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.

- A grant from the Massachusetts Renewable Energy Trust allowed installation of a photovoltaic array consisting of 88 panels (each at 25 ft^2 [2.3 m^2]) that is expected to provide 37,000 kWh annually (about 40% of the building's power needs).
- All of the interior finish woodwork is a Forest Stewardship Council (FSC) certified sustainably harvested product; exterior wood finishes are also FSC certified, including cedar shingles 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.

FOR FURTHER INFORMATION

Summary and real-time energy performance data for the Woods Hole Research Center building can be accessed at: http://www.whrc.org/building/

A description of the building and design process can be found at: http://www.aiatopten.org/hpb/overview.cfm?ProjectID=257

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CHAPTER 2

Environmental Resources

THE DESIGNER OF TODAY'S BUILDINGS will add or reshape spaces on a planet that has, for eons, evolved by using renewable energy arriving from the sun at a generally fixed and limited rate. Suddenly (in geologic time) our planet is experiencing population growth, nonrenewable resource depletion, and apparently global warming. Today's designers have available a vast, yet declining, reservoir of material resources, fossil fuel energy, and water. The building design professions thrive on a rapidly increasing population, each person consuming more resources than did her/his grandparents. Eventually, our planet must live within a fixed budget of renewable energy, water, and material resources. The question is: How can our present building designs best move toward this necessary accommodation with sustainability? How can building designers be environmentally proactive instead of simply reactive?

Population growth is both the source of much of our work as buildings professionals and the underlying source of our greatest problems. Our planet did not support a human population of 1 billion until about 1830, at which time the United States depended almost entirely upon the renewable energy sources of fuel wood and work animals; interior lighting was provided by burning oil or gas. In less than 200 years, 4 billion more people were added to our planet, and the United States shifted to almost total dependence upon nonrenewable fuels: coal, oil, and natural gas (Fig. 2.1). Another 1 billion in population is expected around the year 2010. The building design process plays an active role in deciding where these people will live and work and how much of what kinds of resources they will use. The mechanical and electrical systems that support our new buildings can be part of a growing problem or an important start to a solution.

2.1 INTRODUCTION

Buildings depend upon energy and matter for their very existence and must pay heed to several fundamental rules of science. The First Law of Thermodynamics establishes the conservation of energy and matter (energy/matter can neither be created nor destroyed) and essentially states that you cannot get something for nothing. The Second Law of Thermodynamics expresses the tendency toward disorder that is part of the normal nature of things. Entropy is a measure of such disorder; as disorder increases, so does entropy. The Second Law is a declaration against perpetual motion, and essentially states that not only can't you get something for nothing, you can't even break even, due to unavoidable losses (disorder) that contribute to increased entropy.

The construction and operation of buildings are fundamentally ordering processes. Materials are mined or harvested, refined or shaped, placed in manufactured products, transported to a building site, and assembled. All of these processes consume energy and materials as the various building systems are established. The operation

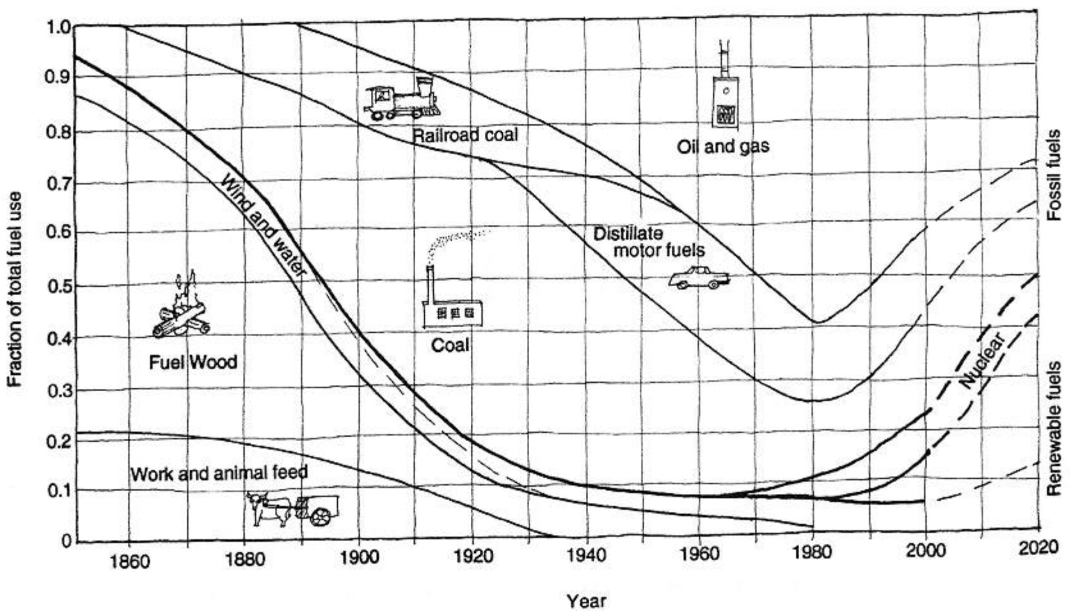


Fig. 2.1 *U.S. fuel sources since 1850, showing a progression from dependence on renewable fuels (wood and work animals) to fossil fuels (coal, then oil and gas). Wind and water power were shifted from mills to electricity generation between 1890 and the present. Although not shown here, much fossil fuel is now converted to electricity before use. (Data 1850–1970 are from Fisher, 1974; data 1970–1980 are from Meyers, 1983; future projections are from Brower, 1990. Drawing by Michael Cockram; © 1998 by John S. Reynolds, A.I.A.; all rights reserved.)*

and maintenance of a building consume further resources, as conditions (temperatures, light levels, flows of water) are established that would not otherwise occur under less-ordered natural conditions. Maintaining building materials and systems over time against the forces of nature requires additional inputs of energy and materials. Buildings are inherently antientropic. This is not necessarily bad (learning and evolving are also antientropic), but it should be considered during the design process. As will be seen later in this chapter, buildings have a substantial collective impact on our patterns of energy, water, and materials consumption.

The design process should consider various scales of concern relative to the impacts of buildings upon the environment. One such scale is geographic. Geographic scales of concern include the micro scale, the site scale, and the macro scale, with design focus historically being at the site scale. The terms *micro* (small) and *macro* (large) are not absolutely defined but are often referenced to a particular site. Thus, the area of influence of a microclimate is smaller than that of a macroclimate—but is usually also smaller than that of the site scale, often applying to one part of a site (perhaps with a steeper slope, lower elevation, or greater shading than other parts). The site scale is normally self-explanatory, running from property line to property line. Energy efficiency issues are typically and historically addressed at the site scale and often ignore (unfortunately) energy consumption off-site (such as electric power plant losses or natural gas transportation losses). Renewable/passive energy systems must consider microscale effects (such as orientation) in order to be successful. Nonrenewable/active systems often are oblivious to any scale of concern.

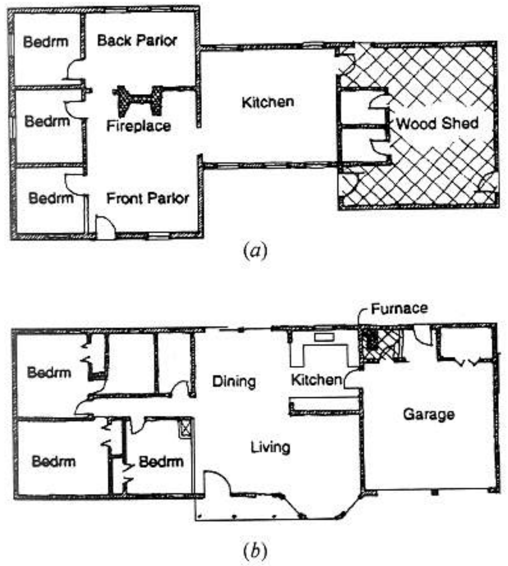
Time is another, and very interesting, scale of concern to building design. The scales typically addressed include *now* and *the future*—although *the past* is sometimes of concern with adaptive reuse and historic preservation projects. The concept of *the future* is usually left quite nebulous unless life-cycle costing is undertaken for a project, in which case the expected lifetimes of systems and equipment are explicitly estimated. It is clear that most buildings have a useful life of 25, 50, perhaps 100 years (or more). Stuart Brand provides an interesting look at buildings over time in *How Buildings Learn: What Happens After They're Built.* The problem with design for the future is that we don't know precisely what it holds. Nevertheless, design for sustainability requires the design team and the design process to consider the needs of future generations. This makes sustainability a very challenging concept and highly objective—but no less important than design for today.

