IN MARCH 1971 VISIONARY ARCHITECT MALCOLM WELLS published a watershed article in *Progressive Architecture*. It was rather intriguingly and challengingly titled “The Absolutely Constant Incontestably Stable Architectural Value Scale.” In essence, Wells argued that buildings should be *benchmarked* (to use a current term) against the environmentally regenerative capabilities of wilderness (Fig. 1.1). This seemed a radical idea then—and remains so even now, over 40 years later. Such a set of values, however, may be just what is called for as the design professions slowly but inevitably move from energy-efficient to green to sustainable design in the coming decades. The main problem with Wells’s “Incontestably Stable” benchmark is that most buildings fare poorly (if not dismally) against the environment-enhancing characteristics of wilderness. But perhaps this is more of a wakeup call than a problem.

As we sit firmly in the first quarter of the twenty-first century, *Progressive Architecture* is no longer in business, Malcolm Wells has sadly passed away, mechanical and electrical equipment has improved, simulation techniques have radically advanced, and information exchange has been revolutionized. In broad terms, however, the design process has changed little since the early 1970s. This should not be unexpected, as the design process

**Fig. 1.1 Evaluation of a typical project using Malcolm Wells's "absolutely constant incontestably stable architectural value scale." The value focus was wilderness; today it might well be sustainability. (© Malcolm Wells. Used with permission from Malcolm Wells. 1981. *Gentle Architecture*. McGraw-Hill, New York.)**
THE BUILDING CONTEXT

is simply a conceptual structure within which to develop a solution to a problem. The values and philosophy that underlie the design process absolutely must change, however, in the coming decades (if not immediately). The beauty of Wells’s rather simple scale was its crystal-clear focus upon the values that accompanied his design solutions—and the explicit stating of those values. To meet the challenges of the coming decades, it is critical that designers consider and adopt values appropriate to the nature of the problems being confronted—both at the individual project scale and globally. Nothing less makes sense.

1.1 INTRODUCTION

The design process is an integral part of the larger and more complex building procurement process through which an owner defines facility needs, considers architectural possibilities, contracts for design and construction services, and uses the resulting facility. Numerous decisions (literally thousands) made during the design process will determine the need for specific mechanical and electrical systems and equipment, and very often will determine eventual owner and occupant satisfaction. Discussing selected aspects of the design process seems a good way to start this book.

A building project typically begins with predesign activities that establish the need for, feasibility of, and proposed scope for a facility. If a project is deemed feasible and can be funded, a multiphase design process follows. The design phases are typically described as conceptual design, schematic design, and design development. If a project remains feasible as it progresses, the design process is followed by the construction and occupancy phases. In fast-track approaches (such as design-build), design efforts and construction activities may substantially overlap.

Predesign activities may be conducted by the design team (often under a separate contract), by the owner, or by a specialized consultant. The product of predesign activities should be a clearly defined scope of work for the design team to act upon. This product is variously called a program, a project brief, or the owner’s project requirements. The design process converts this statement of the owner’s requirements into drawings and specifications that permit a contractor to then convert the owner’s (and designer’s) wishes into a physical reality.

The various design phases are the primary areas of concern to the design team. The design process may span weeks (for a simple building or system) or years (for a large, complex project). The design team may consist of a sole practitioner for a residential project or 100 or more people located in different offices, cities, or even countries for a large project. Decisions made during the design process, especially during the early stages, will affect the project owner and occupants for many years—influencing operating costs, maintenance needs, comfort, enjoyment, and productivity.

The scope of work accomplished during each of the various design phases varies from firm to firm and project to project. In many cases, explicit expectations for the phases are described in professional service contracts between the design team and the owner. A series of images illustrating the development of the Solar Living Center and the Real Goods Store (starting with Figs. 1.2 and 1.3)
is used to illustrate the various phases of a building project. (The story of this remarkable project, and its design process, is chronicled in Schaeffer et al., 1997.) Broadly, the purpose of conceptual design (Fig. 1.4) is to outline a general solution to the owner’s program that meets the budget and captures the owner’s imagination so that design can continue. All fundamental decisions about the proposed building should be made during conceptual design (not that things can’t or won’t change). During schematic design (Figs. 1.5 and 1.6), the conceptual solution is further developed and refined.
During design development (Fig. 1.7), all decisions regarding a design solution are finalized, and construction drawings and specifications detailing those innumerable decisions are prepared.

The construction phase (Fig. 1.8) is primarily in the hands of the contractor, although design decisions have determined what will be built and may dramatically affect constructability. The building owner and occupants are the key players during the occupancy phase (Fig. 1.9). Their experiences with the building will clearly be influenced by design decisions and construction quality, as well as by maintenance and operation practices. A feedback loop that allows construction and occupancy experiences (lessons learned—both good and bad)
to be used by the design team on future projects is essential to good design practice.

### 1.2 DESIGN INTENT

Design efforts should focus upon achieving a solution that will meet the expectations of a well-thought-out and explicitly defined design intent. A design intent is simply a statement that outlines an expected high-level outcome of the design process. Making such a fundamental statement is critical to the success of a design, as it points to the general direction(s) that the design process must take to achieve success. Design intent should not try to capture the totality of a building’s character; this will come only with the completion of the

---

**Fig. 1.8** Construction phase photo of the straw bale walls of the Solar Living Center and Real Goods Store. Design intent becomes reality during this phase. (Reprinted from A Place in the Sun with permission of Real Goods Trading Corporation.)

**Fig. 1.9** The Solar Living Center and Real Goods Store during its occupancy and operations phase. Formal and informal evaluation of the success of the design solution may (and should) occur. Lessons learned from these evaluations can inform future projects. This photo was taken during a Vital Signs case study training session held at the Solar Living Center. (© Cris Benton, kite aerial photographer and professor, University of California–Berkeley; used with permission.)
design. It should, however, adequately express the defining characteristics of a proposed building solution. Example design intents (from among thousands of possibilities) might include the following:

• The building will provide outstanding comfort for its occupants.
• The design will consider the latest in information technology.
• The building will be green, with a focus on indoor environmental quality.
• The building will be carbon neutral.
• The building will provide a high degree of flexibility for its occupants.

Clear design intents are important because they set the tone for design efforts, allow all members of the design team to understand what is truly critical to success, provide a general direction for early design efforts, and put key or unusual design concerns on the table. Professor Larry Peterson, former director of the Florida Sustainable Communities Center, has described the earliest decisions in the design process as an attempt to make the “first, best moves.” Strong design intent will inform such moves. Weak intent will result in a weak building. Great moves too late will be futile. The specificity of the design intent will evolve throughout the design process. Outstanding comfort during conceptual design may become outstanding thermal, visual, and acoustic comfort during schematic design.

