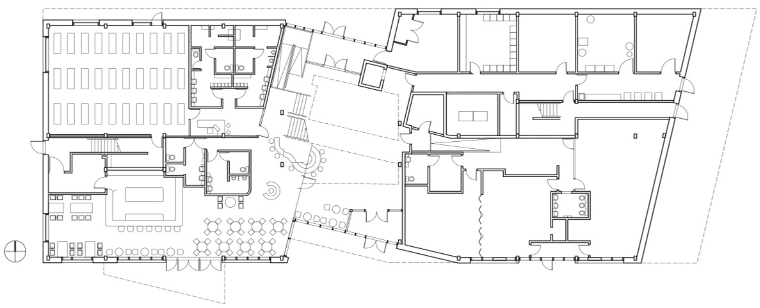
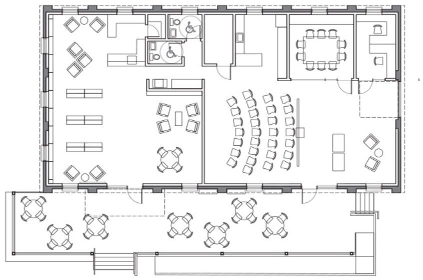
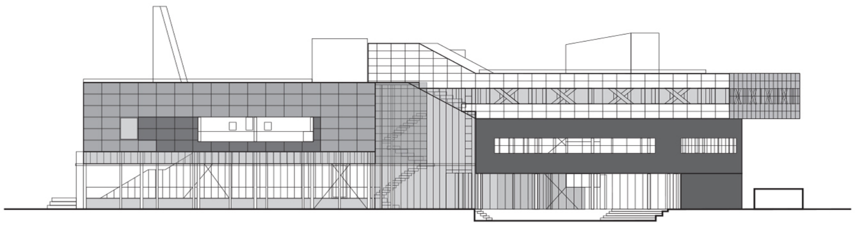
FRANCIS D.K. CHING
IAN M. SHAPIRO

GREEN BUILDING ILLUSTRATED

SECOND EDITION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Green Building *Illustrated*

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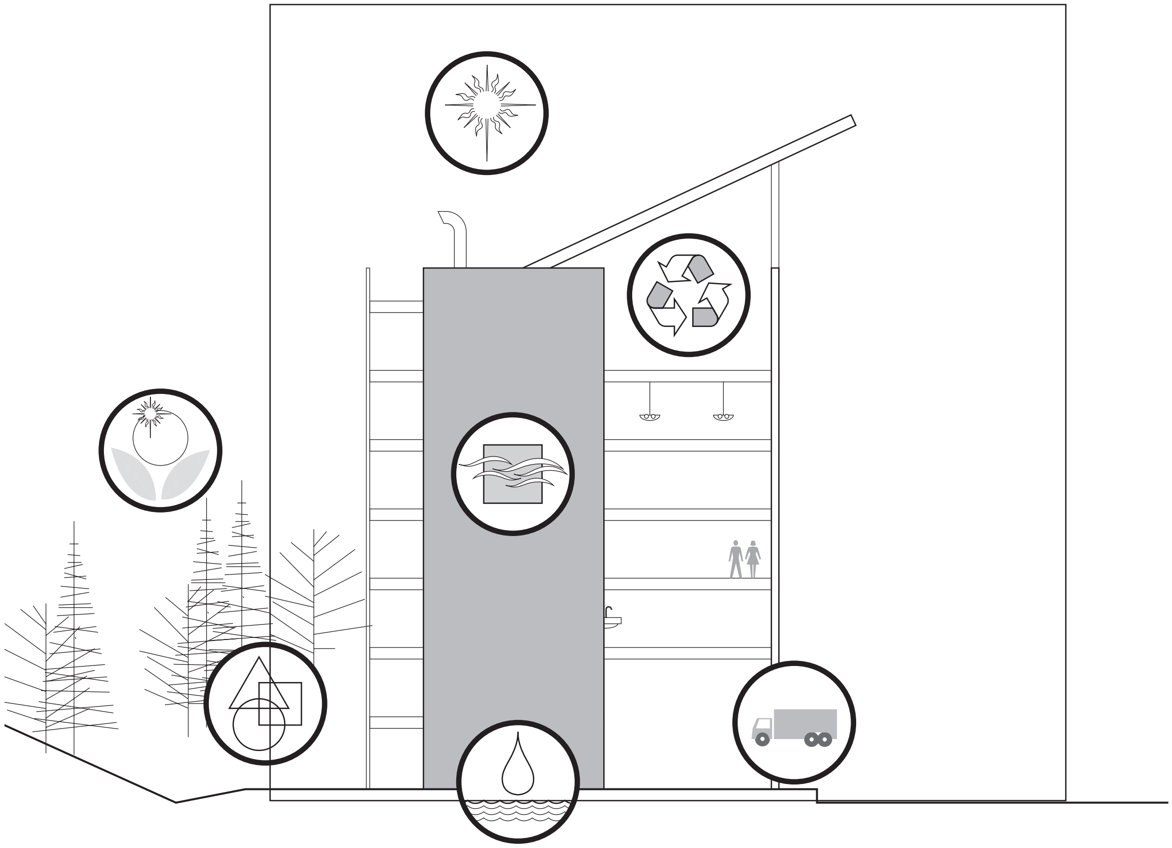

Francis D. K. Ching
Ian M. Shapiro

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Preface

Green building is a relatively new field. Its goal is to substantially reduce the environmental impact of buildings, while providing a healthy environment within buildings. This book seeks to introduce the field of green building, explore a variety of fundamental concepts in green design and construction, and provide guidance to professionals engaged in the field.

This second edition of *Green Building Illustrated* includes expanded discussion and exemplary case studies of zero energy and zero carbon buildings, as well as increased coverage of international building design and construction. There is also added guidance for the schematic design of high-performance buildings and additional material in the area of construction costs and affordability. Specific attention is directed to approaches that simultaneously lower construction costs and reduce greenhouse gas emissions, such as the strategic design of building shape, right-lighting, and more. This second edition also includes a new section on biomimicry and biophilic design; updates to codes and standards; and more information on building electrification through technologies such as heat pumps. Finally, there is increased discussion of place as it relates to green design, and an expanded discussion of climate-specific green design for different regions.

Despite these changes, designing and constructing buildings remains about making choices. It is the creation of choices at the beginning of a project, the evaluation of choices during the design process, the making of choices with the owner, the documentation of choices on drawings, and the implementation of choices through construction. In this book, we have attempted to provide a variety of choices for the design and construction of green buildings.

The book begins by exploring the goals of green buildings and by defining green buildings. It is strongly contextualized within the goal of reducing building-related carbon emissions to counter the increasing impacts of climate change. Various codes, standards, and guidelines are introduced, each of which sets forth requirements to give green buildings further definition.

A methodical exploration of green design is structured by working “from the outside in,” from the community and site, through various layers of the building envelope, and proceeding to examination of the green aspects of lighting, heating, and cooling. Related topics are explored, including water conservation, safeguarding indoor environmental quality, material conservation, and renewable energy.

For energy-related discussions, a variety of first principles of physics are invoked, the combination of which is increasingly referred to as “building science.” For example, first principles of heat transfer are applied to heat loss, and to reducing such loss. We explore aspects of illumination, relating to lighting energy use, and the human interaction and ergonomics of lighting. First principles of fluid dynamics lie behind a discussion of such building-related phenomena as “stack effect” buoyant airflow through buildings. First principles of thermodynamics are applied to the efficient generation and delivery of heat, the transport of heat away from buildings for cooling, and how to increase associated efficiencies in order to reduce energy use.

Detailed illustrations translate these principles and discussions into specific guidance for green building design and construction. A variety of best practices are offered, which are intended to be flexible enough for practitioners to design and construct the green building of the owner’s dreams. The illustrations are also intended to be expansive, to offer a wide array of choices possible for green buildings.

Finally, a discussion of the practice of quality is used to explore how design and construction may most effectively deliver the goals sought for green design and construction.

The reader is advised to treat the methods covered in the book as tools. A building does not need to incorporate all the approaches suggested in this book in order to be green. The book is also a broad brush. It would be difficult to cover all the many emerging green building improvements, methods, and products. The focus is instead on underlying tools and strategies, from which professionals can create the choices necessary to design and construct high-performing green buildings.

Acknowledgments

For this second edition, thanks go to Luna Oiwa for research into a wide number of specialty topics; to Evan Hallas for insight into green building inspections, especially thermal bridging; to Tamar Shapiro-Tamir for work on net-zero case studies; and to Noa Shapiro-Tamir for research on case studies and weather data maps.

For the original edition of this book, thanks to Florence Baveye for research and concept drawings and to Marina Itaborai Servino for checking of facts and calculations. Further checking was done by Zac Hess and Daniel Clark. Double thanks to Roger Beck, for encouraging me to write 40 years ago, and for reviewing the manuscript 40 years later. Thanks go to Mona Azarbayjani of the University of North Carolina at Charlotte and to Jonathan Angier of EPA/Office of Water for reviewing the manuscript. Invaluable reviews and comments were also provided by my wife, Dalya Tamir, my daughter Shoshana Shapiro, Susan Galbraith, Deirdre Waywell, Theresa Ryan, Jan Schwartzberg, Daniel Rosen, Shira Nayman, Ben Myers, Bridget Meeds, and Courtney Royal. Thanks to Lou Vogel and Nate Goodell for information on commissioning, to Javier Rosa and Yossi Bronsnick for information on structural design, and to Umit Sirt for information on modeling. Thanks to Nicole Ceci for energy analysis in the early going. Thanks to all my colleagues at Taitem Engineering for the research, observations, and discussions that are behind so much that is in this book. Thanks to Sue Schwartz for use of her apartment on Cayuga Lake, where I wrote. Thanks to my family – Dalya, Shoshana, Tamar, and Noa, for their support throughout. Thanks to my mother, Elsa Shapiro, for being a sounding board each day, about the day's progress, over tea.

And last, but really most of all, thanks to co-author Francis D.K. Ching, whose work is such a gift to the world. My colleague Theresa Ryan put it best: "We want to live in Frank's drawings." Frank's illustrations, guidance, layout, collaboration, and edits all made this book happen.
—Ian M. Shapiro

Metric Equivalents

The International System of Units is an internationally accepted system of coherent physical units, using the meter, kilogram, second, ampere, Kelvin, and candela as the base units of length, mass, time, electric current, temperature, and luminous intensity. To acquaint the reader with the International System of Units, metric equivalents are provided throughout this book according to the following conventions:

- All whole numbers in parentheses indicate millimeters unless otherwise noted.
- Dimensions 3 inches and greater are rounded to the nearest multiple of 5 millimeters.
- Nominal dimensions are directly converted; for example, a nominal 2 × 4 is converted to 51 × 100 even though its actual $1^1/_2$" × $3^1/_2$" dimensions would be converted to 38 × 90.
- Note that 3487 mm = 3.487 m.
- In all other cases, the metric unit of measurement is specified.