2.2 ENERGY

Energy resources are broadly classified as renewable or nonrenewable. *Renewable* resources are those that are available indefinitely but are generally diffuse and arrive at a rate controlled by nature. For example, the influx of solar energy varies from day to day, but on average it should be available forever and at a generally predictable rate. Likewise, a woodlot produces a limited amount of wood per year but can do so for centuries if properly managed. An analogy for using renewable fuel sources is living on a fixed annual salary—with no hope for spectacular annual raises or unexpected bonuses but with long-term stability if wisely managed.

Nonrenewable energy resources are those that, once exhausted, cannot be replaced in a time frame that is meaningful to the human race. Coal, oil, and natural gas are examples of nonrenewable energy resources. Using nonrenewable fuel sources is analogous to living off a one-time lottery win that can be spent in 1 year or over 50 years, depending upon needs and planning, but that is gone for good when all spent.

The United States, like other industrialized countries, has spent the time since the mid-1800s in an energy transition (Fig. 2.1). This transition began with renewable energy sources, obtained locally, that did relatively low-grade work: animals pulled or pushed, and wood was burned to provide heated air, water, or steam. Buildings and people were directly affected by energy sources; work animals were fed, tended, and housed; fuel wood was cut nearby and stacked in large sheds (Fig. 2.2); fireplaces were social centers of buildings; and smoke from chimneys indicated activity inside. The side effects of energy use were also directly sensed—animal wastes, deforestation, and polluted air. Fuel use depended upon human labor. Architects of the era responded to the visual and spatial organization potentials of fireplaces and chimneys (Fig. 2.3).



(*a*)

(*b*)

Fig. 2.2 *Residential heating: past and present. (a) The house dependent on fireplaces or wood stoves also depends on someone to tend the fire. The warmer area near the fire in this early Oregon farmhouse was used for social purposes; the colder extremities served as sleeping areas and for storage of food and fuel. (Based upon a plan drawn by Philip Dole.) (b) The contemporary suburban home has either a small furnace area or electric heat built into each room. Heating equipment is no longer a major influence on building form.*

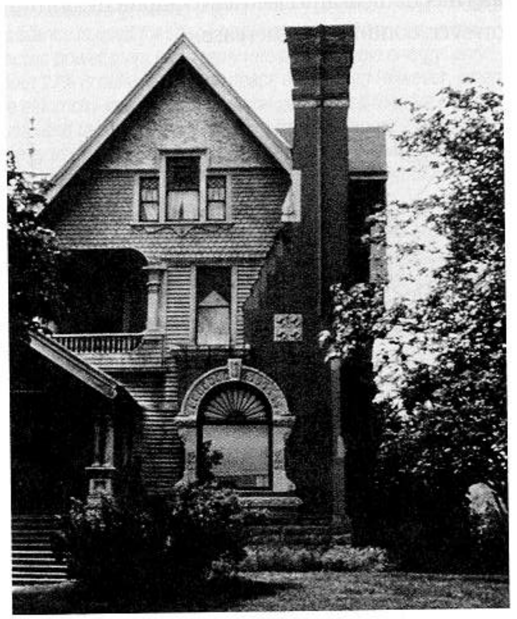


Fig. 2.3 *The fireplace and the more efficient wood stove can inspire architectural form. This chimney symbolizes permanence as well as protection against the cold. The major social space of the house is marked both by the arched window and by the fireplace chimney. (Photo by William Johnston.)*

North America is now almost entirely dependent upon nonrenewable energy resources, an increasing proportion of which consists of imported oil and natural gas and electricity transported across substantial distances (Fig. 2.4). Buildings account for a good percentage of this energy demand. This trend is partly due to rapid growth in both population and per capita energy consumption. It is also due to the allure of highly concentrated energy available from fossil fuels, which encourages the use of high-quality energy sources such as electricity and natural gas for buildings and gasoline for transportation. People are now largely oblivious to their sources of energy: electricity is generated in far-off power plants; natural gas arrives through buried pipelines, and fuel oil via supertankers. The experiential impact of energy use on building design and operation tends to be diluted. Energy consumption is regulated by automatic controls, and heating and cooling equipment is hidden from sight. Building occupants/users—who often do not personally control a thermostat, see climate control equipment, or pay a utility bill—have no direct contact with or concern about energy resources. Clients hire architects to provide for function and comfort. Architects then pay engineers to design (and usually to successfully hide) mechanical and electrical equipment. Entropy, however, continues to increase.

For several reasons, buildings designed for today are likely to rely heavily upon electricity (Fig. 2.5), a situation that carries serious implications for resource depletion and environmental quality:

1. Consumption of electricity is expected to rise about twice as fast as overall energy demand, and we are more often using electricity in place of other energy forms. Part of the reason for this is that, for some primary energy sources (such as coal, heavy fuel oil, or a nuclear reaction), generation of electricity for subsequent (secondary) distribution to buildings is the only convenient usage option.
2. Other than daylighting (unfortunately still rare in today's buildings), electricity is the only source for building illumination. Heat produced by electric lighting may reduce a building's need for space heating, but it increases its need for space cooling—and mechanical cooling is almost universally provided by electric air-conditioning equipment.
3. Electricity is a convenient and versatile energy form; it not only serves such high-quality and highly concentrated (or *high-grade*) tasks as lighting and providing drive power via electric motors, it can also serve such low-quality, low-temperature (or *low-grade*) tasks as cooking, water heating, and space heating (Table 2.1). All-electric buildings are commonplace, even though they are subject to paralysis in blackouts—as any building dependent upon a single energy source is vulnerable to disruptions. As shown in Table 2.1, of a total of 38 quads used for all building energy requirements, the primary energy used for electricity generation was 27 quads, equal to over two-thirds of the total.

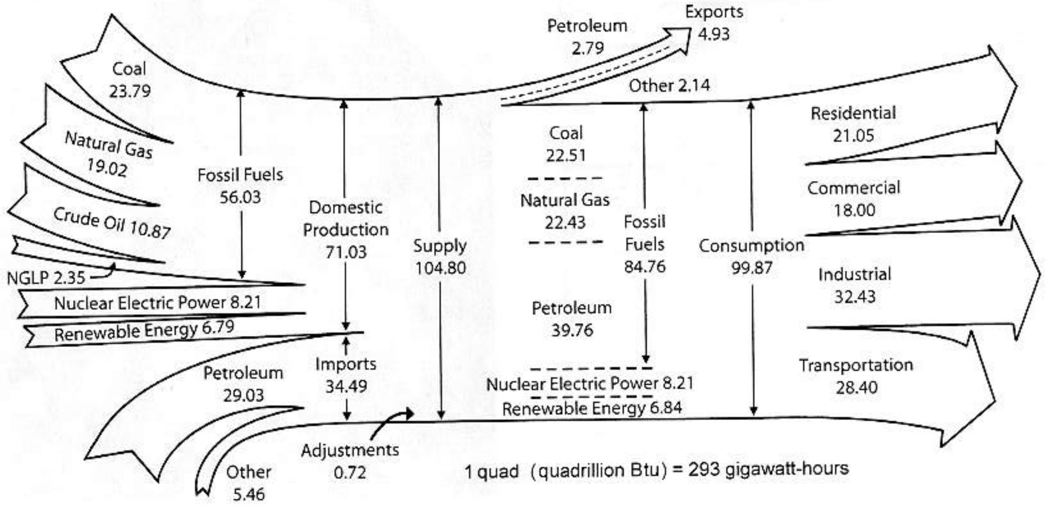


Fig. 2.4 *U.S. energy flow, 2005: sources and end uses. Fuel types and sources are shown to the left and end use sectors to the right. Note the importance of residential and commercial consumption to total U.S. consumption—and the currently minuscule contribution of renewable energy sources to the whole. (Drawing by Nathan Majeski using data from the Energy Information Administration, U.S. Department of Energy,* Annual Energy Review, *2005. This data resource is updated on a regular basis, but the general patterns shown in this figure change slowly.)*