1.3 DESIGN CRITERIA

Design criteria are the benchmarks against which success or failure in meeting design intent is measured. In addition to providing a basis against which to evaluate success, design criteria will ensure that all involved parties seriously address the technical and philosophical issues underlying a project’s design intent. Setting design criteria demands the clarification and definition of many intentionally broad terms used when crafting design intent statements. For example, what is really meant by green, by flexibility, by comfort? If such terms cannot be benchmarked, then there is no way for the success of a design to be evaluated—essentially anything goes, and all solutions are potentially equally valid. Setting design criteria for qualitative issues (such as exciting, relaxing, or spacious) can be especially challenging, but equally important (and possible).

Design criteria should be established as early in the design process as possible—but certainly no later than the schematic design phase. Because design criteria will define success or failure in a specific area of the building design process, they should be realistic and not subject to whimsical change. In many cases, design criteria will be used both to evaluate the success of a design approach or strategy and to evaluate the performance of a system or component in a completed building. Examples of design criteria might include the following:

• Thermal conditions will meet the requirements of ASHRAE Standard 55.
• The power density of the lighting system will be no greater than 0.7 W/ft².
• The building will achieve a LEED® Silver certification.
• Fifty percent of building water consumption will be provided by rainwater capture.
• Background sound pressure levels in classrooms will not exceed RC 35.

1.4 METHODS AND TOOLS

Methods and tools are the means through which design intent is accomplished. They include design methods and tools, such as a heat loss calculation procedure or a sun angle calculator. They also include the components, equipment, and systems that collectively define a building. It is important that an appropriate method or tool be used for a particular purpose. It is also critical that methods and tools (as means to an end) never be confused with either design intent (a desired end) or design criteria (benchmarks for success).

For any given design situation, there are typically many valid and viable solutions available to the design team. It is important that no reasonable solution be overlooked or ruled out as a result of design process short circuits. Although this may seem unlikely, methods (such as fire sprinklers, electric lighting, and sound absorption) are often included as part of a design intent statement. Should this occur, all other possible (and perhaps more desirable) solutions are ruled out by direct exclusion—if electric lighting is seen as an intent, then there is no place for daylighting. This does not serve a client or occupants well, and is also a disservice to the design team.
This book is a veritable catalog of design guidelines, methods, equipment, and systems that serve as means and methods to desired design ends. Sorting through this extensive information will be easier with specific design intent and criteria in mind. Owner expectations and designer experiences will typically inform design intent. Sections of the book that address fundamental principles will provide assistance with establishment of appropriate design criteria. Table 1.1 provides examples of the relationships between design intent, design criteria, and tools/methods.

### 1.5 VALIDATION AND EVALUATION

To function as a knowledge-based profession, design (architecture and engineering) must reflect upon previous efforts and learn from existing buildings. Except in surprisingly rare situations, most building designs are unique—comprising a collection of elements not previously assembled in precisely the same way. Most buildings are essentially a design team hypothesis—"We believe that this solution will work for the given situation." Unfortunately, the vast majority of buildings exist as untested hypotheses. Little in the way of performance evaluation or structured feedback from the owner and occupants is typically sought. This is not to suggest that designers do not learn from their projects, but rather that little research-quality, publicly shared information is captured for use on other projects. This is not an ideal model for professional practice from the perspective of society at large.

(a) Conventional Validation/ Evaluation Approaches

Design validation is very common, although perhaps more so when dealing with quantitative concerns than with qualitative issues. Many design validation approaches are employed, including hand calculations, computer simulations and modeling, physical models (of various scales and complexity), and opinion surveys. Numerous design validation methods are presented in this book. Simple design validation methods (such as broad approximations, lookup tables, or nomographs) requiring few decisions and little input data are typically used early in the design process. The later stages of design see the introduction of more complex methods (such as computer simulations or multistep hand calculations) requiring substantial and detailed input.

Building validation is much less common than design validation. Structured evaluations of occupied buildings are rarely carried out. Historically, the most commonly encountered means of validating building performance is the post-occupancy evaluation (POE). Published POEs have typically

<table>
<thead>
<tr>
<th>Issue</th>
<th>Design Intent</th>
<th>Possible Design Criterion</th>
<th>Potential Design Tools</th>
<th>Potential Implementation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal comfort</td>
<td>Acceptable thermal comfort</td>
<td>Compliance with ASHRAE Standard 55</td>
<td>Standard 55 graphs/tables or comfort software</td>
<td>Passive climate control and/or active climate control systems</td>
</tr>
<tr>
<td>Lighting level</td>
<td>Acceptable illumination</td>
<td>Compliance with recommendations in the IESNA Lighting Handbook</td>
<td>Hand calculations or computer simulations</td>
<td>Daylighting and/or electric lighting</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>Minimal energy efficiency</td>
<td>Compliance with ASHRAE Standard 90.1</td>
<td>Handbooks, simulation software, manufacturer’s data, experience</td>
<td>Envelope strategies and/or system and equipment strategies</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>Outstanding energy efficiency</td>
<td>Meet the requirements of the ASHRAE 50% Advanced Energy Design Guide for the building type</td>
<td>Handbooks, simulation software, manufacturer’s data, experience</td>
<td>Envelope strategies and/or system and equipment strategies</td>
</tr>
<tr>
<td>Green design</td>
<td>Obtain green building</td>
<td>Meet the requirements for a LEED Gold rating</td>
<td>LEED materials, handbooks, experience</td>
<td>Any combination of approved strategies to obtain sufficient rating points</td>
</tr>
</tbody>
</table>

### TABLE 1.1 Relationships between Design Intent, Design Criteria, and Design Tools/Methods
focused upon some specific (and often nontechnical) aspect of building performance, such as way-finding or productivity. The building commissioning process and evaluative case studies of projects are finding more application as approaches to building validation. Third-party validations, such as ENERGY STAR certified buildings and the Leadership in Energy and Environmental Design (LEED) rating system, are popular approaches.

(b) Commissioning

Building commissioning is a proven approach to quality assurance. An independent commissioning authority (an individual or, more commonly, a team) verifies that design decisions and related building assemblies, equipment, and systems can meet the owner’s project requirements (design intent and criteria). Verification is accomplished through review of design documents, observation of component installation, and detailed testing of equipment and systems under conditions expected to be encountered with building use. Historically focused upon mechanical and electrical systems, commissioning is currently being applied to numerous building systems—including envelope, security, fire protection, and information systems. Active involvement of the design team is critical to the success of the commissioning process (ASHRAE, 2013; Grondzik, 2009).