1
Introduction

In the span of a few years, the planning, design, and construction fields have been swept up in a dynamic discussion of sustainability and green buildings. In design studios and on construction sites, we are learning to share new goals and new standards and even a new language. For many, our professional lives have been greatly enriched as we learn the meanings and means of this new language. For others, questions swirl: How did this all come about? What is it all about?

Sustainability is about the promises of things that will last—buildings with long and useful lives, forms of energy that are renewable, communities that endure. Green building is about turning the promises of sustainability into reality.

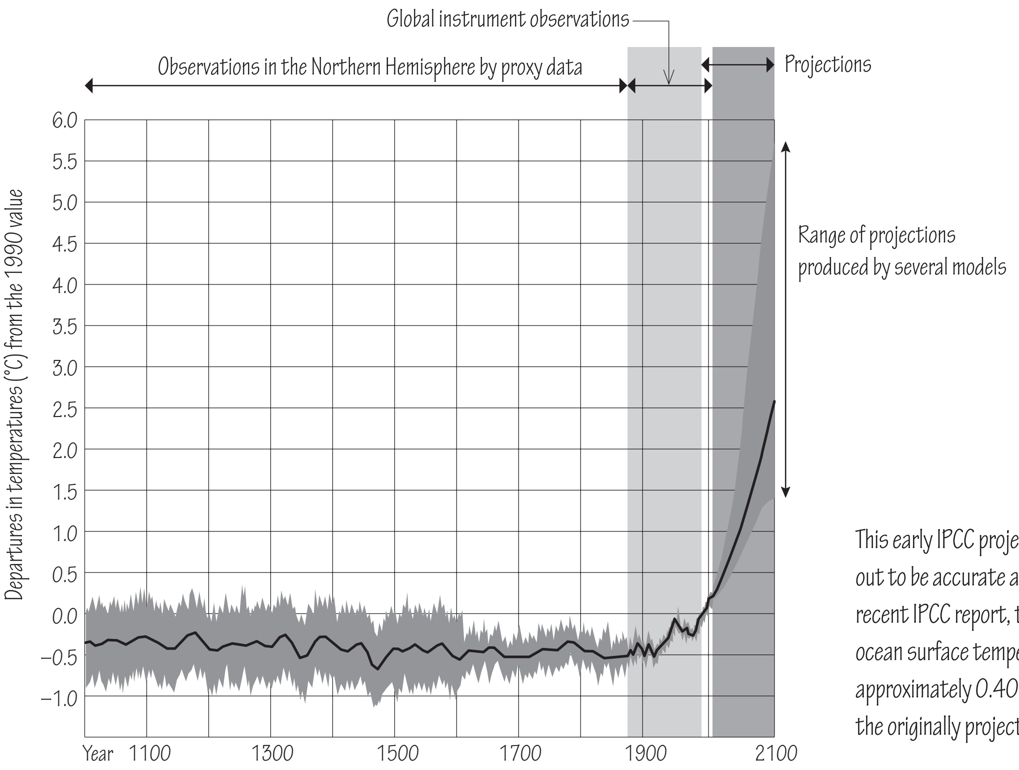
Parallel to the promises of sustainability, and even calling for their fulfillment, is the insistent reminder of scientists who caution about environmental hazards, hazards that are increasingly affirmed by our own observations. However, there is something deeply empowering in not shying away from these hazards, in turning and facing them, in weighing them collectively, and in developing strategies for addressing them. Ultimately, this may be the greatest promise of sustainability—the impetus to consider the environmental challenges we face and to find ways to overcome them.

1.01 The fragility of life on Earth has been emphasized through views of the planet from space, such as the 1990 photograph from the *Voyager 1* spacecraft. The astronomer Carl Sagan described Earth as the pale blue dot, "the only home we've ever known." (Source: NASA)

Facing Environmental Challenges

Several environmental crises are motivating us to reevaluate how we plan, design, and construct buildings. Air and water pollution resulting from fossil fuel use, fallout from nuclear power plant accidents, and the incipient and potential devastation of climate change all point to a critical need to reduce energy use. Human illness resulting from exposure to toxic chemicals compels us to reexamine their intensive use, especially in building materials.

Of particular concern is climate change. The Intergovernmental Panel on Climate Change (IPCC), which includes more than 1,300 scientists from the United States and other countries, reports that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level." According to the IPCC, the impacts of climate change have already begun and are expected only to get worse. The consequences of climate change also include such extreme weather events as increased cyclone activity and longer, more frequent, and more intense heat waves; reduced snow cover and greater incidence of coastal and inland flooding; shifting plant and animal ranges and loss of biodiversity; and reduced water availability for human consumption, agriculture, and energy generation.

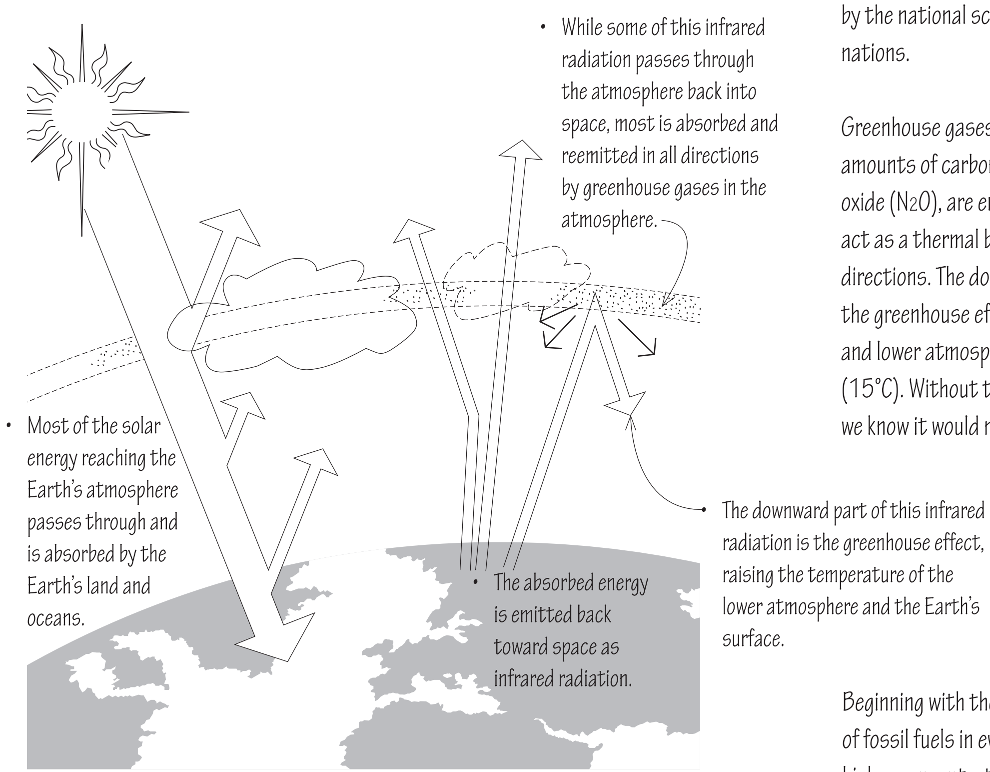


This early IPCC projection of temperature increases has turned out to be accurate and even on the low side. From the most recent IPCC report, the globally averaged combined land and ocean surface temperature data show an actual warming of approximately 0.40 °C over the period 1990 to 2010, exceeding the originally projected warming of 0.25°C over that period.

1.02 Variations in the Earth's surface temperature from the year 1000 to 2100. (Source: IPCC)

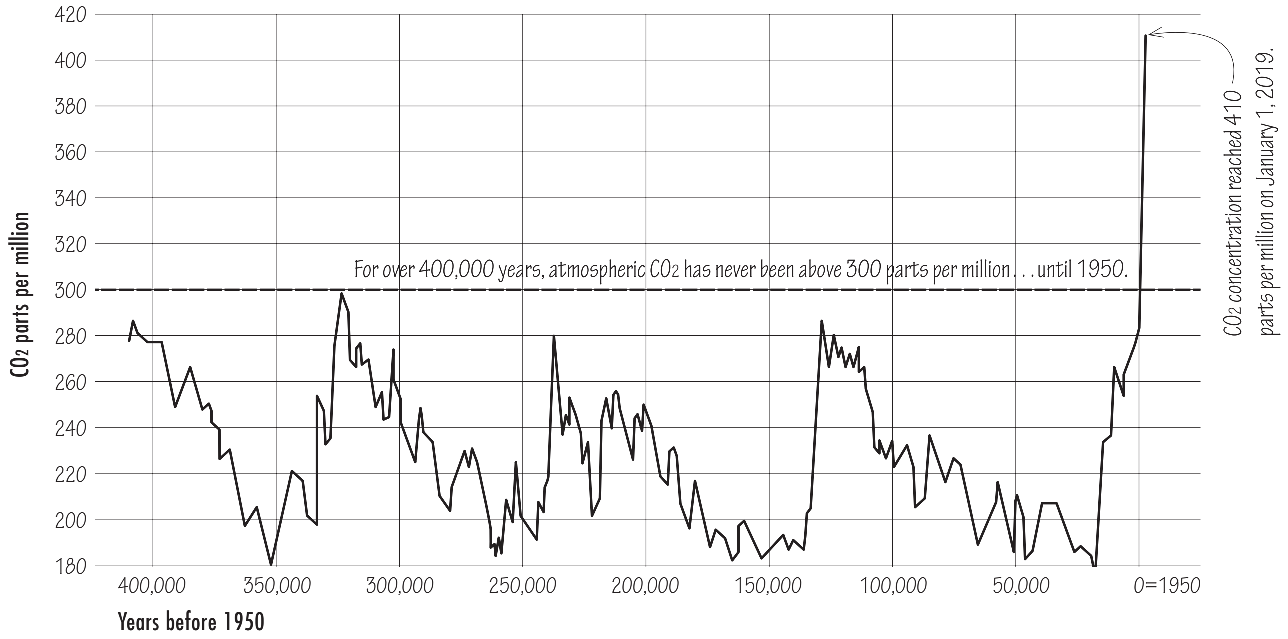
The major cause of climate change is the increasing concentrations of greenhouse gases (GHG) produced by human activities, such as deforestation, changes in land use, and especially the burning of fossil fuels. This finding is recognized by the national science academies of all major industrialized nations.

Greenhouse gases, primarily water vapor but including smaller amounts of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), are emissions that rise into the atmosphere and act as a thermal blanket, absorbing heat and reemitting it in all directions. The downward portion of this reradiation is known as the greenhouse effect and serves to warm the Earth's surface and lower atmosphere to a life-supporting average of 59°F (15°C). Without this natural greenhouse effect, life on Earth as we know it would not be possible.



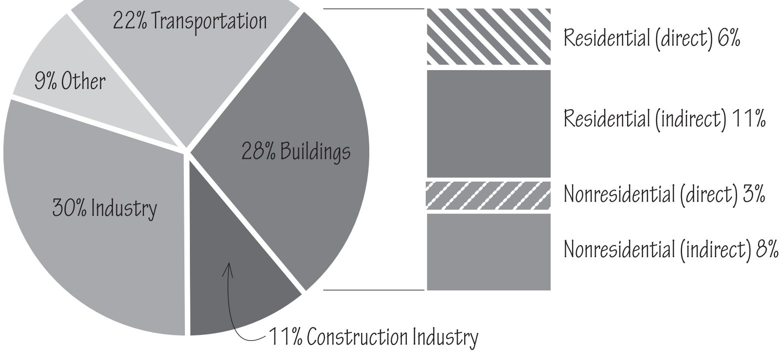
1.03 The greenhouse effect.

