer may assign weightings to the multiple issues and factors that appear to impact the design solution, the relative importance of these issues and their relationships to each other often changes dynamically during the design process. So also do the boundaries of the problem space and the goals and objectives of the desired outcome. In other words, under these circumstances decision making is an altogether dynamic process in which both the rules that govern the process and the required properties of the end result are subject to continuous review, refinement, and amendment.
- Observation of designers in action has drawn attention to the important role played by experience gained in past similar situations, knowledge acquired in the general course of design practice, and expertise contributed by persons who have detailed specialist knowledge in particular problem areas. The dominant emphasis on experience is confirmation of another fundamental aspect of the decision-making activity. Designers seldom start from first principles. In most cases, the designer builds on existing solutions from previous design situations that are in some way related to the problem under consideration. From this viewpoint, the decision-making activity involves the modification,

refinement, enhancement, and combination of existing solutions into a new hybrid solution that satisfies the requirements of the given design problem. In other words, building and environmental design can be described as a process in which relevant elements of past prototype solution models are progressively and collectively molded into a new solution model. Very seldom are new prototype solutions created that do not lean heavily on past prototypes.

- Finally, there is a distinctly irrational aspect to design. Donald Schön refers to a "… reflective conversation with the situation …" (Schön, 1983). He argues that designers frequently make value judgments for which they cannot rationally account. Yet, these intuitive judgments often result in conclusions that lead to superior solutions. It would appear that such intuitive capabilities are based on a conceptual understanding of the situation that allows the designer to make knowledge associations at a highly abstract level.

Based on these characteristics, the design activity can be categorized as an information-intensive process that depends for its success largely on the availability of information resources and, in particular, the experience, reasoning capabilities, and intuition capacity of the designer. The appropriate blending of these skills is as much an art as a science.

Much of the science of design falls under the rubric of building science, which includes climatic and thermal design determinants, daylighting and artificial lighting, and acoustics. The field of building science is built on solid rational foundations that are based on scientific concepts and principles. This does not mean, however, that an in-depth knowledge of science and mathematics is necessarily required for the application of consistent building science principles during the design process. In most cases an understanding of the higher-level technical notions involved is sufficient for the designer to make the necessary decisions during the early design stages, when the conceptual design solution is formulated. However, it is most important that those decisions are sound, so that they can be translated into detailed solutions during later design stages by consultants with specialized expertise.

Accordingly, the purpose of this book is to describe and explain the underlying concepts and principles of the thermal, lighting, and acoustic determinants of building design, without delving into the detailed methods that are applied by engineers and other technical consultants to design and implement actual system solutions. Nevertheless, there are some fundamental mathematical methods and scientific concepts that are a prerequisite for a full understanding of even those largely qualitative descriptions and explanations. For this reason Chapter 1 is dedicated to brief explanations of mathematical methods, such as the principal rules that govern the solution of equations, the notion of logarithms, and elementary statistical methods, as well as some basic scientific concepts such as the notion of stress and strain, the difference between objective and subjective measurements, temperature scales and other units of measurement that are used in building science, and the idealized notion of a *black body* in physics. Readers who have an engineering or science background may well wish to pass over this chapter.

Exploration of the thermal building environment is divided into four chapters. Chapter 2 deals with the principles of thermal comfort, and Chapter 3 translates these principles into conceptual building design solutions. Chapter 4 examines the heat-flow characteristics of the building envelope and explains *steady-state* design methods that form the basis of most building codes, with examples. Chapter 5 explores the sun as a natural heat source and describes the principles of active and passive solar building design solutions.

The treatment of light is divided into three chapters. Chapter 6 introduces the scientific principles of light, color, and vision. In particular, it provides an historical account of the difficulties that were encountered by physicists in formulating a scientifically plausible and consistent explanation of the nature of light. Chapter 7 stresses the importance of daylight in building design, presents the *Daylight Factor* design concept and methodology, and concludes with a discussion of glare conditions and their avoidance. Artificial lighting is the subject of Chapter 8. This chapter delves into the prominent role that electricity plays in the production of light by artificial means and compares the efficacy and characteristics of the various commercially available light sources in terms of the energy-to-light conversion ratio, lifespan, available intensity range, color rendition properties, and cost.

The various aspects of sound that impact the design of the built environment are also divided into three chapters. Chapter 9 discusses the nature of sound as a physical force that sets any medium through which it travels into vibration. This chapter lays the foundations for the treatment of sound as an important means of communication and source of pleasure in Chapter 10, and as a disruptive disturbance that must be controlled in Chapter 11.

Chapters 2 to 11 are largely historical, because they deal with the concepts and principles of building science that were mostly established during the emergence of this field of architecture in the post-World War II period of the 1950s and 1960s. Based on existing scientific premises in physics and other sciences, these foundations have gradually become an increasingly important component of the education and training of architects. However, it can be argued that except for some innovations in artificial light sources, relatively minor mechanical system improvements, and alternative energy explorations, little was added to this body of knowledge during the concluding years of the twentieth century.

There are strong indications that this will change quite dramatically during the twenty-first century, owing to an increased awareness of the human impact on the ecology of planet Earth. Clearly, the *sustainability* movement will have a major impact on the design and construction of the built environment during the coming decades. For this reason the final section of this book, Chapter 12, provides an introduction to ecological design concepts and describes both the objectives that are being established and the approaches that are emerging for meeting sustainability targets in building design and construction during the twenty-first century.

Multiple choice questions and answers for all chapters except Chapters 1 and 12 can be found on the website

www.wiley.com/go/pohlbuildingscience.