(c) Case Studies

Case studies represent another approach to design/construction validation and evaluation. The underlying philosophy of a case study is to capture information from a particular situation and convey the information in a way that makes it useful to a broader range of situations. A building case study attempts to present the lessons learned from one case in a manner that can benefit other cases (future designs). In North America, the Vital Signs and Agents of Change projects have focused upon disseminating a building performance case study methodology for design professionals and students—with an intentional focus upon occupied buildings (à la POEs). The American Institute of Architects and the U.S. Green Building Council have developed case studies dealing with design process/practice. In the United Kingdom, numerous case studies have been conducted under the auspices of the PROBE (Post-Occupancy Review of Buildings and Their Engineering) project.

1.6 INFLUENCES ON THE DESIGN PROCESS

The design process may appear to revolve primarily around the needs of a client and the capabilities of the design team—as exemplified by the establishment of design intent and criteria. There are several other notable influences, however, that affect the conduct and outcome of the building design process. Some of these influences are historic and affect virtually every building project; others represent emerging trends and affect only selected projects. Several of these design-influencing factors are discussed below.

(a) Codes and Standards

The design of virtually every building in North America will be influenced by codes and standards. Codes are government-mandated and -enforced documents that stipulate minimum acceptable building practices. Designers usually interface with codes through an entity known as the authority having jurisdiction. There may be several such authorities for any given locale or project (fire protection requirements, for example, may be enforced separately from general building construction requirements or energy performance requirements). Codes essentially define the minimum response that society deems acceptable for dealing with a particular building design issue. In no way is code compliance—by itself—likely to be adequate to meet the needs of a client. On the other hand, code compliance is indisputably necessary.

Codes may be written in prescriptive language or in performance terms. A prescriptive approach mandates that something be done in a certain way. Examples of prescriptive code requirements include minimum R-values for roof insulation, minimum pipe sizes for a roof drainage system, or a minimum number of hurricane clips per length of roof. The majority of codes in the United States are fundamentally prescriptive in nature. A prescriptive code defines means and methods. By contrast, a performance code defines outcomes. A performance approach presents an objective that must be met. Examples of performance approaches to code requirements include a maximum permissible design heat flow
through a building envelope, a minimum design rainfall that can be safely drained from a building roof, or a defined wind speed that will not damage a roof construction. Some primarily prescriptive codes offer performance “options” for compliance. This is especially true of energy codes and for smoke control requirements in fire protection codes.

Codes in the United States are continually in transition. Each jurisdiction (city, county, and/or state, depending upon legislation) is generally free to adopt whichever model code it deems most appropriate. Some jurisdictions (typically large cities) use homegrown codes instead of a model code. Historically, there were four model codes (the Uniform Building Code, the Standard Building Code, the Basic Building Code, and the National Building Code) that were used in various regions of the country. This regional code pattern has changed, with development and widespread use of a single model, the International Building Code, to provide a more uniform and standardized set of code requirements. Canada has its own National Building Code. Knowledge of current code requirements for a project is a critical element of the design process.

Standards are documents that present a set of minimum requirements for some aspect of building design. Such requirements have been developed by a recognized authority (such as Underwriters Laboratories, the National Fire Protection Association, or the American Society of Heating, Refrigerating and Air-Conditioning Engineers). Standards do not carry the weight of government enforcement that codes do, but they are often incorporated into codes via reference. Standards play an important role in building design and are often used by legal authorities to define the level of care expected of design professionals. Standards are typically developed under a consensus process with substantial opportunity for external review and input. Guidelines and handbooks are less formal than standards, usually with less formal review and/or consensus. General practice, the least formalized basis for design, captures the norm for a given locale or discipline. Table 1.2 provides examples of codes, standards, and related design guidance documents.

(b) Costs

Costs are a historic influence on the design process and are just as pervasive as codes. Typically, one of the earliest and strictest limits on design flexibility is the maximum construction budget imposed by the client. First cost (the cost for an owner to acquire the keys to a completed building) is the most commonly used cost factor. First cost is usually expressed as a maximum allowable construction cost or as a cost per unit area. Life-cycle cost (the cost for an owner to acquire and use a building for some defined period of time) is generally as important as, or more important than, first cost, but is often ignored by owners and usually not well understood by designers.

Over the life of a building, operating and maintenance costs can far exceed the cost to construct or acquire a building. Thus, whenever feasible, design decisions should be based upon life-cycle cost analyses and not simply first cost. The math of life-cycle costing is not difficult. The primary difficulties in implementing life-cycle cost analysis are estimating future expenses and the uncertainty naturally associated with projecting future conditions. These issues are not as difficult as they might seem, however, and a number of well-regarded life-cycle cost methodologies have been developed. Appendix J provides basic information on life-cycle cost factors and procedures. The design team may find life-cycle costing a persuasive ally in the quest to convince an owner to make important, but apparently expensive, decisions.

(c) Passive and Active Approaches

The distinction between passive and active systems may mean little to the average building owner, but it can be critical to the building designer and occupant. Development of passive systems must begin early in the design process, and requires early and continuous attention from the architectural designer. Passive system operation will often require the earnest cooperation and involvement of building occupants and users. Table 1.3 summarizes the identifying characteristics of passive and active systems approaches. These approaches are conceptually opposite in nature. Individual systems that embody both active and passive characteristics are often called hybrid systems. Hybrid systems are commonly employed as a means of tapping into the best aspects of both approaches.

The typical building will usually include both passive and active systems. Passive systems may be used for climate control, fire protection, lighting, acoustics, circulation, and/or sanitation. Active systems may also be used for the same purposes and for electrical distribution and signaling.
### TABLE 1.2 Codes, Standards, and Other Design Guidance Documents

<table>
<thead>
<tr>
<th>Document Type</th>
<th>Characteristics</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>Government-mandated and government-enforced (typically via the building and occupancy permit process); may be a legislatively adopted standard</td>
<td>Florida Building Code; California Title 24; Chicago Building Code; International Building Code (when adopted by a jurisdiction)</td>
</tr>
<tr>
<td>Standard</td>
<td>Usually a consensus document developed by a professional organization under established procedures with opportunities for public review and input</td>
<td>ASHRAE Standard 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings; ASTM E413-87, Classification for Rating Sound Insulation; ASME A17.1, Safety Code for Elevators and Escalators</td>
</tr>
<tr>
<td>Guideline</td>
<td>Usually a consensus document developed by a professional organization, but within a looser structure and with less stringent public review</td>
<td>ASHRAE Guideline 0, The Commissioning Process; IESNA Advanced Lighting Guidelines; NEMA LSD 12, Best Practices for Metal Halide Lighting Systems</td>
</tr>
<tr>
<td>Handbook</td>
<td>Development can vary widely—involving formal committees and peer review or single/multiple authors with no formal external review</td>
<td>IESNA Lighting Handbook, ASHRAE Handbook—Fundamentals; NFPA Fire Protection Handbook</td>
</tr>
<tr>
<td>Design guide</td>
<td>Development by experienced practitioners and educators; may offer schematic design process guidance, address architectural implications, links to other resources</td>
<td>Design procedures; general sizing procedures; green design strategies; case studies</td>
</tr>
<tr>
<td>General practice</td>
<td>The prevailing norm for design within a given community or discipline; least formal of all modes of guidance</td>
<td>System sizing approximations; generally accepted flashing details</td>
</tr>
</tbody>
</table>

Image Sources: code—used with permission of the International Code Council; standard—used with permission of the American Society of Heating, Refrigerating and Air-Conditioning Engineers; guideline and handbook—used with permission of the Illuminating Engineering Society of North America; general practice—used with permission of John Wiley & Sons.