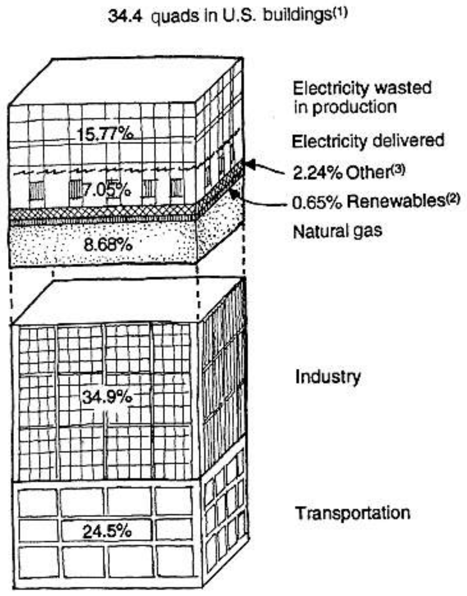


Fig. 2.5 *Energy resources as consumed by various end-use sectors in the United States, 1996. Total: 94.0 quads (1 quad = 1015 Btu). Not included are raw materials used in manufacturing. (1) Both residential and commercial buildings are included. (2) Renewables do not include passive solar energy use; hydroelectricity and PV are included in "electricity." (3) "Other" includes fuel oil, liquefied natural gas, coal, kerosene, and other petroleum products. (Data from U.S. Office of Building Technologies, Core Databook, 1998. Drawing by Michael Cockram; © 1998 by John S. Reynolds, A.I.A.; all rights reserved.)*

4. Electricity generated by thermal processes (except for cogeneration) delivers to the end user less than one-third of the total energy that goes into its production; more than two-thirds is usually lost as waste heat at the generating plant (Fig. 2.6). (In Table 2.1, for every 1 quad of electricity delivered, 3.22 quads were assumed used in generation.)

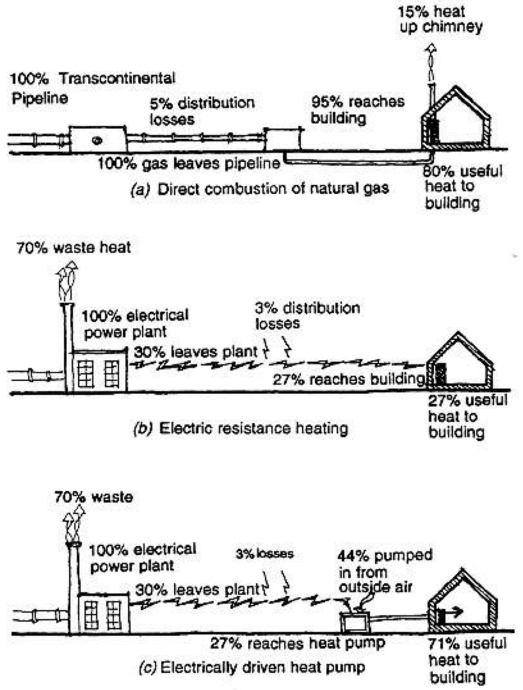


Fig. 2.6 *Variations on higher-grade energy and lower-grade tasks. (a) Natural gas (a fossil fuel) is often burned in furnaces to provide low-grade space heating. With today's high-efficiency furnaces, well over 80% of the energy in the gas is delivered to the building as space heat. (b) However, when that natural gas is used instead to generate (higher-grade) electricity, and electric resistance is used for space heating, the inefficiencies at the electric power plant cut deeply into the available energy: only about 27% is delivered to the space as heat. (c) However, when the electricity generated by natural gas is used to drive a heat pump and the outdoor air is above freezing, about 71% of the energy in the gas is delivered as space heat. (Drawing by Michael Cockram; © 1998 by John S. Reynolds, A.I.A.; all rights reserved.)*

As we consume our planet's resources, including fossil fuels, many look to a return to renewable and sustainable energy. This vision will be partially implemented by solar energy converted directly to electricity (through photovoltaics [PV]) on or near the building requiring the electricity. Solar collectors (some for heating water, others for producing electricity) will shape the roofs and silhouettes of buildings. Building design professionals can choose to ignore or embrace such opportunities.

Hydrogen may be stored and distributed as a high-grade fuel, produced from water using electricity generated from renewable resources such as solar energy and wind. The lifetimes of mechanical and electrical equipment specified today will probably overlap such a future. In this near future, lower-tech processes such as biomass conversion (combustion of wood and waste products) may develop faster than higher-tech processes such as PV. PV is growing very rapidly, though; its growth

TABLE 2.1 Energy End-Use in U.S. Buildings, by Fuel Type (Quads)[a]

End Use	Natural Gas	Fuel Oil[b]	LPG	Other Fuel[c]	Renewable Energy[d]	On-Site Electric	On-Site Total	On-Site %	Primary Electric[e]	Primary Total	Primary %
Space heating[f]	4.96	1.02	0.30	0.19	0.40	0.69	7.55	38.6	2.21	9.08	23.7
Space cooling	0.01					1.43	1.45	7.4	4.62	4.63	12.1
Ventilation[g]						0.31	0.31	1.6	1.01	1.01	2.6
Water heating	1.74	0.19	0.05		0.05	0.55	2.58	13.2	1.77	3.79	9.9
Lighting						2.12	2.12	10.9	6.84	6.84	17.8
Refrigeration[h]						0.76	0.76	3.9	2.45	2.45	6.4
Cooking	0.47		0.03			0.25	0.75	3.8	0.81	1.31	3.4
Wet clean[i]	0.07					0.29	0.36	1.8	0.94	1.01	2.6
Computers						0.20	0.20	1.0	0.65	0.65	1.7
Electronics						0.62	0.62	3.2	2.00	2.00	5.2
Other[j]	0.38	0.02	0.24	0.05	0.10	0.48	1.28	6.5	1.56	2.35	6.1
Adjustments[k]	0.64	0.22				0.73	1.59	8.1	2.34	3.21	8.4
Total	8.27	1.46	0.62	0.24	0.54	8.45	19.58	100	27.20	38.33	100

Source: U.S. DOE (2004). Data are for the year 2002.

[a] Quad = 10^{15} Btu (1 Ej).

[b] Includes distillate fuel oil (1.38 quads) and residual fuel oil (0.08 quad).

[c] Kerosene (0.08 quad) and coal (0.11 quad) are assumed to be attributed to space heating; motor gasoline (0.05 quad) is assumed to be attributed to "other" end uses.

[d] Passive solar space heating is not included. It includes wood space heating (0.39 quad), geothermal space heating (<0.01 quad), solar water heating (0.05 quad), biomass (0.01 quad), and solar PV (<0.01 quad).

[e] Site-to-source electricity conversion = 3.22 due to generation and transmission losses.

[f] Includes electric furnace fans (0.25 quad).

[g] Commercial only (residential fan and pump energy use included proportionally in space heating and cooling).

[h] Includes refrigerators (1.37 quads) and freezers (0.43 quad) and commercial refrigeration.

[i] Includes clothes washers (0.10 quad), natural gas clothes dryers (0.07 quad), electric clothes dryers (0.76 quad), and dishwashers (0.08 quad).

[j] Includes commercial service station equipment, emergency electric generators, fuel oil cooking, natural gas-driven pumps, natural gas lighting, automated teller machines, telecommunications equipment, medical equipment, residential pool/hot tub heating, residential small electric devices, outdoor grilles, outdoor natural gas lighting, and the like.

[k] Energy Information Administration (EIA) adjustment to address discrepancies among data sources. Energy is attributable to the residential and commercial buildings sector, but not directly to specific end uses.

curve is as steep as that during the first 15 years of computer technology. One major oil company's energy scenario (in the late 1990s) anticipated 50% of world energy demand being met by alternatives to fossil fuels by the year 2050.

