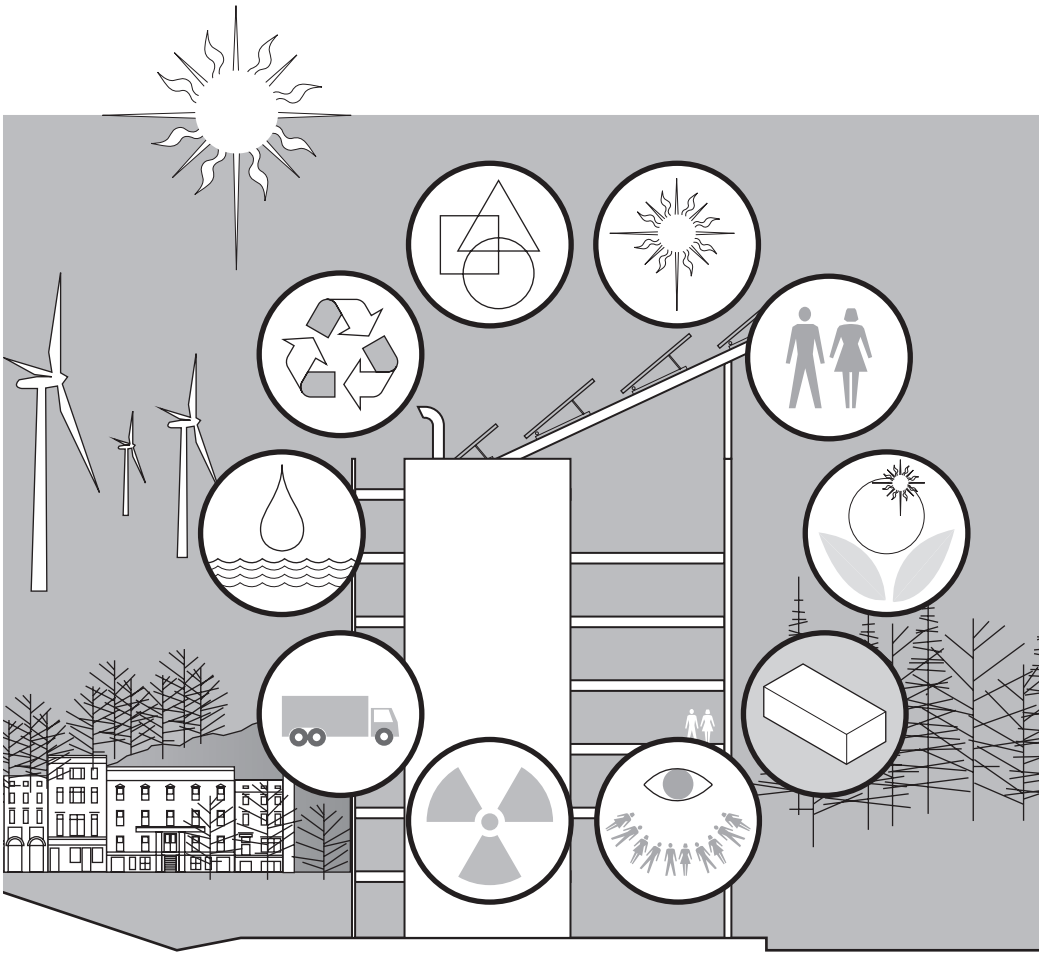
# Green Building *Illustrated*



Francis D. K. Ching
Ian M. Shapiro

WILEY

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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.

Designing and constructing buildings is 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

First, 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 Paul Drougas at Wiley for his thoughtful editorial input. 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 x 4 is converted to 51 x 100 even though its actual 1 1/2" x 3 1/2" dimensions would be converted to 38 x 90.
- Note that 3487 mm = 3.487 m.
- In all other cases, the metric unit of measurement is specified.

# 1
# Introduction

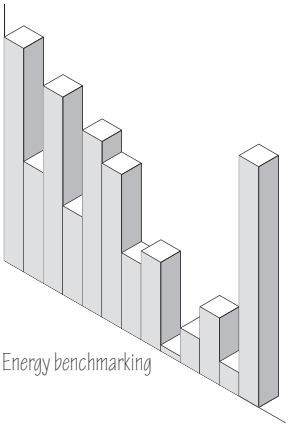
In the span of a few years, the planning, design, and construction fields have been swept up in a dynamic discussion of sustainability and green buildings. In design studios and on construction sites, we are learning to share new goals and new standards and even a new language. For many, our professional 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.

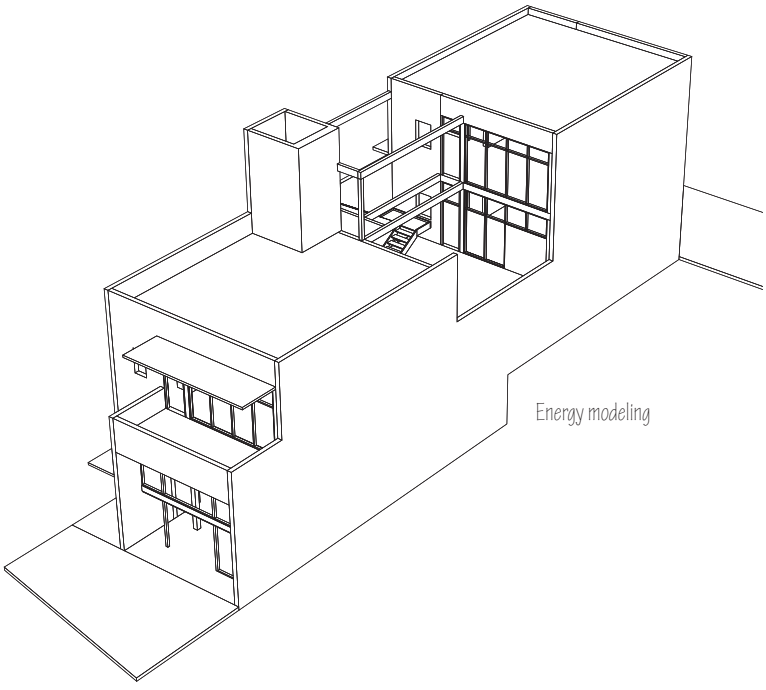
Parallel to the promises of sustainability, and even calling for their fulfillment, is the insistent reminder of scientists who caution about environmental hazards, hazards that are increasingly affirmed by our own observations. However, there is something deeply empowering in not shying away from these 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.



Infrared thermography



Energy benchmarking



Energy modeling

**1. 07** Each year new approaches, new tools, and new products become available, offering ways to reduce energy and material use in buildings.

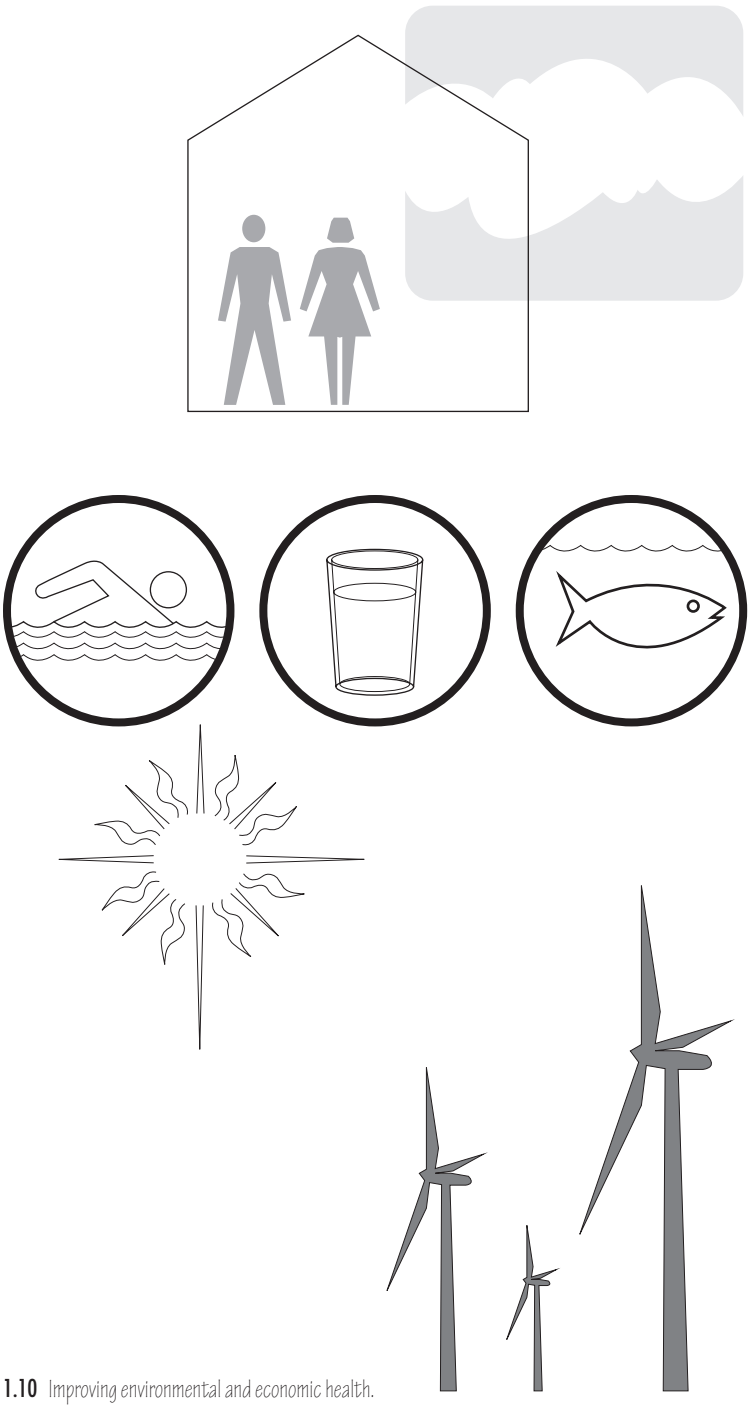
## New Information, New Risks, New Opportunities

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.



**1.10** Improving environmental and economic health.

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.

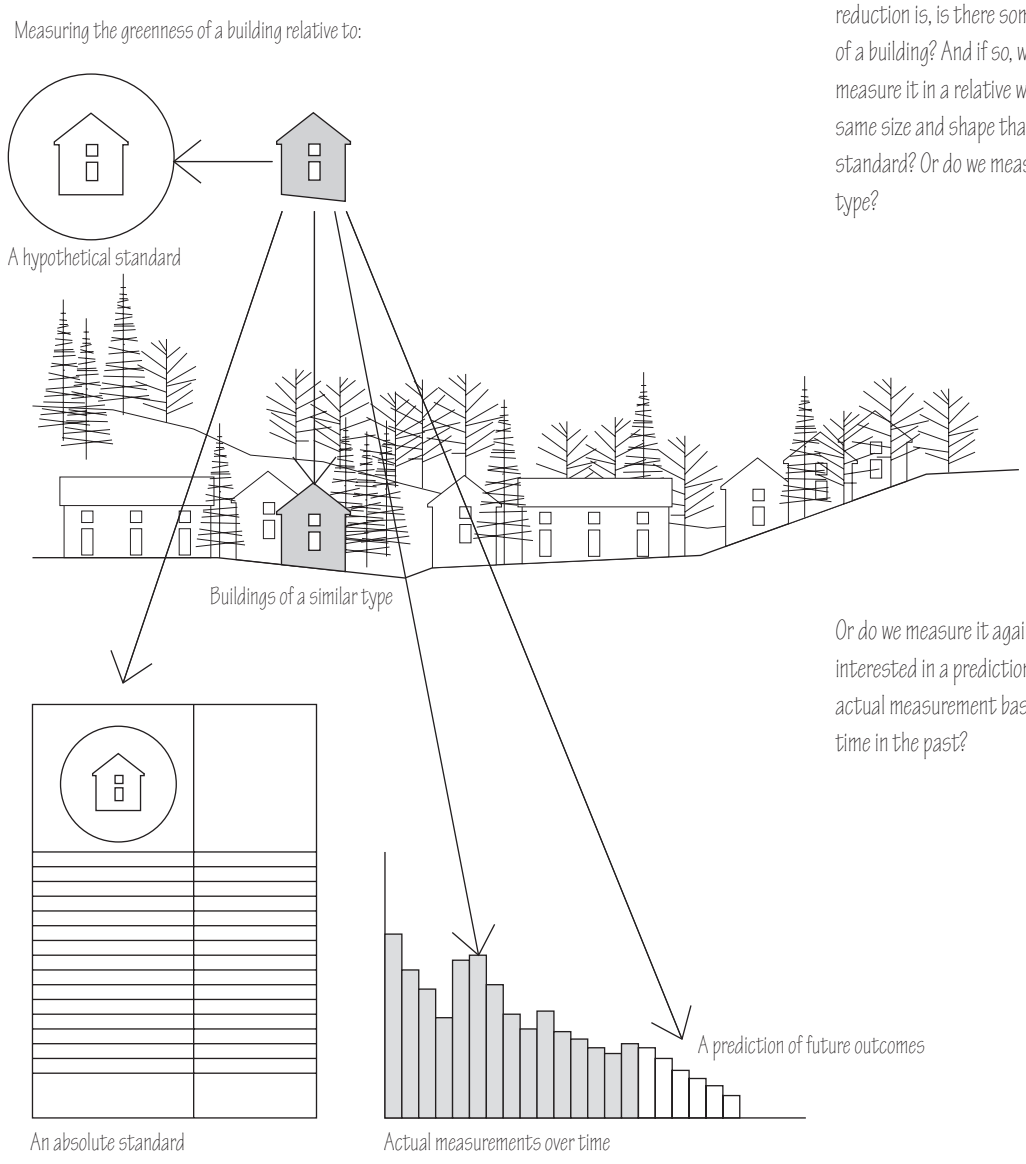
# 2
# First Principles

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?




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?

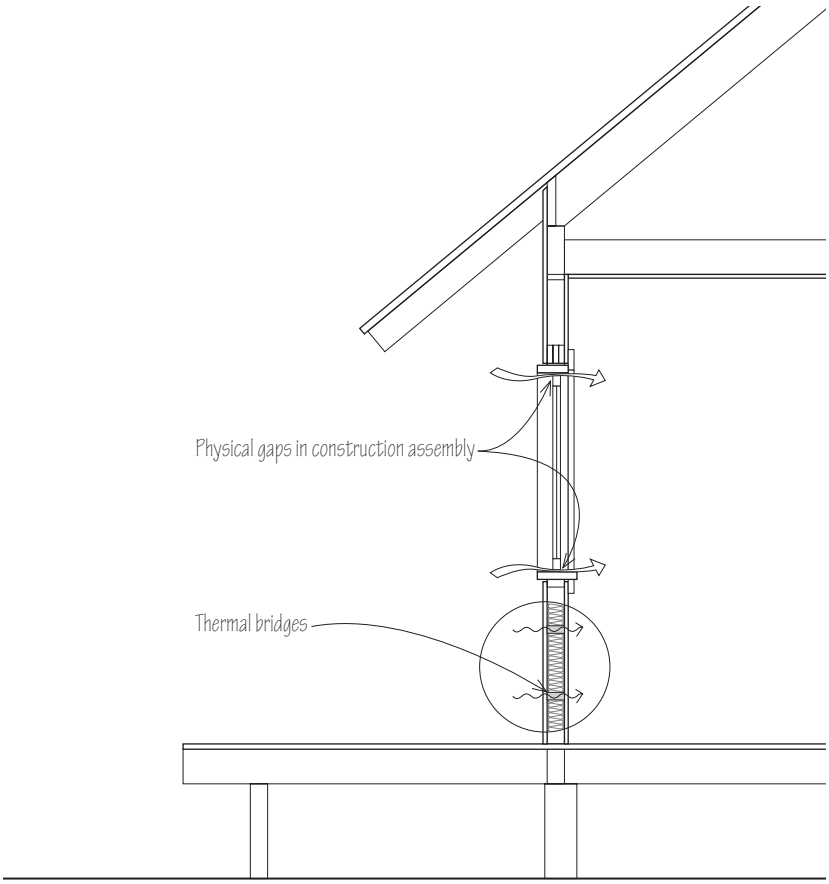
**2.01** How should we gauge the greenness of a building?

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.

## Continuity

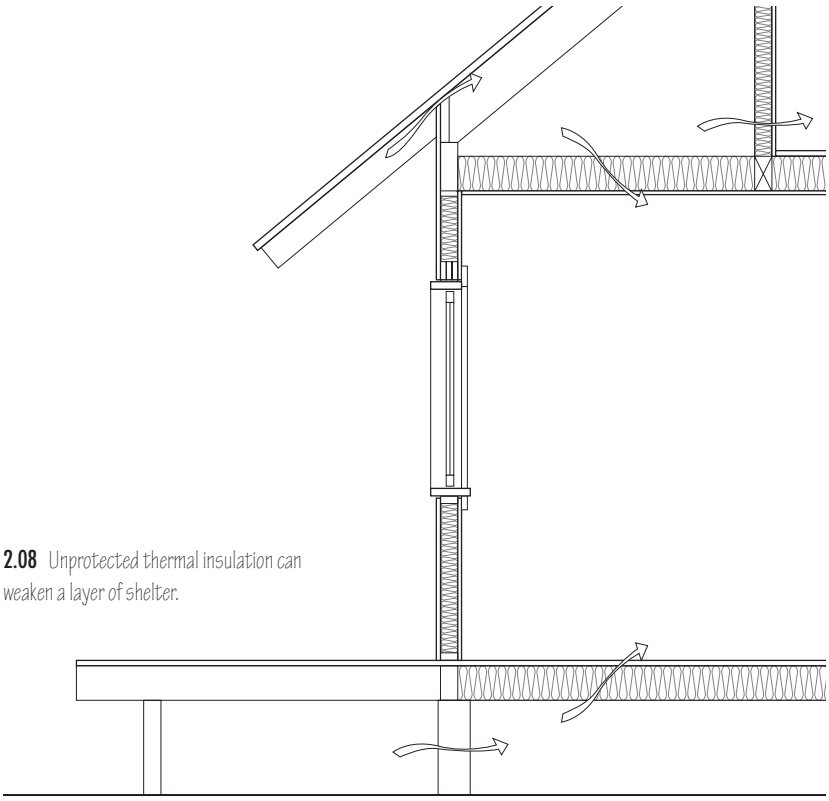
Another principle of green design is to not only design strong and robust layers but also ensure the continuity of each layer of shelter. The importance of continuity for the thermal boundary of buildings has been widely recognized in recent years. Such layers are weakened when they are broken or are 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.




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

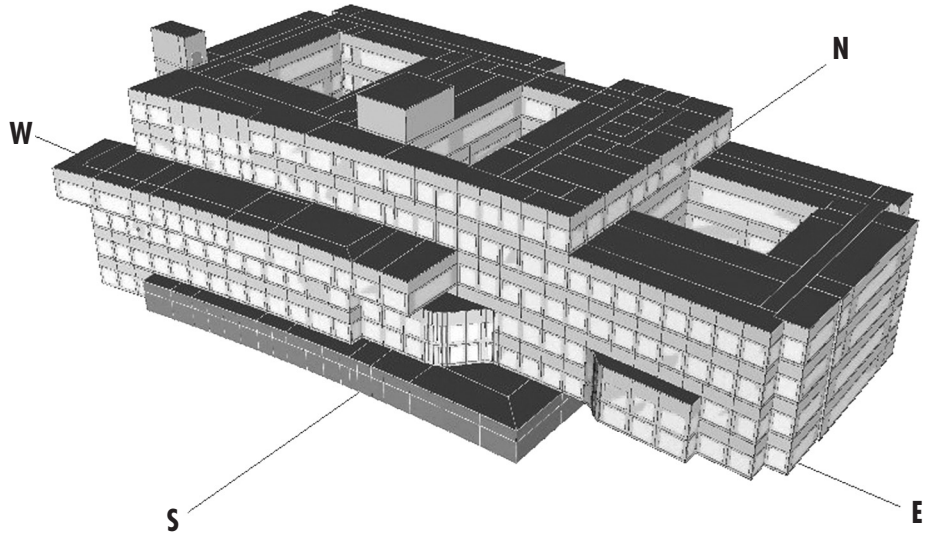
Walls, floors, and roofs having unprotected insulation only on one side are typically weak layers of shelter. For example, the ceilings of basements or crawlspaces often have insulation that is detached. Knee walls in attics are often insulated only on one side, with the insulation at risk of damage 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.



**2.08** Unprotected thermal insulation can weaken a layer of shelter.

## Energy Modeling

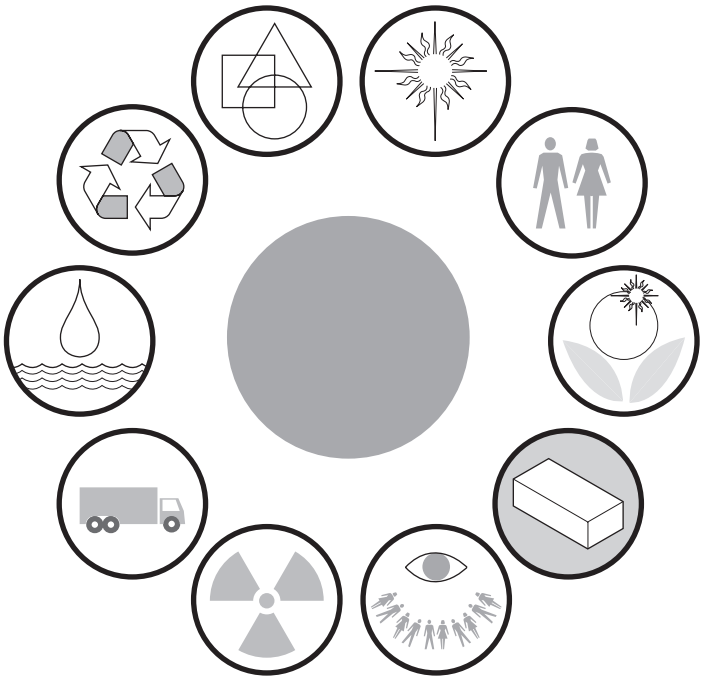
As building designs are refined, it is relatively easy to examine tradeoffs using energy models of proposed buildings. Tradeoffs of wall design, window design, building shape, heating system selection, and other schematic design parameters are readily prepared in less than a day. More advanced energy models, which can examine detailed tradeoffs of such systems as daylighting or energy controls, take longer to prepare and interpret, but are still often worthwhile when compared to the future costs of energy use over a building's life. There is no longer the need for speculation in refining building designs to achieve energy efficiency. Energy modeling should be regarded as essential for green building design.




**2.14** VA Mental Health and Research Complex, Seattle, Washington, Stantec Architecture and Consulting. Energy modeling uses computer software to analyze a building's numerous thermal components, including the materials of the walls and the rest of the building envelope; the size, shape, and orientation of the building; how the building is occupied and operated; the local climate; system performance; and energy use over time.

# 3
# Codes, Standards, and Guidelines

A variety of green building codes, standards, and guidelines have been developed in recent years. Each of these reflects an invaluable commitment to protecting the environment and human health. Each reflects slightly differing views and values. Each has nudged the green building endeavor forward. And each, like all of we humans, is probably in some ways imperfect.