### (d) Energy Efficiency

Some level of energy efficiency is a societally mandated element of the design process in most developed countries. Code requirements for energy-efficient building solutions were generally instituted as a result of the energy crises of the 1970s and have been updated on a periodic basis since then. As with all code requirements, mandated energy efficiency levels represent the minimum performance level that is considered acceptable—not an optimal performance level. What is considered acceptable minimum performance has evolved over time in response to changes in energy costs and availability.
TABLE 1.3 Defining the Characteristics of Passive and Active Systems

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Passive System</th>
<th>Active System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy source</td>
<td>Uses no purchased energy (no electricity, natural gas, fuel oil, etc.)—example: daylighting system</td>
<td>Uses primarily purchased (and nonrenewable) energy—example: electric lighting system</td>
</tr>
<tr>
<td>System components</td>
<td>Components play multiple roles in system and in the building as a whole—example: concrete floor slab that is structure, walking surface, and solar collector/storage</td>
<td>Components are commonly single-purpose elements—example: gas furnace</td>
</tr>
<tr>
<td>System integration</td>
<td>System is usually tightly integrated (often inseparably) with the overall building design—example: natural ventilation system using windows</td>
<td>System is usually not well integrated with the overall building design, often seeming an add-on—example: window air-conditioning unit</td>
</tr>
</tbody>
</table>

Passive and active systems represent opposing philosophical concepts. Design is seldom so straightforward as to permit the exclusive use of one philosophy. Thus, the hybrid system. Hybrid systems are a composite of active and passive approaches, typically leaning more toward the passive. For example, single-purpose, electricity-consuming (active) ceiling fans might be added to a natural ventilation (passive) cooling system to extend the performance of the system and thus reduce energy usage that would otherwise occur if a fully active air-conditioning system were turned on instead of the fans.

and also in response to changes in the costs and availability of building technology.

In the United States, ANSI/ASHRAE/IESNA Standard 90.1 (published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, cosponsored by the Illuminating Engineering Society of North America, and approved by the American National Standards Institute) is the most commonly encountered energy efficiency benchmark for commercial/institutional buildings. Some states (such as California and Florida) utilize state-specific energy codes. Residential energy efficiency requirements are addressed by several model codes and standards (including the International Energy Conservation Code, the International Green Construction Code, and ANSI/ASHRAE Standard 90.2). Appendix H provides a sample of energy efficiency requirements from Standard 90.1.

Energy efficiency requirements for residential buildings tend to focus upon minimum envelope (walls, floors, roofs, doors, windows) and mechanical equipment (heating, cooling, domestic hot water) performance. Energy efficiency requirements for commercial/institutional buildings address virtually every building system (including lighting and electrical distribution). Most energy codes present a set of prescriptive minimum requirements for individual building elements, with an option for an alternative means of compliance to permit innovation and/or a systems-based design approach.

Efficiency is simply the ratio of system output to system input. The greater the output for any given input, the higher the efficiency. This concept plays a large role in energy efficiency standards through the specification of minimum efficiencies for many items of mechanical and electrical equipment for buildings. Energy conservation implies saving energy by using less. This is conceptually different from efficiency but is an integral part of everyday usage of the term. Energy efficiency codes and standards include elements of conservation embodied in equipment control requirements or insulation levels. Because of negative connotations that some associate with “conservation” (doing without), the term energy efficiency is generally used to describe both conservation and efficiency efforts in buildings.

The majority of energy efficiency standards deal solely with on-site energy usage. The reason for this approach lies in the controversy surrounding assigning site-source energy adjustment factors that do not disadvantage one fuel over another (there is no such controversy regarding renewable energy sources). Off-site energy consumption (for example, that required to transport fuel oil or natural gas, or the substantial process losses from electrical generation plants) is not typically addressed in energy efficiency regulations. A site-source focus can seriously skew thinking about energy efficiency design strategies, and this should be recognized by the design team. Off-site energy consumption that
is directly tied to on-site consumption is real, can be substantial, and contributes to carbon emissions and fossil fuel depletion.

Passive design solutions usually employ renewable energy resources. Several active design solutions, however, also utilize renewable energy forms. Energy conservation and efficiency concerns are typically focused upon minimizing depletion of non-renewable energy resources—even when not explicitly stated. The use of renewable energy sources (such as solar radiation and wind) changes the passive versus active discussion, should change the perspective of the design team, and may affect the way compliance with energy efficiency codes/standards is evaluated.

(e) Passive House Performance

At the risk of sowing confusion, it is appropriate to discuss Passive House performance in conjunction with energy efficiency. Passive House (with caps) is a building performance guideline with stringent energy benchmarks for both site (specifically space conditioning) and source energy. A Passive House (denoting annual energy performance) is not necessarily a house with passive heating/cooling/lighting systems—although a Passive House will have a well-designed enclosure system (which is very much a passive approach). To stir potential confusion a bit more, a Passive House does not need to be a house; it may be an office, school, or other building type. Some time on the horizon, the designation “Passive House” may change. In any event, a building certified under Passive House guidelines will be a highly energy-efficient building that approaches net-zero energy performance levels.

Currently, the benchmark requirements for Passive House performance in the United States (PHIUS) are:

Heating energy: ≤ 4.75 kBtu/ft²/yr (15 kWh/m²/yr)
Cooling energy: ≤ 4.75 kBtu/ft²/yr (15 kWh/m²/yr)
Total source (primary) energy: ≤ 38.1 kBtu/ft²/yr
(120 kWh/m²/yr)

The general performance of a Passive House home ranks around 30–40 within the HERS rating spectrum (Fig. 1.10), depending on the size of the home, the climate, and if a solar thermal system is installed (without added photovoltaics). Several other performance targets (such as those set by LEED for Homes and Architecture 2030) are also shown in Fig. 1.10.