Beginning with the Industrial Revolution, however, the burning of fossil fuels in ever-increasing amounts has contributed to higher concentrations of carbon dioxide, methane, and nitrous oxide in the atmosphere, intensifying the natural greenhouse effect and contributing to global warming and climate change.

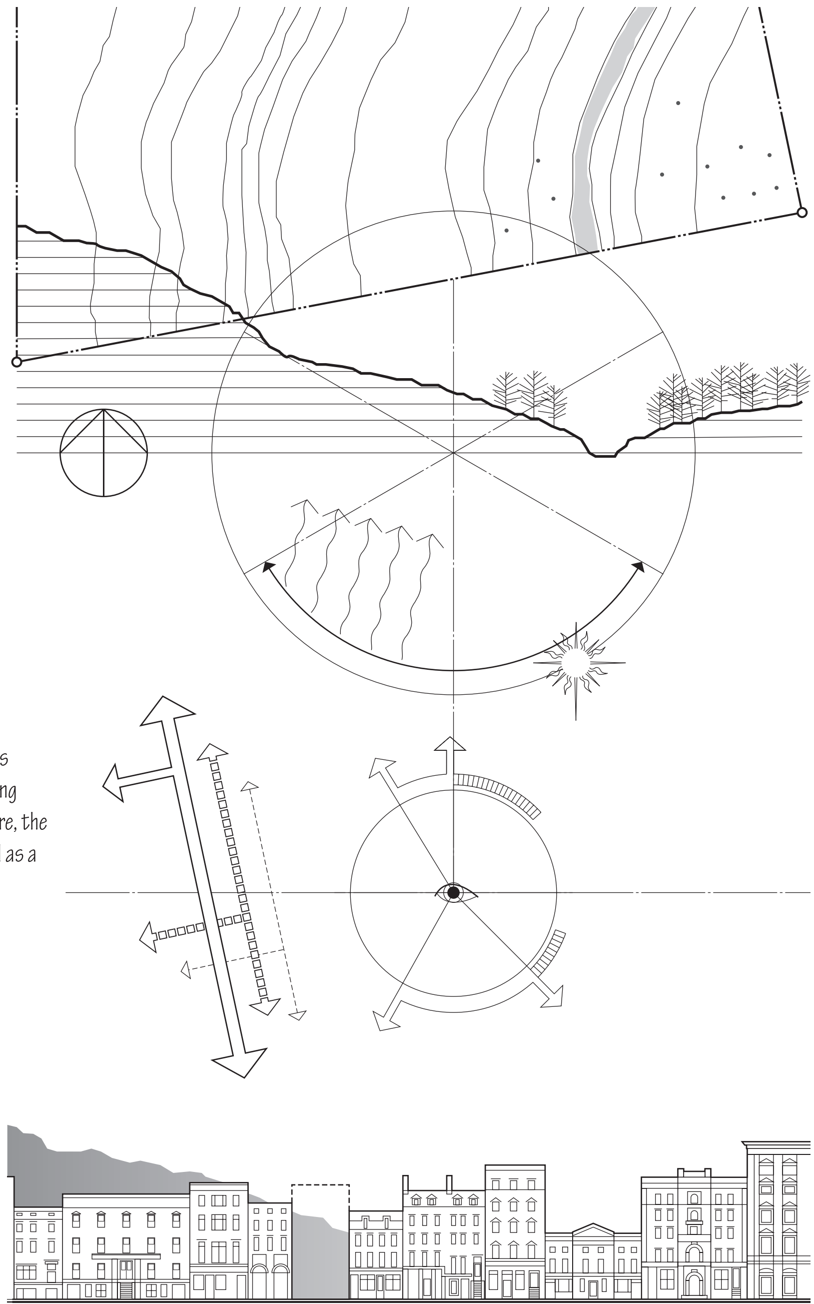


1.04 Atmospheric samples contained in ice cores and more recent direct measurements provide evidence that atmospheric CO_2 has increased since the Industrial Revolution. (Source: NOAA)

Data from the International Energy Agency indicates that buildings are responsible for almost 40% of global greenhouse gas emissions. Most of the building sector's energy consumption is not attributable to the production of materials or the process of construction, but rather to operational processes, such as the heating, cooling, and lighting of buildings. This means that to reduce the energy consumption and GHG emissions generated by the use and maintenance of buildings over their life span, it is necessary to properly design, site, and shape buildings and incorporate efficient heating, cooling, ventilation, and lighting strategies. However, as operational energy use is reduced, attention will increasingly also need to be directed to reducing the embodied energy of construction materials.



1.05 Share of global energy-related CO_2 emissions by sector. (Source: 2018 Global ABC Report; IEA)



1.06 Well-sited and energy-efficient buildings could reduce carbon emissions in other sectors as well, by using less energy to produce and transport building materials and for people to be transported to and from buildings. Furthermore, the potential benefit of a future stream of reduced energy costs has been viewed as a way to offset the initial investment required to reduce carbon emissions.

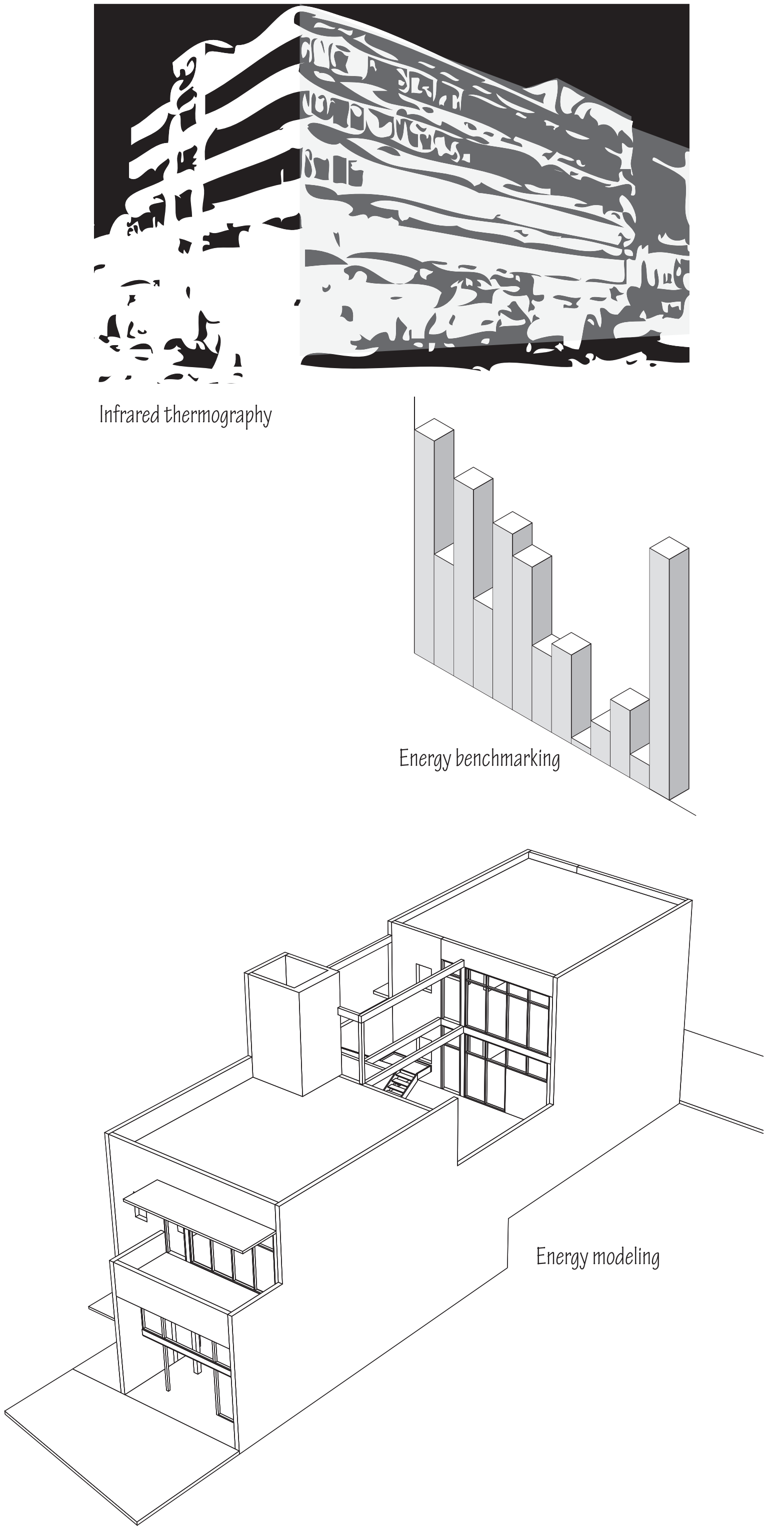
New Information, New Risks, New Opportunities

As knowledge of climate change and other environmental risks have been emerging, formal and informal research in buildings during the past few decades has given insights into how buildings work, how they can fail environmentally, and, as importantly, how such failures can be prevented. The converging demands of our multiple environmental crises and the relatively new information about how buildings perform and can be developed more sustainably offer opportunities for approaching the design of buildings in new ways. The field of green buildings is young and infinitely rich. New opportunities abound in design and construction to improve energy and resource efficiencies, to reduce the use of toxic chemicals, and to do so in a more affordable way.

However, there are many potential risks and pitfalls in green building design and construction. It is easy to be drawn to new products or approaches that claim to be green, but are in fact ineffective or are so costly as to prevent balanced investment in other, more cost-effective improvements. Our challenge is to use common sense, to reject token, showy, or ineffective building improvements, all while staying open to new, potentially valid ideas and tools. There is an urgent need both for critical thinking when scrutinizing new ideas and for flexibility when adapting to change that is occurring at a rapid pace.

Green building design need not focus solely on simply adding features to buildings to make them greener. While increasing thermal insulation values will improve the energy efficiency of a building and adding solar photovoltaic systems will reduce the need for electricity derived from nonrenewable sources, there is also much to be gained through judicious design that is not simply additive but rather more integrated and organic in nature. For example, we could select more reflective surfaces for interior finishes that would require fewer artificial light sources while delivering the same interior light levels. We could select building shapes that have less exposed surface area and so use less energy for the same floor area than more complex building shapes.

Being always mindful of the aesthetic nature of what we design and build, we might also ask: What is the effect of green design on the beauty of the built environment? Fortunately, beauty need not be sacrificed in order for buildings to be green. Green buildings may challenge conventional notions of what is beautiful, but the opportunity arises to reevaluate our notions of beauty, to reexamine how we define beauty in buildings, and to explore beauty in new architectural forms.



1.07 Each year new approaches, new tools, and new products become available, offering ways to reduce energy and material use in buildings.

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Reduce

Reuse

Recycle

1.08 *Symbols for green materials, processes, and practices.*

What Is a Green Building?