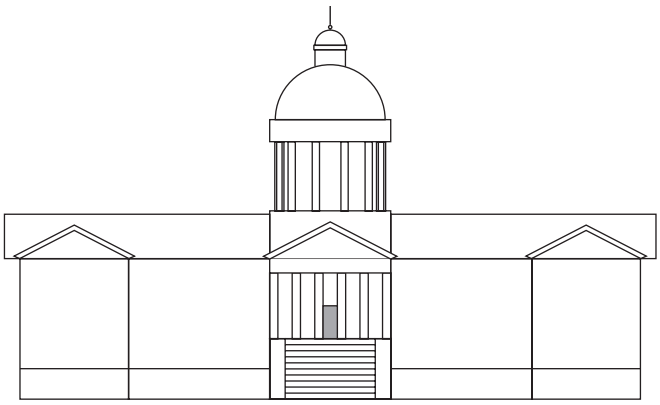


## Guidelines

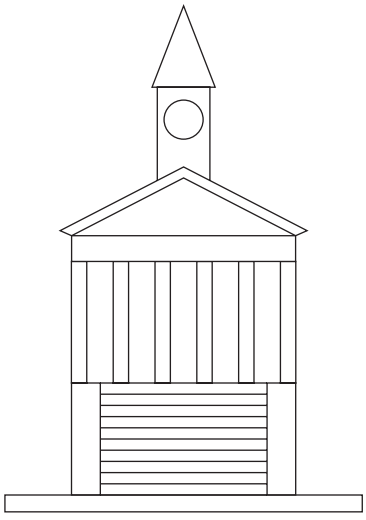
A number of green building guidelines have been developed by federal and state agencies, universities, nongovernmental organizations, private companies, and even local municipalities.

An example of a green guideline is the *Residential Environmental Guidelines*, developed by the Hugh L. Carey Battery Park City Authority in New York City, written in 1999 and first published in 2000. Like the LEED certification program, the guidelines address energy efficiency, enhanced indoor environmental quality, conserving materials and resources, water conservation, and site management. A section on education, operations, and maintenance is also included.

Some guidelines are limited to a specific area of green design. An example is the Sustainable Sites Initiative, developed by the American Society of Landscape Architects (ASLA), the Lady Bird Johnson Wildflower Center at The University of Texas at Austin, and the United States Botanic Garden. Modeled on the LEED certification program, these guidelines more deeply explore environmentally sensitive sites, addressing the benefits of various ecosystem services such as pollination, articulating a strong host of principles for green sites, and then laying out an extensive set of best practices through the usual set of prerequisites and credits in a scoring system.



State governments



Municipalities

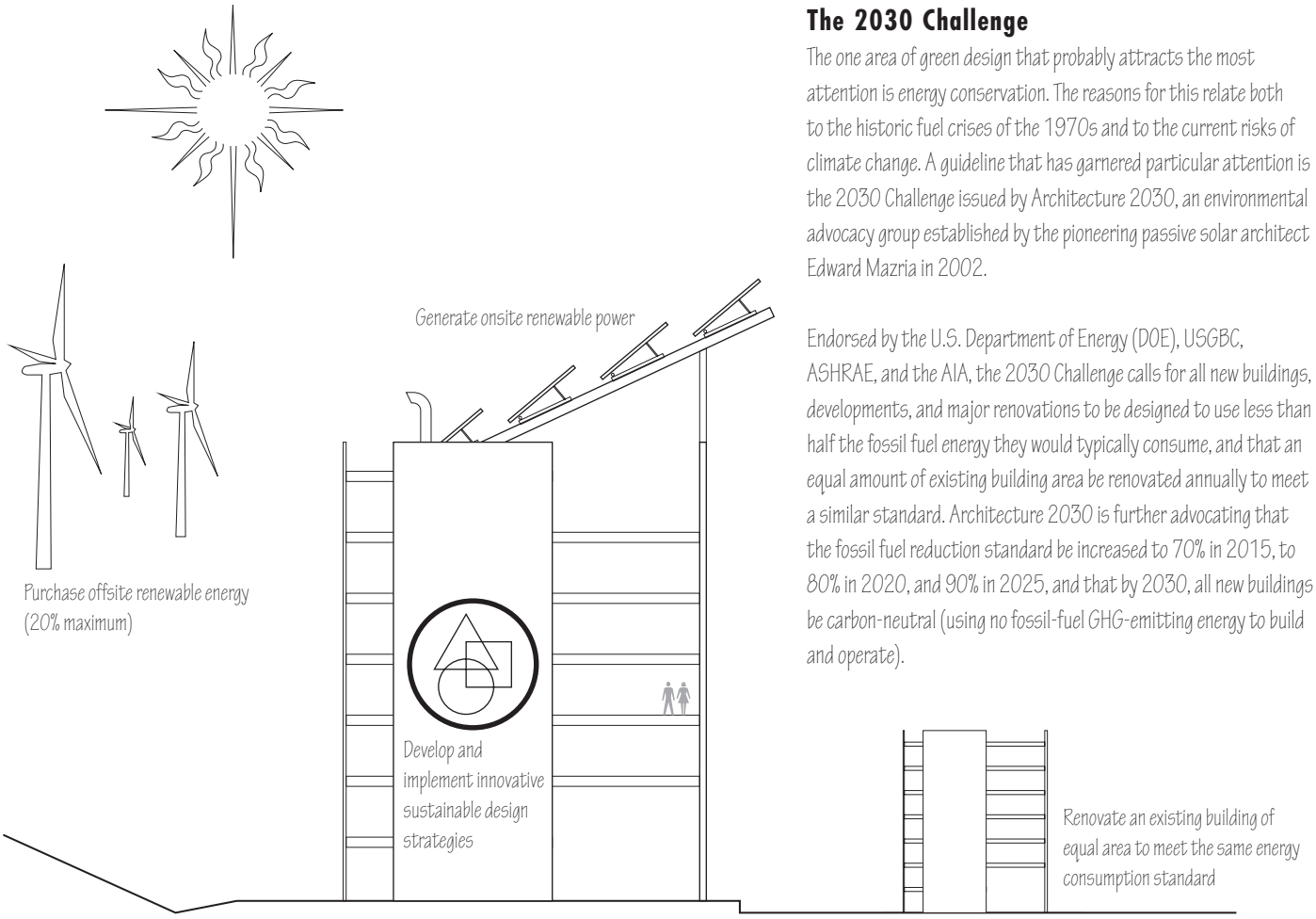


Universities



Developments

**3.10** Entities using customized green building guidelines.

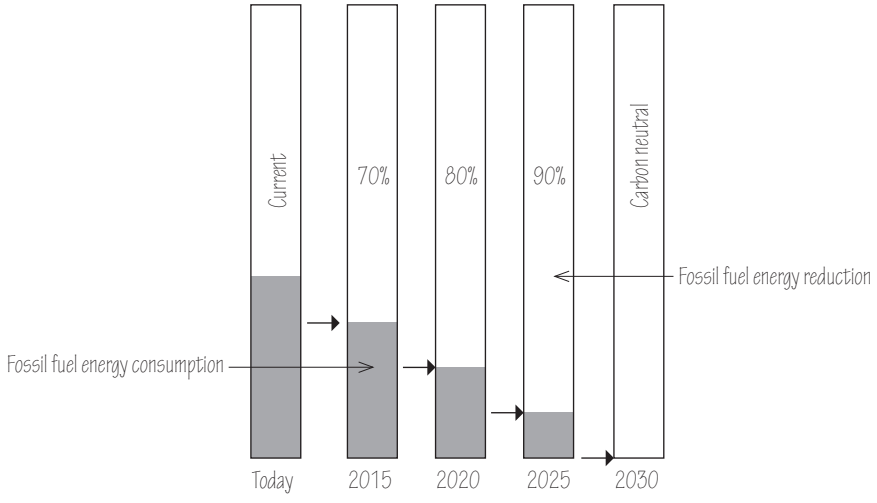



**3.11** Strategies for slowing and eventually reversing the growth rate of greenhouse gas emissions from the burning of fossil fuels.

## The 2030 Challenge

The one area of green design that probably attracts the most attention is energy conservation. The reasons for this relate both to the historic fuel crises of the 1970s and to the current risks of climate change. A guideline that has garnered particular attention is the 2030 Challenge issued by Architecture 2030, an environmental advocacy group established by the pioneering passive solar architect Edward Mazria in 2002.

Endorsed by the U.S. Department of Energy (DOE), USGBC, ASHRAE, and the AIA, the 2030 Challenge calls for all new buildings, developments, and major renovations to be designed to use less than half the fossil fuel energy they would typically consume, and that an equal amount of existing building area be renovated annually to meet a similar standard. Architecture 2030 is further advocating that the fossil fuel reduction standard be increased to 70% in 2015, to 80% in 2020, and 90% in 2025, and that by 2030, all new buildings be carbon-neutral (using no fossil-fuel GHG-emitting energy to build and operate).




**3.12** Targets set by the 2030 Challenge.

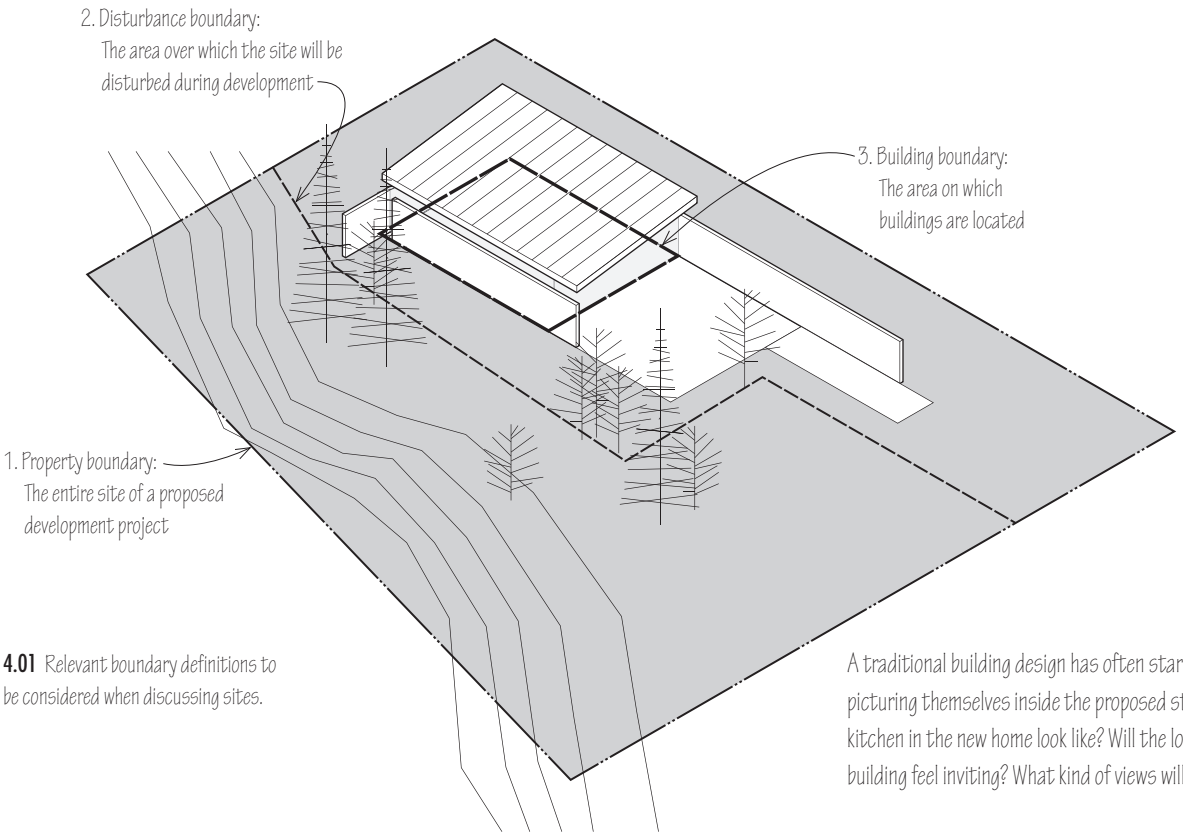
# 4
# Community and Site

The community in which we build, and the site on which we build, can inform and influence every aspect of the building we choose to build.

Primary goals in community and site selection for green buildings include protecting sensitive sites, preserving undeveloped sites, restoring and reusing previously developed sites, reducing impact on flora and fauna, promoting connection to community, and minimizing transportation impacts both on the environment and energy use.

Implicit in these goals is a deep reverence for the natural and the wild and the search for a balance between developed and undeveloped areas, rather than viewing natural areas merely as resources for human settlement. At the same time, we have to pay attention to reducing light pollution, minimizing construction waste, managing storm water, and curtailing site water use.

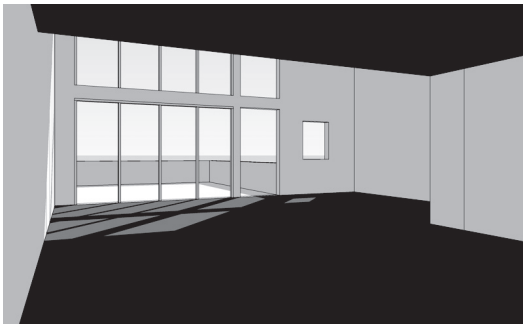
Interestingly, at this early phase of a project, options are available to substantially reduce energy and water use, as well as improve indoor environmental quality inside the future building itself. These options, which have an impact on what happens inside a building by what is done outside, will be explored in some detail and form the beginning of a theme that will run throughout this book.




**4.01** Relevant boundary definitions to be considered when discussing sites.

A traditional building design has often started with the owners picturing themselves inside the proposed structure. What will the kitchen in the new home look like? Will the lobby of the new office building feel inviting? What kind of views will the corner office offer?

With green design, we take a different approach. Instead of imagining ourselves inside the unbuilt building, we begin our journey by picturing the building in a community. Where will the building be located, relative to schools, workplaces, and community centers? What will the transportation options be? Is public transportation available as an option?

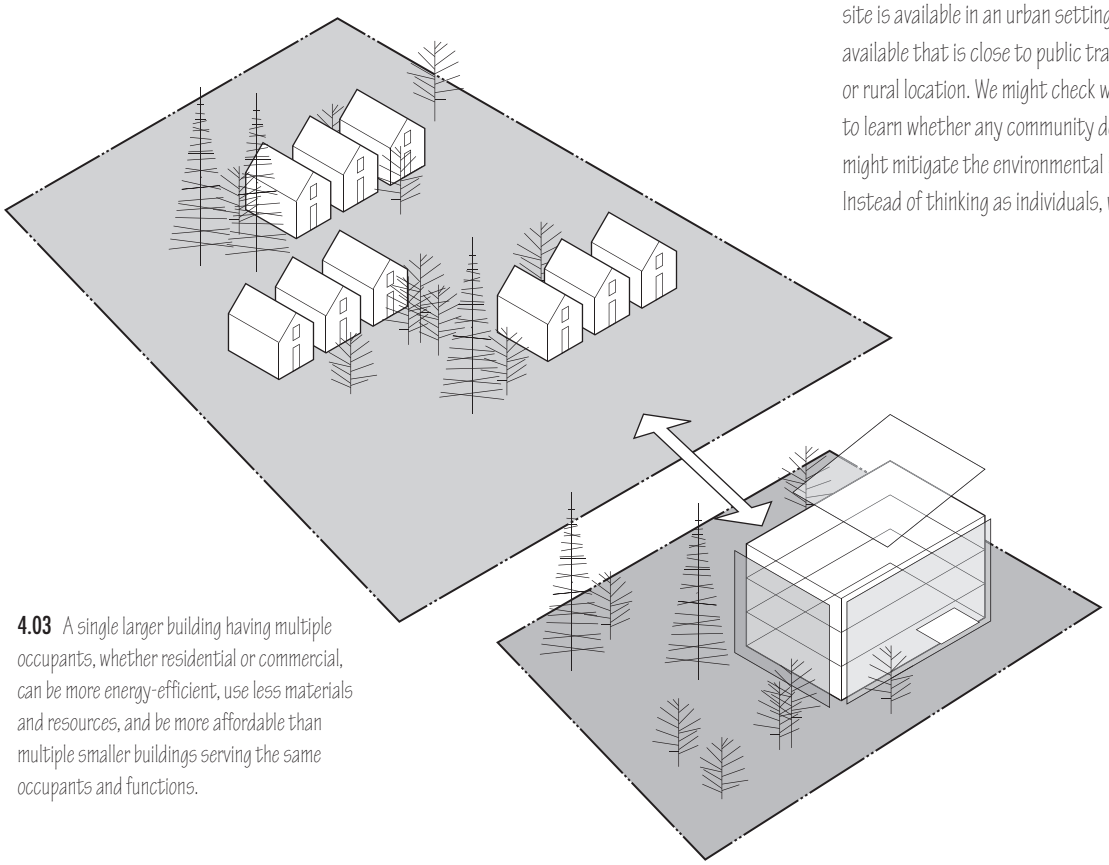


Working from the inside out



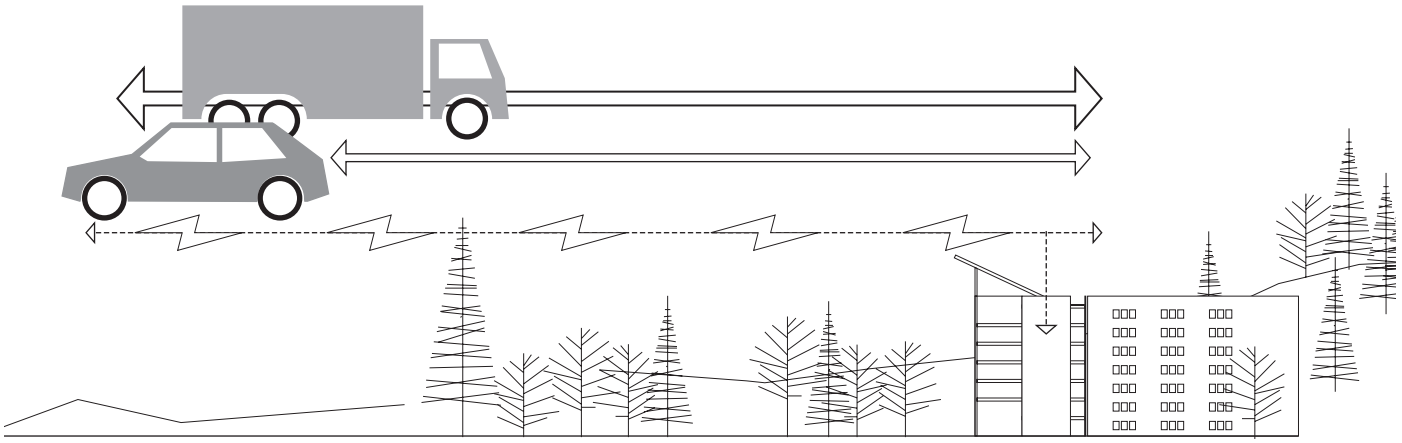

**4.02** Approaching the design of a building from the outside in—with a view of its place in a community—instead of from the inside out

As we seek to picture the building in a community, we ask whether renovating a derelict building downtown might be a better option than building on an undeveloped rural site. We ask whether an infill site is available in an urban setting. Or we ask whether a site is available that is close to public transportation, even if in a suburban or rural location. We might check with our local planning department to learn whether any community developments are under way that might mitigate the environmental impact of the new construction. Instead of thinking as individuals, we try to think as a community.

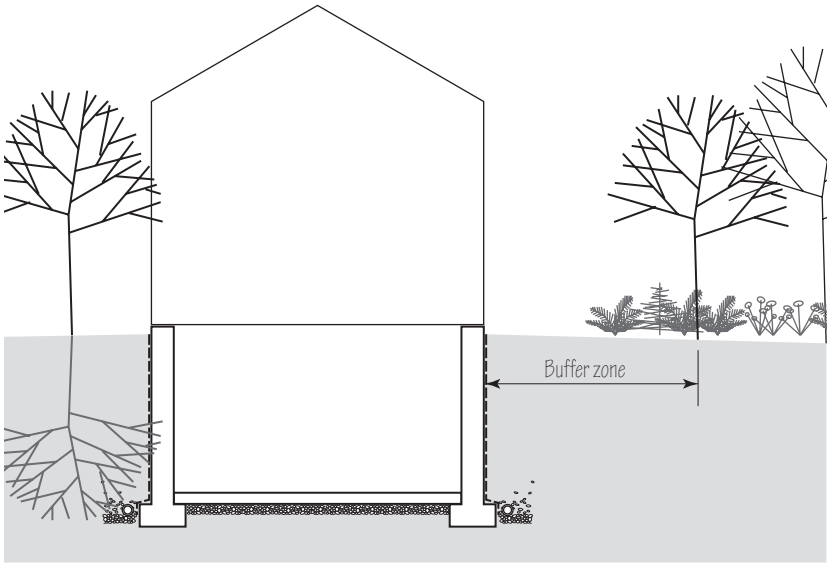


**4.03** A single larger building having multiple occupants, whether residential or commercial, can be more energy-efficient, use less materials and resources, and be more affordable than multiple smaller buildings serving the same occupants and functions.

Residents of a building are not the only energy users whose consumption depends on the building's location. The energy use of people providing delivery and other services also varies, depending on the distance of a building from community and work centers. Also, the energy requirements for both pumping water and transporting electricity increase with buildings located farther from a centralized community.



**4.04** Energy is expended for transportation—for both commuting and deliveries—and utilities transmission to distant sites.