Today's fossil-fueled economy seems so entrenched as to defy a transition to renewable energy. A common question is often heard: Is solar energy adequate for our energy needs? Table 2.2 compares the Earth's receipt of solar energy at the surface in a single day with other energy phenomena. There appears to be adequate resource availability—given the will to move toward renewable and site-based resources. Energy efficiency efforts will play a critical role in making such a transition feasible.

To date, societal focus has been primarily upon using less energy—energy efficiency. The oil embargo of the 1970s spurred the development of energy efficiency standards, which have remained a fixture of building design ever since. In general, such standards seek to reduce building energy consumption—not to shift energy resources from nonrenewable to renewable. The green building design movement has provided momentum for a serious look at both reduced energy use and the use of energy from renewable resources (see Appendix G).

2.3 WATER

The building design profession's efforts toward a more resource-efficient product have, for the past 30-some years, focused primarily upon energy. This focus has been warranted by the limits upon nonrenewable energy sources imposed by the laws of thermodynamics. There is no option for the reuse or recycling of fossil fuel energy (as may be done with water and materials). Water concerns, however, are at crisis level in many parts of the United States, and water may well be the emerging limit to growth and development—especially locally and regionally—rather than energy.

TABLE 2.2 Daily Arrival of Solar Energy on Earth Compared to Other Energy Quantities

Solar energy received each day	1
Melting of an average winter's snow during the spring	1/10
A monsoon circulation between ocean and continent	1/100
Use of energy by all mankind in a year	1/100
A mid-latitude cyclone	1/1,000
A tropical cyclone	1/10,000
Kinetic energy of motion in earth's general circulation	1/100,000
The first H bomb	1/100,000
A squall line containing thunderstorms and perhaps tornados	1/100,000
A thunderstorm	1/1,000,000
The first A bomb	1/100,000,000
The daily output of Boulder Dam	1/100,000,000
A typical local rain shower	1/10,000,000,000
A tornado	1/100,000,000,000
Lighting New York City for one night	1/100,000,000,000

Source: Reprinted by permission from Lowry, W. 1988. *Atmospheric Ecology for Designers and Planners*. Peavine Publications, McMinnville, OR.

Concerns about a viable supply of potable water have dominated politics and civil engineering in the arid western United States for a century. Surprisingly, Tampa, Florida, in the heavily rained-upon Southeast, has a desalination plant to provide water for an otherwise underresourced region. Although water is a recyclable resource, it is not a renewable resource (no new daily supplies are being delivered to Earth). A quote generally attributed to *National Geographic* (October 1993) made this point succinctly: "All the water that will ever be is, right now" (UNH, 2004). In addition, where the water is, is not necessarily where it is wanted. Periodic water rationing is an unpleasant fact in many areas. Table 2.3 compares regional water resources with sustainable water usage capacity; it is clear that some areas of the United States now have serious water shortages. Accelerated depletion of underground water stocks (from aquifers, which are analogous to fossil fuel reserves) and maxed-out imports (both hydrologically and politically) suggest more trouble on the way. On a global scale, the disparities become even greater. Mostafa Tolba, former executive director of the UN Environment Program, speaking of the international picture, notes: "We used to think that energy and water would be the critical issues for the next century. Now we think water will be the critical issue" (UNH, 2004).

As with energy, per capita use of water involves more than consumption within a building. In the case of energy, transportation and industrial uses influence per capita consumption; with water, energy production and agricultural uses play a role. About half of all U.S. fresh and saline water withdrawals in 2000 were used in conjunction with thermoelectric power generation. Most of this was surface water used for once-through cooling at power plants. Withdrawals for this use have been relatively stable since 1985. (In a quirky turnabout, the California State Water Resources Control Board estimates that 6.5% of California's total electricity use is related to pumping and treating water.)

Irrigation remains the largest use of freshwater. Since 1950, irrigation has accounted for about 65% of total water withdrawals, excluding those for power generation. Historically, more surface water than groundwater has been used for irrigation. The percentage of total irrigation withdrawals from groundwater has continued to increase, from 23% in 1950 to 42% in 2000. Irrigated acreage more than doubled between 1950 and 1980, then remained constant before increasing nearly 7% between 1995 and 2000 (USGS, 2004).

Public water supply withdrawals in 1950 were 14 Bgal/day (53 GL/day); in 2000, more than 43 Bgal/day (163 GL/day). During 2000, about 85% of the U.S. population obtained drinking water from public suppliers, compared to 62% during 1950. Surface water provided 63% of the total during 2000, compared to 74% during 1950. Potable water obtained from a surface source via a public supply system is becoming the norm; private well

TABLE 2.3 Comparison of Regional Water Use versus Resources for the Continental United States

Water Resources Region[a]	Consumptive Use	Renewable Water Supply[b]	Ratio (Use/Supply)
New England	0.6	78.4	0.8%
Mid-Atlantic	1.3	80.7	1.5%
South Atlantic/Gulf	6.1	233.5	2.6%
Great Lakes	1.9	74.3	2.6%
Ohio	2.3	139.6	1.7%
Tennessee	0.3	41.2	0.7%
Souris-Red-Rainy	0.5	6.5	7.7%
Upper Mississippi	2.3	77.2	3.0%
Lower Mississippi	40.3[c]	484.8	8.3%
Missouri	17.5	52.9	33.1%
Arkansas-White-Red	9.6	68.7	14.0%
Texas Gulf	9.1	33.1	27.5%
Rio Grande	3.5	5.4	64.8%
Upper Colorado	4.2	13.9	30.2%
Lower Colorado	10.6[c]	10.3	103.0%
Great Basin	3.5	10.0	35.0%
Pacific Northwest	11.2	276.2	4.1%
California	25.8	74.6	34.6%

Source: Adapted from *United States Geological Survey*, 1984, with 1995 updates for water usage: http://water.usgs.gov/watuse/misc/consuse-renewable.html

[a] These are water resource areas generally independent of state boundaries.

[b] Renewable water supply represents a long-term sustainable resource: precipitation plus imports less evaporation, exports, and water needed to maintain minimal stream flows.

[c] These values are for the entire river system.

systems are less common than in the past. As with energy, population increases are increasing overall consumption, while efficiency efforts provide some counterbalancing effect.

Water efficiency standards are not nearly as extensive or ubiquitous as energy efficiency standards, although most building users are aware of low-flow toilet requirements, flow restrictors for showers, and self-closing bathroom faucets in public facilities. Surprisingly, given the few design restrictions that exist, per capita water use in the United States has remained flat for the past several years—and is currently 25% lower than in the late 1970s. This is partly because overall per capita use involves important sectors other than buildings (agriculture and power generation, for example) and partly due to increasing awareness of the value of water.

As with renewable energy sources, green building design efforts have also increased awareness of and design for water supply savings and alternatives. Part V, "Water and Waste," discusses many design alternatives that would likely be used in a green building. The role of water in the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system is outlined in Appendix G.

2.4 MATERIALS

A global or even countrywide perspective on materials resources is more difficult to obtain than is the case for energy and water. In the United States there appears to be a general upward trend in per capita consumption of materials. In the early 1900s, per capita consumption (in metric tons per person) was around 3.0, about 50% of which was construction materials; in 1950 about 6.0, with about 60% in construction materials; and from 1970 to 1990 about 10.0 (with ups and downs), with about 65% in construction materials.

Given the scarcity of quantitative data, a qualitative comparison with water must suffice. Many materials used in building construction and upkeep come from a generally fixed resource base. Like water, materials (at least many) may be recycled, but there is a fixed quantity of resources available on Earth. For many materials, what we have now is what we will have in the future, a marked exception being those organic materials (such as fiber products) that are renewable.

Finding adequate material resources for a building directly on the building site is rare: wood, straw, and earthen construction systems, for example, require large land areas to supply the materials for even a small building. The most commonly used construction systems involve materials brought to a site from some distance. A designer can generally select between imported renewable or nonrenewable materials and between imported virgin or recycled materials. The common thread is *imported*—not necessarily from overseas, but from a distance. Reducing the transportation distance and finding local materials when available are emerging design strategies.