(f) Net-Zero Energy

Pushing energy efficiency toward its limits will lead to the realm of building performance associated with net-zero energy buildings. High efficiency alone is not sufficient to produce a net-zero building, but it is a practical prerequisite. By definition (National Renewable Energy Laboratory, NREL), a net-zero energy building will—on

![HERS Index](image-url)
an annual basis—produce as much energy from renewable resources (solar and wind, for example) as it consumes. Such a building will, despite aggressive energy-efficiency efforts, still use energy (for things such as domestic water heating, electric lighting, space heating/cooling, and appliances). Any such residual energy requirements will, however, be provided by renewable energy resources that match the magnitude of fossil-fuel-based energy consumption. Thus the use of the term “net-zero energy,” as opposed to “zero-energy” (which would essentially mean an unused building).

Looking at a net-zero energy building from another perspective—such a building may use energy derived from fossil fuels (such as electricity from a coal-fired power plant) to meet its programmatic and occupancy needs. But, every Btu (kWh) of energy from a nonrenewable resource must be matched by a Btu (kWh) of energy from a renewable resource. A net-zero energy building is not a no-energy building, and it is not a no-nonrenewable-energy building. It is, however, a low-energy building that employs at least 50% (annually) renewable energy. This is a big step on the road to sustainability. Sustainability (on the energy front) may lie in what some designers are describing as plus-energy buildings. More on sustainability in a following section.

There is no net-zero energy building code in the United States. Designers thus have some flexibility in defining a net-zero energy building within the clear limits of energy balance described above. This flexibility lies in the setting of system boundaries. The system boundaries may be spatial, temporal, and/or organizational. Life can become complicated. Some examples follow:

- Today, the most common perception of a net-zero energy building is one that is net-zero considering operational energy measured at the site boundary.
- The system boundaries may be expanded back to the proximate source of the building’s energy, such that source (versus site) energy is balanced; this is roughly three times more challenging for an all-electric building (as a result of generation and transmission losses that are not included in a site-based analysis).
- One could, in theory, extend the analysis boundary back to the ultimate source of the building’s energy (such as a coal mine or gas well); this is rarely done.
- Rather than considering only operational energy, the net-zero analysis boundary might be extended backward in time to include construction process energy (and perhaps design process energy).
- An owner might want to consider not just the building as the system, but also the organizational efforts supported by (or perhaps required by) the building: employee commuting energy might be considered, and/or the energy required to clean and maintain the building.

The source of renewable energy inputs to a net-zero building may also be addressed as a function of site boundary. For example, the renewable energy component might come from a green power purchase agreement (with the energy production occurring remotely), or the energy might be produced from systems located on or adjacent to a building. The authors’ philosophical preference is for site-based renewables—such that the design team is directly responsible for necessary energy production. In this case, the design process (relative to energy, and perhaps also water) will be seen as a job of balancing demand with supply.

(g) Green Building Design Strategies

Green design considerations—whether part of a formal building rating or just a matter of better design—are entering the design process for many buildings. Green design goes beyond energy-efficient design in order to address both the local and global impacts of building energy, water, and materials usage. Energy efficiency is a key, but not sole, element of green design. The concept that is broadly called “green design” arose from concerns about the wide-ranging environmental impacts of design decisions. Although there is no generally accepted concise definition of green, the term is typically understood to incorporate concern for the health and well-being of building occupants/users and respect for the larger global environment. A green building should maximize beneficial impacts on its direct beneficiaries while minimizing negative impacts on the site, local, regional, national, and global environments.

Several rating systems have found wide acceptance as benchmarks for “greenness.” These include
the U.S. Green Building Council’s LEED system, the Green Building Initiative’s Green Globes Environmental Assessment system, and an international evaluation methodology entitled GBTool. Green building rating systems are in active use in the United Kingdom, Canada, and Japan. Most green building ratings systems are voluntary and would be correctly termed guidelines. A code-language set of green building design requirements, however, was developed by a coalition of professional organizations under the auspices of ASHRAE Standard 189, *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*.

Typical of green guidelines, the LEED systems (there are a number of rating schemes for a variety of project types) present a palette of design options from which the design team can select strategies appropriate for a particular building (Fig. 1.11) and its context. Amassing points for selected strategies provides a means of attaining green building status—at one of several levels of achievement—via a formal third-party certification procedure. Prerequisite design strategies (such as baseline energy efficiency and acceptable indoor air quality) provide an underpinning for the palette of optional strategies.

The emergence of green building rating systems has greatly rationalized design intent and design criteria in this particular realm of architecture. Prior to the advent of LEED (or GBTool), anyone could claim greenness for his/her designs. Although green design is entered into voluntarily (few codes currently require it, although a number of municipalities require new public buildings to be green), there are now several generally accepted standards against which performance can be measured. Appendix H provides an excerpt from the LEED-NC green building rating system to provide a sense of the scope of green building expectations.

### (h) Carbon-Neutral Design

Climate change and global warming are growing concerns in the design community, as evidenced by the positive response of many professional organizations to the 2030 Challenge issued by Architecture 2030 (Architecture 2030). Design to reduce carbon emissions is becoming an issue on many building projects. The term *carbon-neutral design* is generally used to express this concern, and it accurately represents a primary design intent in a number of innovative projects. The Aldo Leopold Legacy Center in Baraboo, Wisconsin, is an exciting example of such a project.

Carbon dioxide (CO₂) is a major greenhouse gas; methane is another. Greenhouse gasses trap heat below the Earth’s atmosphere in more or less the same way that glass traps heat from solar radiation in a greenhouse (or in a passive solar heating system). This trapping of heat increases temperatures and leads to climate change (ASES, 2007). Buildings are important contributors to carbon dioxide emissions and are therefore logical targets for mitigation in an attempt to reduce climate change potential. See Fig. 1.12 for an estimate of the role buildings play in producing CO₂ emissions.

---

*Fig. 1.11* (a) The Jean Vollum Natural Capital Center, Portland, Oregon. A warehouse from the industrial era was rehabilitated by Ecotrust to serve as a center for the conservation era. (b) LEED plaque on the front façade of the Vollum Center. The plaque announces the success of the design team (and owner) in achieving a key element of their design intent. (© 2004 Alison Kwok; all rights reserved.)
At an organizational scale, carbon (and other climate-changing) emissions may be classified in three broad categories (EPA), termed scopes:

- **Scope 1**: All direct GHG (greenhouse gas) emissions (such as from a gas-fired boiler or wood-burning stove)
- **Scope 2**: Indirect GHG emissions from consumption of purchased electricity, heat, or steam
- **Scope 3**: Other indirect emissions, such as from the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g., transmission and distribution) not covered in Scope 2, outsourced activities, waste disposal, etc.