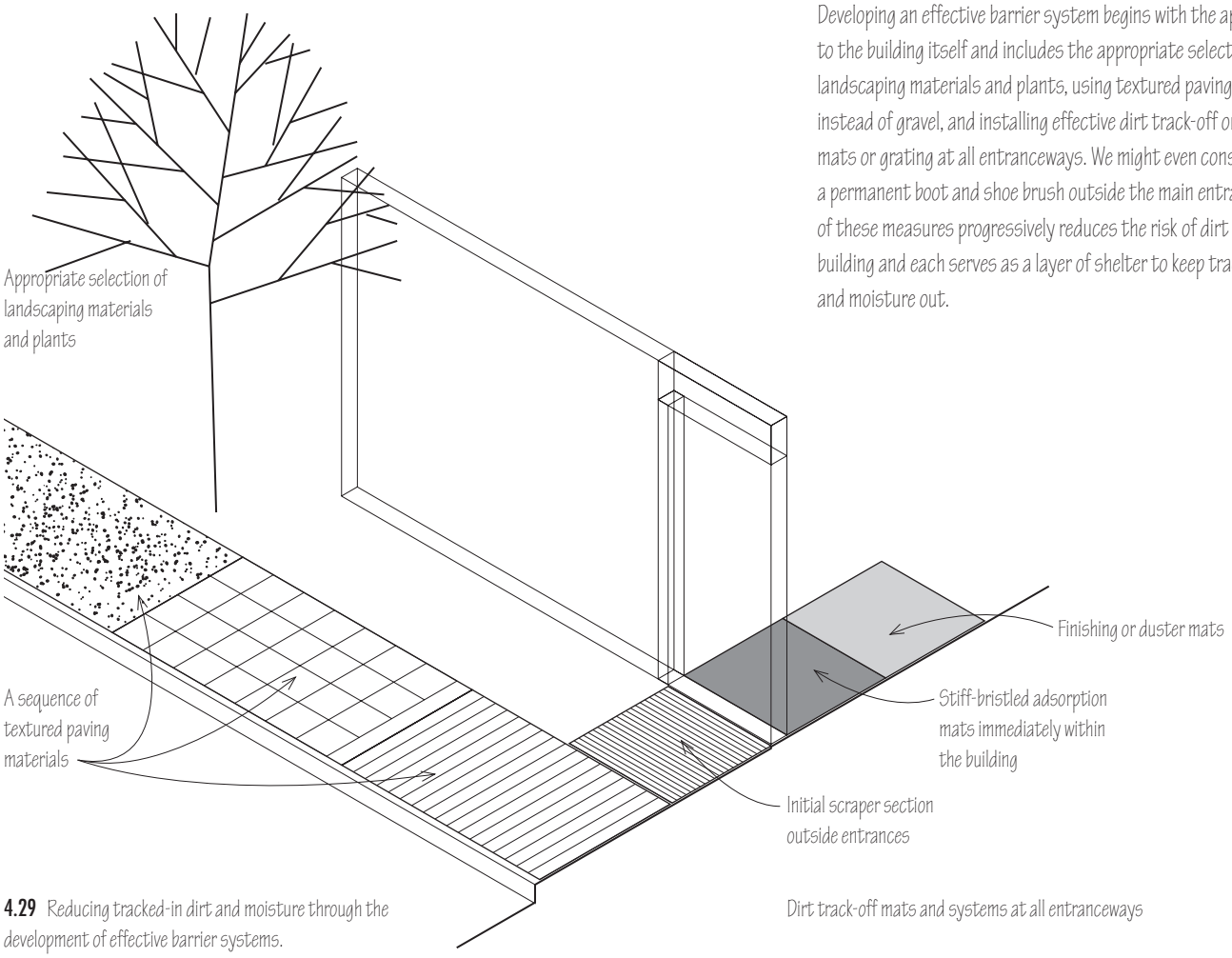

**4.28** A buffer zone between a building and the surrounding vegetation is advisable when the root and branch systems of trees and brush can damage and penetrate the building envelope.

## Other Site Issues

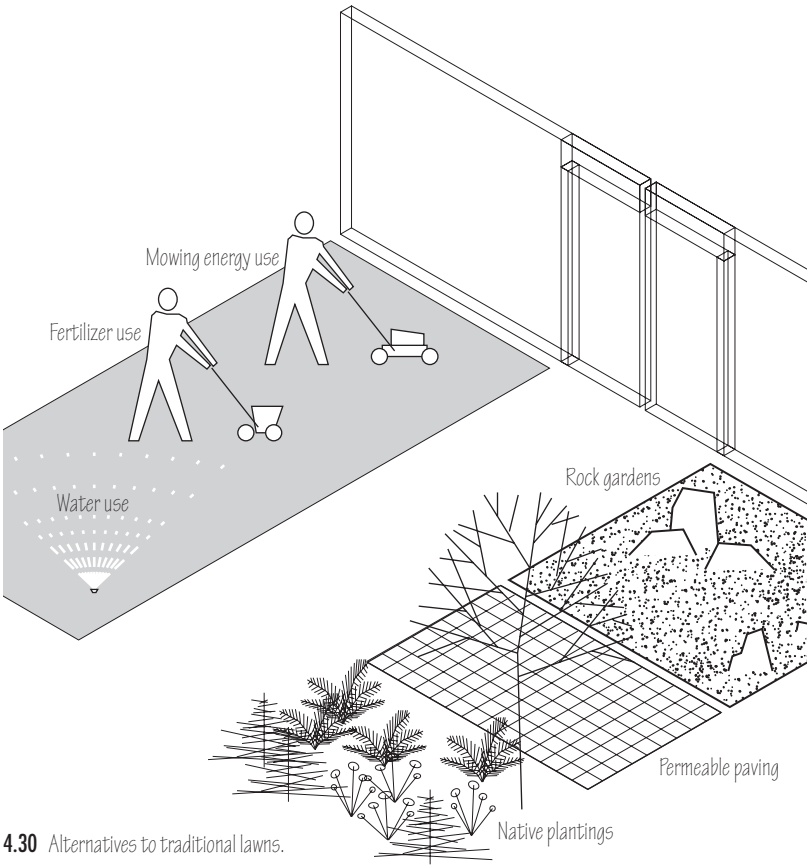
Interestingly, trees and other vegetation, which can be so helpful for shading and protecting a building from the energy effects of sun and wind exposure, can adversely contribute to high humidity and other indoor environmental problems if located too close to buildings. Trees and vegetation can also threaten a building's structure with their roots and branches. Vines can penetrate storm windows, separate windows from their frames, and do extensive damage to siding and roofs on buildings. Buildings need a buffer zone to protect them from such vegetation and this buffer zone serves as a layer of shelter. The one exception may be purposefully vegetated roofs, which provides protection in the form of reducing heat island effects, lessening storm water runoff, and absorbing carbon dioxide in the air. The subject of green roofs is covered in Chapter 7, Outer Envelope.

Green site design can also promote indoor environmental quality by protecting a building from the dirt and moisture that can be tracked in on the footwear of its occupants.

Developing an effective barrier system begins with the approaches to the building itself and includes the appropriate selection of landscaping materials and plants, using textured paving materials instead of gravel, and installing effective dirt track-off or walk-off mats or grating at all entranceways. We might even consider placing a permanent boot and shoe brush outside the main entrance. Each of these measures progressively reduces the risk of dirt reaching the building and each serves as a layer of shelter to keep tracked-in dirt and moisture out.



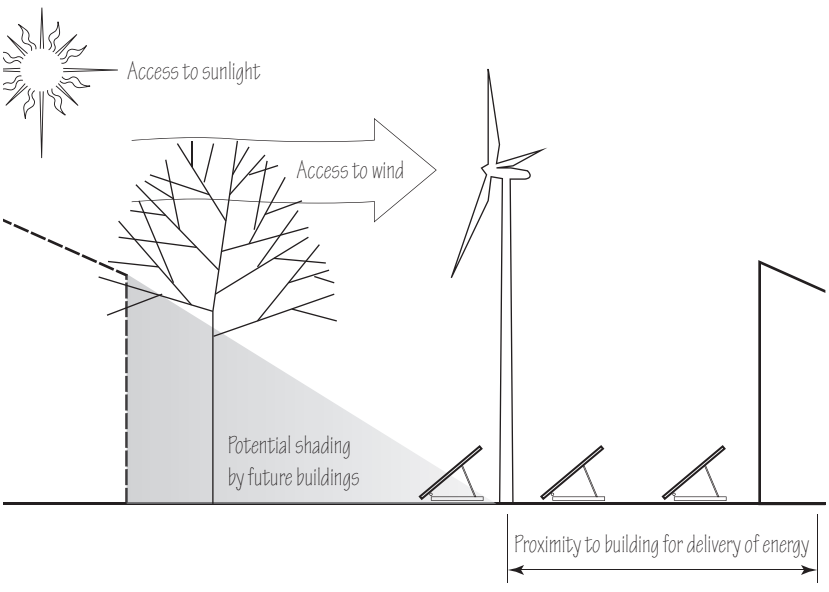

**4.29** Reducing tracked-in dirt and moisture through the development of effective barrier systems.




**4.30** Alternatives to traditional lawns.

If closed-loop geothermal heat pumps are under consideration, early evaluation of soil conditions should be undertaken to fully evaluate the efficacy of such heat pumps. For example, if soil heat transfer characteristics are poor, a larger well field would be required and the cost of a closed-loop geothermal heat pump system will be higher.

The question arises whether traditional lawns are appropriate for green building sites. Lawns are often maintained with fertilizers, pesticides, and other chemicals. Lawns require irrigation in dryer climates and require energy-intensive mowing. Rock gardens, native vegetation, and permeable paving provide alternatives to traditional lawns.




**4.31** Site considerations for wind turbines and ground-mounted solar panels.

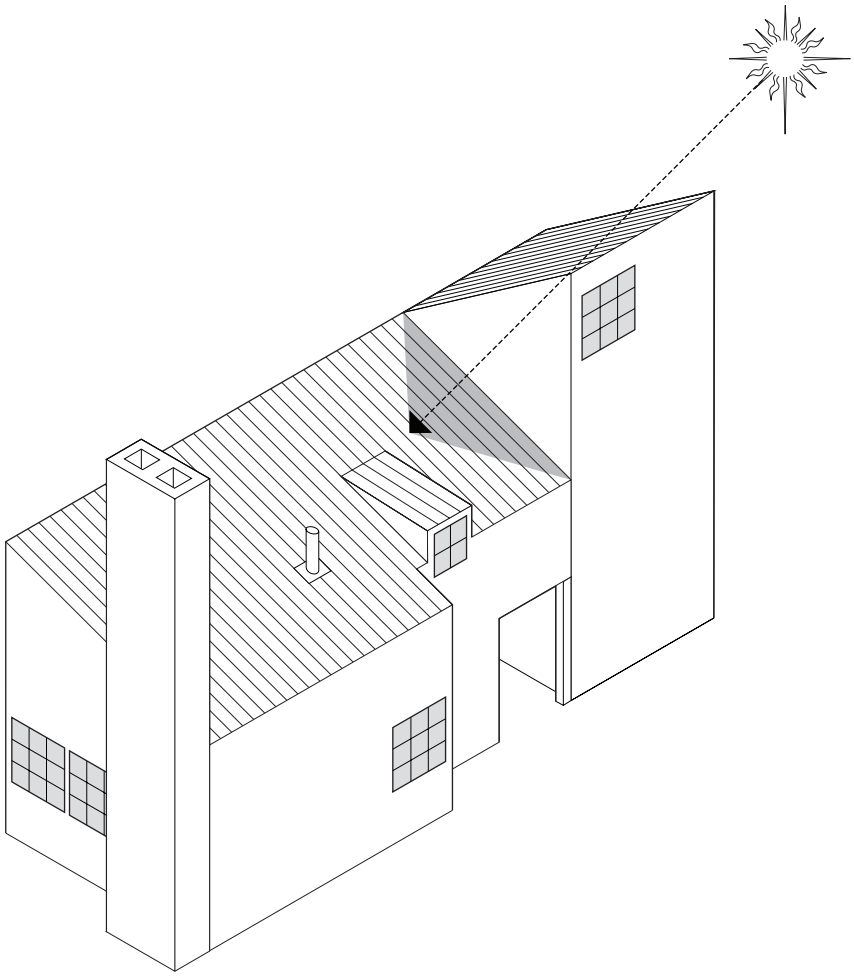
## Site and Renewable Energy

A final note regarding sites relates to renewable energy. For a variety of reasons, the best location for solar panels is on roofs. If, however, a roof cannot accommodate solar panels, one option is to locate ground-mounted panels on the site. Site planning for solar panels must include shading studies, including anticipation of potential shading by trees and adjacent buildings. If we plan on shielding a building from wind with tree plantings, they can be located at a sufficient distance from buildings so as to not shade solar panels.

Similarly, if wind turbines are being considered, the best time for a feasibility study is during the site selection and planning phase. Locating ground-mounted solar panels and wind turbines must also take into account their distance from the building to keep trenching and wiring costs reasonable. Finally, the aesthetics of ground-mounted renewable energy components can be sensitive and should be weighed through renderings early in the site design process.

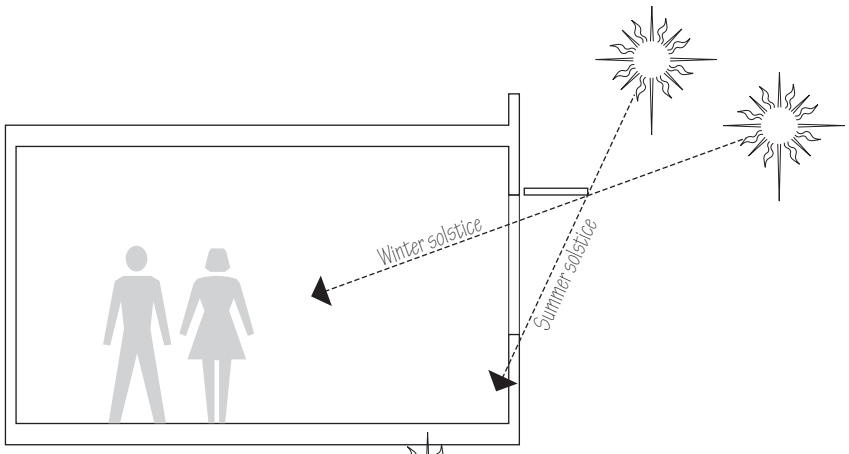
# 6
# Near-Building Features

Near-building features include such structures and devices as overhangs, awnings, solar panels, balconies, and shutters. Many of these features can be usefully applied as added layers of shelter. If misapplied, however, some near-building features can inadvertently increase energy use in buildings.

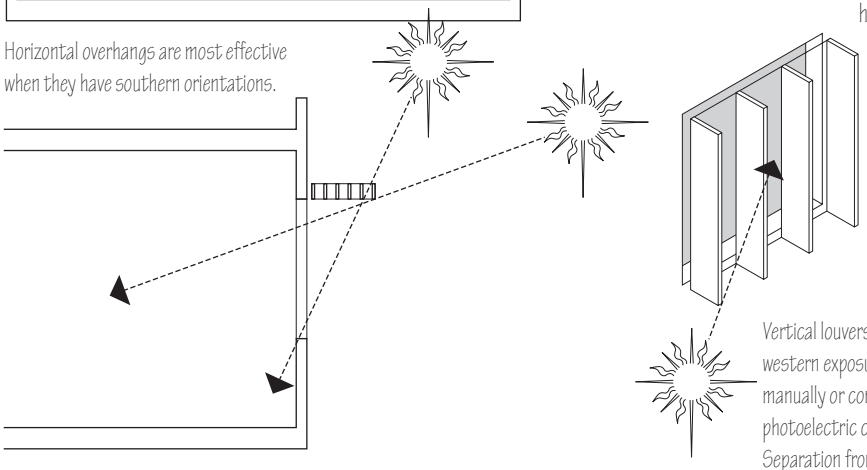


## Overhangs and Awnings

Overhangs and awnings that face east, south, or west reduce solar gains in summer, and so reduce the energy required for air-conditioning. If sized correctly, they allow solar gains in winter when the sun's heat is useful. Overhangs also shield walls and windows from water intrusion and protect building materials, such as wood and some types of caulk, from deterioration caused by exposure to the sun's ultraviolet rays. Exterior shutters can serve similar purposes. There is far greater value in blocking the sun before it reaches a building rather than trying to shield its rays with blinds or shades indoors, after they have passed through windows and carried heat into the building.




Horizontal overhangs are most effective when they have southern orientations.



Horizontal louvers parallel to a wall permit air circulation near the wall and reduce conductive heat gain. The louvers may be operated manually or controlled automatically with time or photoelectric controls to adapt to the solar angle.



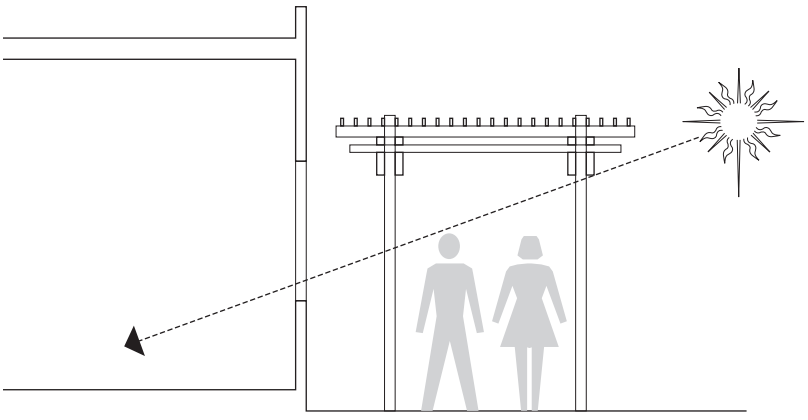
Vertical louvers are most effective for eastern or western exposures. The louvers may be operated manually or controlled automatically with time or photoelectric controls to adapt to the solar angle. Separation from the wall reduces conductive heat gain.

**6.01** Shading devices shield windows and other glazed areas from direct sunlight to reduce glare and excessive solar heat gain in warm weather.

Overhangs can be sized in a variety of ways, including numerical calculation, building models, and computer simulation. The following table shows overhang depths required for 48-inch (1,220) tall, south-facing windows at noon on August 22 to provide full shade along the height of the window at various latitudes. Fortunately, where they are needed most, in warmer climates, the required overhang is shorter.

| °Latitude | Depth in Inches (mm) |
|---|---|
| 24 | 11 (280) |
| 32 | 16 (405) |
| 40 | 26 (660) |
| 48 | 36 (915) |

Required east and west overhang depths are much greater and, at 6 feet (1,830) or more, can quickly become more extended than is feasible. An alternative are vertical louvers or fins, which offer more effective shading protection for eastern and western exposures. Trellises, other exterior structures, and even vegetation are other options for external shading.

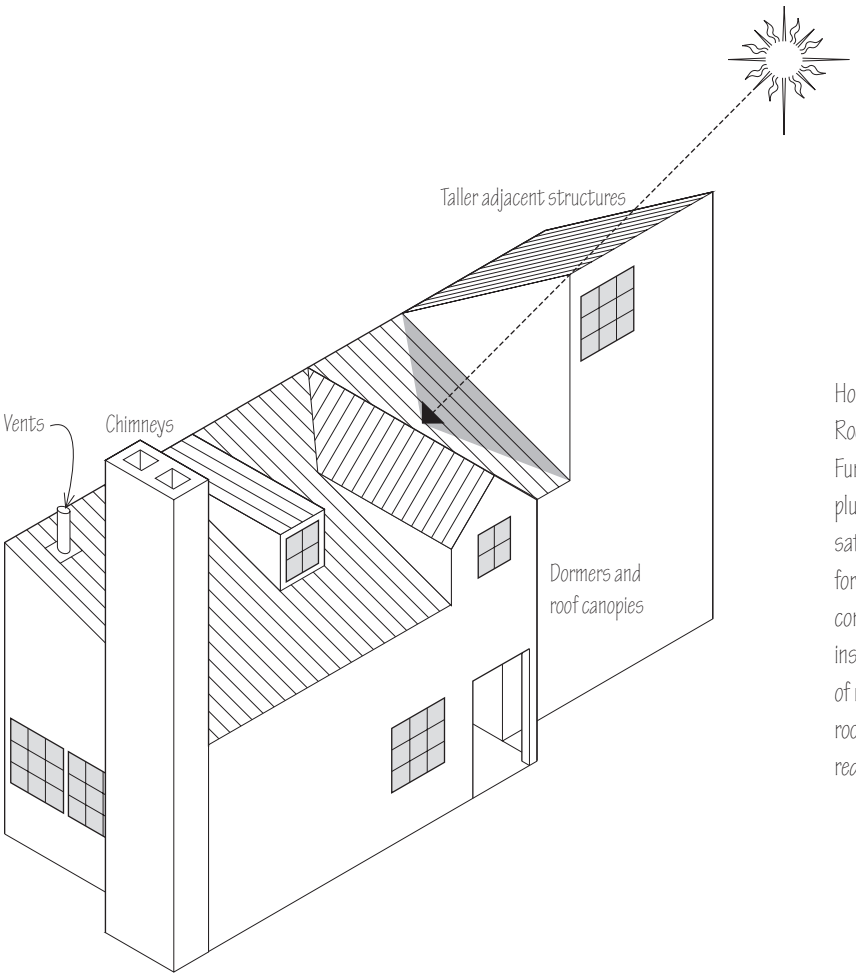


**6.02** Trellises and other exterior structures can provide shade depending on their proximity, height, and orientation, especially for east and west exposures requiring greater overhang depths.

## Solar Panels

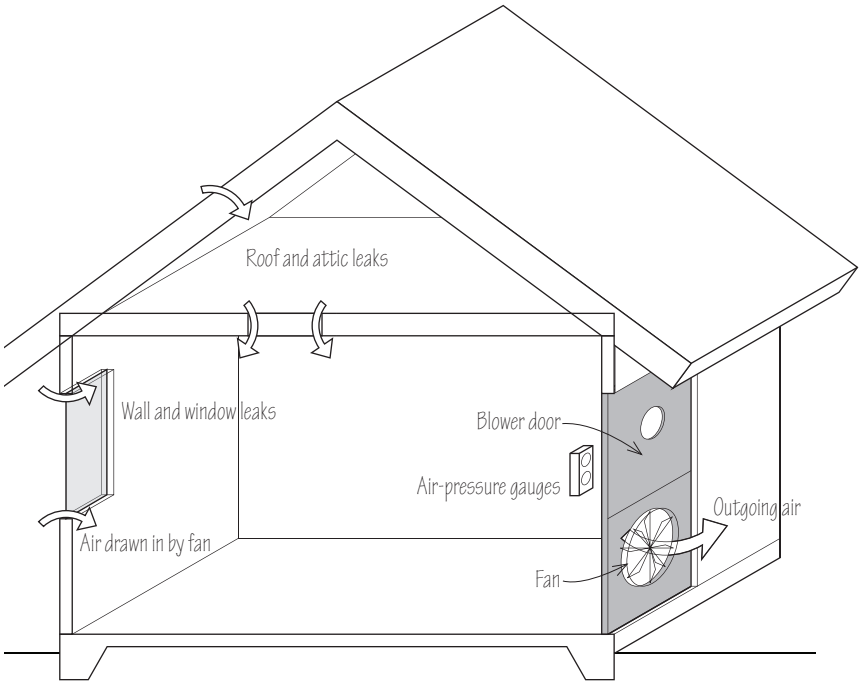
Solar panels consist of an array of either solar thermal collectors or photovoltaic modules. As we design from the outside in, it is important to direct attention to potential locations for solar panels before finalizing the roof design for a building.

Roofs are a logical location for solar panels. The inherent structure of a building makes roof-mounted installations more affordable than ground-mounted installations, which require their own foundation. The elevation of a roof reduces the risk of shading by the building itself, by adjacent buildings and structures, or by vegetation. Limited access to roofs also lessens the risk of theft, vandalism, and other damage to the solar panels.