Wood is the only renewable construction material currently in wide use in North America. It is easily worked, supports a wide variety of finishes, has moderate structural strength, requires regular maintenance for long life, burns easily, and has only moderate value either as thermal mass or as insulation. This common building material illustrates the impact a rapidly increasing population can have on a fixed, even if renewable, resource base. As huge old trees are harvested to the point of disappearance, growing demand for wood outstrips the supply available from younger, smaller trees. New production methods are devised (such as laminates, particle board, and engineered lumber) to allow large wood members to be constructed from smaller timber. The value of salvaged older wood members increases.

Nonrenewable materials are by far the most commonly used materials in mechanical and electrical systems; metals and plastics predominate. Their advantages include strength, durability, fire resistance, and conductivity or resistivity as required. Most such materials are obtained, however, at a significant energy cost to mine/manufacture, transport, and shape them for our use.

With rapidly increasing demand for both renewable and nonrenewable materials, how can a designer on a planet with fixed resources respond? What are the key materials issues for the design team to consider?

(a) Embodied Energy

One issue is *embodied energy*, a complex and therefore elusive indicator of how much energy must be invested to mine/harvest/produce, fabricate, and transport a unit of building material. Table 2.4 summarizes information on embodied energy for common units of today's prevalent construction materials. Such apparently simple numbers are complicated by variations in availability of the raw resource (more work needed to extract materials requires more energy), variations in distance from raw resource to manufacturing locations, and variations in the fuels used (and their efficiency of use) in the refining or fabricating processes.

Consider two alternatives for exterior wall cladding: wood siding and aluminum siding. Wood has embodied energy from a renewable resource—the sun. It takes the energy of human beings and chain saws to cut the trees and fuel to haul them, perhaps 100 miles (160 km), to a mill. At the mill, more energy is invested as logs become lumber, and still more energy is used as lumber becomes finished siding—which is then transported to a construction site. Aluminum begins as bauxite, which requires energy to mine, then more energy to ship great distances to smelters, which use large quantities of electricity in the refining process. Cheap electricity (as in the Pacific Northwest, with its once-surplus hydropower) attracts bauxite mined thousands of miles away. Once aluminum ingots are formed at the smelter, they are shipped—again, sometimes thousands of miles—to factories that make products such as siding; the products are then transported to a construction site. For a given surface area of finished siding, the aluminum alternative represents about 100 times as much embodied energy as the wood. This, however, is not the end of the story—as a designer must consider the impacts of these two siding materials on building energy consumption and envelope maintenance and replacement needs and schedules.

(b) Recycled or Virgin Material

It seems paradoxical that, while the world's population is increasing and its raw materials are decreasing, labor costs are growing so much faster than the costs of raw materials. One consequence is that labor-intensive practices become less economically attractive. Recycling is one such labor-intensive practice (see examples in Chapter 23), whether at the scale of a household, an office building, or an entire industry.

Building construction, renovation, and demolition involve many opportunities for recycling, but at present these activities represent a major source of waste. The U.S. Environmental Protection Agency's 1998 report *Characterization of Building-Related Construction and Demolition Debris in the United States* estimated that 136 million tons per year (123 Mg) of such material are produced in the United States and that 65% to 85% of that total ends up in landfills.

Consider building demolition. If more of a demolished building can be recycled, more of the energy embodied in its material can be recovered, and fewer virgin materials will be required for some other project. At present, the recovery of usable materials from demolition is limited because the cost of labor is high and the cost of energy and new products is relatively low. It is currently easier, quicker, and cheaper to reduce a building to rubble and haul it to a landfill than to recycle. As landfill capacity becomes scarce, design regulations concerning recycled material use can be expected.

An Atlantic City, New Jersey, project was able to recycle 90% of its demolition waste. Of a total of 1583 tons (1400 Mg) of demolition waste, only 152 tons (140 Mg) were nonrecyclable. Concrete and masonry became crushed aggregate for road building. Glass became "glasphalt" embedded in road surfaces as reflectors. Wood waste became mulch. At Fort Ord in California, four buildings totaling about 11,000 ft^2 (1022 m^2) were dismantled rather than demolished, saving roofing boards, framing lumber, and tongue-and-groove wood flooring. Unpainted drywall was reclaimed for composting.

Construction recycling opportunities include crushed wallboard as a replacement for lime in agriculture, carpet ground up for attic insulation, plate glass crushed for use in glass fiber insulation, and pulverized wood as a composting aid at sewage sludge treatment facilities. Used acoustic ceiling tiles can become part of the slurry from which new acoustic tiles are made. Building materials are now increasingly being made from recycled materials: reinforcing bars from ferrous scrap metal; cellulose insulation from newsprint; parking lot bumper strips, fence posts, and park benches from recycled plastics; and nonstructural concrete from incinerator ash. Even plastic yogurt containers, complete with scraps of aluminum foil, are made into a terrazzo-like floor tile.

Architect Pliny Fisk, codirector of the Austin, Texas-based Center for Maximum Potential Building Systems, has developed a wide array of such applications. His "Advanced Green Builder" home near Austin displays several applications of "ashcrete," made with coal fly ash and bottom ash, producing a 97% recycled-content concrete. This is used as ferro-cement for columns and beams and is foamed for hollow wall infill. Numerous other innovative recycled-material applications are showcased as well.

The most effective form of recycling involves reuse of a building or building shell. Audubon House in New York City is an excellent and well-publicized example of this level of reuse. The next most effective form of recycling involves the reuse of a building component as is. A residential demolition-by-hand salvage project in Portland, Oregon, recovered doors, windows, bathroom fixtures, framing lumber, plywood, siding, flooring, and bricks. The energy and economic summary for this project is shown in Table 2.5.

As with water and renewable energy sources, much of the current interest in lowering the embodied energy content of construction materials and increasing the recycling and reuse of products is attributable to green design efforts. The role of LEED in promoting a change in thinking about materials is outlined in Appendix G. The impact of building materials on occupant health and well-being is also an emerging area of concern and interest. There is a direct link between the selection and maintenance of building materials and indoor air quality (see Chapter 5). Although beyond the scope of this book, LEED also looks at this aspect of materials use, and several reference texts provide fundamental information on design for healthy buildings. Many building products with substantially reduced heath impacts have been developed and marketed during the past 10 years.

TABLE 2.5 Residential Salvage for Reuse

	Embodied Energy[a] Btu/ft^2 Floor Area (kJ/m^2 Floor Area)	Value U.S. \$/ft^2 Floor Area (U.S. \$/m^2 Floor Area)
Total for reusable salvage[b]	46,890 (532,497)	4.90 (52.74)
Demolition energy consumed[c]	−3,380 (−38,384)	
Value of energy embodied in salvage[d]		+0.50 (5.38)
Value of avoided dumping fees		+2.70 (29.06)
Total energy savings and value	43,510 (494,112)	8.10 (87.19)

Source: Joslin et al. (1993).

[a] Based on Stein et al. (1981).

[b] Framing lumber alone constituted 38% of this embodied energy.

[c] Gasoline for transportation and hauling, plus human labor at 254.6 Btu/h (268.6 kJ/h).

[d] Assumed at \$.04/kWh, very low rate typical of the Pacific Northwest.

2.5 DESIGN CHALLENGES

The buildings we design today are very likely, over their lifetimes, to experience major changes in the way they are used and in their sources of energy supply. The societal value of water and embodied materials will also probably change. The resource perspective of the future is unlikely to be that which we hold today. This poses some overall challenges to the designer.

(a) Design for Building Recycling

Designing for the recycling of buildings is a two-part balancing act. First, the designer should provide enough flexibility to prolong the useful life of a building by enabling it to adapt easily to changed usage. Flexibility, however, can be expensive to implement physically and can result in a bland "sameness" throughout a building. The latter characteristic is easier for the designer to change than the former. Second, the design can allow for demounting of parts so that the structure can remain safely intact while reusable materials and components are removed. This can result, however, in heavier buildings in which floor systems are not structurally integrated with beams. This approach also discourages integration of mechanical and structural systems, as discussed in Chapter 10. Furthermore, a demountable building may be especially subject to energy leaks, such as from cracks widening around self-contained components of the façade.