These scopes apply at the scale of a single project, but as with net-zero energy analyses, it might be useful to consider that buildings produce (or are linked to) carbon dioxide emissions in several distinct ways that may be of concern to an owner:

- **As a result of fossil fuel energy consumed during the design process** (computer use, printing, site visits, etc.)
- **As a result of fossil fuel energy consumed during the construction process** (by equipment, worker commutes, site conditioning, etc.)
- **Through the disposal of organic construction waste that decomposes**
- **As a result of ongoing fossil fuel energy consumption for heating, cooling, lighting, and building support operations**
- **As a result of vehicle use associated with building functions and siting** (including fossil fuels used for employee commuting, product deliveries, etc.)
- **As a result of waste produced by a building in operation**

![U.S. Carbon Dioxide Emissions (Mt C)](image)

**Fig. 1.12** Contribution of the buildings sector (commercial and residential) to U.S. carbon dioxide emissions (Mt C = million metric tons of carbon dioxide), and the relative impact of various use categories on commercial and residential carbon impacts. (Drawing by Tyler Mavichien. Source: 2011 Buildings Energy Data Book. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.)
Of these various carbon release mechanisms, energy consumption for building operation is likely the largest contributor and the most readily available target for reductions. A reminder: Energy use itself is not the carbon culprit, but rather the use of fossil fuels to produce the energy.

Options for reducing carbon emissions from the operation of building systems include: improving the efficiency of building envelopes and systems (the ultimate, and unrealistic, goal being a zero-energy project); using renewable energy to meet the energy needs that remain after aggressive efficiency moves (the goal being a net-zero-energy building); and purchasing or obtaining carbon offsets (or credits) to mitigate the effects of residual carbon emissions not stemmed by efficiency and renewables. Carbon credits are somewhat controversial, being akin to buying one’s way out of trouble—but they are an appropriate means of reducing carbon impacts beyond what can reasonably be achieved by skillful design solutions.

As cities begin requiring energy benchmarking for buildings, it is important for designers and building owners who need to quantify savings and create energy and carbon reduction goals to have an understanding of energy use and associated emissions metrics. Building plans, occupancy, energy loads, utility data, and areas associated with different uses are needed to calculate energy use intensity (EUI), which is measured in Btu/square foot/year. EUI is defined as the annual on-site intensity estimate for a design that accounts for all energy consumed at the building location (EPA Target Finder).

Another metric used to gauge how well a building performs in terms of greenhouse gas emissions is CO$_2$e. The term CO$_2$e is used because it takes into consideration several additional greenhouse gases such as methane and nitrous oxide (Bryan and Trusty, 2008). For example, on a personal scale, if we wanted to calculate the carbon emissions from plug loads in a typical U.S. single-family home, we would first calculate the EUI of all appliances (take kWh used in a year by all appliances, divide by the area of the house, convert kWh to Btu) and multiply by the operational CO$_2$e conversion for grid-delivered electricity. The EPA’s ENERGY STAR program provides an online tool called Target Finder to allow designers who work with more complex projects to compare both the estimated building energy use and the estimated CO$_2$e emissions for their projects to a national standard.

At this time, there is no code, standard, or guideline that defines “carbon neutral” and only limited formal design guidance to assist in reaching that goal. This situation should change as interest in and demand for carbon-neutral projects grow.

(i) Design Strategies for Sustainability

Unlike green design, the meaning of “sustainability” in architecture has not yet been rationalized. The term sustainable is used freely—and often mistakenly—to describe a broad range of intents and performances. This is unfortunate, as it tends to make sustainability a meaningless term—and sustainability is far too important to be rendered meaningless by baseless claims. For the purposes of this book, sustainability will be defined as follows (paraphrasing the Brundtland Commission): Sustainability involves meeting the needs of today’s generation without detracting from the ability of future generations to meet their needs.

Sustainability for most is essentially long-term survival under an assumed standard of living. In architectural terms, sustainability involves ensuring the survival of an existing quality of life for future generations. From the standpoint of energy, water, and materials, it can be argued that sustainability requires zero use of nonrenewable resources. Any long-term removal of nonrenewable resources from the environment will surely impair the ability of future generations to meet their needs (with fewer resources being available, as a result of our actions). Because sustainability is so important a concept and objective, the term should not be used lightly. It is highly unlikely that any single building built in today’s economic environment can be sustainable (yielding no net resource depletion). Sustainability at the community scale is more probable; examples, however, are rare.

(j) Regenerative Design Strategies

Energy efficiency is an attempt to use less energy to accomplish a given design objective (such as thermal comfort or adequate lighting). Green design is an attempt to maximize the positive effects of design while minimizing the negative ones—with respect to energy, water, and material resources. Sustainable design is an attempt to solve today’s problems while reserving adequate resources to permit future
generations to solve their problems. Energy efficiency is a necessary constituent of green design. Green design is a necessary constituent of sustainable design. **Regenerative design** goes beyond sustainability.

The goal of energy efficiency is to reduce net negative energy impacts. The goal of green design is to reduce net negative environmental impacts. The goal of sustainability is to produce no net negative environmental impacts. The goal of regenerative design is to produce a net positive environmental impact—to leave the world better off with respect to energy, water, and materials. If design for sustainability is difficult, then regenerative design is even more difficult. Nevertheless, there are some interesting examples of regenerative design projects, including the Eden Project in the United Kingdom and the Center for Regenerative Studies (Fig. 1.13).

---

**Fig. 1.13** (a) The Center for Regenerative Studies (CRS), California Polytechnic State University–Pomona. (b) Plants provide water treatment and generate biomass in an aquacultural pond at the Center for Regenerative Studies, Cal Poly–Pomona. (c) Site plan for the CRS. It’s not easy being regenerative—the highlighted elements relate only to the water reclamation aspects of the project. (Photos © 2013 Terri Meyer Boake; used with permission; drawing from John Tillman Lyle. 1994. Regenerative Design for Sustainable Development. John Wiley & Sons, Hoboken, New Jersey.)
in the United States. Both projects involve substantial site remediation and innovative design solutions.

1.7 A PHILOSOPHY OF DESIGN

From a design process perspective, the operating philosophy of this book is that development of appropriate design intent and criteria is critical to the successful design of buildings and their mechanical and electrical systems. Passive systems should generally be used before active systems (this in no way denigrates active systems, which will be necessary features of almost any large-scale building); life-cycle costs should be considered instead of simply first cost; and green design is a desirable intent that will ensure energy efficiency and provide a pathway toward sustainability. Design validation, commissioning, and post-occupancy evaluation should be aggressively pursued.

John Lyle presented an interesting approach to design (that elaborates upon this general philosophy) in his book *Regenerative Design for Sustainable Development*. The following discussion presents an overview of his approach. The strategies provide design teams with varied opportunities to integrate site and building design with components and processes. Those strategies most applicable to the design of mechanical and electrical systems are presented here. This approach guided the design of the Center for Regenerative Studies at the California Polytechnic State University at Pomona, California (Fig. 1.13).