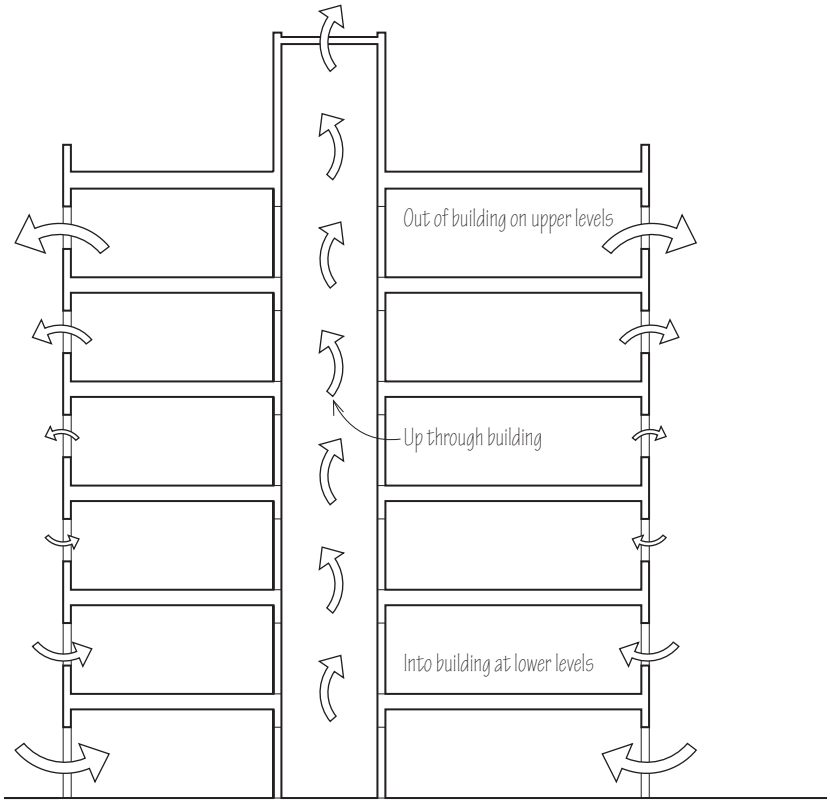



**6.03** Obstructions that may interfere with the most effective locations for solar panels.

However, roofs are often not designed or built to host solar panels. Roof orientation relative to the sun is frequently not optimal. Furthermore, roof-mounted building components, such as chimneys, plumbing and mechanical vents, dormers, stairwell penthouses, and satellite dishes, often interfere with the most effective locations for solar panels. These components can obstruct otherwise large contiguous roof areas, breaking them into sections and making the installation of continuous solar arrays more difficult. Some sections of roof may be too small to host even a single panel. Portions of roofs are sometimes shaded by higher sections of the same building, reducing their effectiveness as locations for solar panels.




**7.03** Blower door test.




**7.04** Airflow from the stack effect in winter.

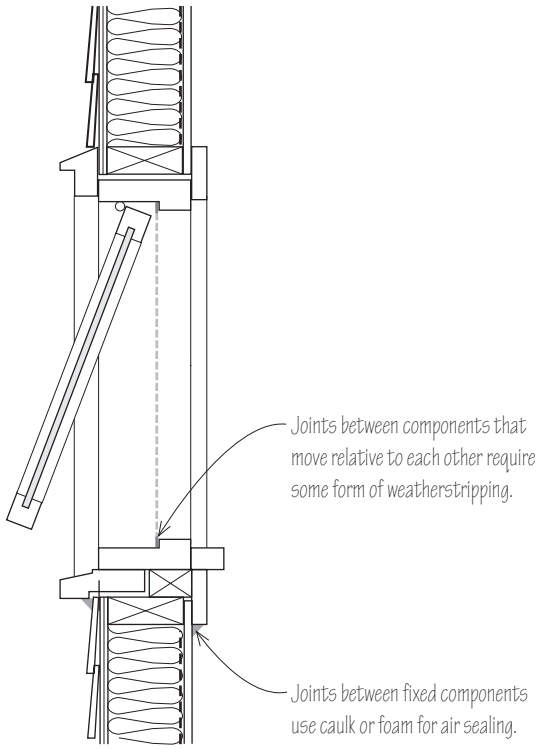
## Infiltration

The impact of infiltration on energy use in buildings is substantial. "Infiltration" is the term commonly used to describe the exchange of air between a building and the outdoors. Although the pure definition of infiltration is air entering a building—as opposed to exfiltration, which is air leaving a building—the term is more commonly used to represent air that enters and leaves a building, either simultaneously or in alternating cycles. Recent years have given a deeper understanding into the mechanisms of infiltration and its effect on energy use. The advent of the blower door test, which pressurizes or depressurizes a building, has allowed both the quantification of infiltration and understanding where it happens. The blower door has most commonly been applied to single-family homes, but it has also been used occasionally for larger buildings, and the insights that have been gained apply well to all building types.

The information provided by a blower door test is readily perceived during the assessment procedure. In a building depressurized with a blower door, outdoor air can be felt rushing in throughout the building—around door and window frames; through electrical outlets; around air grilles and light fixtures; through wall panel seams; through exhausts and flues; and through piping and wiring penetrations.

In recent years, much understanding has been gained about the stack effect, which is a significant driving force of infiltration, drawing air into the lower stories of buildings in winter and forcing it out of the upper stories. The stack effect can also occur in the reverse, downward direction in an air-conditioned building. Most pronounced in tall buildings, the stack effect is nonetheless active and evident in buildings as low as two stories, or even in single-story buildings with basements. It can be observed by slightly opening a basement or first-floor window in winter and feeling the inrush of cold air.

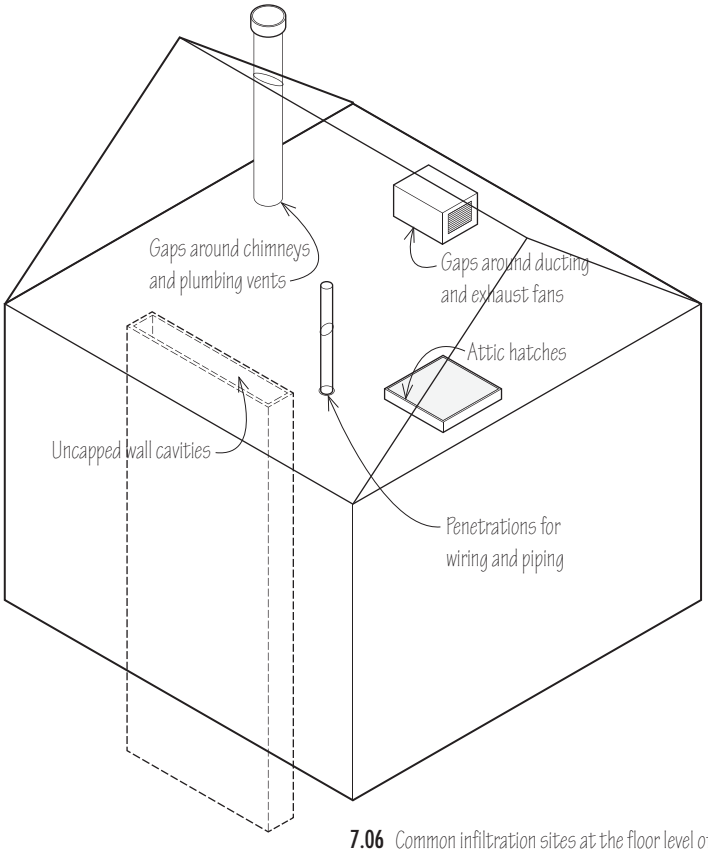
Stack effect is not the only driver of infiltration. Wind pressure is also a substantial contributor. Furthermore, without either wind or stack effects, a building can still experience infiltration through its many cracks and openings, driven by a variety of air pressure changes within buildings, such as those induced by exhaust fans, ventilation intake systems, ducted heating and cooling systems, and even the opening and closing of doors and windows.




**7.05** Types of joints that require air sealing.

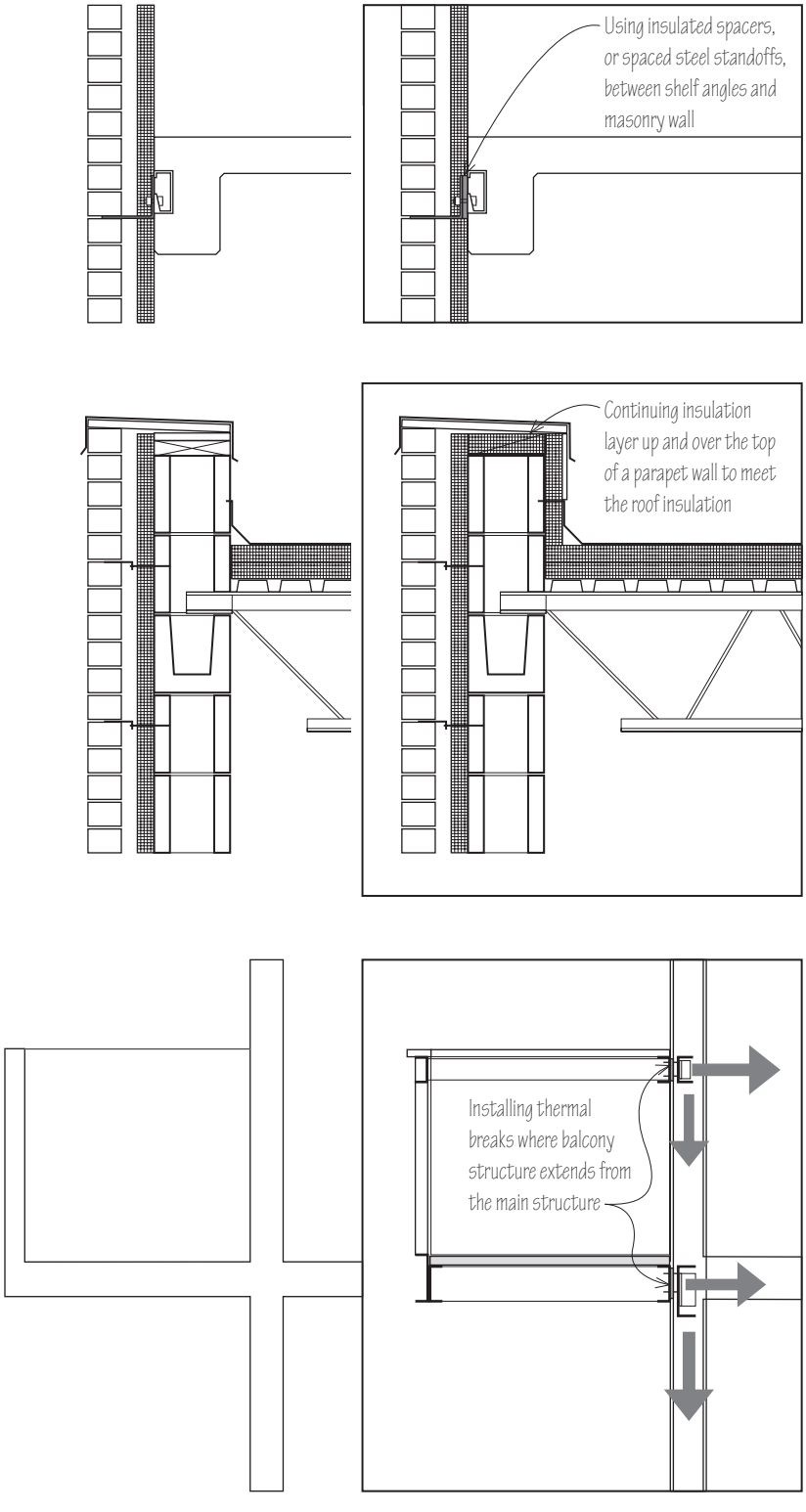
There are numerous locations of infiltration, even in buildings that appear well-designed and well-built. Substantial sources are windows and doors, which exhibit two distinct modes of infiltration. The first mode is air flowing past components that have the ability to be moved, such as a swinging door or a window sash in a double-hung window. The requirement of a door or window sash to be movable in its frame establishes a natural site for infiltration. The second mode of infiltration is air moving through the gaps between a door or window frame and the wall itself, which are often concealed by moldings. This second mode of infiltration is between components that are fixed in place.

The methods for countering infiltration are different for the two different modes of infiltration. On the one hand, preventing infiltration at components that have relative motion requires seals that allow this movement to occur. These are typically referred to as weatherstripping. Weatherstripping comes in many forms, including spring metal, V-strips, and a variety of foam strips that compress on the closure of a window or door. On the other hand, the infiltration between fixed surfaces, such as between a window frame and a wall, can be prevented with materials, such as caulk or foam, which do not need to allow motion of the building components.




**7.06** Common infiltration sites at the floor level of attics.

Another common group of infiltration sites can be found at the floor level of attics. These include attic hatches and uncapped wall cavities; gaps or cracks around recessed light fixtures, chimneys, plumbing vents, ducts, and exhaust fans; and penetrations of wiring and fire sprinkler piping.




**7.14** Ways to reduce or eliminate thermal bridging in masonry walls.

## Walls

### Masonry Walls

Masonry walls often use concrete masonry units (CMU) as the main structural material for both low-rise and high-rise construction. A wide variety of claddings serve to finish and protect the outside of the building, including brick, stone, stucco, terra cotta, and metal siding. Similarly, on the interior, a variety of finishes can be used, including gypsum board over metal or wood studs and furring strips. In some cases, the CMU can be left exposed on the interior.

High-performance concrete masonry units are available, which are typically 40% lighter than traditional CMU and, having R-values between R-2.5 and R-3.0, offer over 30% better thermal resistance. If insulated with Perlite or similar insulation fillers, high-performance CMU has R-values between R-7 and R-10.

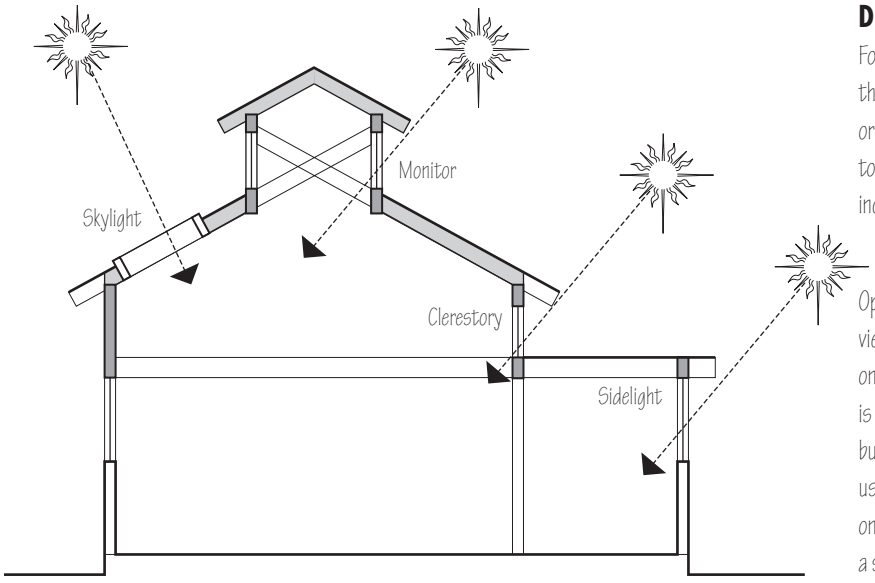
Thermal bridging occurs in masonry walls in several ways, each of which may be reduced or eliminated:

- Shelf angles used to support wall cladding, such as brick, offer paths for thermal conductance. A thermal improvement is to use insulated spacers between the shelf angles and the main CMU wall, or to use spaced steel standoffs between the shelf angles and the CMU.
- Where a masonry wall rises above the roof line to form a parapet, the wall itself can act as a thermal bridge as it rises between the layer of exterior rigid insulation and the roof insulation that terminates at the wall. A thermal improvement is to continue the wall insulation up over the top of the parapet and down to meet the roof insulation. The top of the parapet is still protected by a coping over the top of the continuous insulation.
- Any structural steel that penetrates the thermal barrier acts as a thermal bridge. One option is to use stainless steel instead of plain carbon steel for these penetrating components because stainless steel has lower thermal conductivity. Another option is to insulate around the exterior of any penetrating structural steel.
- External structures, such as balconies, can break the continuity of the thermal insulation layer. A thermal improvement for balconies is to support them externally rather than connect them both structurally and thermally to the main building. Another option is to use nonconductive spacers between the balcony structure and the main building structure.

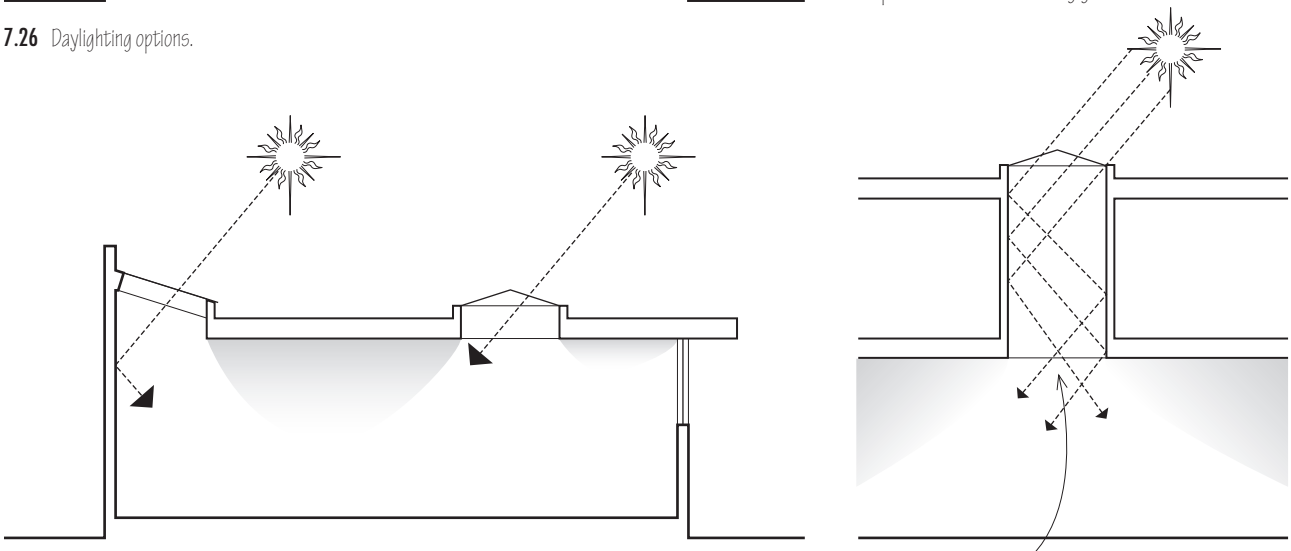
## Daylighting

For green buildings, windows offer the potential for energy savings through daylighting. Daylighting can be provided by sidelighting and or by toplighting. Sidelighting is supplied by windows in walls while toplighting may be provided by a variety of roof-mounted windows, including skylights and roof monitors.

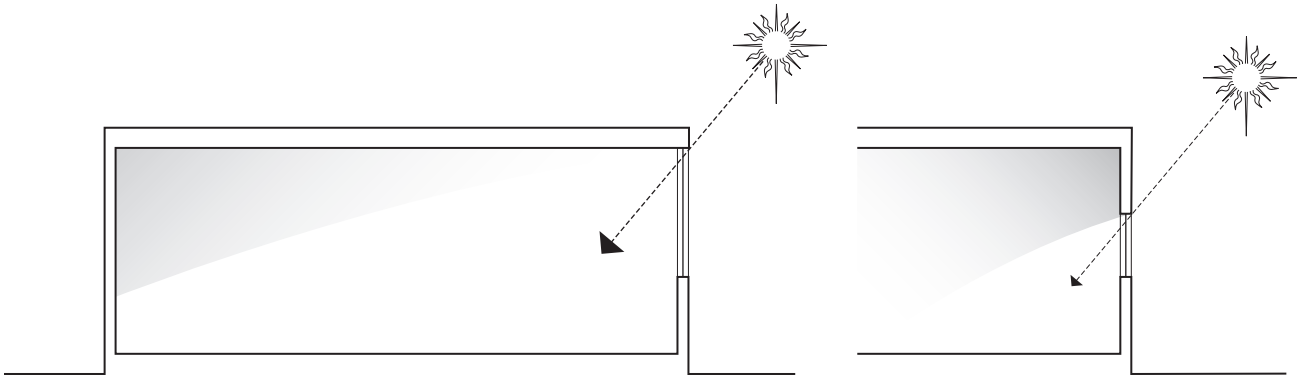
Optimum glazing for daylighting is different from the glazing for views. The best daylighting approach is evenly spaced toplighting on the flat roof of a building, casting light evenly over a space. This is limited to single-story buildings, to the top floor of multistory buildings, or to those floors that can be readily reached through the use of light tubes. For sidelighting, windows are ideally located high on a wall, close to the ceiling, to cast light as deeply as possible into a space without introducing glare.




**7.26** Daylighting options.



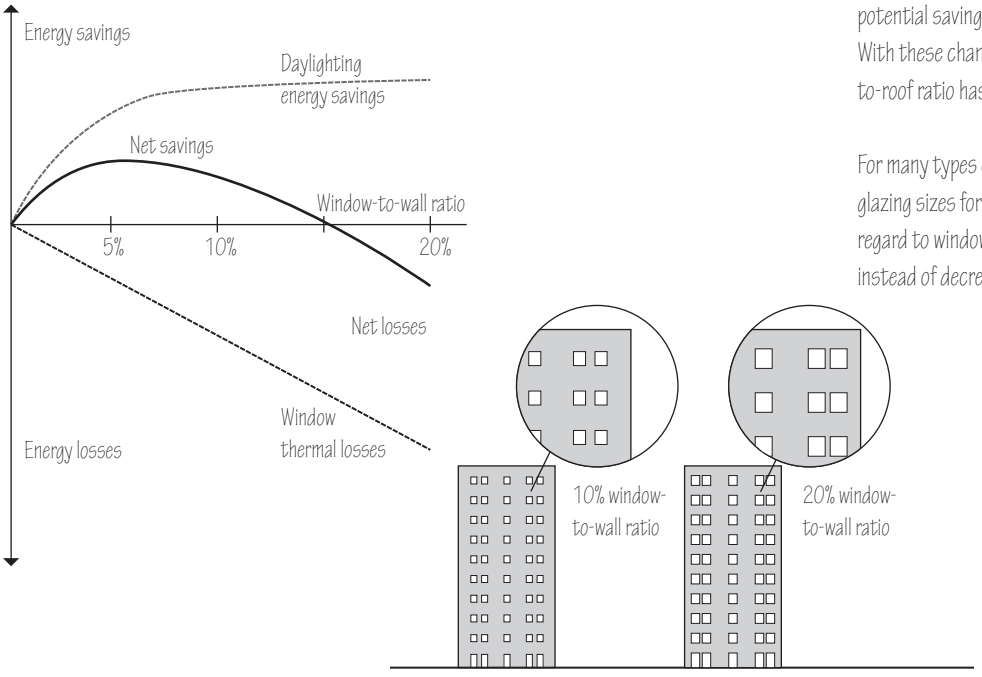
**7.27** Toplighting is largely limited to single-story buildings or the top floors of multistory buildings, although a variety of light tube products have been introduced that allow extending light penetration through attics and top floors to reach the floors below.



**7.28** Sidelighting windows should be located high enough on a wall to cast light as deeply into a space as possible.



**7.29** Example of a global illumination technique that uses sophisticated algorithms to more accurately simulate the illumination of a space or scene. These algorithms take into account not only the light rays that are emitted directly from one or more sources. They also track the light rays as they are reflected or refracted from one surface to another, especially the diffuse inter-reflections that occur among the surfaces in a space or scene.




**7.30** Example of optimizing window sizes for daylighting.

Daylighting is a complex topic, best handled with models of illuminance, optimized for energy efficiency by trading off lighting gains against window heating and cooling losses, with the risk of glare evaluated and prevented, and implemented with careful attention to daylighting controls. Daylighting is best addressed at exactly this phase of the design, during consideration of the outer envelope, when it can be optimized, and before the design of artificial lighting begins.