In this book, the question "What is a green building?" is repeatedly posed. This question takes many forms: Is a green building one that is greener than it could have been? Is a green building one that meets a green building standard? Is a green building one that has low or zero negative impact on the environment and on human health? Should all buildings be green? Are green buildings a passing fad? Do green buildings stay green over time?

The answer to "What is a green building?" is still evolving. Some buildings certified as green according to one of the green building standards have been found to be, in fact, high energy users or in some other way polluting. Conversely, many zero-energy or near-zero-energy buildings have been successfully designed and built but have not been certified as green by any rating system. This is not to question the environmental performance of all certified green buildings. Green building standards and certification systems have contributed immeasurably to the advancement of sustainable design and will continue to do so. However, we may still have a way to go before a green building certification guarantees a high level of energy efficiency or low level of pollution.

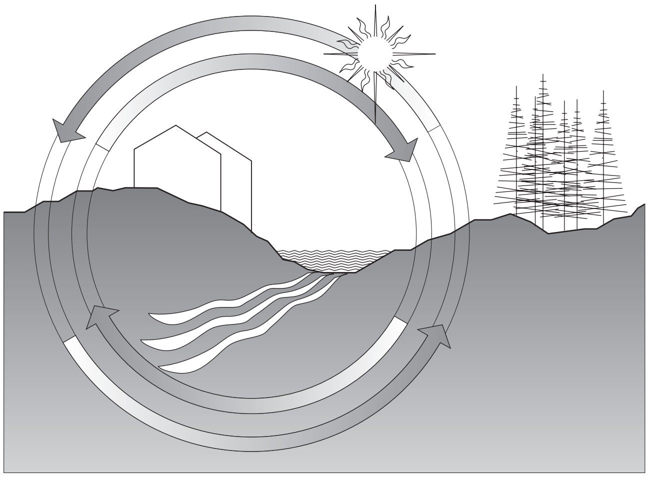
Parallel to the question "What is a green building?" is a similar but different question, "What is a greener building?" In many specific areas of building design, the relative merits of different approaches can be weighed by asking which of multiple available options is greener. This is not to advocate for small or incremental improvements in green design. The overall goal of a meaningfully green building remains paramount. However, when facing the many design decisions that need to be made in planning a building, "Is this approach greener?" can be a useful question—one that is often worthwhile asking, regardless of compliance with a specific green building code, standard, or guideline.

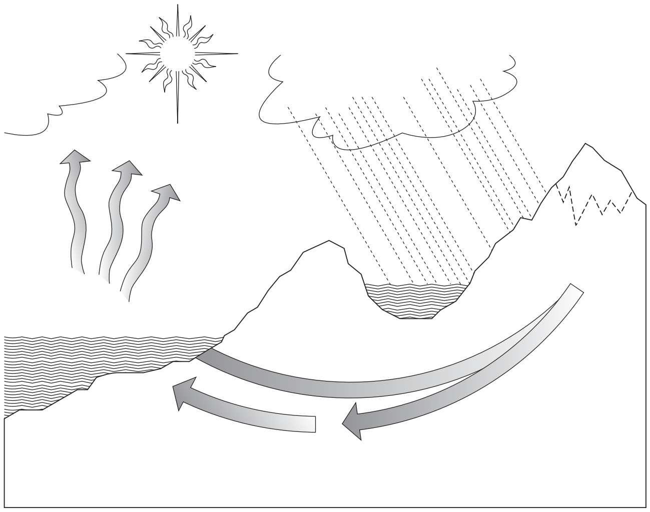
Green Building Goals

There are many goals that motivate the planning and design of green buildings.

Perhaps the most widely recognized goals address environmental degradation:

- Mitigate global warming through energy conservation and resulting reduction of GHG emissions.
- Minimize environmental impacts resulting from the extraction of coal, natural gas, and oil, including oil spills; the mountaintop removal mining of coal; and the pollution associated with hydraulic fracturing for natural gas.
- Reduce pollution of air, water, and soil.
- Protect clean water sources.
- Reduce light pollution that can disrupt nocturnal ecosystems.
- Protect natural habitats and biological diversity, with specific concern for threatened and endangered species.
- Prevent unnecessary and irreversible conversion of farmland to nonagricultural uses.
- Protect topsoil and reduce the impacts of flooding.
- Reduce use of landfills.
- Reduce risk of nuclear contamination.





1.09 Mitigating environmental degradation through conservation, reduction of pollutants, and protection of water and natural resources and habitats.

Goals for green buildings include providing for improved human health and comfort:

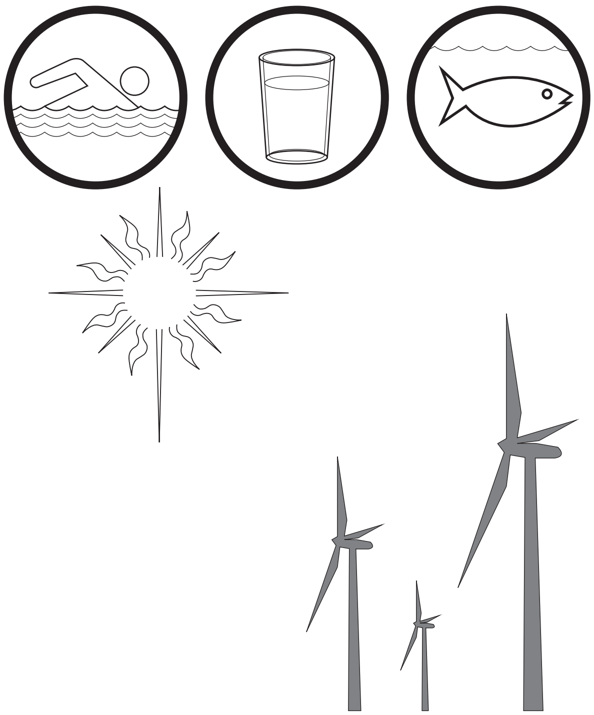
- Improve indoor air quality.
- Improve indoor water quality.
- Increase thermal comfort.
- Reduce noise pollution.
- Improve morale.

Some goals might be considered economic in nature:

- Reduce energy costs.
- Improve productivity.
- Create green jobs.
- Increase marketing appeal.
- Improve public relations.

Some goals might be considered political in nature:

- Reduce dependence on foreign sources of fuel.
- Increase national competitiveness.
- Avoid depletion of nonrenewable fuels, such as oil, coal, and natural gas.
- Reduce strain on electric power grids and risk of power outages.



1.10 Improving environmental and economic health.

Some people broaden the goals of green buildings to include social or societal goals:

- Follow fair labor practices.
- Provide access for the disabled.
- Protect consumers.
- Protect parklands.
- Preserve historic structures.
- Provide affordable housing.

1.11 Meeting social and societal goals.

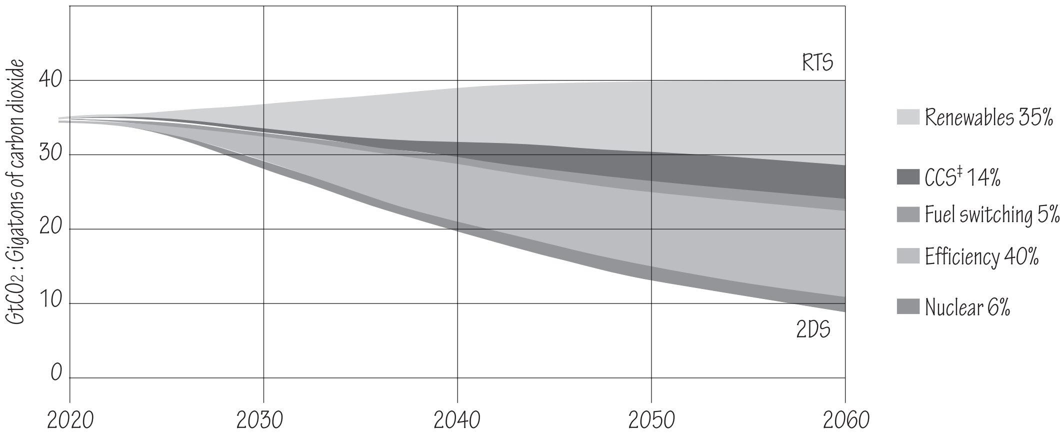
And some goals reflect the unique needs of the human spirit:

- Express deep connection to and love of the Earth and nature.
- Be self-reliant.
- Satisfy the quest for beauty.

Some goals may not be explicitly stated but represent some of our less nobler needs, such as the quest for status or prestige.

Regardless of how the stated goals are grouped, there is an ongoing and valid conversation to be had about what the goals are and how to prioritize them. In most instances, constructing green buildings supports one or more of the goals in a harmonious way. However, in some cases, conflicts may occur between two or more goals and the reconciliation of these conflicts represents a vital sorting-out of what is important to us as humans.

In the face of almost unanimous agreement among scientists about the consequences of climate change, and with impacts well under way, such as shifting plant and animal ranges, more frequent flooding of low-lying areas, and receding of polar ice, a major focus of the green building field will remain the reduction of energy consumption and associated carbon emissions.

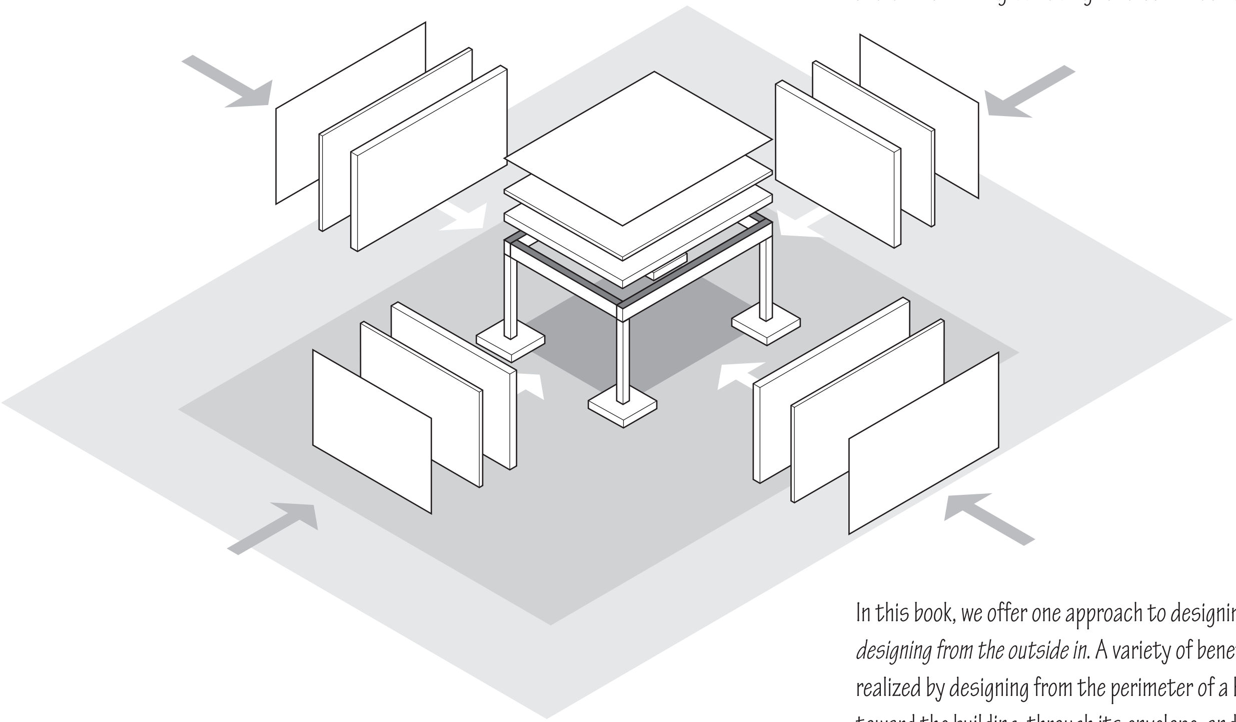


1.12 *Global CO_2 emissions reductions by technology area: RTS* to 2DS*†.
(Source: IAE) Energy-efficient technologies dominate the cumulative CO_2 emissions reductions achieved in the industry, buildings, and transport sectors, reinforcing the importance of efficiency as the "first fuel" for achieving the 2DS vision. Therefore, reducing energy consumption and associated carbon emissions remains of paramount importance in the way we plan, design, and construct buildings.