(a) Let Nature Do the Work

This principle expresses a preference for natural/passive processes over mechanical/active processes. Designers can usually find ways to use natural processes on site (Fig. 1.14), where they occur, in place of dependence upon services from remote/nonrenewable sources. Smaller buildings on larger sites are particularly good candidates for this strategy.

(b) Consider Nature As Both Model and Context

A look at this book reveals a strong reliance upon physical laws as a basis for design. Heat flow, water flow, electricity, light, and sound follow rules described by physics. This design principle, however, suggests looking at nature (Fig. 1.13) for biological, in addition to the classical physical, models for design. The use of a Living Machine to process building wastes, as opposed to a conventional sewage treatment plant, is an example of where this strategy might lead.

(c) Aggregate Rather Than Isolate

This strategy recommends that designs focus upon systems, and not just upon the parts that make up a system—in essence, seeing the forest through the trees. The components of a system should be highly integrated to ensure workable linkages among the parts and the success of the whole. An example would be optimizing the solar heating performance of a direct-gain system involving glazing, floor slab, insulation, and shading components, even though such optimization might reduce the performance of one or more constituent parts of the system (Fig. 1.15).
(d) Match Technology to the Need

This strategy seeks to avoid using high-grade resources for low-grade tasks (Fig. 1.16). For example, it is wasteful to flush toilets with purified water, but perhaps less obviously wasteful (but equally a mismatch) to use electricity (a very-high-grade energy form) to heat water for bathing. The concept of exergy (discussed in a subsequent chapter) relates to this design strategy.

A new tool offered by Architecture 2030 is the 2030 Palette, an interactive online platform that gives the designer guiding principles, information, and resources to select appropriate technologies for a variety of scales: building, site, district, city, and region (http://2030palette.org/).

In 2007, the AIA published 50to50, a resource offering 50 strategies with useful guidance to assist architects and the construction industry toward a 50% reduction in fossil fuels by 2010, and carbon neutrality by 2030. The strategies include a range of broad site and planning objectives to building-specific concepts. Each strategy includes an overview of the subject, typical applications, emerging trends, links to information sources, and important relationships to other carbon reduction strategies (American Institute of Architects, 2007).

(e) Seek Common Solutions to Disparate Problems

This approach requires breaking out of the box of categories and classifications. An understanding of systems should lead to an increased awareness of systems capabilities—which will often prove to be multidisciplinary and multifunctional. Making a design feature (Fig. 1.17) serve multiple tasks (perhaps mechanical, electrical, and architectural in nature) is one way to counteract the potential problem of a higher first cost for green design features. Solutions can be as simple and low-tech as using heat from garden composting to help warm a greenhouse.

(f) Shape the Form to Guide the Flow

The most obvious examples of this strategy are solar-heated buildings that are shaped (Fig. 1.18) to
gather winter sun, or naturally ventilated buildings shaped to collect and channel prevailing winds. Daylighting is another obvious place to apply the “form follows flow” strategy, which can have a dramatic impact upon building design efforts and outcomes.

(g) Shape the Form to Manifest the Process

This is more than a variation on the adage “If you’ve got it, flaunt it.” This strategy asks that a building inform its users and visitors about how it works both inside and out (Fig. 1.19). In passive solar-heated and passively cooled buildings, much of the thermal performance is evident in the form of the exterior envelope and the interior space, rather than hidden in a closet or mechanical penthouse. Professor David Orr of Oberlin College addresses this issue succinctly by asking, “What can a building teach?”

(h) Use Information to Replace Power

This strategy addresses both the design process and building operations. Knowledge is suggested as a substitute for brute force (and associated energy waste). Designs informed by an understanding of resources, needs, and systems capabilities will tend to be more effective (successfully meeting intent) and efficient (meeting intent using fewer resources) than uninformed designs. Building operations informed by feedback and learning (Fig. 1.20) will tend to be more effective and efficient than static, unchangeable operating modes. Users of buildings can play a leading role in this approach by being allowed to make decisions about when to do what it takes to maintain desired conditions. Reliance on a building’s users is not so much a direct energy saver—most controls use very little power—as it is an education. A user who understands how a building receives and conserves heat in cold weather is likely to respond by lowering the indoor temperature and reducing heat leaks. Furthermore, some studies of worker comfort indicate that with more personal control (such as operable windows), workers express feelings of comfort across a wider range of temperatures than with centrally controlled air conditioning.

(i) Provide Multiple Pathways

This strategy celebrates functional redundancy as a virtue—for example, providing multiple and
separate fire stairs for emergency egress. There are many other examples, from backup heating and cooling systems, to multiple water reservoirs and piping pathways for fire sprinklers, to emergency electrical and lighting systems. This strategy also applies to climate–site–building interactions in which one site-based resource may temporarily weaken but can be replaced by another (Fig. 1.21).
summer nights, coolth (the conceptual opposite of heat) can be stored in these same surfaces and used to condition the room by day. Most storage solutions will strongly impact building architecture.

1.8 LESSONS FROM THE FIELD

Bill Bordass, with the Usable Buildings Trust in the United Kingdom, has occasionally presented the Society of Building Science Educators (SBSE) list-serv with summaries of lessons learned through extensive post-occupancy evaluation (POE) studies of buildings. This chapter is an appropriate place to digest some of the design recommendations that flow from these findings.

Bordass notes that building design features tend to have four attributes, sometimes possessing these attributes simultaneously:

- **Physical:** Fit and forget—if the designer and contractor have done a good job, the feature does its job and users can take it for granted.
- **Administrative:** Fit and manage—the feature needs looking after, and the question arises: Are the vigilance demands clear to the client and the operator? Often design features turn out to be more demanding on the operator than is realized at the time of design.
- **Behavioral:** Implement and internalize—the users have to understand the feature to make effective use of it. Often, however, the design intent is not clear, the feature has not been properly delivered, how it should be used has not been explained to the occupants, and use does not make sense or go with the flow of occupancy, even if explained.
- **Perverse:** Risk and freedom—often design features have both good and bad effects; it is easy for designers to get excited by the good ones and forget about the bad ones.