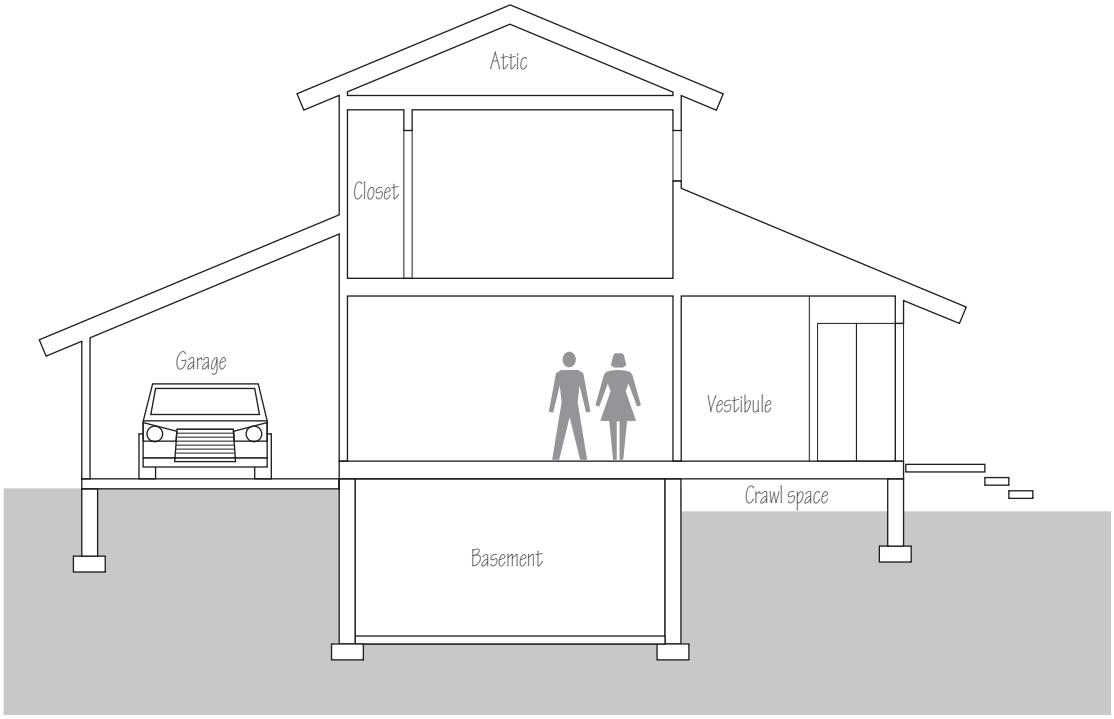
Daylighting involves more than just adding windows to buildings. There is a significant tradeoff between the energy savings gained through daylighting and the heating and cooling losses resulting from larger window areas. The savings in electricity increase along with the expansion of window areas for daylighting, but window thermal losses also increase. For smaller window areas, the reduction in electric lighting requirements resulting from daylighting is typically greater than the negative impact of window thermal losses on heating and cooling loads, and so there are net savings. However, the savings in electricity from daylighting reach a maximum as window areas increase, whereas the negative impact of window thermal losses continues to increase with increased window area. So, there is an optimum window size, above which thermal losses reduce the net savings from daylighting.

The potential energy savings from daylighting has decreased in recent years because of greater efficiencies in artificial lighting technologies and the increasing use of controls for reducing the duration of use of artificial lighting. There is a further decrease in potential savings if the reflectance of interior surfaces is increased. With these changes, the optimum window-to-wall ratio or window-to-roof ratio has also decreased.

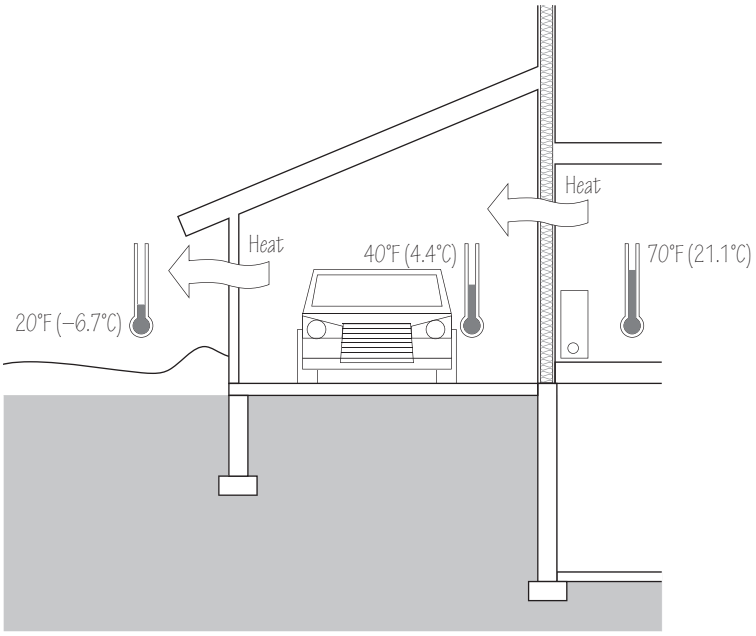
For many types of buildings and occupancies, if the recommended glazing sizes for daylighting are applied indiscriminately, without regard to window thermal losses, building energy use may increase instead of decrease.

# 8
# Unconditioned Spaces

Unconditioned spaces are spaces that are neither heated nor cooled. There can be a variety of unconditioned spaces between the outer envelope and the inner envelope of a building. These spaces include attics, basements, crawl spaces, attached garages, mud rooms, vestibules, mechanical rooms, and storage rooms.

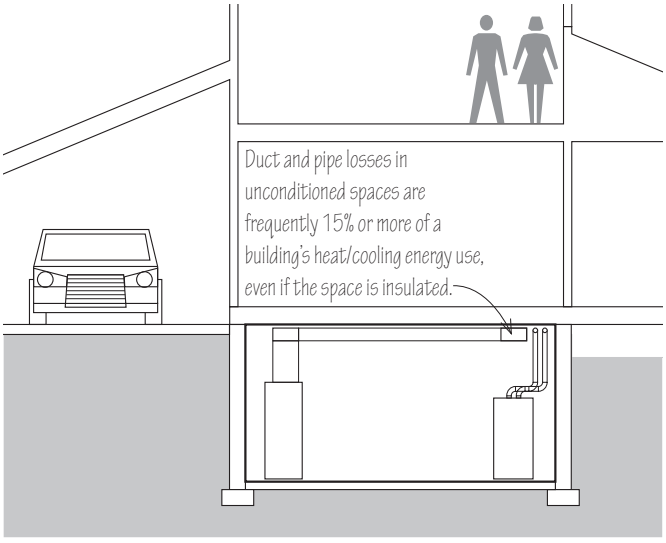



**8.01** Unconditioned spaces.



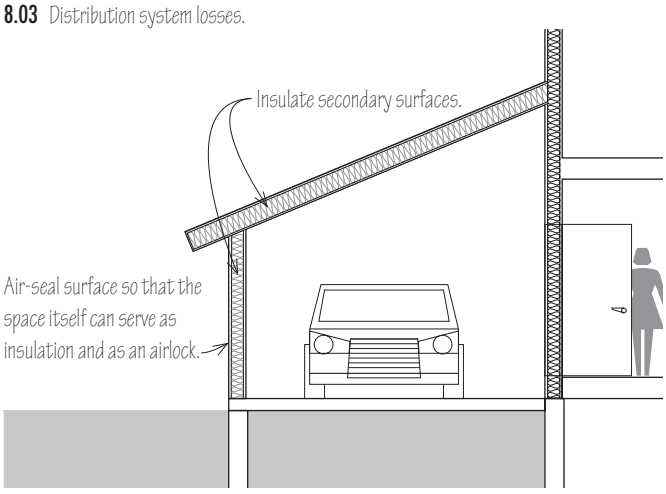

**8.02** Heat loss through unconditioned spaces.

Unconditioned spaces receive some heating or cooling passively. In winter, heat travels across shared walls, from heated spaces into unconditioned spaces, and then from the unconditioned spaces to the outdoors. The opposite is true in summer, with heat flowing into the building. Unconditioned spaces typically are at an equilibrium temperature somewhere between the temperature of the conditioned spaces and the outdoors. As a result, even though the unconditioned spaces receive heating or cooling passively, this heat transfer must ultimately be made up in the conditioned spaces, and so the heat loss through the unconditioned spaces uses energy.




**8.03** Distribution system losses.

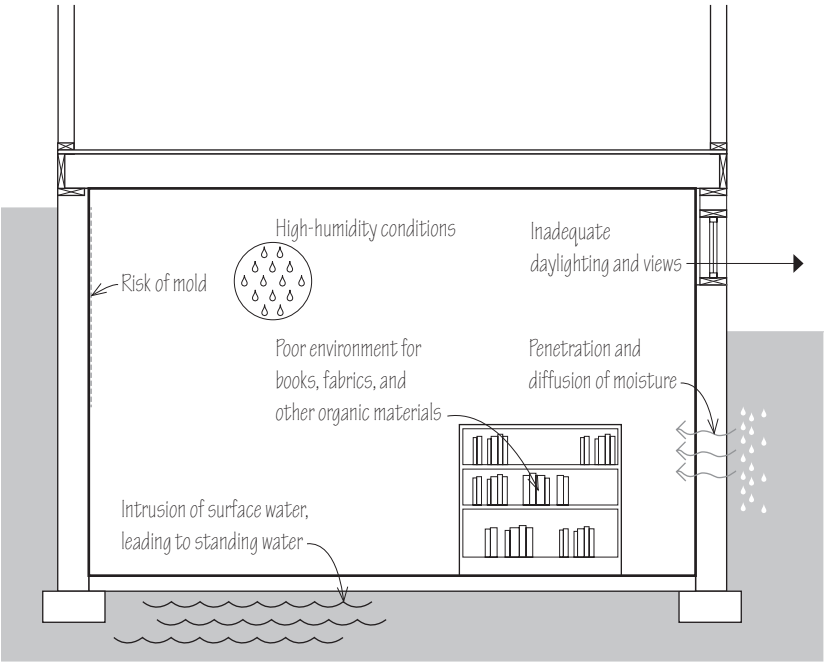
Unconditioned spaces have a second energy-related vulnerability. They are often spaces through which heating and cooling distribution systems are routed. These distribution systems comprise ductwork or piping, or both. Because the unconditioned spaces, by definition, do not need to be conditioned, heat loss to and from these distribution systems in any unconditioned space results in wasted energy.



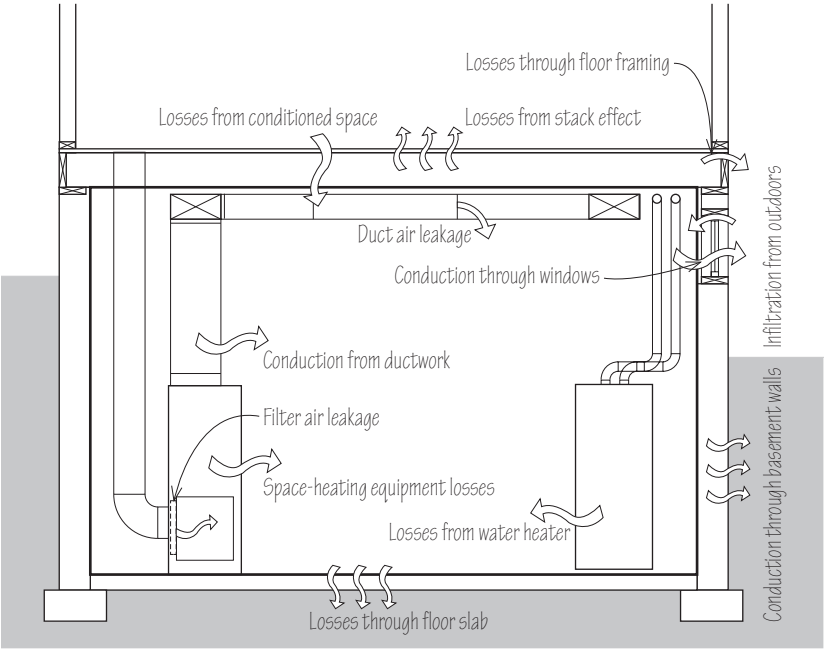

**8.04** Putting unconditioned spaces to use to reduce energy consumption.

These energy vulnerabilities of unconditioned spaces need attention. We can go beyond just solving these problems and instead take advantage of unconditioned spaces by putting them to use as another layer of shelter. Unconditioned spaces are, essentially, trapped air that can be used as a form of insulation. Furthermore, unconditioned spaces usually have at least one uninsulated surface, either between the unconditioned space and the outdoors or between the unconditioned space and an adjacent conditioned space. This allows insulation to be added, often affordably, to firm up an additional layer of shelter. Finally, unconditioned spaces can serve as an airlock and reduce infiltration as people enter and leave a building.

Later in this chapter, we will examine a variety of common types of spaces to see which ones might be changed from being typically conditioned to being unconditioned. This can further reduce energy use as well as reduce construction costs.




**8.05** Environmental quality issues in basement spaces.




**8.06** Energy losses in basement spaces.

## Basements

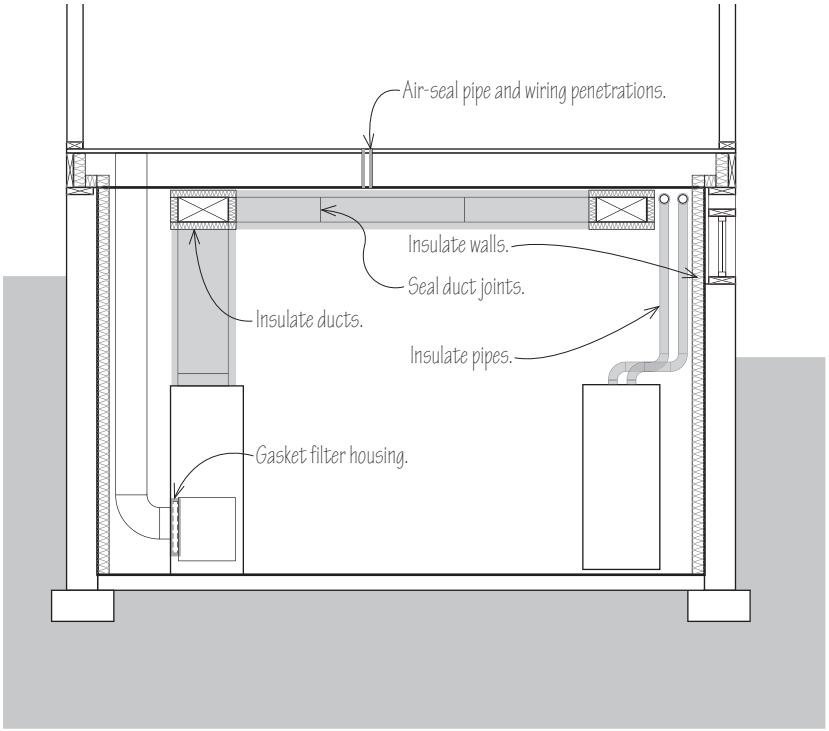
Basements are common in homes and are also found in many commercial buildings. These partially or wholly underground spaces are convenient for providing storage and work areas, locating mechanical equipment, and concealing various utilities, such as piping, ductwork, and electrical distribution systems. Basements are sometimes occupied and used as TV rooms, dens, and, with proper daylighting and ventilation, as offices, bedrooms, even full apartments. From a heating and cooling point of view, basements are spaces that are mostly earth-bermed and so have lower heat losses and gains than spaces that are fully exposed to outdoor air. Basements can, nevertheless, lose or gain a significant amounts of heat.

On the negative side, basements can suffer from high humidity if moisture is transported through concrete foundation walls and slabs into the space. Surface water can also find its way by gravity into basements. As unconditioned spaces having a utilitarian function, basements are relatively expensive due to the excavation and foundation work required for their construction. Basements offer little or no daylight, little or no views, and can be unwelcoming as occupied spaces.

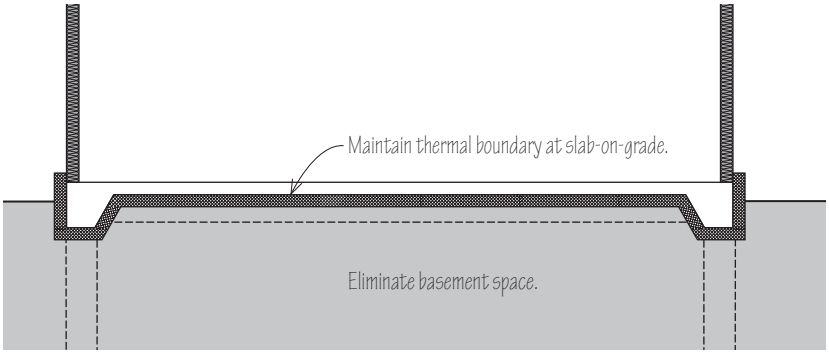
Basements are not always recognized to be either conditioned or unconditioned spaces, which can lead to indecisiveness as to whether to actually condition or not condition these spaces. Basement ceilings are sometimes insulated, but often are not, and so they serve as a path for heat loss from the heated space above down to the basement.

Basements are sites where a large amount of energy is lost in heating and cooling distribution systems. Recent studies have confirmed the substantial effect of such losses. Energy is lost by conduction from the equipment and distribution system, including boilers, furnaces, ductwork, pipes, valves, and pumps. Energy is also lost by air leakage into and out of forced-air systems along ductwork seams, at duct connections, from the air handlers themselves, and at filters. For buildings in which the heating and cooling equipment and distribution are located in a basement, 15% or more of the heating and cooling energy used in the building can be lost in such basement distribution systems. Distribution systems in basements are also vulnerable to deterioration over time. Duct and pipe insulation can detach or be removed and not be replaced; duct blanket insulation can compress, reducing its thermal resistance; duct air leaks can develop and get worse over time; and duct grilles that are intended to be shut can inadvertently be left open.

Another energy penalty attributable to basements relates to the stack effect. Basements add another story to buildings, which amplifies the stack effect, even in buildings that have only one main floor. Basements are typically leaky and cold air in winter can be readily drawn into the basement from such locations as sill plates, ill-fitting windows, and basement doors. Basements are rarely well-sealed relative to the heated spaces upstairs, so stack-effect air can rise readily from the basement up to the first floor of the building through doorways; pipe, duct, and electrical penetrations; and between floorboards or joints in subflooring. As soon as this air enters a heated space, it becomes an added load on the building's energy use. The heated air then leaves the building through the windows and walls of upper floors, and through the attic.




**8.07** Reducing energy losses in basement spaces.




**8.08** Eliminating basement losses.

Basements can be made more energy efficient by air-sealing walls, windows, and basement ceilings, and ensuring that basement doors to the upstairs are weatherstripped. Ducts, pipes, and pipe fittings can also be insulated and ducts air-sealed. Conduction losses can be reduced by insulating walls and basement ceilings and improving the thermal performance of windows.

A common misconception is that insulating basement walls brings them into the thermal envelope, negating any basement heat losses. As long as a basement is unconditioned, losses in the basement are still losses and can be significant. For example, ASHRAE's Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems only estimates a small reduction in distribution losses, from 19.1% to 17.6% for a typical house, when basement walls are insulated.

Another option is to not include basements in green buildings. The potential energy savings can be significant when we consider the elimination of heating and cooling distribution losses; the reduced stack effect and infiltration losses to heated spaces above; and the removal of conduction heat losses from the upstairs down to the basement and out through the foundation walls and slab.

Unconditioned basements historically were large mechanical rooms. Although large mechanical rooms might have been needed 100 years ago, when boilers and furnaces were much larger than they are today, basements now are larger than necessary to serve only as mechanical rooms.

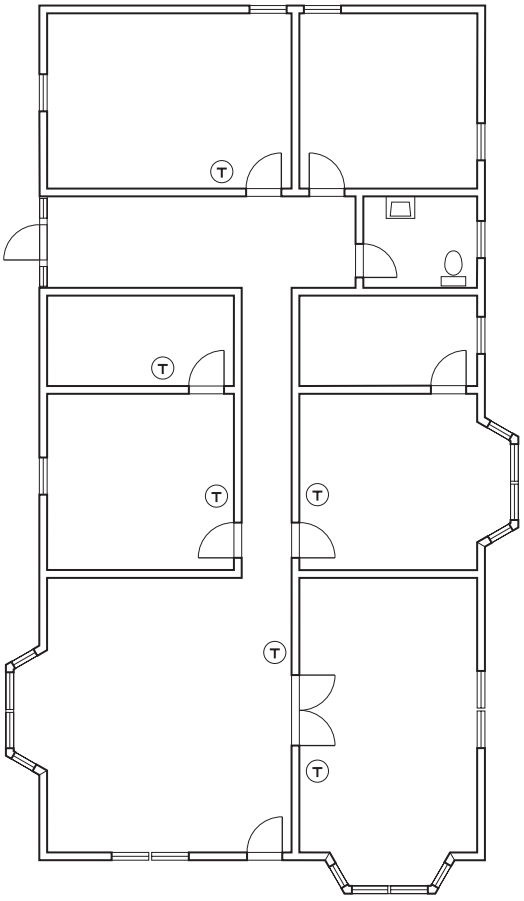
Basements with high humidity are not ideal for storing materials such as paper, books, clothing, and other organic materials. Humid conditions and any collected water can also present indoor air quality problems. Being partly or wholly underground, it is also a challenge for basement spaces to have access to natural light and views.

When the sum total of energy problems, air quality problems, and the absence of views and natural light are examined, we are left with the question as to whether basements can be considered healthy spaces for green buildings, unless substantial measures are taken to prevent the full gamut of problems.

# 10

# Thermal Zoning and Compartmentalization

Thermal zoning and compartmentalization help to reduce energy use by using interior layers of shelter to limit the unwanted flow of heat and air within a building.

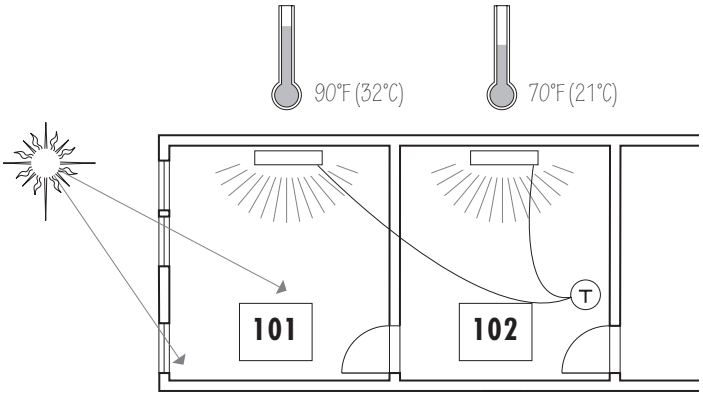



**10.01** Thermal zoning incorporates separate temperature controls for different areas of a building.

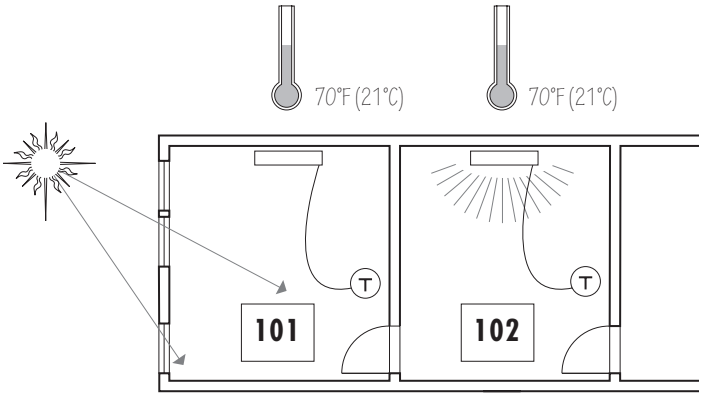
## Thermal Zoning

Thermal zoning enables different areas of a building to have separate temperature controls and respond better to individual temperature preferences. It can also save energy, in two primary ways:

- Thermal zoning can prevent overheating in spaces receiving heat from other sources, such as the solar gains on the south side of a building; the unusually high occupancy rates of conference rooms, classrooms, and other assembly spaces; and the unusually high internal gains from machinery or lighting.
- Thermal zoning can allow conditioned spaces to be left unconditioned at appropriate times. Lowering the air temperature in a space in winter or raising the temperature in summer in this manner reduces heating and cooling loads.