*RTS: Reference technology scenario ('business as usual')
†2DS: Scenario to reduce carbon emissions to control global warming to 2°C
‡CCS: Carbon capture and sequestration

Approaches to Green Building

In green building design and construction, it often helps to use a commonsense approach. Most of the energy- and water-efficiency trade-offs of different technologies and strategies are readily quantifiable and so can guide decision-making. Hazardous materials are reasonably well-known and identifiable and so can be avoided. Common sense can also be helpful in addressing some of the more complex trade-offs, guiding consideration of new technologies, and preventing design paralysis, which may arise when faced with the many choices and unknowns in green design and construction.



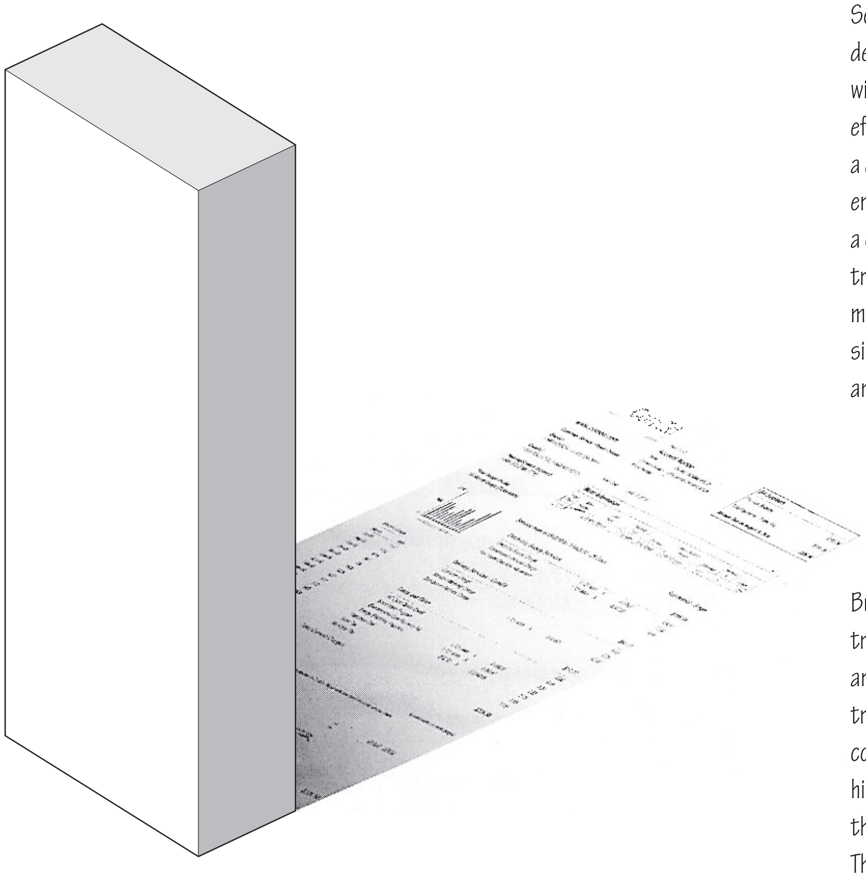
1.13 Designing from the outside by incrementally adding layers of shelter.

In this book, we offer one approach to designing green buildings: *designing from the outside in*. A variety of benefits can be realized by designing from the perimeter of a building site, toward the building, through its envelope, and to its core. By incrementally adding *layers of shelter* and ensuring the integrity and continuity of each of these layers, various energy loads can be substantially reduced. In doing so, the accumulation of green building improvements can actually reduce construction costs, making possible buildings that not only use less energy, less water, and fewer materials, but are more affordable to construct.

Building on some of the notable, recent developments in building science, this book focuses on design strategies for green building rather than on compliance with specific requirements of any particular code, standard, or guideline. However, the principles and approaches presented are intended to be robust enough to meet or exceed the requirements of existing codes, standards, and guidelines, and be applicable to all types of buildings, whether they be wood-frame residences or high-rise structures of steel and concrete.

The various standards for green building design are generally consistent with the approaches suggested by designing from the outside in. However, many existing green building standards calculate energy savings relative to a hypothetical reference building or focus on energy use per unit floor area, and take the building shape as given. Green building standards tend not to question the floor area or the building shape itself. In designing from the outside in, everything is up for questioning, including the floor area and building shape.

Some approaches to green buildings take a particular building design, invest in improved construction (such as thicker walls with more insulation, tighter construction, more energy-efficient windows, or higher-efficiency heating), and have as a goal a building that uses perhaps 10%, 20%, or 30% less energy. While this approach is fully valid, it can be enhanced by a complementary approach, which is to design not an improved traditional building but rather a different type of building that meets the same human needs, for which the goal is to use significantly less energy or preferably net-zero energy and with an eye to affordability throughout.



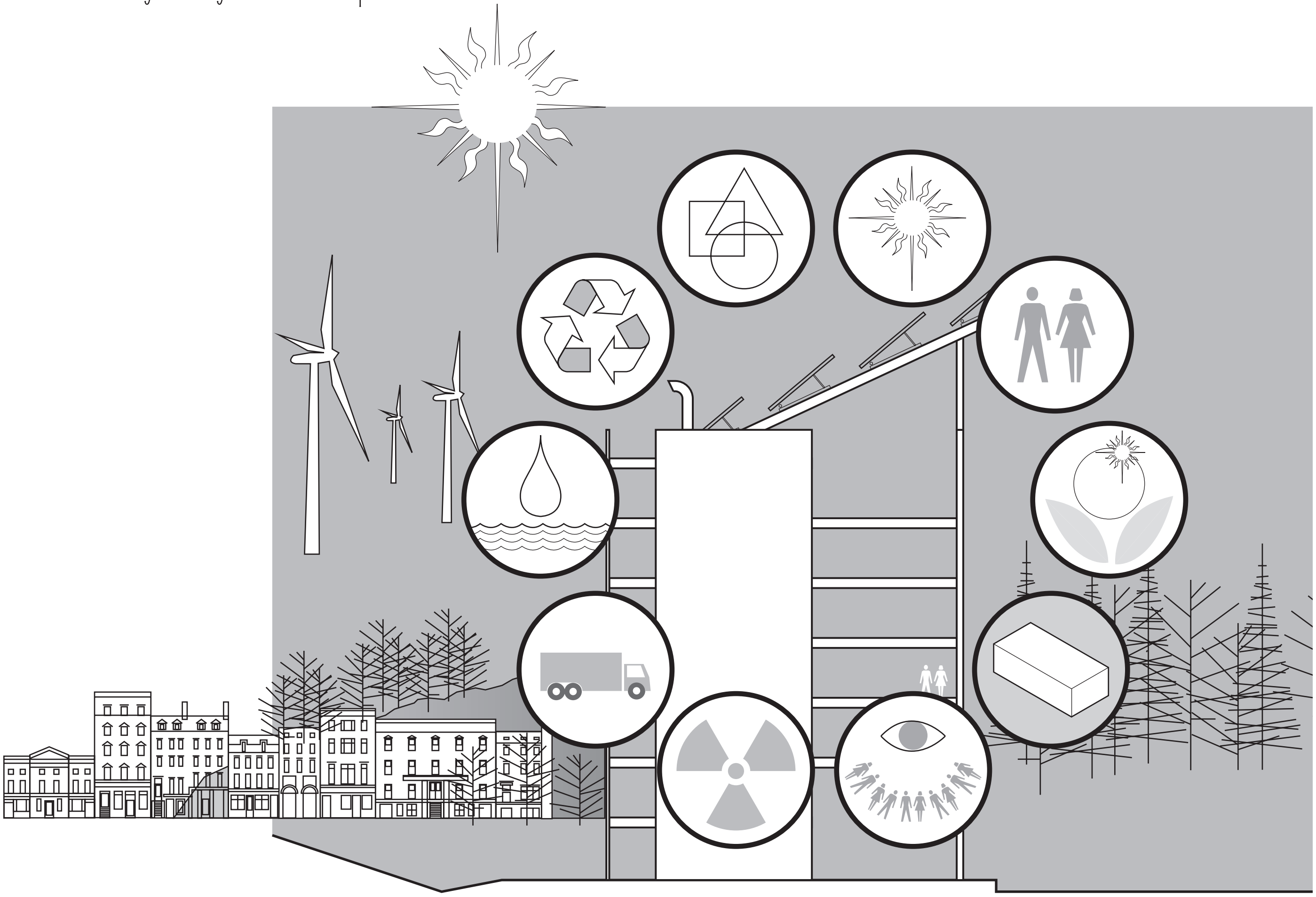
1.14 We can trace a building's energy use through its utility bills.

Buildings leave a trace of their greenness in their utility bills, a trace that will last for decades to come. Increasingly, buildings are judged by this trace, as online databases in recent years track energy use in individual buildings and perform widespread comparisons of energy use between buildings. The judgment of history has already begun to weigh more heavily on buildings that waste energy, particularly buildings that claim to be green. The good news is that the tools to design and build energy-efficient buildings are increasingly available. The challenge lies in their application.

To architectural form and function, a new dimension in building design is presenting itself: performance. In addition to serving the needs of its occupants and appealing to the eye, mind, and spirit, a building must now perform well, and perform persistently well over time, consuming less energy and fewer resources while providing a high level of comfort and conditions conductive to good health. On one hand, an added set of constraints has been placed on building design. On the other, an opportunity exists to clear a higher bar, do better work, and avoid wasteful and unhealthy buildings.

The reader is invited to join an exploration of the promise of buildings that impact the environment as lightly as possible and use significantly less energy, water, and materials than at present. Let us explore the promise of buildings that could cost less than current buildings while being more comfortable and conducive to human health. Let us explore the promise of buildings that are more strongly integrated into our human communities and the natural world. Let us explore the promise of buildings that we can be proud of.

And then let us try to boldly deliver on these promises.