Some initial guidelines for recyclable buildings are as follows:

1. Design the structure to be separable from everything else and to be easily disassembled. Extensive remodeling is then possible without major structural modifications, and at the end of a building's life, elements of its structure can be reused elsewhere.
2. Design for "breathing room" where possible: between a building and its neighbors or between major spaces within a building. Some expansion is thus possible without rebuilding. This could include designing the columns and footings to support an extra floor or two for vertical expansion.
3. Maximize the utilization of on-site (natural) forces such as sun and wind. The less sophisticated the mechanical and electrical equipment, the less obvious will be the obsolescence of such equipment with the passing of time.
4. Use materials and components distinctly: avoid combinations that make recycling of these elements difficult. A steel or plastic pipe embedded in a concrete slab is neither easily repaired nor easily recycled; some "sandwiches" (manufactured building panels) do not allow metals, plastics, and other products they contain to be separated for reuse at the end of the panel's life.

Although maximum savings of embodied energy can be realized when a building component is reused as is, even the crushing and reprocessing of some (separated) building materials will save energy compared to their original manufacture from virgin material (see Chapter 23).

(b) Design for Energy Transition

Two more challenges to designers arise:

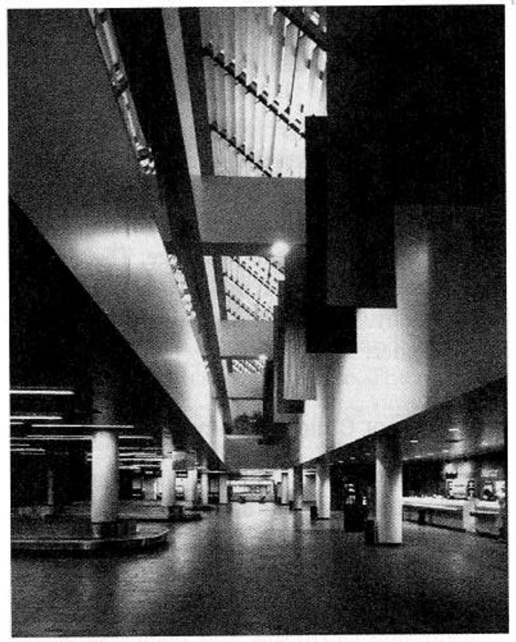
1. To design buildings not only to save energy, but also so that they can eventually be weaned away from dependence on nonrenewable fuels. A transition away from electricity from the utility grid, to site-generated photovoltaic or fuel-cell electricity, seems easy enough given appropriate building orientation, collection surfaces, and equipment spaces.
2. To use energy wisely; to expect only a fair share of locally available renewable fuels, recognizing that such resources are limited even though they are continuously available. For example, in a high-density setting, it may be tempting to erect a large solar collector to intercept sunlight that would otherwise be utilized by a neighboring building. This temptation grows stronger as a building is designed to

rely more heavily upon the sun. The concept of a *solar envelope* to protect each building's fair share is discussed in Section 3.6.

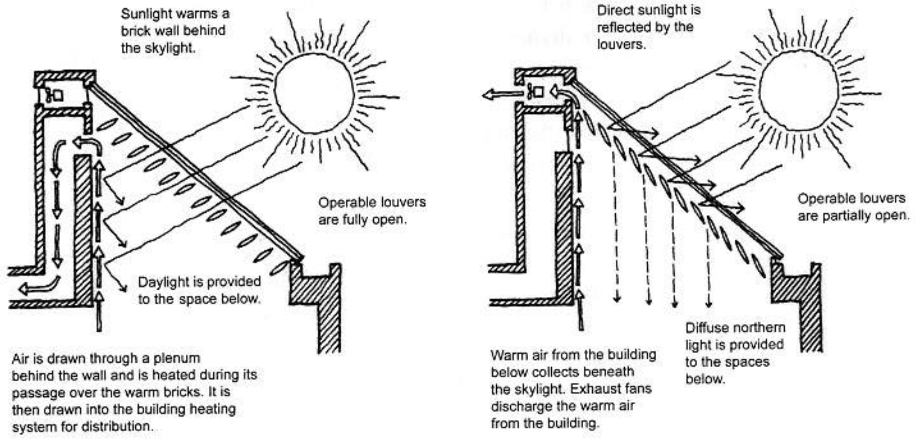
(c) Design for the Information Age

Controls for mechanical and electrical systems have become much more sophisticated, thanks to developments in information systems and electronics. With the advent of *smart houses, intelligent buildings*, and *smart appliances*, it is now possible to regulate an array of building systems collectively and across great distances to optimize performance and minimize resource consumption. For a building, with some zones requiring heating and other zones cooling, some zones with available daylight and others without, an automatic central control system can, without human intervention, integrate the flow of fresh air, sunlight through movable shading devices, and intensity of electric lighting to achieve maximum use of on-site renewable energy.

The Albany County Airport in New York State uses automated controls to regulate solar gain through a large central skylight (Fig. 2.7). A computer monitors indoor and outdoor temperatures, keeps track of solar altitude and azimuth, and then regulates the insulated shading louver position according to the building's heating or cooling needs. Solar gain is stored in a masonry wall that supports the skylight. A plenum behind the wall then heats air to be supplied to the vestibule areas of the airport, where winter heat losses are greatest. Photoelectric controls turn off electric lighting when daylight is adequate. The skylight provides 40% of the lighting and 20% of the heating needs of this 57,000 ft^2 (5295 m^2) building.



(*a*)



Sunny Winter Day
The sun is used to provide heat and light.

Sunny Summer Day
The sun is used to provide light, but is not allowed to penetrate the building and generate excessive heat.

(*b*)

Fig. 2.7 *The Albany County (New York) Airport features a central skylight (a) that provides 40% of the light and 20% of the heat for the building. (b) The insulated louvers are controlled by computer to admit or block the sun and to store heat within the building on winter nights. (Courtesy of Einhorn Yaffee Prescott, Architects, Albany, NY. Redrawn by Amanda Clegg.)*

Information systems promise enormous energy conservation achievements while using very small amounts of energy themselves. They also require one of the least space-consuming distribution systems, or *distribution trees*, of all building service systems, especially compared to air ducts and plumbing pipes. In return for such agreeable characteristics, building designers must recognize that developments in information technology are so rapid that the nature of these systems is likely to undergo frequent and dramatic change. Information system distribution spaces may be quite small, but they must be highly accessible. Where information can be transmitted without wires or cables, the impact on building service space demands is even smaller. Adaptable information systems can make more feasible the renovation, rather than demolition, of older buildings for new tenants. These potentials notwithstanding, the need of occupants to play some role in the use and control of their environments should not be ignored.

(d) Design for Transportation

There are clearly links among design decisions at regional and neighborhood scales (urban planning and subdivision design), transportation, and resulting energy use for commuting, shopping, and recreation. This sphere of concern, however, is beyond the scope of this book. The link between transportation systems and building mechanical/electrical equipment may seem obscure, but consider the impact on buildings of the automobile and its internal combustion engine. Fresh air intakes at street level face significant pollution from engine exhausts. Parking lots below buildings compete for space with heavy mechanical and electrical equipment such as boilers, chillers, ice storage tanks, and switchgear and greatly complicate vertical transportation design. Sloped parking floors make future space use for other purposes quite difficult. Ventilating parking levels to remove fumes from automobiles requires large fans and energy to run them.

In a likely future of electrically powered vehicles, photovoltaic arrays over parking areas can provide electricity for a building and recharge the batteries of parked cars throughout the day (Fig. 2.8). In an alternative future of hydrogen fuel cell-powered

Fig. 2.8 *"Building" integrated photovoltaics (BIPV) provide shelter, shading, and power for a fueling station/convenience store in Eugene, Oregon. Note the green roof on the store and the biofuel pumps. (Photo by Nathan Majeski.)*

vehicles, engine discharge consists simply of water. No fumes are emitted from such cars, saving fan space and energy. To the extent that cars become smaller, or are replaced by public transit or bicycles, significant space may be reclaimed from parking for other uses. When entire buildings are now built as single-purpose parking garages, skillful design for reuse might allow such buildings to be renovated to serve new functions rather than demolished.