**No zoning** One thermostat controls heat in different spaces. Solar gains overheat Room 101.

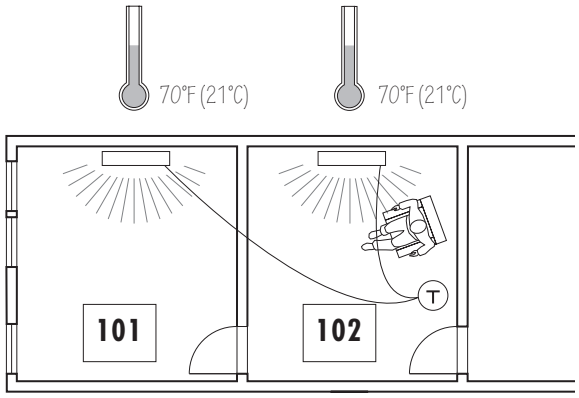



**Zoning** Separate thermostat in Room 101 prevents simultaneous operation of furnace during times of solar gain, thereby saving energy.

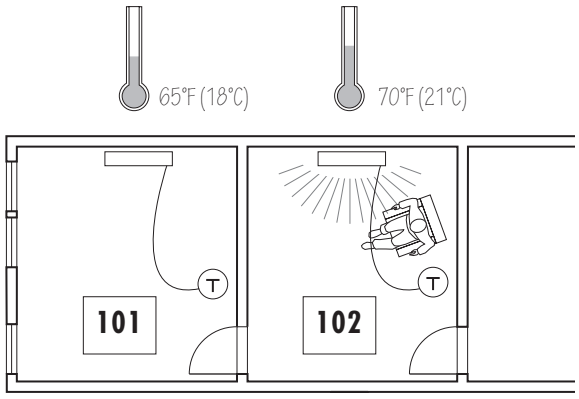
▲

**10.02** Preventing overheating of spaces receiving heat from other sources.

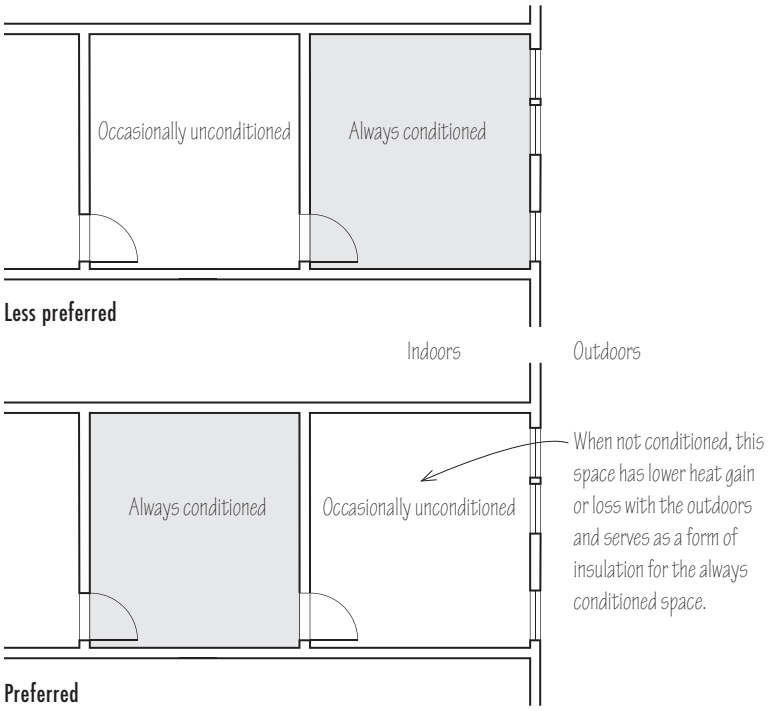
**10.03** Allowing conditioned spaces to be left unconditioned at appropriate times. ▶




**No zoning** One thermostat controls heat in different spaces. Both spaces are heated even though Room 101 is unoccupied.



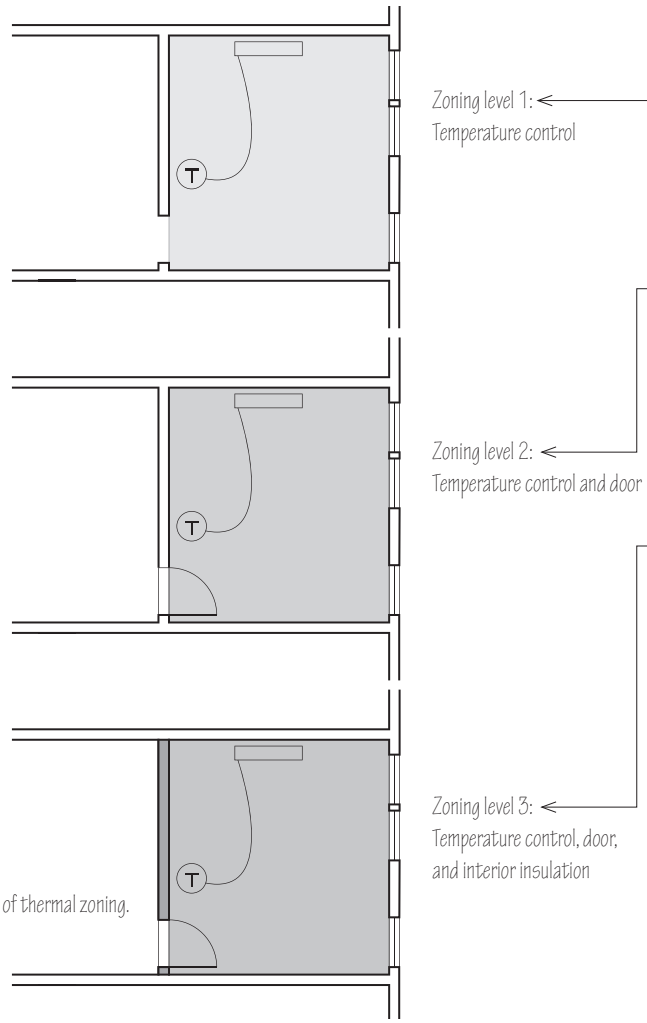

**Zoning** Separate thermostat in Room 101 prevents heating when the room is unoccupied, thereby saving energy.




**10.04** Locating occasionally unconditioned spaces.

Because thermal zoning for either of these reasons can save significant energy, it is important to identify spaces that may not always require heating or cooling.

For spaces that can, at times, be left unconditioned, it is constructive to locate them on outside walls where possible. In this way, they can serve to reduce heat loss from heated spaces to the outdoors.



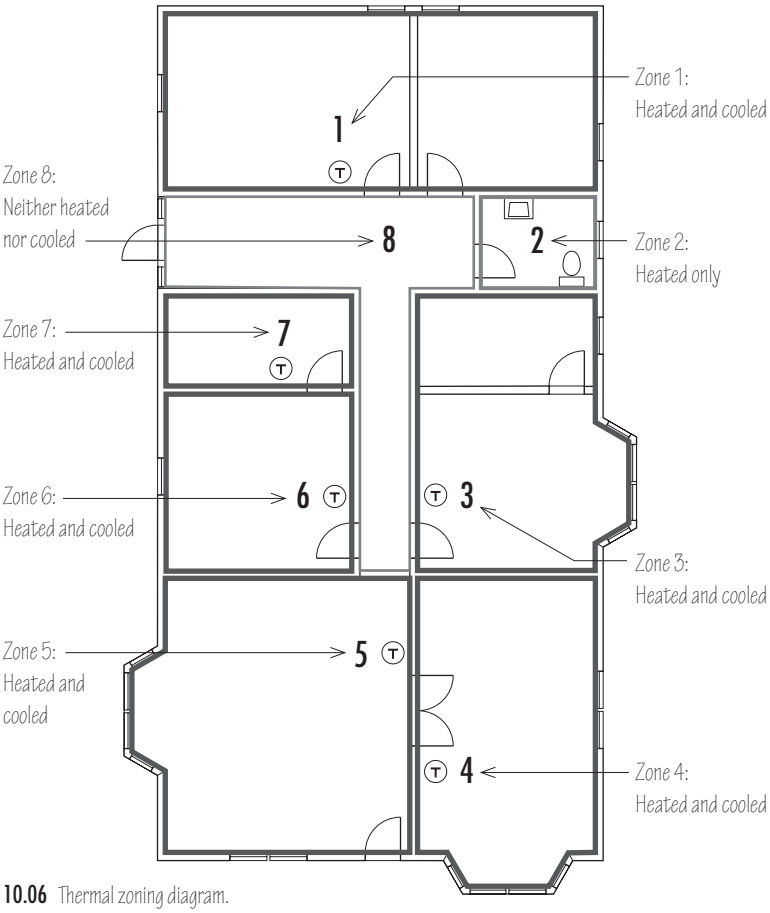

**10.05** Three levels of thermal zoning.

We can consider three levels of thermal zoning:

1. Temperature control: Required. Without temperature control, thermal zoning is not possible. Temperature control means that a zone has its own thermostat or other means to control the device that delivers heating or cooling to the zone of interest.

2. Doors for closing off a zone: Recommended. To increase the energy savings for a zone, doors should prevent losses from the migration of air between conditioned and temporarily unconditioned zones. An example is the placing of a door at the top or bottom of a stairway to create two zones—upstairs and downstairs—in a two-story office building.

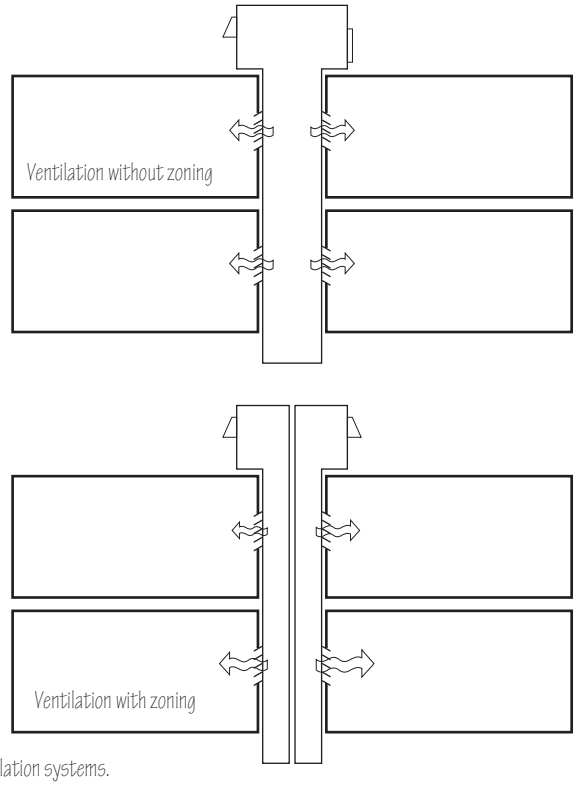
3. Thermal isolation of a zone: Optional. The interior walls, floor, and ceiling separating one zone from another should be insulated and air-sealed, and doors weatherstripped. This makes the most sense if a zoned space is unoccupied for long stretches of time. Examples might include a guest bedroom or study in a house or the guest rooms in a hotel.




**10.06** Thermal zoning diagram.

Because some heating and cooling systems cannot support thermal zoning, it is helpful to define the thermal zones first, before selecting an appropriate heating and cooling system that supports thermal zoning.

A thermal zoning diagram might be included in the construction documents to help delineate which zones are controlled by which temperature controls; which spaces are heated but not cooled; and which spaces are altogether unconditioned.




**10.07** Zoning ventilation systems.

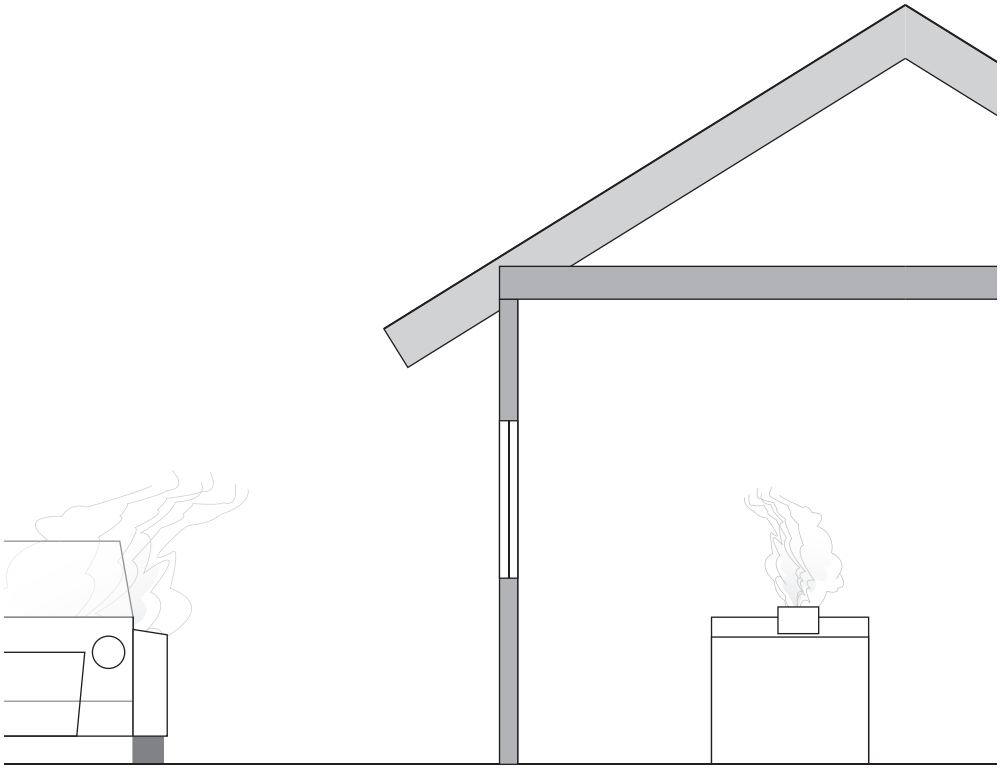
The concept of dividing a building into zones can also be applied to ventilation. A large commercial building often has large air handlers that serve significant portions of a building. Such larger systems are less able to respond to localized ventilation needs, and so they risk either over-ventilating a particular zone, wasting energy in the process, or under-ventilating the zone and placing indoor air quality at risk. By dividing a building into smaller zones, each zone's ventilation system can respond appropriately to its own ventilation needs and deliver acceptable indoor air quality at a lower energy cost.

The impact of thermal zoning on construction costs can be negative or positive. When additional temperature controls, doors, or insulation are necessary, costs go up. However, when heating or cooling can be removed from spaces, cost savings accrue.

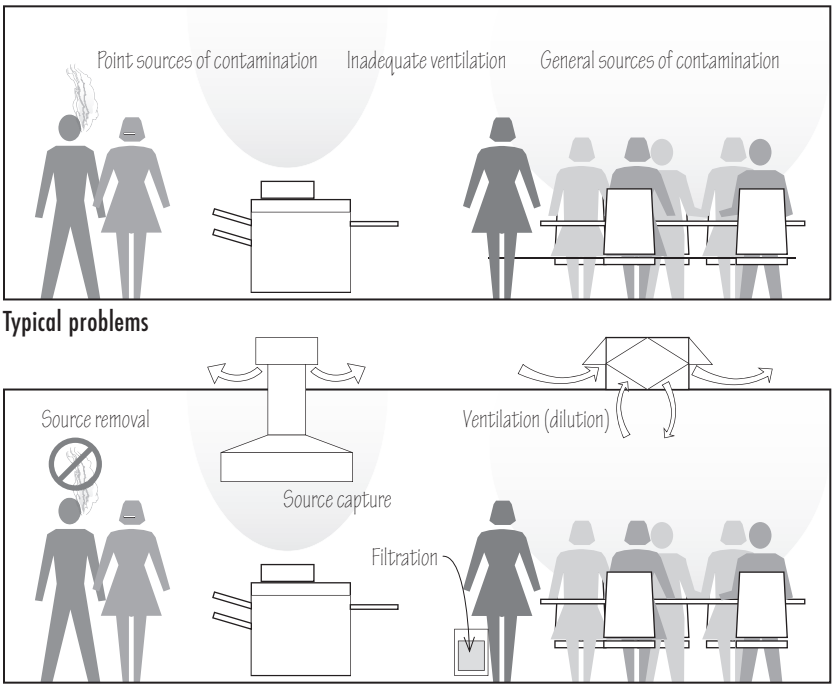
# 13
# Indoor Environmental Quality

## Indoor Air Quality

Indoor air of good quality does not have objectionable concentrations of airborne contaminants, such as dust particles, carbon dioxide, hazardous chemicals, tobacco smoke, odors, humidity, and biological contaminants. Airborne contaminants constitute a load on a building but with the added complication that the load does not only originate outside the building; it can also originate inside the building.



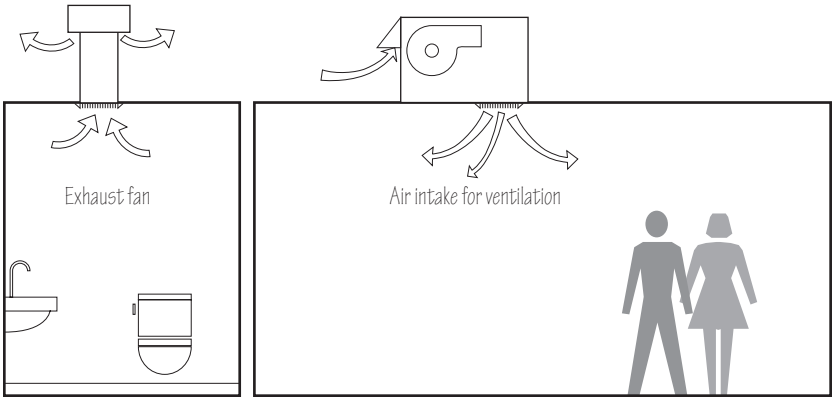
**13.01** Airborne contaminants originate not only from outside a building but from the inside as well.




**13.02** Approaches to providing good indoor air quality.

The four main approaches to providing good indoor air quality are contaminant source reduction, contaminant capture, filtration, and dilution. The best approach is to start at the source. We first seek to eliminate indoor sources of contaminants, such as by banning indoor smoking or by using paints and carpeting that emit fewer chemicals. Contaminant capture involves intercepting contaminants before they reach the human breathing zone. This typically means the installation of exhaust fans in kitchens and bathrooms, fume hoods, and the like. Filtration removes contaminants from the air. The first three approaches are all sound but they can miss contaminants that cannot be eliminated, captured, or filtered. Examples include trace chemicals emitted from new products and the carbon dioxide in exhaled air. This is the purpose of the final approach to providing good indoor air quality—dilution with outdoor air, otherwise known as ventilation.

For ventilation, a presumption is made that the air outdoors is clean, but steps are also taken to ensure that it is in fact as clean as possible.

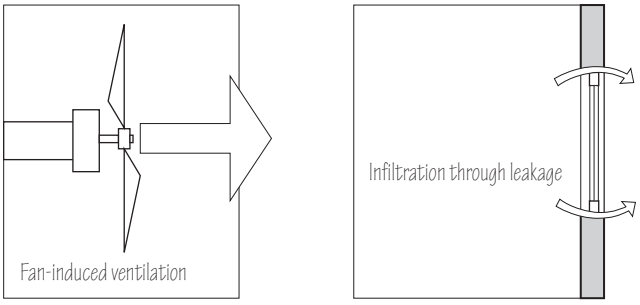



**13.03** The distinction between exhaust fans and intakes for ventilation with outdoor air.

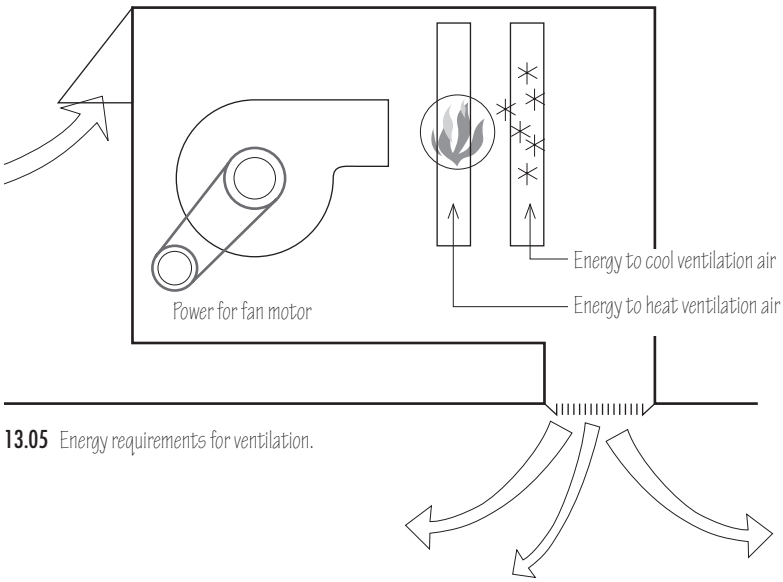
There can be confusion between exhaust fans, which are means of contaminant capture, and ventilation with outdoor air, which is the dilution of contaminants. The confusion arises because both are often referred to as ventilation and are analyzed together. The two often also interact, because exhaust causes the intake of outside air into a building.

Confusion also arises because of the interrelationships between ventilation and infiltration. Ventilation is typically fan-induced. However, infiltration can deliver the same effect as ventilation by bringing in outside air to dilute indoor airborne contaminants. Also, as with the interaction between exhaust fans and infiltration, ventilation with outdoor air and infiltration can also interact. If air is brought into a building for ventilation with a fan but without any accompanying fan exhaust, then air will leak out of the building. So discussions of ventilation inevitably include discussions of infiltration as well.