2

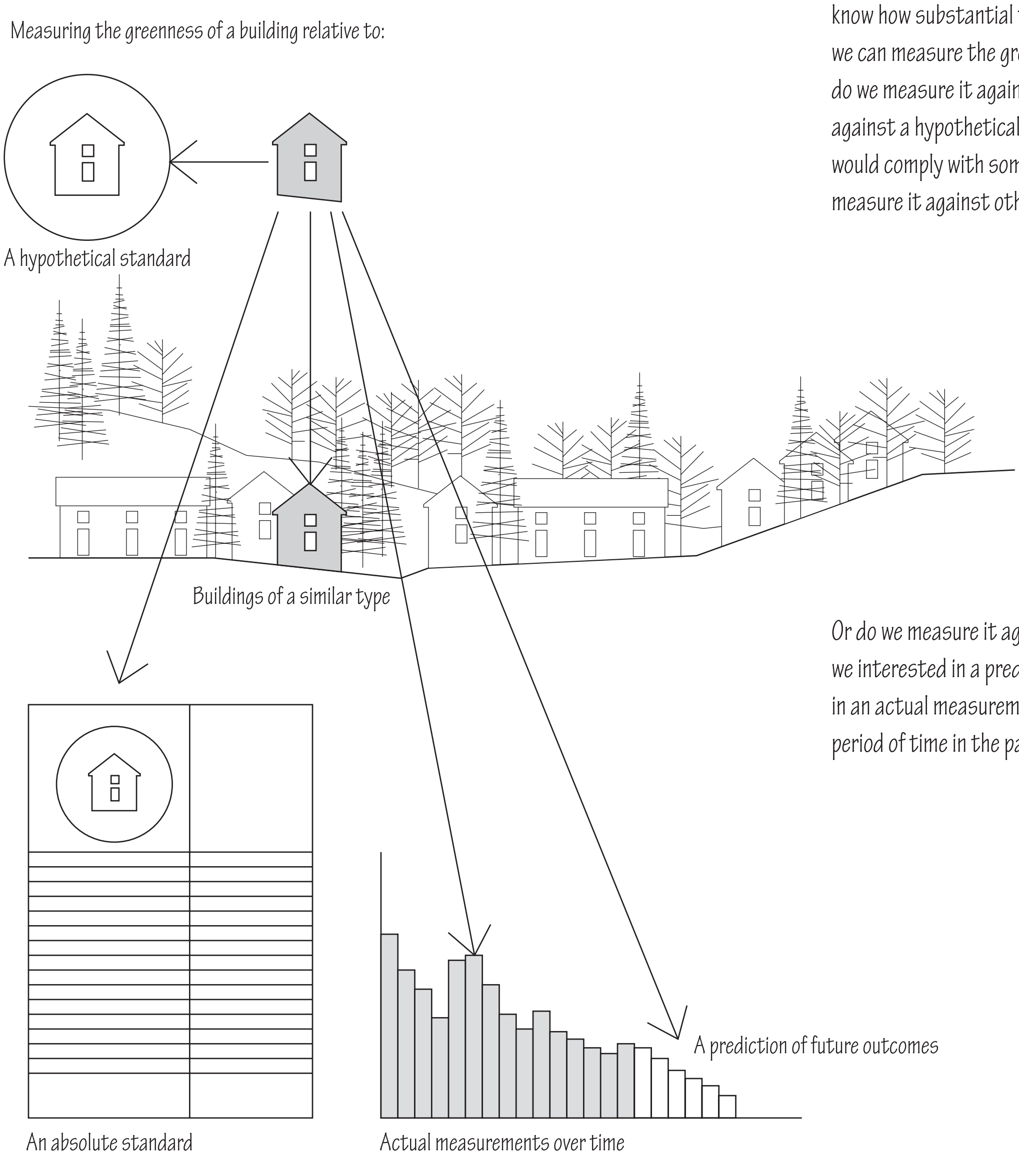
First Principles

What is a green building? In the introduction, we examined the significant impacts of buildings on our natural environment and made the case for buildings that mitigate these effects, not only by lowering their use of energy and water but also reducing the amount of materials and resources used in their construction. Reducing their impact on the natural environment is a major goal of green buildings.

Is there anything else that makes a building green? In discussions of green building and the various green building codes and standards, we find some widely accepted goals that do not contribute directly to reducing the impact of buildings on the natural environment. These include such goals as improving indoor air quality, providing views from the building interior to the outdoors, and enhancing thermal comfort. And so we can and should broaden the definition of green buildings to include the design of indoor environments that are conducive to human health.

Let us begin with the following working definition: A green building is a building that has a substantially reduced impact on the natural environment and that provides indoor conditions conducive to human health.

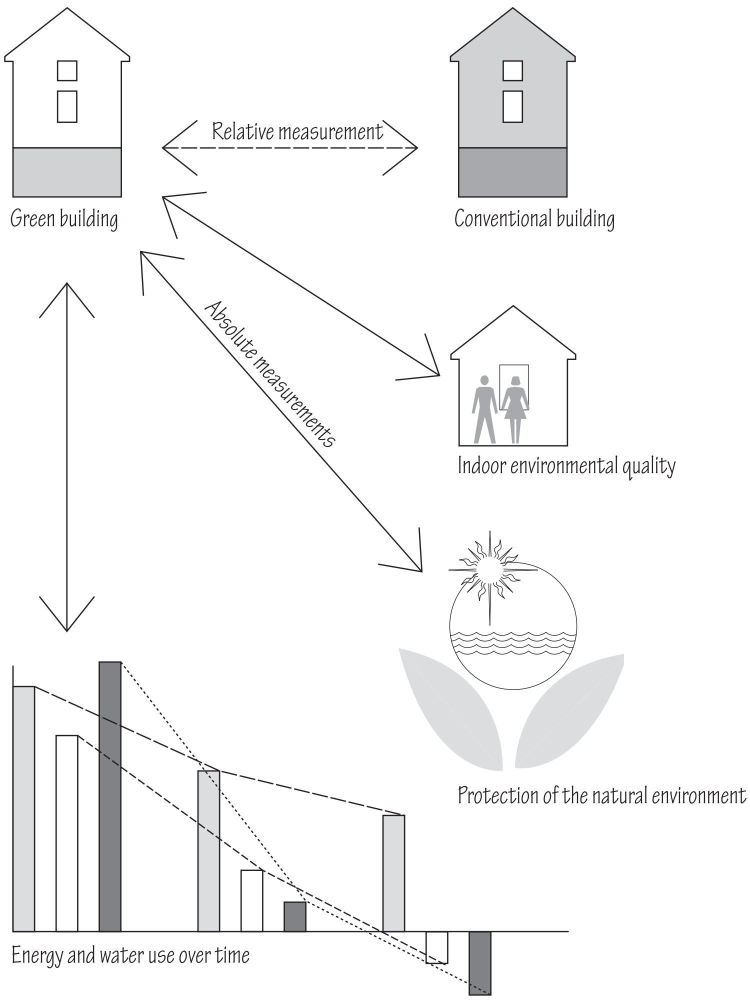
However, other questions quickly arise. When we say "substantially reduced impact on the natural environment," how substantial does the reduction need to be? And, in order to know how substantial the reduction is, is there some way that we can measure the greenness of a building? And if so, what do we measure it against? Do we measure it in a relative way, against a hypothetical building of the same size and shape that would comply with some current code or standard? Or do we measure it against other buildings of a similar type?



2.01 How should we gauge the greenness of a building?

Or do we measure it against some absolute standard? And are we interested in a prediction of the building's future impact, or in an actual measurement based on the building's impact over a period of time in the past?

These questions are good ones, with which the green building community is actively wrestling. And in our uniquely human way—full of debate and discourse—they are questions we may be slowly but steadily answering.



2.02 Relative versus absolute greenness.

Relative and Absolute Green

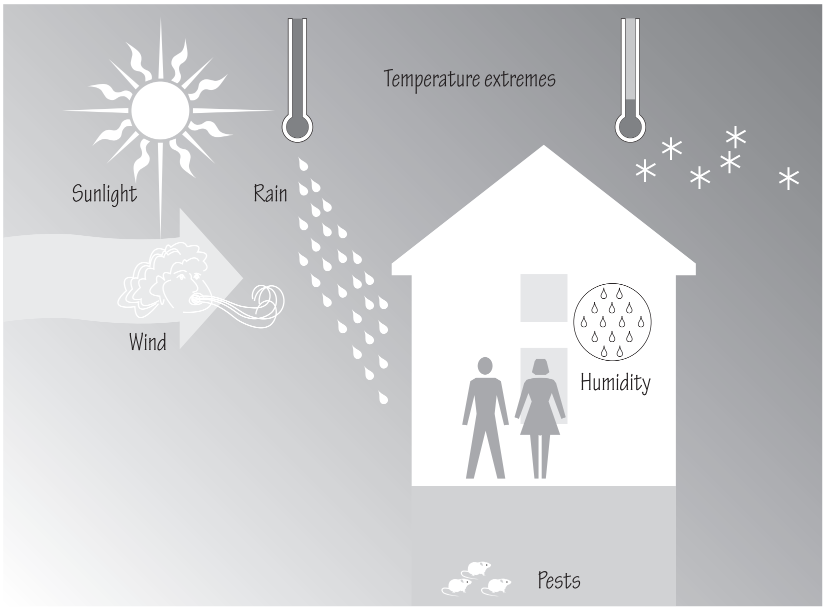
For the question "What baseline should we use?" much can be gained by comparing a proposed green building to a hypothetical building of the same size and shape that might have been designed and built without any green features, but meets current building codes and generally accepted construction standards. Let us call this the relative approach to green building design. The goal here is to have a substantially reduced impact on the environment and provide substantially improved human health, relative to that hypothetical "same building without green building features." However, an important discussion is emerging about whether we should not also be examining absolute measurements of environmental impact and improved health, such as meeting specific goals of energy and water use per unit area of building, or even meeting a goal of zero energy and water use in the building.

In the areas of energy and water, a building's predicted future use has much value and can guide many decisions and standards. A consensus is also developing that actual energy and water use must also be measured, to actively demonstrate conservation rather than relying only on predictions.

Other areas, such as material conservation and indoor environmental quality, are slightly harder to define and measure than energy and water consumption, but we nonetheless have made strides to develop consensus on what constitutes being green in order to set goals and measure our progress toward these goals.

The answer to the question "What is a green building?" will continue to change and evolve, as will our own standards of what impact on the natural environment is acceptable and what level of human health is desirable. In fact, to effectively design and construct green buildings will likely always mean repeatedly asking, "What is a green building?" and continually seeking consensus-based answers to the question.