2.6 HOW ARE WE DOING?

From the preceding discussion and that in Chapter 1, it might seem that, environmentally, the building professions are doing pretty well. There are minimum standards for energy efficiency and plumbing fixture water consumption that affect virtually every North American building. Such standards are also common internationally. There is growing interest in green buildings, generally fueled by private sector and government owners seeking to set an example, which is moving design beyond the just-acceptable minimum requirements of codes and standards. Concern for energy consumption, renewable energy use, water resources and quality, and materials resources and consumption is an integral element of the green building movement. Per capita energy and water use in the United States appears to be stable and/or decreasing.

From the perspective of yesterday, today's building designs (even the worst) are arguably more resource-efficient and respectful of the environment (this does not necessarily mean they are better designs). The question is: From the perspective of tomorrow, is today's good design good enough? The answer in one context is, unfortunately, no. That context is the *environmental footprint*. Environmental footprints are a concept promoted by Rees and Wackernagel (1995) that plot the gross resource demands of a geographic area as a *footprint* on the planet. Figure 2.9 provides an illustration of the environmental footprint concept applied specifically to water resources. The area in question may be a city, state or province, or country. If the footprint is larger than the geographic boundaries of the area in question, then the area is stepping on someone else's environmental toes. Such a city, state/province, or country needs more land to support itself than is available—thereby surviving through imports from other places. All is well as long as there are other places with surpluses; all is not well when surpluses diminish or disappear. Table 2.6 shows estimated ecological footprints for several countries. It is clear that some countries are substantially overstepping their boundaries, while others are able to accommodate that overstep because of their less consumptive lifestyle. Continuing worldwide population growth makes the footprint balance tenuous. Table 2.7 provides similar environmental benchmarking for the same countries with respect to energy and water use and carbon dioxide (CO_2) emissions. CO_2 is becoming the key environmental metric in the United Kingdom and parts of Europe (Roaf, 2004).

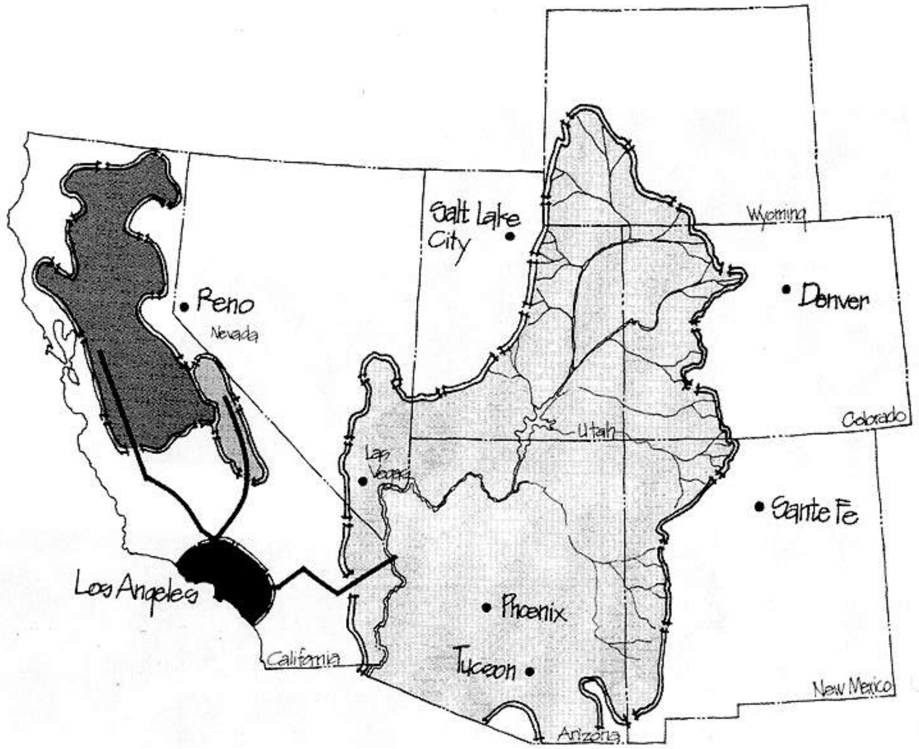


Fig. 2.9 The effective watershed of the greater Los Angeles area. The area (even if partial) needed to provide water to this metropolitan area (its water footprint) is vastly greater than the politically defined city limits. (From Design for Human Ecosystems *by John Tillman Lyle. Copyright © 1999 by Harriet Lyle. Reproduced by permission of Island Press, Washington, DC.)*

The ecological footprint for the "world" shown in Table 2.6 should lead to serious reflection regarding the meaning of sustainability. One unfortunate offspring of the growing interest in green design is a seemingly endless stream of one-upmanship that glibly promotes "sustainable" this and "sustainable" that—including buildings (virtually impossible in today's economic climate), communities (possible, but rare today), and states (perhaps necessary in the future). The term *sustainable* has lost almost any meaning through incessant misuse. This is unfortunate if one believes the story of the ecological footprint—sustainability is essentially keeping the Earth's footprint on the planet. A good idea, as it is the only planet we have right now.

TABLE 2.6 Ecological Footprints[a] for Selected Countries

Country	1997 Population	Footprint (ha/cap)[b]	Available Capacity (ha/cap)	Surplus (if +) or Deficit (if –)
Australia	18,550,000	9.0	14.0	5.0
Austria	8,053,000	4.1	3.1	–1.0
Bangladesh	125,898,000	0.5	0.3	–0.2
Brazil	167,046,000	3.1	6.7	3.6
Canada	30,101,000	7.7	9.6	1.9
China	1,247,315,000	1.2	0.8	–0.4
Egypt	65,445,000	1.2	0.2	–1.0
Germany	81,845,000	5.3	1.9	–3.4
India	970,230,000	0.8	0.5	–0.3
United States	268,189,000	10.3	6.7	–3.6
WORLD	5,892,480,000	2.8	2.1	–0.7

Source: http://www.ecouncil.ac.cr/rio/focus/report/english/footprint/ranking.htm/

[a] Updated 1997.

[b] The ecological footprint, available ecological capacity, and surplus or deficit capacity are in hectares/capita (multiply hectares by 1.66 to obtain acres).

TABLE 2.7 Per Capita Energy[a] and Water[b] Use and CO_2 Emissions[c] for Selected Countries

Country	1997 Population	Energy Use[d]	Water Use[e]	CO_2 Emissions[f]
Australia	18,550,000	5,975	1,250	16.8
Austria	8,053,000	3,790	261	7.9
Bangladesh	125,898,000	145	576	0.2
Brazil	167,046,000	1,064	345	1.8
Canada	30,101,000	8,000	1,494	16.2
China	1,247,315,000	887	494	2.7
Egypt	65,445,000	695	1,013	1.7
Germany	81,845,000	4,264	572	10.2
India	970,230,000	514	635	1.0
United States	268,189,000	7,921	1,682	19.8
WORLD	5,892,480,000	1,631	633	6.1

[a] *Source:* World Resources Institute, Earth Trends: The Environmental Information Portal; http://earthtrends.wri.org/searchable_db/

[b] *Source:* World Resources Institute, Earth Trends: The Environmental Information Portal; http://earthtrends.wri.org/searchable_db/

[c] *Source:* Nationmaster.com; http://www.nationmaster.com/; from World Resources Institute. 2003. Carbon Emissions from Energy Use and Cement Manufacturing, 1850 to 2000. Available online through the Climate Analysis Indicators Tool (CAIT) at http://cait.wri.org. Washington, DC: World Resources Institute.

[d] Units are thousand metric tons of oil equivalent per person per year. Data are for 2001. World per capita consumption has been stable over the past 10 years; that of the United States has increased slightly (7538 in 1990; 7921 in 2001).

[e] Units are cubic meters of water withdrawals per person per year. Data are for 2000.

[f] Units are thousand metric tons of carbon dioxide per 1000 people per year. Data appear to be for 2000.