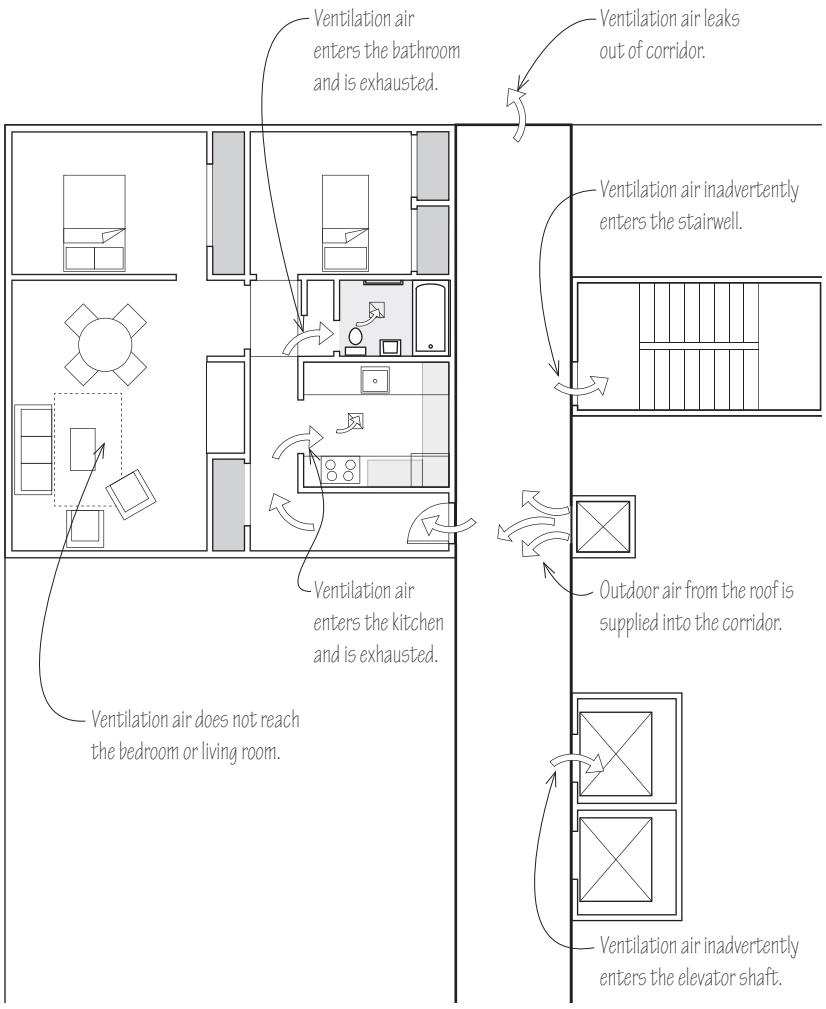
Finally, confusion can arise between ventilation and cooling because ventilation is at times used for cooling.




**13.04** The distinction between ventilation and infiltration.




**13.05** Energy requirements for ventilation.




**13.06** Ventilation air does not always reach the people for whom it is intended.

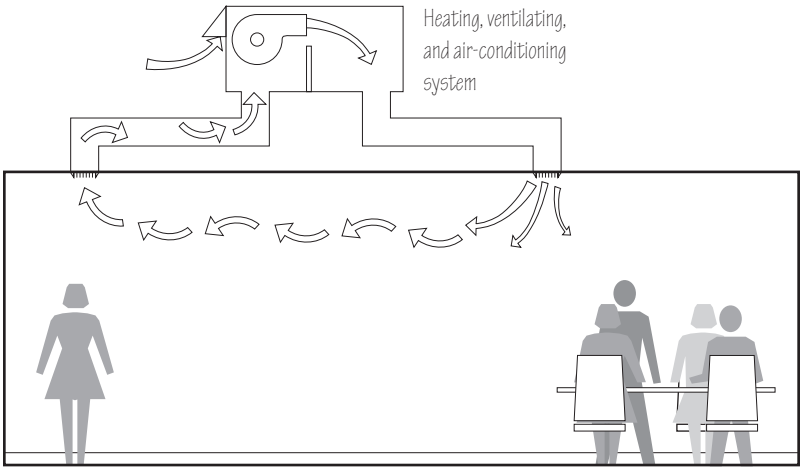
## Ventilation Challenges

The traditional approach to improving indoor air quality is through ventilation but ventilation also presents many challenges.

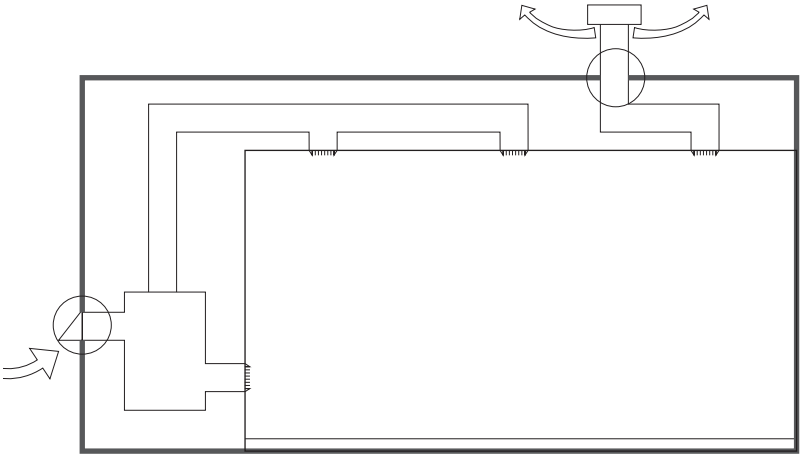
Ventilation uses much energy. Electricity is required to run the motors that turn the fans that move ventilation air. Even more significantly, energy is used to heat and cool the ventilation air that is brought into a building. The rate of energy use in a building is extremely sensitive to ventilation. A measurable increase in ventilation will result in an immediate and significant increase in a building's energy use.

It is a challenge to bring outdoor air into a building without causing discomfort. If it is not heated or cooled, outdoor air enters a building at whatever temperature it happens to be. It is very different to bring 0°F (−18°C) outdoor air into a building than when the outdoors is 32°F (0°C), or 70°F (21°C), or 100°F (38°C). The main challenge is that the energy required to heat or cool the outdoor air keeps changing as the outdoor temperature changes. The problem is especially critical in heating, where the risk of discomfort is high. Documented problems include the overheating of ventilation air and the associated spaces into which it is supplied, failed heaters, and ventilation systems that have been shut off due to inadequate temperature control.

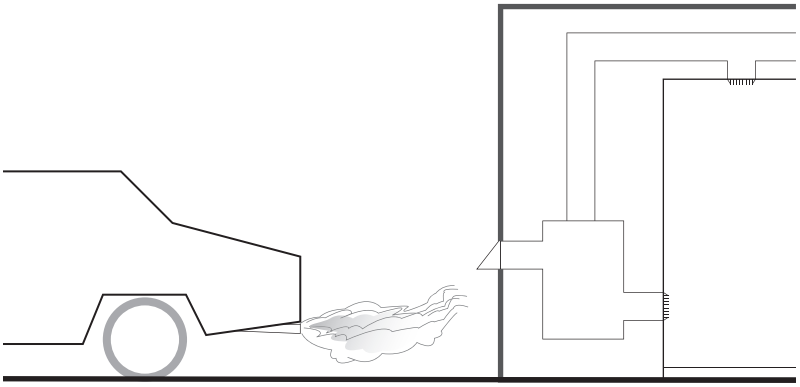
Ventilation often does not reach the people for whom it is intended. For example, in many high-rise apartment buildings and hotels, ventilation air is drawn in from above the roof and supplied to the corridors through grilles in the corridor walls, usually just above head height. The ventilation system is designed to have air flow into the corridor and under the doors of the apartments or hotel rooms. However, a significant portion of this air never reaches the people for whom it was intended. Rather, much of the air moves back out of the building via elevator shafts, stairwells, trash chutes, and corridor windows. Some of the air does flow under the doors into apartments or hotel rooms, but much of this air usually then just flows out of the kitchen or bathroom exhaust. Kitchens and bathrooms are typically located near the entrance to the apartment or hotel room, away from the perimeter of the building. So the fresh air flows out of the building without having reached the people who are in the living rooms or bedrooms.




**13.07** Ventilation can bypass the breathing zone of occupants.



**13.08** Ventilation openings break the continuity of the thermal boundary.



**13.09** Ventilation can introduce contaminants into a building if air intake openings are located too close to sources of contaminants.

Similar bypass issues, also termed ineffectiveness, occur in buildings that have ventilation air transported with heating or cooling air. In many such buildings, the air is both supplied at ceiling level and also returned to ductwork at the ceiling level, so that much of the ventilation does not reach the breathing zone of the occupants.

Another problem with ventilation is the unintended consequence of introducing holes into a building and breaking the continuity of the thermal boundary. These holes are supposed to enable the ventilation air to flow. A properly designed ventilation system has ventilation air flowing only when the air is needed. For example, an office building does not need ventilation air at night, when the building is empty. The ventilating holes are typically closed at these times with dampers, which are valve-like devices that can open or close. But air is a fluid, adept at finding its way past dampers—in other words, leaking. And dampers break and stick, either permanently open and leaking more air than necessary or permanently closed and not providing ventilation at all.

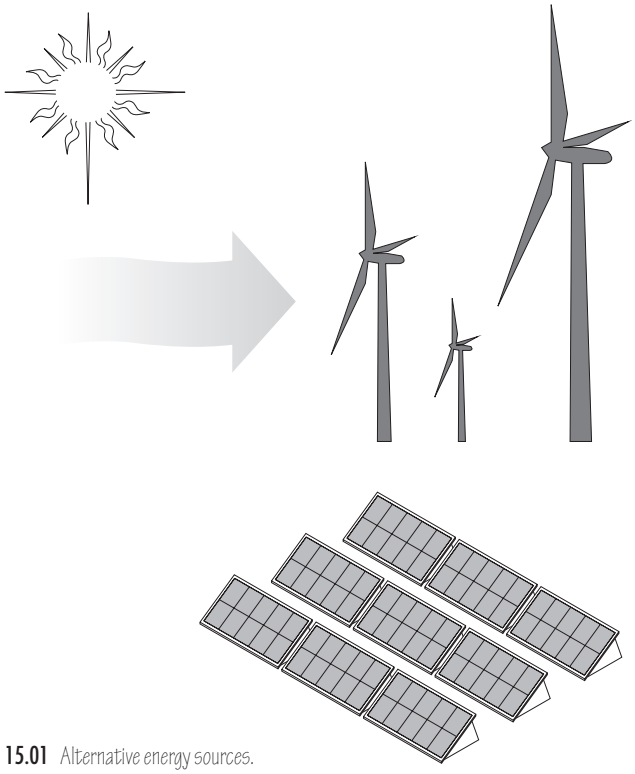
Ventilation is difficult to measure and ventilation systems are difficult to inspect and to understand. As a result, building inspectors usually cannot tell if something is wrong with the design or installation. So ventilation systems not only fail after a building is built, they often fail before the building is even occupied. Even when a ventilating system fails, the building occupants or operators typically do not realize that it has failed. Compare ventilation to other things that fail in a building. If the heating or cooling fails, we know within a few hours because the building gets cold or hot. Or if an elevator fails, we usually know immediately. If the hot water heater fails, we also usually know when we open a faucet. But ventilation is different. If the ventilation fails, often it is not noticed, sometimes not for months or years.

Even if the ventilation system is working and can provide enough air to the right locations, it is a challenge to reduce and increase the ventilation in response to occupancy that comes and goes. The closest we have come to achieving this is demand-controlled ventilation, typically using carbon-dioxide sensors that increase ventilation if the concentration of carbon dioxide gets too high. This has been a significant advance. However, demand-controlled ventilation is typically applied only in commercial buildings. It has not reached a variety of other common building types, such as single-family homes, multifamily buildings, or hotels.

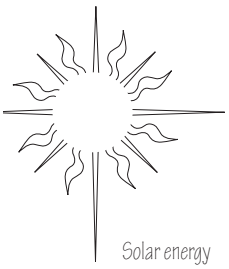
Another problem with ventilation is that air intake openings are sometimes located close to the sources of contaminants. So instead of diluting indoor air contaminants with fresh outdoor air, the ventilation introduces contaminants into the building. Evidence of this is seen in the traces of vehicle exhaust fumes, such as the black smudges on air grilles, in buildings that have loading docks or parking lots close to air intakes.

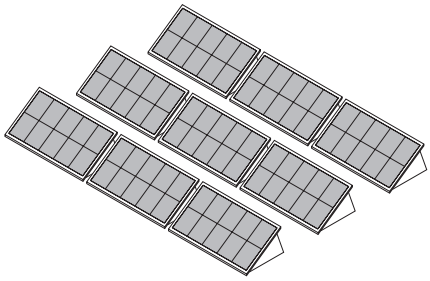
# 15
# Renewable Energy

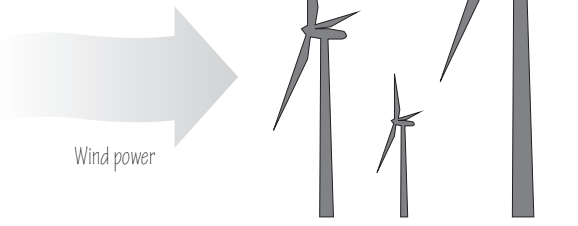
Renewable energy is energy that is provided by renewable sources, such as the sun or the wind. Renewable energy is contrasted with energy generated by fuels that are subject to depletion, such as oil, natural gas, and coal, which were formed over millions of years and which society is consuming at a rate faster than the rate at which the fuels were formed. Renewable energy is also contrasted with the energy generated by fuels that create pollution that will have a lasting effect, such as nuclear energy.



**15.01** Alternative energy sources.



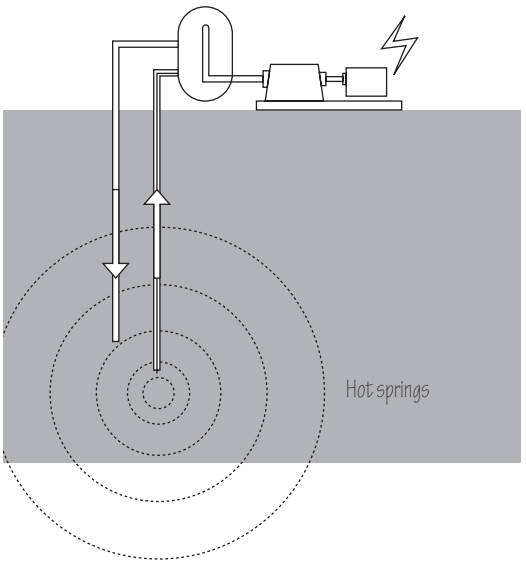



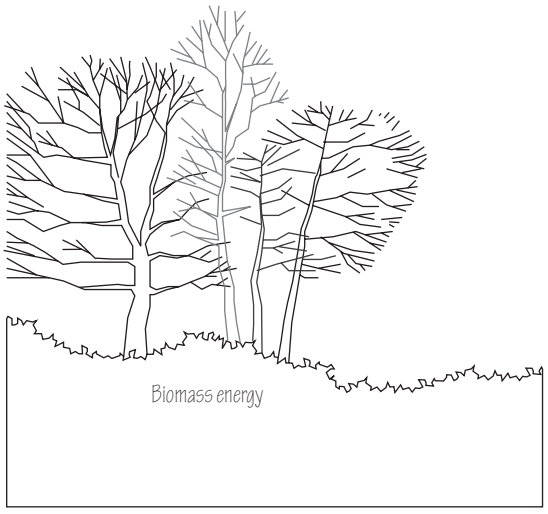



Having designed a low-energy building, attention can now be directed to renewable energy to provide some or all of the remaining energy needs of the building. Renewable energy is most effectively addressed at this point because it generally costs more to install than many building-efficiency improvements and it is frequently more cost-effective to address all building-efficiency improvements first. Separately, renewable energy equipment itself contains the embodied energy of manufacturing and transportation processes and so represents an energy penalty as a partial offset to the energy it produces.

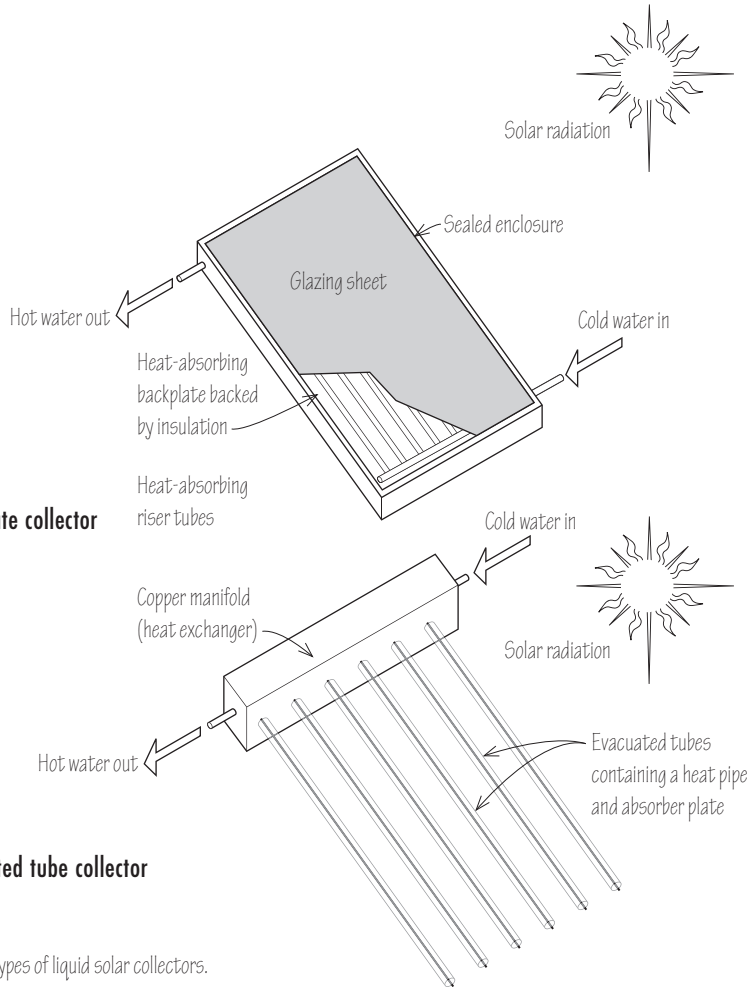
At this juncture in design from the outside in, the building should be receptive to the renewable energy equipment because of prior attention to receptivity, as in roof or site design. For example, the roof has been oriented to maximize solar radiation and obstructions have been removed to maximize the area available for solar panels.

The renewable systems considered here are primarily solar and wind. The use of biomass for heating is sometimes considered to be a renewable energy but was separately addressed in Chapter 14, Heating and Cooling. Geothermal heat pumps are sometimes described as a renewable energy technology but this is a misnomer. Geothermal heat from hot springs might validly be considered renewable whereas geothermal heat pumps rely on electricity just as other types of heat pumps do and therefore cannot be considered renewable.




**15.02** Renewable energy sources.




**15.05** Types of liquid solar collectors.

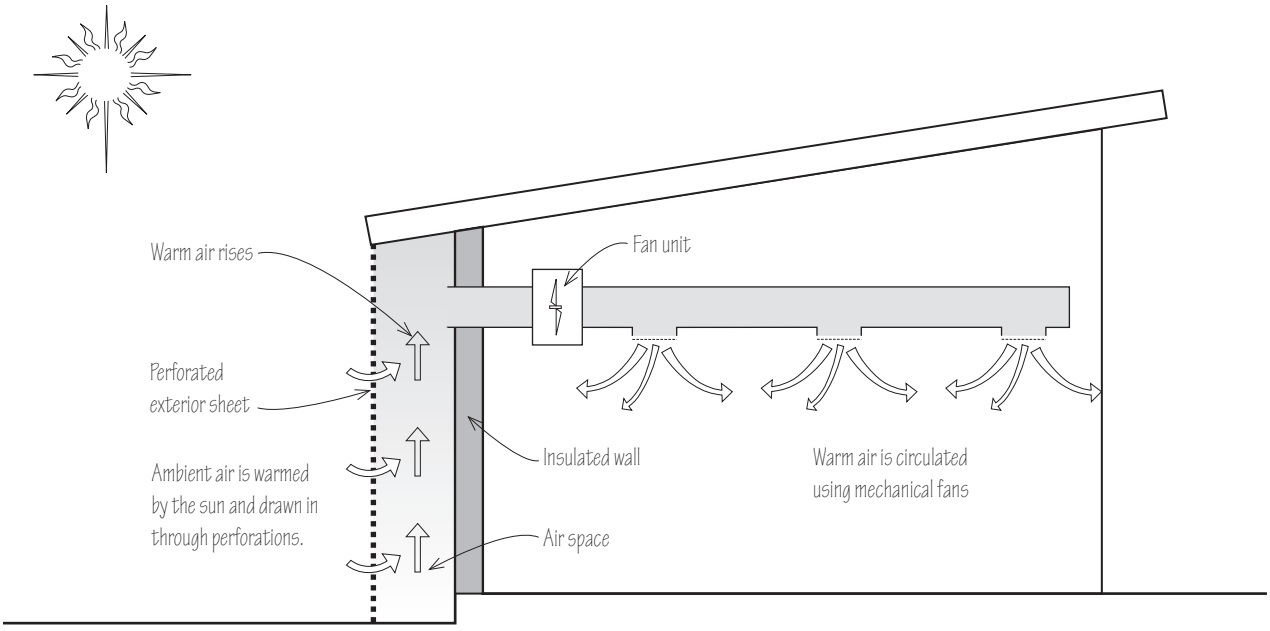
Common liquid collector types include flat-plate collectors and evacuated tube collectors. Flat-plate collectors are lower in cost but are also generally lower in efficiency. Evacuated tube collectors are higher in cost but higher in efficiency and can be easier to install on a roof because the collector is field-assembled from modular tubes.

Air-based systems can either heat outdoor air that is being drawn in for ventilation or heat indoor air. The ventilation application is common in a type of collector known as a transpired solar collector, where the air is drawn in through holes in the collector. Systems that heat air can be considered active, using a fan to circulate air, or passive, operating without a fan.