An intriguing recommendation, based upon the results of the Usable Buildings Trust POE studies is: “Keep it simple and do it well, and only after that begin to be clever.” This guidance can be illustrated in the following sets of words to guide the wise designer:

- **Process before product**—then product and back to process
- **Passive before active**
- **Simple before complicated**
CASE STUDY—DESIGN PROCESS

1.9 CASE STUDY—DESIGN PROCESS

Gilman Ordway Campus of the Woods Hole Research Center

Project Basics

- Location: Falmouth, Massachusetts, USA
- Latitude: 41.3°N; longitude: 70.4°W; elevation: near sea level
- Heating degree days: 5426 base 65°F (3014 base 18.3°C); cooling degree days: 2973 base 50°F (1652 base 10°C); annual precipitation: 45.5 in. (1156 mm) (degree day data are for New Bedford; rainfall is for Woods Hole)
- Building type: Remodeled and new construction; commercial offices and laboratory
- Building area: 19,200 ft² (1784 m²); four occupied stories
- Completed February 2003
- Client: Woods Hole Research Center
- Design team: William McDonough + Partners (and consultants)

Background. The Gilman Ordway Campus of the Woods Hole Research Center involved both new construction and extensive remodeling of a venerable old house to provide office and laboratory facilities. The building generated a lot of interest, received a number of awards, and has collected detailed performance data. The clients are quite pleased with the facility and are using it as a vehicle to promote awareness of the environment and green design. (The discussion that follows was extracted from information provided by William McDonough + Partners and the Woods Hole Research Center.)

Context. The work of the Woods Hole Research Center is focused upon the related issues of climate change and defending the world’s great forests. When a new headquarters was considered, it was decided that the facility should reflect the Research Center’s core values, support its research and education mission, and provide a healthy environment for building occupants and the outside world. Fund-raising was a major issue for this project and substantially impacted the design process and scheduling. Perhaps the most valuable lesson to be learned from this project is the inestimable value of perseverance and the benefit that a clearly enunciated set of objectives (design intent and criteria) can provide in seeing a donor-supported project through to completion.

Design Intent. The Woods Hole Research Center project sought to demonstrate that a modern building can “harmonize with a habitable earth” while providing a healthy, comfortable, and enjoyable workplace. Enhanced productivity and job satisfaction for employees were key intents, as was far-beyond-code-minimum energy performance. In addition, the building was intended to serve as a teaching tool, providing an exemplar of a thoughtful approach to energy production and use, water quality and conservation, site design, and materials selection.

Design Criteria and Validation. The aggressive energy performance criteria set by the client and design team required the use of ENERGY 10 computer simulations and the ongoing services of an energy systems consultant. Interestingly, this same strong energy-related design intent allowed the retention of critical mechanical system elements during an extensive value engineering phase that cut approximately 15% from the construction budget. The owner retained an independent authority for building commissioning.
**Key Design Features**

- Extensive daylighting throughout the building
- Operable windows throughout the building
- An exceptionally tight and carefully detailed building envelope featuring triple-glazed windows and Icynene foam insulation (that also serves as an air barrier)
- A Ruck wastewater system, 95% on-site retention of storm water, and collection of rainwater for site irrigation
- A ground-source heat pump system for heating and cooling (coupled with a valence delivery system in office spaces)
- A rooftop, net-metered, photovoltaic array
- A 100-kW on-site wind turbine (added after initial construction)

**Post-Occupancy Validation Methods.** The client has installed an extensive energy-monitoring and -reporting system. Data collected by this system are available to the public via the World Wide Web (see “For Further Information,” at the end of this section) and are also being used internally to optimize systems operations. Soils scientists from the Center are studying the effectiveness of the innovative septic system. In addition, the client has a very open and reflective attitude toward evaluation of the building and its systems. With a relatively small number of occupants, informal exchanges among Research

---

*Fig. 1.23 Initial concept sketch for the Woods Hole Research Center (WHRC)—the “leaf.” This is an exceptional example of a conceptual design phase product. (© William McDonough + Partners; used with permission.)*

*Fig. 1.24 Schematic design phase section through WHRC showing spatial organization and photovoltaic array locations. (© William McDonough + Partners; used with permission.)*
Center users appear to be proving an effective means of POE.

Performance Data. As this is a case study of design process as much as of a building, much of the following performance information relates to process outcomes. Energy data from three years of monitoring, however, are also given to describe success in the energy realm of design intent.

- The building design received an AIA/COTE Top Ten Green Projects Award (2004).

Fig. 1.25 The site/floor plan of WHRC is representative of the evolution of a project as it moves into and through the design development phase. (© William McDonough + Partners; used with permission.)

Fig. 1.26 Construction phase photos of WHRC: (a) showing the structure for the new addition and the existing house being remodeled, (b) showing the merger of new and remodeled parts of the building as the envelope enclosure is finalized. (© William McDonough + Partners; used with permission.)
and siding and Brazilian ipé wood for the extensive porch, deck, and entrance stairway.
• Paints and coatings meet low volatile organic compound (VOC) criteria; no carpet is used in the building.
• A grant from the Massachusetts Renewable Energy Trust supported installation of a photovoltaic array consisting of 88 panels (each at 25 ft² [2.3 m²]) that is expected to provide 37,000 kWh annually (compare this estimate with the measured data that follow).
• Measured data from the first year of occupancy show an energy consumption of about 20,000 Btu/ft² (63 kWh/m²) per year; this is roughly 25% of the consumption of a typical office building and a 75% reduction from the energy density of the Research Center’s previous facility.
• In 2010, the building consumed roughly 202,000 kWh of grid-provided electricity, the wind turbine produced 151,000 kWh of
electricity, the PV system produced 33,000 kWh, and the net annual electricity consumption was 20,200 kWh.

- In 2011, the building consumed roughly 155,000 kWh of grid-provided electricity, the wind turbine produced 129,000 kWh of electricity, the PV system produced 30,000 kWh, and the net annual electricity consumption was -3800 kWh (thus operating as a net-plus building).

- In 2012, the building consumed roughly 146,000 kWh of grid-provided electricity, the wind turbine produced 109,000 kWh of electricity, the PV system produced 38,000 kWh, and the net annual electricity consumption was essentially zero.

FOR FURTHER INFORMATION
Summary information for the Woods Hole Research Center building can be accessed at: http://www.whrc.org/about/greencampus.html
Building performance information may be viewed from the project dashboard: http://buildingdashboard.net/whrc/woodwell/#/whrc/woodwell/
A description of the building and design process can be found at: http://www2.aiatopten.org/hpb/overview.cfm?ProjectID=257

References and Resources
Agents of Change. Department of Architecture, University of Oregon. http://agentsofchange.uoregon.edu/
Aldo Leopold Legacy Center. www.aldoleopold.org/Visit/leopoldcenter.shtml
National Renewable Energy Laboratory NREL. http://www.nrel.gov/
PHIUS. Passive House Institute U.S. http://www.passivehouse.us/
Solar Living Center (and The Real Goods Store). http://www.solarliving.org

Usable Buildings. http://www.usablebuildings.co.uk/


U.S. Environmental Protection Agency (EPA). http://www.epa.gov/