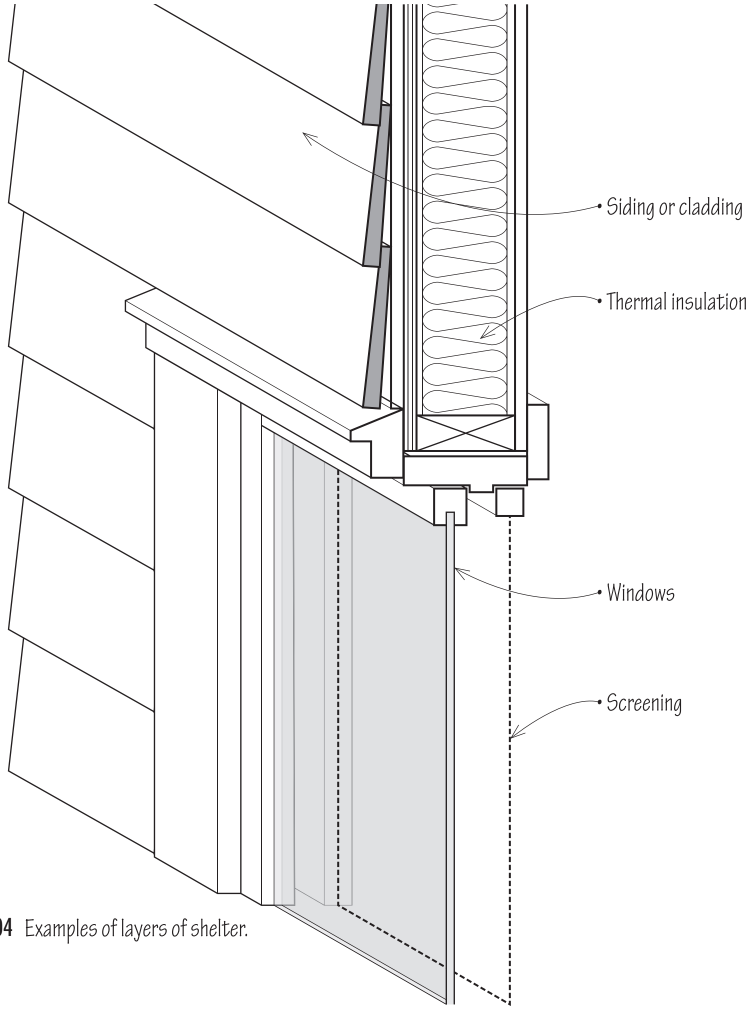
The enterprise of designing and constructing a building is extremely challenging. Thousands of decisions are required to complete any single building, as trade-offs of program, form, quality, cost, scheduling, and regulations are weighed. A green building presents even more challenges, with added constraints and often difficult performance goals to achieve. Designing and building an affordable green building—one that performs well in meeting the needs of its occupants, does not harm the environment, is conducive to good human health, and meets its owner's budget—is the ultimate challenge. Guiding principles can sometimes help to manage how we meet a challenge as large as this.



2.03 Types of loads.

Loads and Layers

Buildings shelter their occupants from a wide variety of outdoor elements, which we might refer to as *loads*. These loads are in some ways stresses or pressures, both on our buildings and on our everyday lives. Important among these loads are temperature extremes, the reason we heat and cool buildings. There are loads other than temperature extremes from which we also seek shelter, such as winds, rain, and sun. We seek protection from the ultraviolet rays of the sun, which can contribute to skin cancer and deteriorate artwork and building materials. Some loads are more subtle in their effects, such as humidity, which can compromise human health and the integrity of our possessions. Some loads are simple, such as darkness. Some loads are living, such as insects, rodents, birds, and other animal life. And some loads result from human activity, such as noise, air, and light pollution.



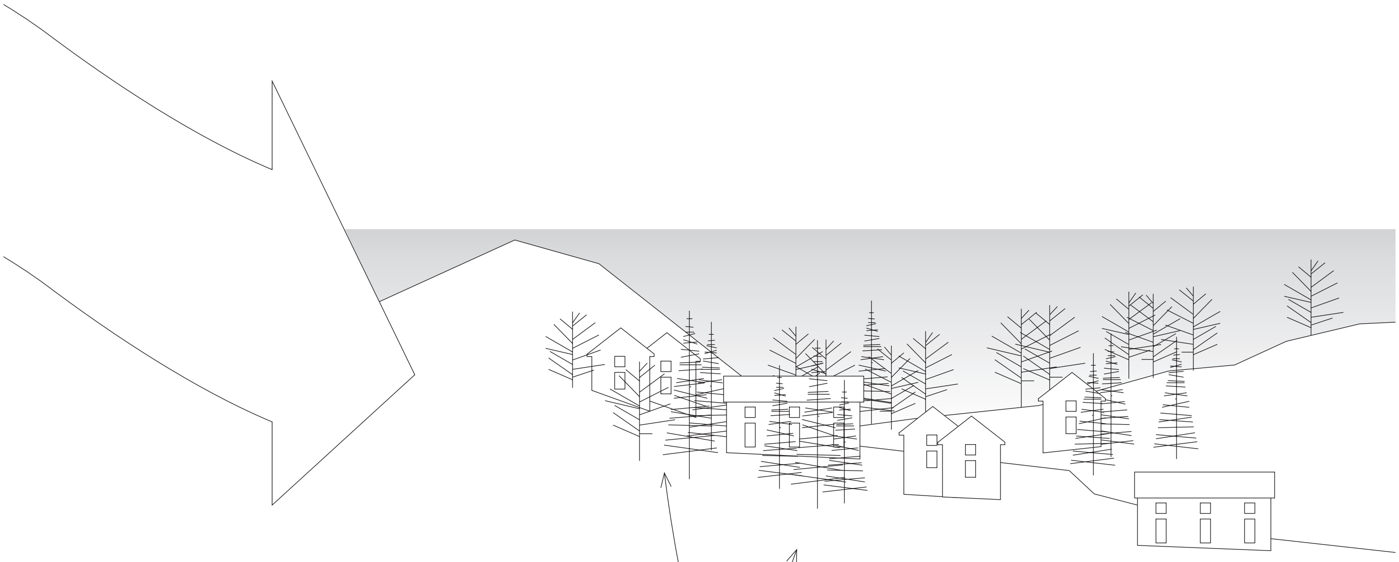
2.04 Examples of layers of shelter.

Buildings are important to us because they are the settings in which we live, work, teach, learn, shop, and congregate for social activities and events. We also recognize that a fundamental and functional role of buildings is to provide shelter from the many loads in our world.

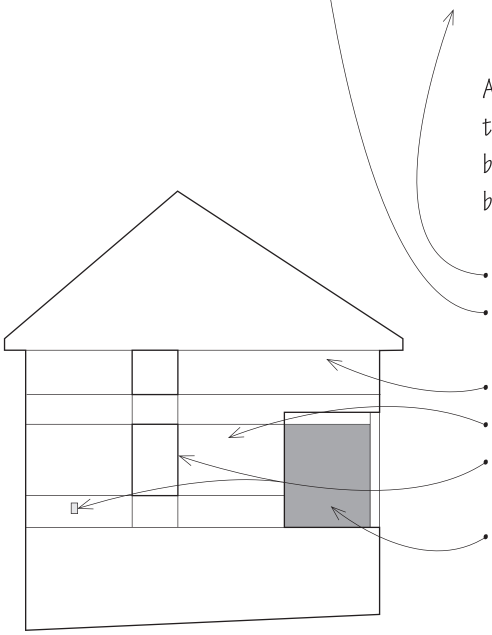
We define a *layer of shelter* as a building component that protects against loads. Thermal insulation in a wall is a layer of shelter that serves to moderate the impact of temperature extremes. The siding or cladding on a building is a layer of shelter that keeps out wind and rain and shields against the effects of ultraviolet radiation and other loads.

Some layers of shelter are intentionally selective, purposefully letting in desired elements while filtering out other loads. For example, windows let in daylight while keeping out hot and cold air. Screens let in fresh air, but keep insects out.

A principle of green design is to use multiple layers of shelter to improve the effectiveness of protection from loads. For example, air infiltration is recognized to be a major contributor to heating and cooling loads in buildings. Air barriers and weatherstripping are better able to resist wind-induced infiltration if the wind has first been slowed by trees or other wind breaks. In other words, trees can serve effectively as a layer of shelter. Likewise, if a wall is well sealed with caulked window frames and gasketed electrical receptacles, infiltrating air is less likely to find paths into the building, as each layer of the wall assembly sequentially contributes to resisting the infiltration.



Another principle of green design is to work from the outdoors, through the various layers of shelter, toward the interior of a building. In the above example, the full spectrum of layers that can be used to protect against wind and air infiltration might include:



- Selecting a site naturally sheltered from wind
- Using trees, fencing, and possibly adjacent buildings as wind barriers
- Installing a continuous form of siding
- Using insulation that resists air movement
- Sealing exterior wall assemblies, as by caulking exterior joints and gasketing electrical receptacles
- Positioning an unheated vestibule to buffer interior spaces

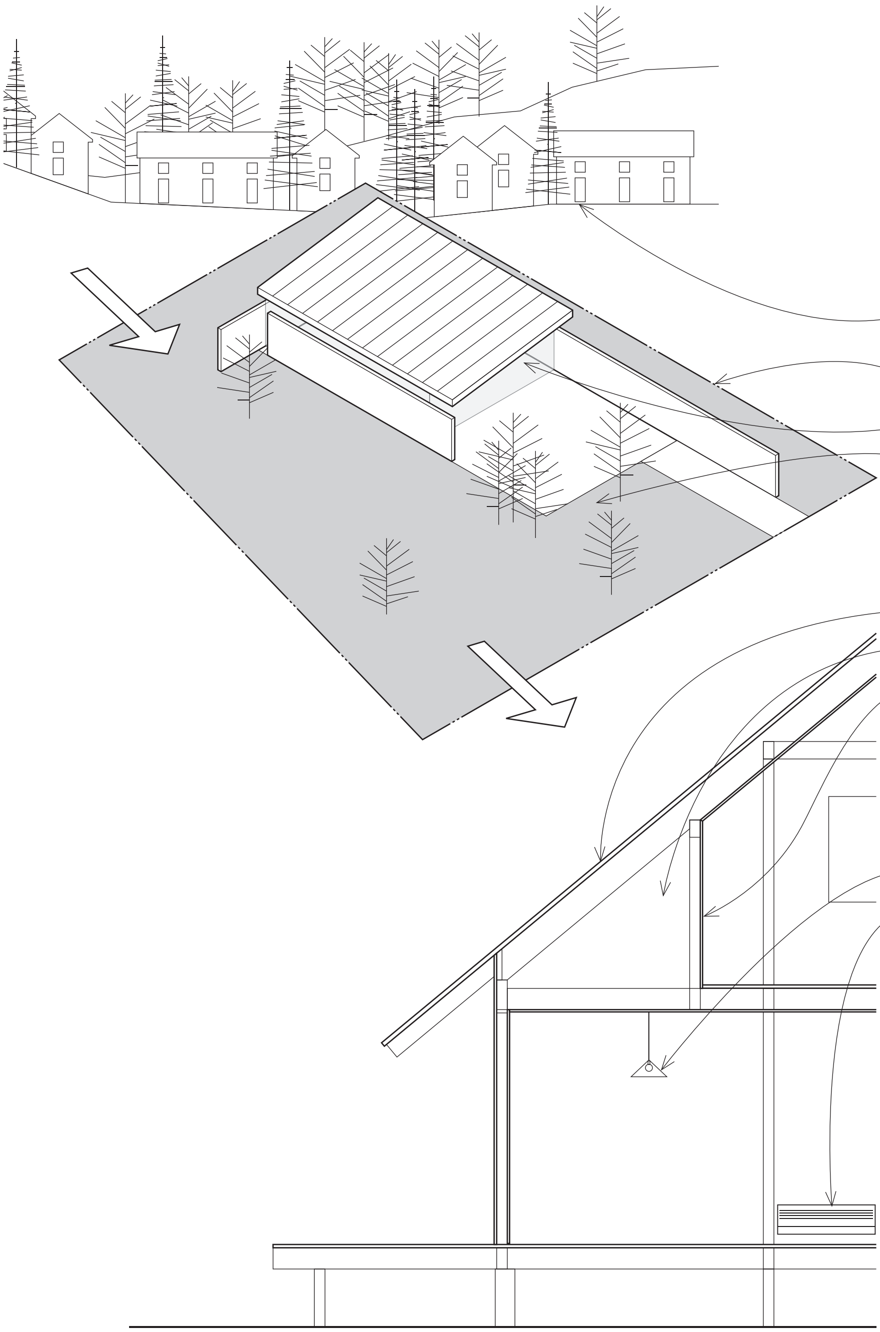
2.05 *Sheltering against wind and air infiltration.*

Starting far from the building and working inward is akin to solving the problem at its source, rather than trying to solve the symptom. If the symptom is a cold, drafty building, solving the symptom would be adding heat, which is simple but inefficient. Solving the problem at its source is reducing wind loads and preventing infiltration through a structured approach with multiple layers of shelter. Working from the outside in is analogous to the medical approach of "prevention instead of pills" when dealing with health issues.