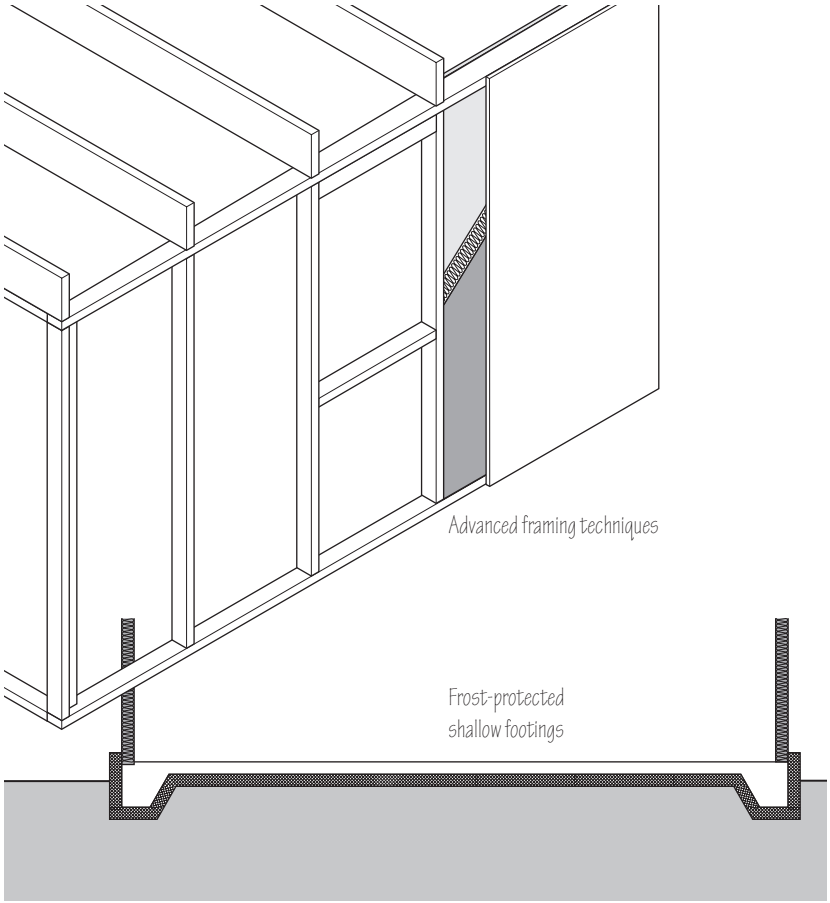
Whether active or passive, solar thermal systems typically have three components:

- Collection, to receive the sun's energy
- Storage, to store heat from periods when the sun is available and deliver it when the sun is not available
- Controls, to initiate collection and storage of solar energy when it is available and to prevent losses when the sun is not shining

These three components are important for the effectiveness of a solar thermal system. Without the three components, a solar thermal system may lose more heat than it gains, as collectors can lose energy as easily to the night sky as they can gain energy from the daytime sun, if not correctly collected, stored, and controlled.




**15.06** Solar transpiration system.

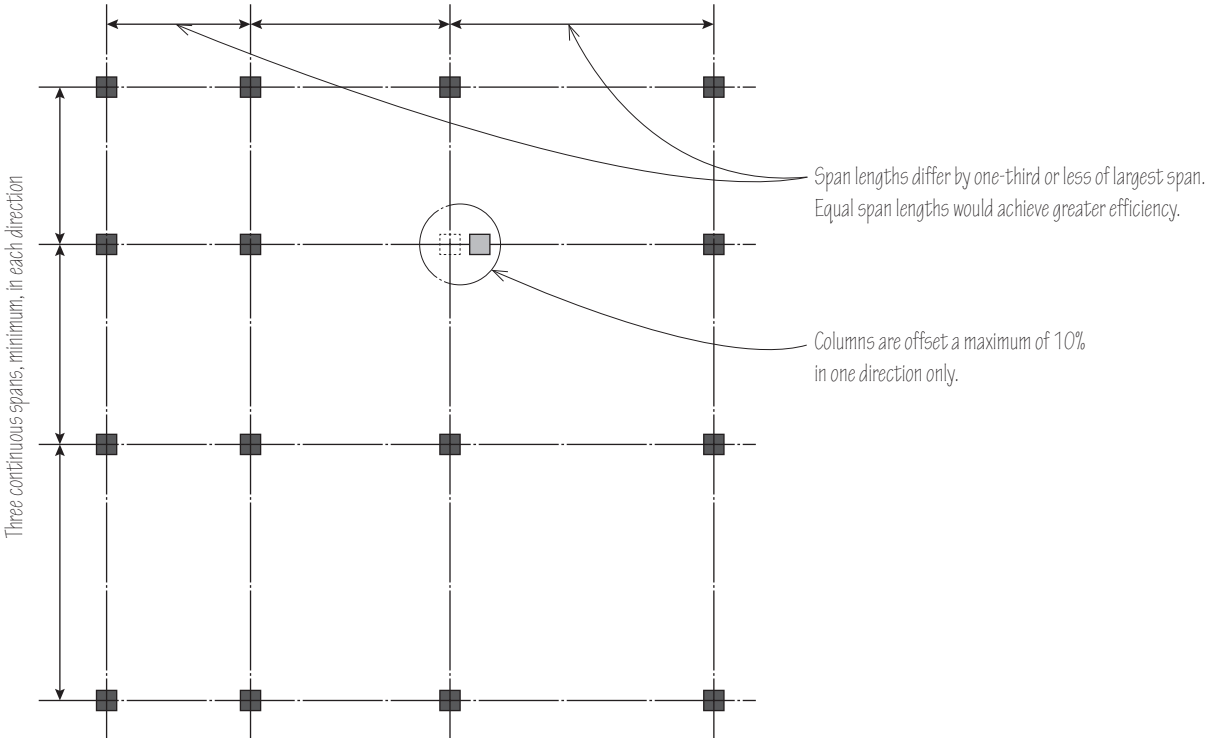



**16.04** Examples of material conservation through advanced construction techniques.

Another approach to reducing material use is through material-efficient design. Earlier, we discussed advanced framing techniques, specifically in the context of reducing thermal bridging. In so doing, less material is typically used. Examples include using 24-inch (610) stud spacing instead of 16-inch (405) spacing; single headers and single top plates; single studs at window and door openings; and simplified corners such as the two-stud corner. The prior discussion focused on exterior walls and on energy losses due to thermal bridging. For the purpose of material use reduction, interior walls can also be examined. Instead of standard 16-inch (405) spacing for both wood studs and steel studs, 24-inch (610) is allowed by code and can be considered. Another example of material-efficient advanced design is the use of frost-protected shallow foundations instead of regular foundation walls with footings. Frost-protected shallow foundations have been successfully used in the United States and over 1 million homes have been built with these foundations in Scandinavian countries.

Eliminating attics in pitched-roof buildings is another approach to reducing material use, as two structures—the attic floor and the roof—are combined into one.

When detailed structural design is done, rather than using rules of thumb or age-old practices, opportunities for reducing materials may be identified. For example, a 4-inch- (100) thick concrete slab might well be feasible for a particular floor, rather than a 5-inch- or 6-inch- (125 or 150) thick slab.

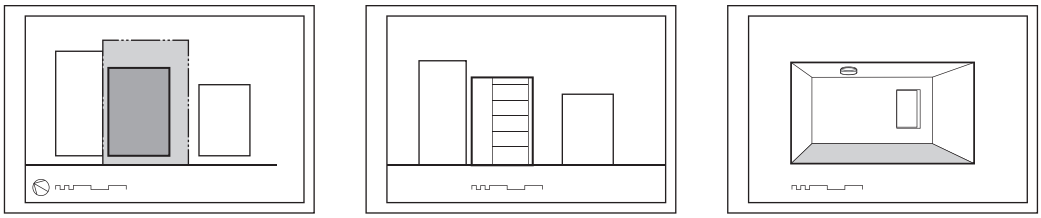



**16.05** Example of maximizing structural efficiencies to reduce material use.

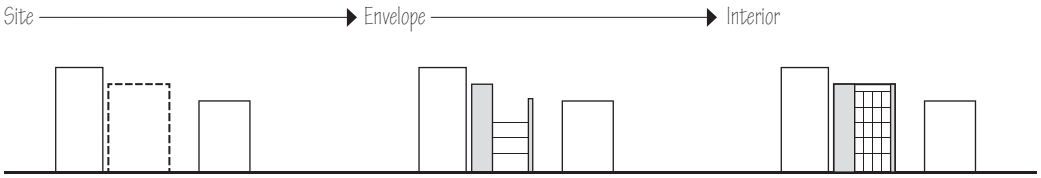
# 17
# Schedules, Sequences, and Affordability

## Schedules and Sequences

Design from the outside in parallels the typical sequence of events in a building project. Construction starts with the site, proceeds to the envelope, and is completed on the interior.

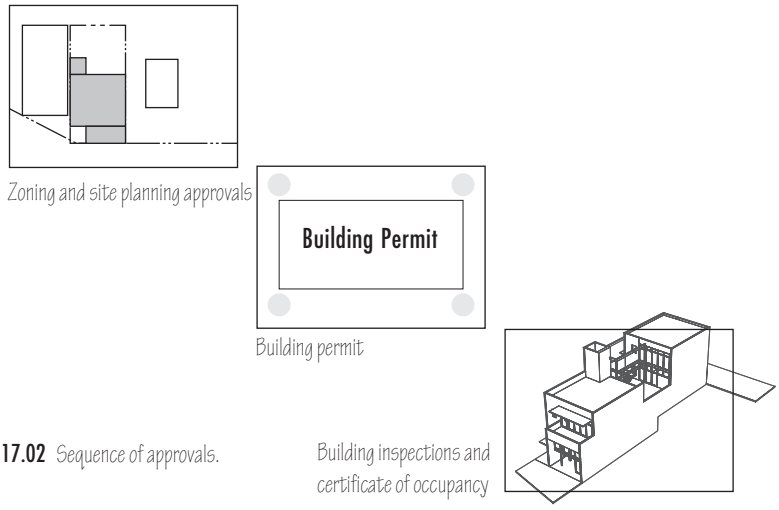


Design

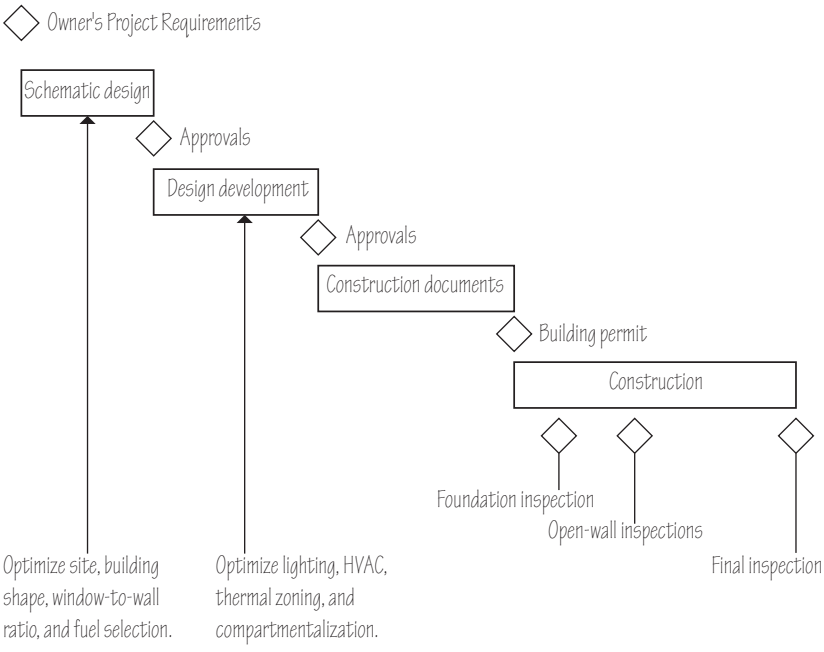



Construction

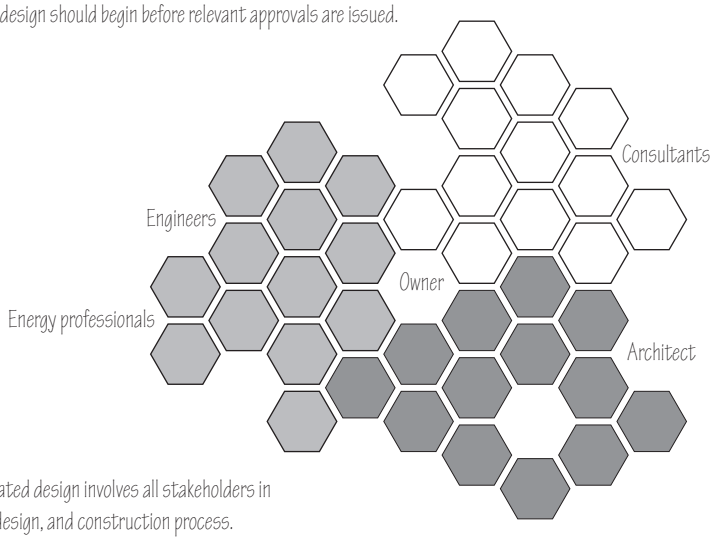
17.01 Designing from the outside in, from site to envelope to interior, parallels the sequence of construction.




**17.02** Sequence of approvals.




**17.03** Green design should begin before relevant approvals are issued.



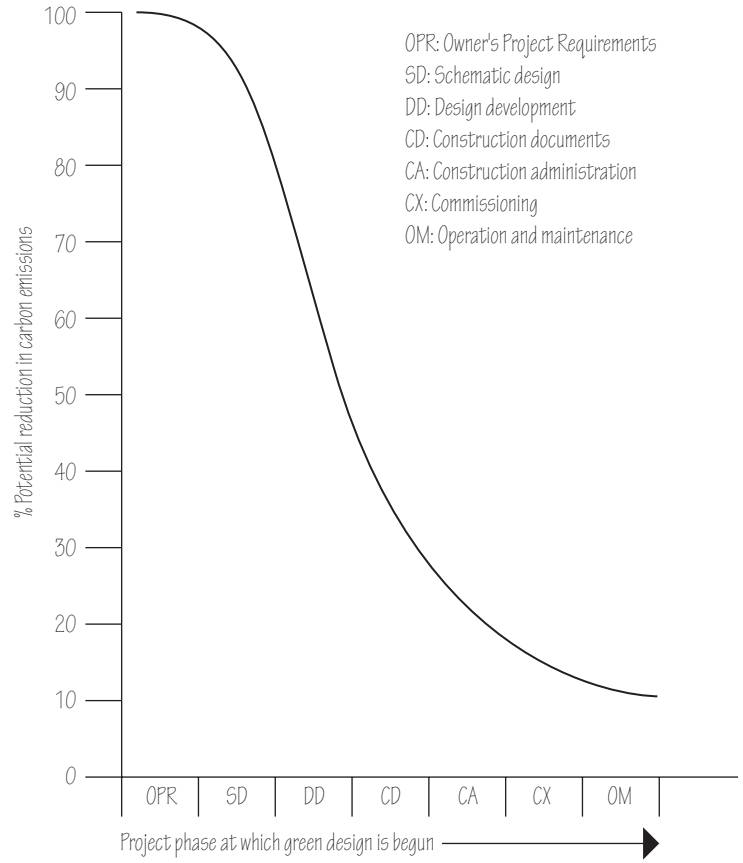

**17.04** Integrated design involves all stakeholders in the planning, design, and construction process.

Various approvals also follow the sequence from the outside in. Site planning approval typically occurs well before a building permit is issued. Foundation and structural approvals occur before electrical and mechanical inspections, which in turn frequently occur before final interior walk-throughs by the building inspector.

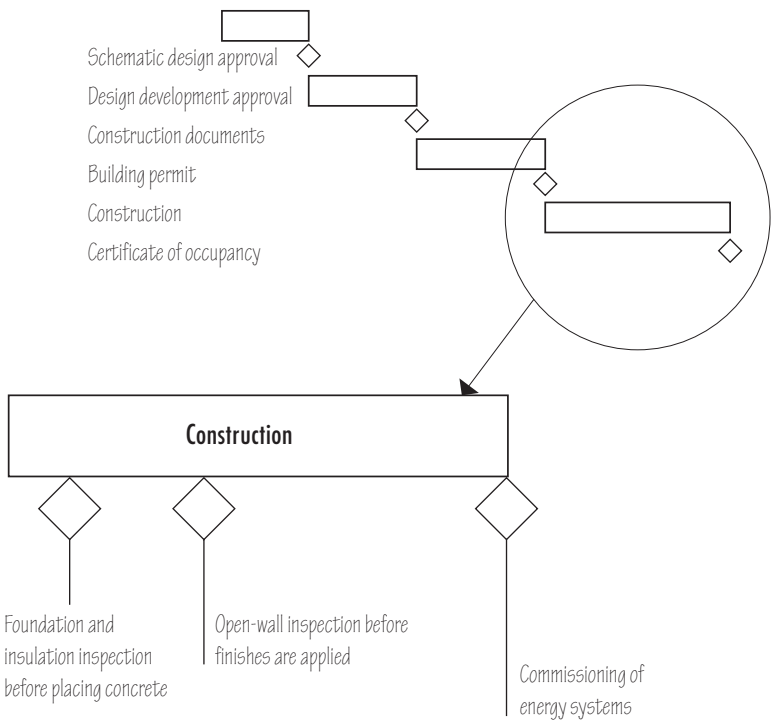
This is not to say that green design should happen in parallel with construction, or even in parallel with approvals. Green design is most effectively launched before approvals are issued. Otherwise, the building facade might obtain zoning approval, at which point aspects such as the building shape or window design can no longer be optimized for low energy use. At the least, the energy system optimization needs to happen before approvals start.

By approvals we mean not only approvals by local authorities but also approvals by the building owner or developer. If an owner chooses a building design before energy systems or impacts have been examined and the design turns out to be inefficient, the architect and the owner are put in the difficult position of having to either defend an inefficient design or having to go through the effort of altering the design.

Proponents of integrated design have advocated for involvement of the entire design team, including energy professionals and the owner, from the beginning of design projects. This has been a positive development. Without integrated design, energy models are sometimes built retroactively for buildings that have been finalized in design, and for which the most significant purpose of the energy model, which is to influence design, is no longer possible. At this junction, only incremental improvements can be made to the design to reduce energy use by an amount that is sometimes so small that it is not measurable in utility bills. Therefore, the owner or tenants are committed to paying unnecessarily high utility bills for the life of the building. They may also be committed to paying for construction costs that are higher than they need to be. Early examination of energy design can prevent these shortfalls.



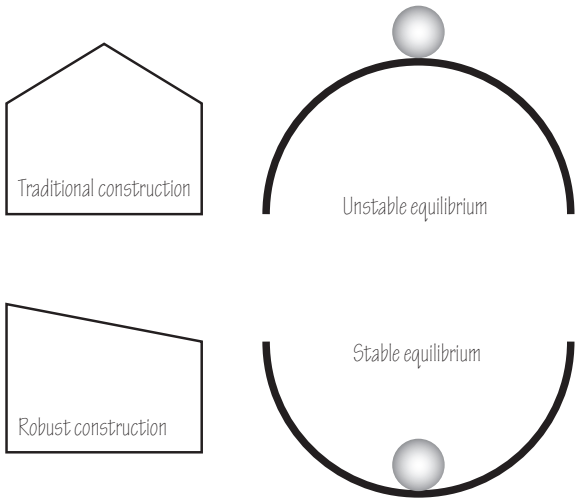

**17.05** Reducing carbon emissions by paying attention to green aspects from the beginning of a design project.




**17.06** Critical junctures in green construction inspections.

Another lens through which to view design and construction is the potential to reduce carbon emissions. If attention is directed to green design from the very beginning of a project, carbon emissions may potentially be reduced by 100%, relative to a traditional building. Possibilities for affecting carbon emissions drop rapidly during the early phases of design. If green aspects are not examined during schematic design, for example, and the building shape and window-to-wall area ratio are set, with limited roof or site area for renewable energy sources, the potential for impacting carbon emissions is dramatically reduced. If, furthermore, green aspects are not examined through design development, potential carbon emission impacts of building layout, unconditioned spaces, lighting, and HVAC system type are reduced. If green aspects are only begun during the construction documents phase, only minor carbon emissions reductions are possible through incremental and marginal improvements, such as window U-factors or HVAC efficiency. Finally, if no green design is applied, then the potential for reduced carbon emissions represents only those improvements that can be obtained in operating and maintaining the building.

During construction, the contractor sometimes accelerates decisions to keep building activities on schedule and to minimize costs. This acceleration can sacrifice attention to detail, most critically in the area of continuity of the thermal boundary and and in the functionality of the energy systems. This is when added holes creep into the building shell—the gas pipe penetration that is not sealed; the sill plate that is not sealed; the electrical penetration that is not sealed; the floor-to-floor pipe penetration that is not sealed; the window frame that is not sealed; the door frame that is not sealed. Most of these unsealed holes are then permanently covered by finishes. This is where there is need for quality control during construction. Schedule acceleration during and after energy systems are installed, such as the lighting, heating, and cooling systems, can result in increased energy use as well. There are important junctures at which there is need for quality control during construction. Building inspectors and design professionals need to look for these energy deficiencies and must be able to inspect buildings prior to when foundations, walls, windows, roofs, and floors are being finished or hidden from view, and prior to when energy systems are deployed.




**17.07** A metaphor for comparing traditional and more robust construction.

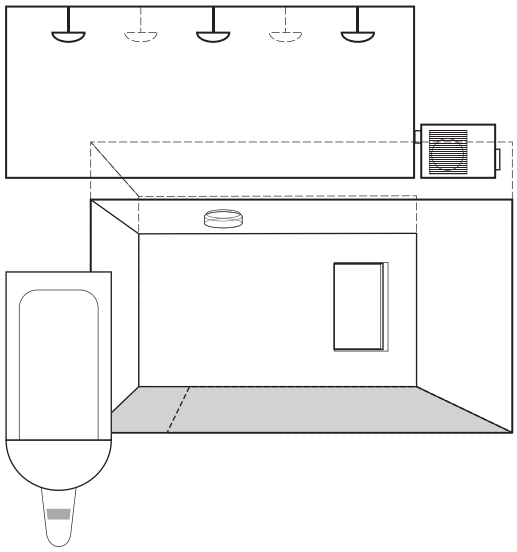
A complementary approach is to design buildings that are more robust—for example, ones that have fewer joints and penetrations, and with the heating and cooling within the thermal envelope. Such buildings are less likely to have construction deficiencies and will have fewer potential air-leakage sites, thermal bridging sites, and distribution losses. Starting from the outside in—simplify the building shape to minimize the number of corners and joints; then minimize the number of penetrations for doors, windows, ventilation penetrations, and combustion penetrations; and use monolithic and strong layers such as SIP panels, insulated concrete forms, and other walls and roof structures which have minimal penetrations, joints, and thermal bridging opportunities. With fewer potential sites for deficiencies, low-energy building performance is less reliant on identifying deficiencies during construction inspection. We might think of a metaphor of a marble in equilibrium on either of two surfaces. On top of an inverted hemisphere, the marble is in a dangerous equilibrium and will roll off if there is any disturbance unless inspected and corrected back to its quasi-stable position. On the other hand, at the bottom of a hemispherical bowl, the marble is in a stable equilibrium. It will always return to its equilibrium, even if there is a disturbance. It is robust by design.

## Affordability

Improvements suggested by green design may reduce construction cost, may be cost-neutral, or may increase construction cost. Costs of improvements vary by geographic location, according to local economic conditions, and over time. However, improvements may be grouped according to their overall construction cost impact.

**Group I**: Improvements that generally reduce construction cost. Examples include:

- Reducing floor area
- Reducing surface area
- Using advanced framing
- Eliminating heating and cooling in spaces not needing it
- Reducing heating and cooling equipment and distribution size due to reduced loads
- Using fewer light fixtures due to reduced lighting loads, resulting from optimized design, more highly reflective walls and ceilings, and avoiding recessed lighting and high ceilings
- Reducing air-conditioning system and distribution size due to reduced artificial lighting
- Eliminating cold water piping and valves from fixtures, such as waterless urinals
- Reducing construction waste
- Using imperfect materials
- Combining multiple uses or tenants in one building rather than in several smaller buildings
- Using structure as finish; unfinished surfaces
- Exposing utilities such as pipes and ducts
- Eliminating attics and pitched roofs
- Reducing number of exterior doors
- Reducing window size and quantity



**17.08** Group I improvements: Cost saving.