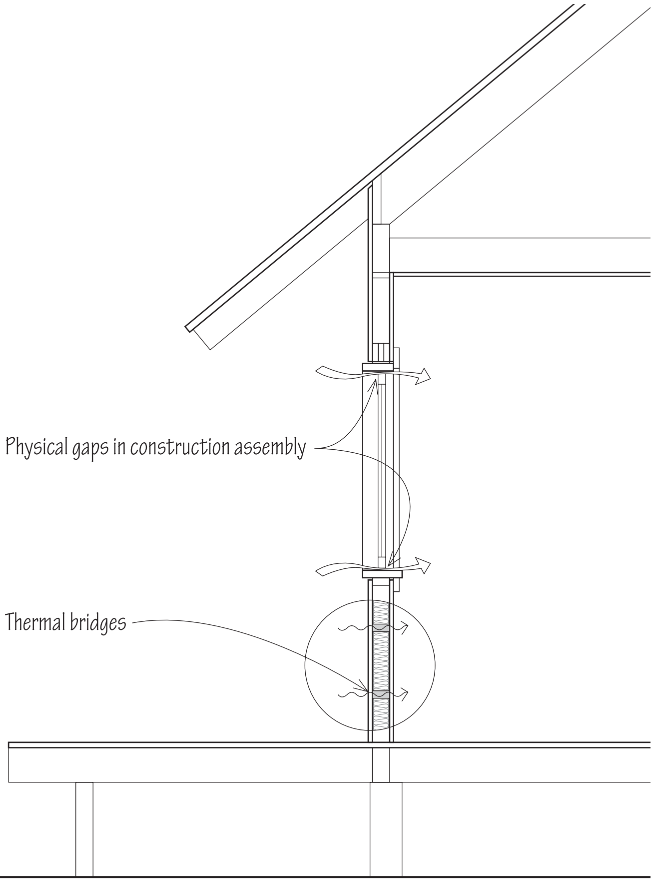
An ordered prioritization of the layers of shelter that can be used to protect a building against loads, working from the outside in, includes:

- Community
- Site
- Building shape
- Near-building features
- Outer building envelope
- Unconditioned spaces
- Inner building envelope
- Thermal zoning and compartmentalization
- Lighting and other electric loads
- Heating and cooling

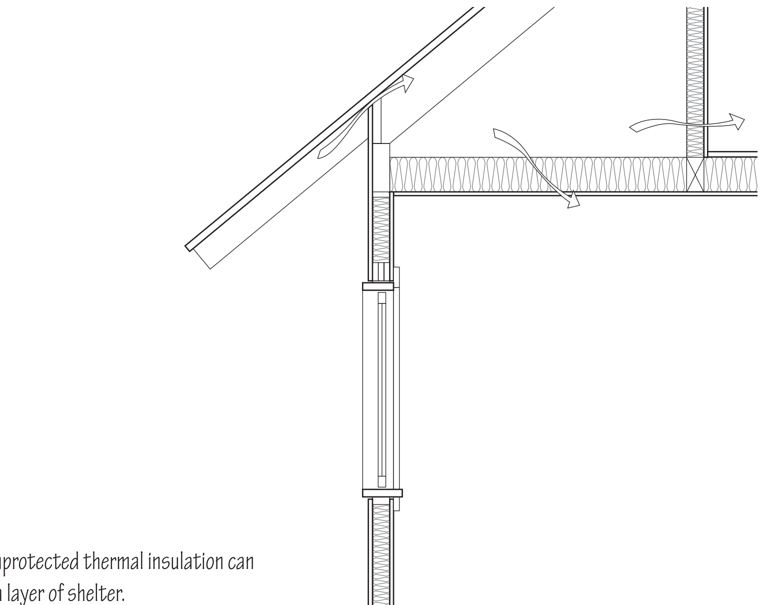
These will be explored in sequence.



2.06 Prioritizing the layers of shelter.



2.07 A weak layer of shelter is one that has many discontinuities, whether they be physical gaps or thermal bridges.



2.08 Unprotected thermal insulation can weaken a layer of shelter.

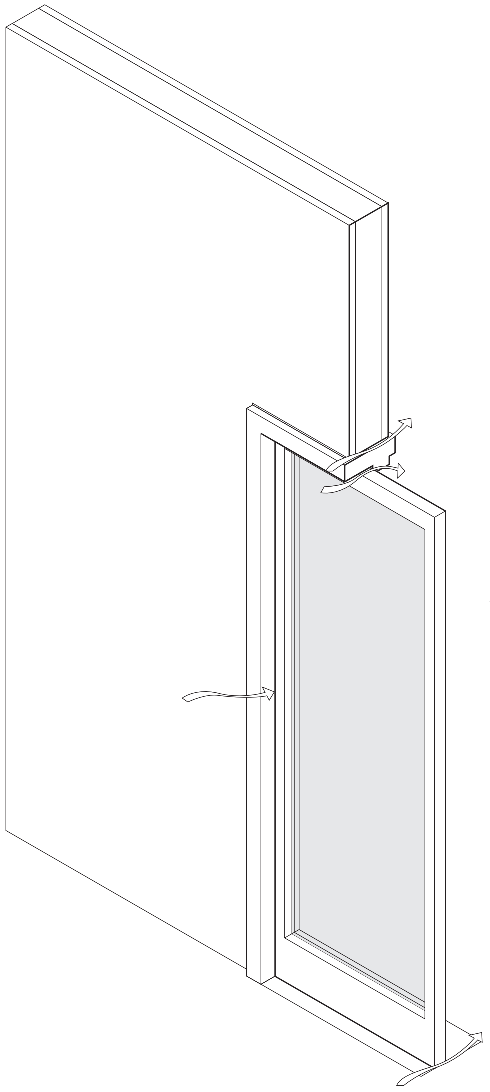
Continuity

Another principle of green design is not only to design strong and robust layers but also to ensure the continuity of each layer of shelter. The importance of continuity for the thermal boundary of buildings has been widely recognized in recent years. Such layers are weakened when they are broken or are discontinuous. Most conventional buildings have many such discontinuities. For example, attic floors of pitched-roof buildings have been found to have such discontinuities as uncapped wall chases; unsealed gaps around light fixtures, exhaust fans, plumbing vents, and chimneys; and leaky attic hatches.

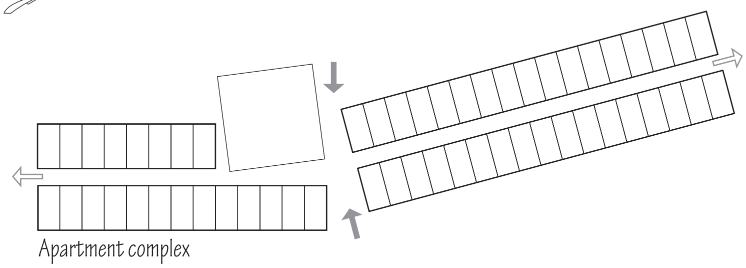
Physical voids are not the only kind of disruptions a thermal boundary can suffer. Discontinuities can also be created by thermal bridges, which are conductive materials that penetrate or interrupt the thermal insulation layer in a wall, floor, or roof assembly. For example, the wood or metal studs in a framed wall can act as thermal bridges, allowing heat to move through the wall.

Walls, floors, and roofs having unprotected insulation only on one side are typically weak layers of shelter. For example, the ceilings of basements or crawlspaces often have insulation that is detached. Knee walls in attics are often insulated only on one side, with the insulation at risk of damage or removal. Even if the insulation stays in place, air can move readily around the insulation to the cold side of the interior wall finish, increasing heat loss in the space.

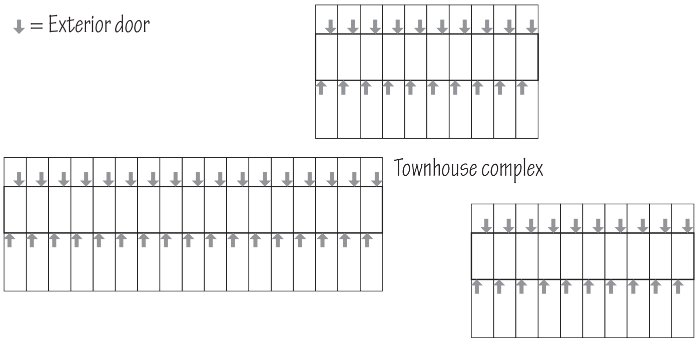
Weak layers are weak from the start. They are intrinsically weak. We define a nonrobust layer as one that may be strong to start, but weakens over time. A well-insulated door, with good weatherstripping, a door sweep, and a storm door, may well start out as a strong layer of shelter. However, over time, the door frame may shift and settle, the door sweep may move out of position, the caulking around the door frame may shrink and crack, the weatherstripping may compress or fall off, and the storm door may not close fully due to a failed spring. A door assembly is intrinsically nonrobust, its wear and tear over time weakening its function as a layer of shelter.



2.09 While walls normally are robust layers, the sheltering layer of doors can weaken over time as their frames shift or settle, caulking shrinks or cracks, or weatherstripping fails.



2.10 Comparison of an apartment complex with interior corridors providing access to units and a layout of townhouses, each with its own set of exterior doors.



A rigid wall is always more robust than a door assembly, serving as a stronger layer of shelter for a longer period of time. Buildings obviously cannot be built without doors, but if the number of exterior doors are in question, the fewer the better. For example, an apartment building with two exterior doors and an interior corridor for access to each unit has fewer exterior doors than townhouses that have one or two exterior doors for each apartment.