2.7 CASE STUDY—DESIGN PROCESS AND ENVIRONMENTAL RESOURCES

Philip Merrill Environmental Center, Chesapeake Bay Foundation

PROJECT BASICS

- Location: Annapolis, Maryland, USA
- Latitude: 38.9 N; longitude: 76.5 W; elevation: near sea level
- Heating degree days: 4707 base 65°F (2615 base 18.3°C); cooling degree days: 3709 base 50°F (2061 base 10°C) for Baltimore, MD; annual precipitation: 42 in. (1063 mm)
- Building type: New construction; commercial offices and interpretive center
- 32,000 ft^2 (3000 m^2); two occupied stories
- Completed December 2000
- Client: The Chesapeake Bay Foundation
- Design team: SmithGroup (and consultants)

Background. The Philip Merrill Environmental Center was one of a half-dozen buildings certified as LEED Platinum at the time this case study was prepared. Platinum is the highest possible LEED rating. Elements of the design process for the Environmental Center are presented in the following sections, in order to emphasize the critical importance of an appropriate design process to the development of high-performance buildings. Design team and client values were important to the success of this project—and led to the development of explicit and aggressive green design intent and criteria. Concern for energy efficiency and water conservation led to much of the distinctive form of the building—especially the signature water storage tanks on the entry façade. (The information that follows was provided by SmithGroup.)

Context. The Chesapeake Bay Foundation (CBF) is an environmental advocacy, restoration, and education organization headquartered in Annapolis, Maryland. Before the creation of the Philip Merrill Environmental Center, CBF's facilities included three properties in Annapolis and a small building outside of town. The functioning and unity of the organization suffered from the disparate locations and consequent separation of departments, justifying the creation of a new headquarters that could unify and house CBF in an optimum environment.

Design Intent. The new headquarters would not only house the Foundation, but would also be a reflection on CBF's mission. It would serve as a paragon for the Bay's watershed region of sustainable development—"walking the talk," "practicing what CBF preaches." The design was to emulate the regional vernacular and utilitarian functions of working on the Bay. The building was to respond to habitats, vegetation, soils, buffer zones, views, solar orientation, topography, prevailing wind direction, and functional requirements. The organization of the elements on the site would tell the story of CBF's mission to educate and involve the public in taking responsibility for the health of the Bay.

The leading principles behind the design were as follows:

- Set a precedent for sustainable development on the Chesapeake Bay.
- Provide for the functional needs of CBF.
- Create an effective work environment.
- Embody a sense of unity and connectiveness.
- Push the envelope of green building.
- Reflect the utilitarian nature of CBF.
- Mesh indoor and outdoor spaces.
- Create interactive spaces.
- Integrate CBF's departments while preserving distinction.
- Enhance public service.
- Facilitate an educational experience.

Design Criteria and Validation. The project was intended to achieve a LEED Platinum rating. At the time design commenced, LEED was a largely unknown rating system in its pilot phase of development. The LEED system was used both as a benchmark and as an assessment tool—a way of validating the design's sustainability. Energy modeling using Energy 10 software was performed during the preliminary design phases. The overall energy modeling during subsequent phases used Trace software.

Post-Occupancy Validation Methods. A full year of monitoring and POE was performed by the National Renewable Energy Laboratory (NREL). NREL provided the monitoring equipment to measure the resource consumption (water, electricity, propane) of the building and to measure the energy generated by the building. The Department of Energy performed a productivity analysis of the workers inside the building in an effort to evaluate how green buildings can not only save energy, but can create a healthier and more productive work environment.

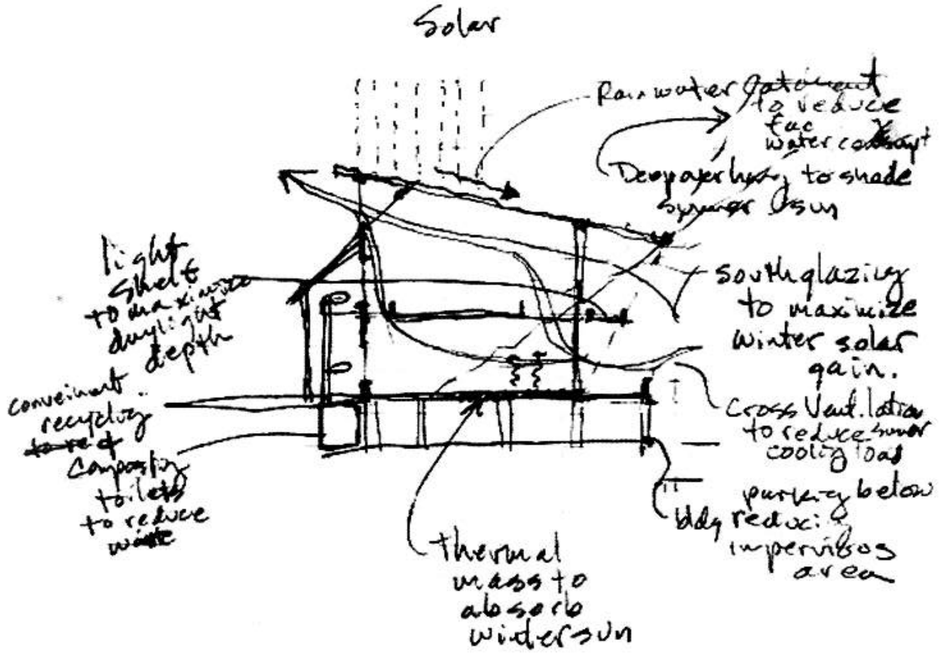


Fig. 2.10 *Conceptual design sketch showing the earliest concept of the Philip Merrill Environmental Center and illustrating how the form of the building was directly related to the environmental goals for the project. This sketch is used by the design team as an ongoing example of how early goal setting allows designers to shape a building to respond to goals, thus creating an integrated design. (© SmithGroup; used with permission.)*

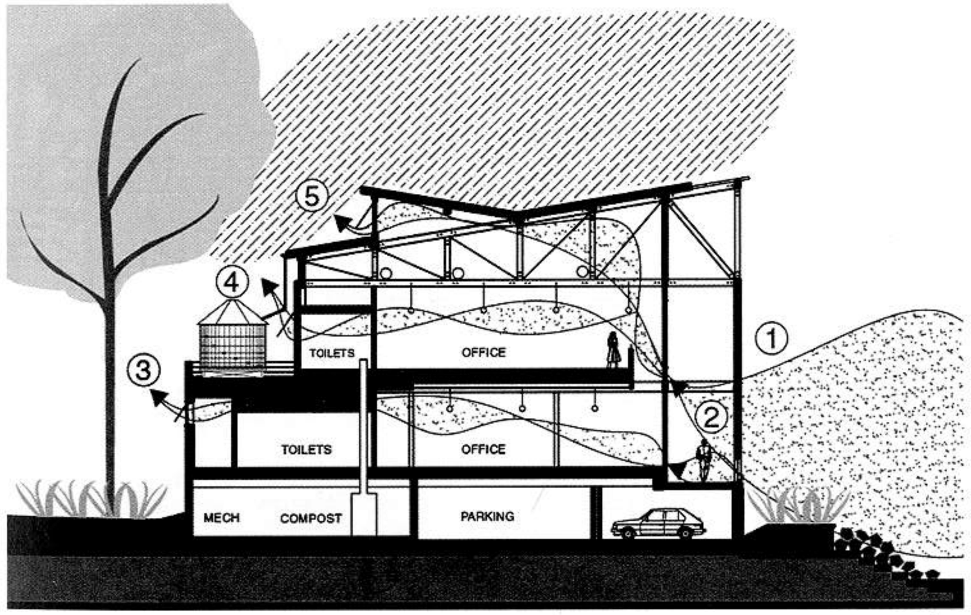


Fig. 2.11 *Schematic design diagram illustrating how the conceptual design idea was refined, and the role that natural ventilation, passive solar heating, rainwater collection, and daylighting and views played in shaping the building. Energy and water are clearly focal elements. (© SmithGroup; used with permission.)*

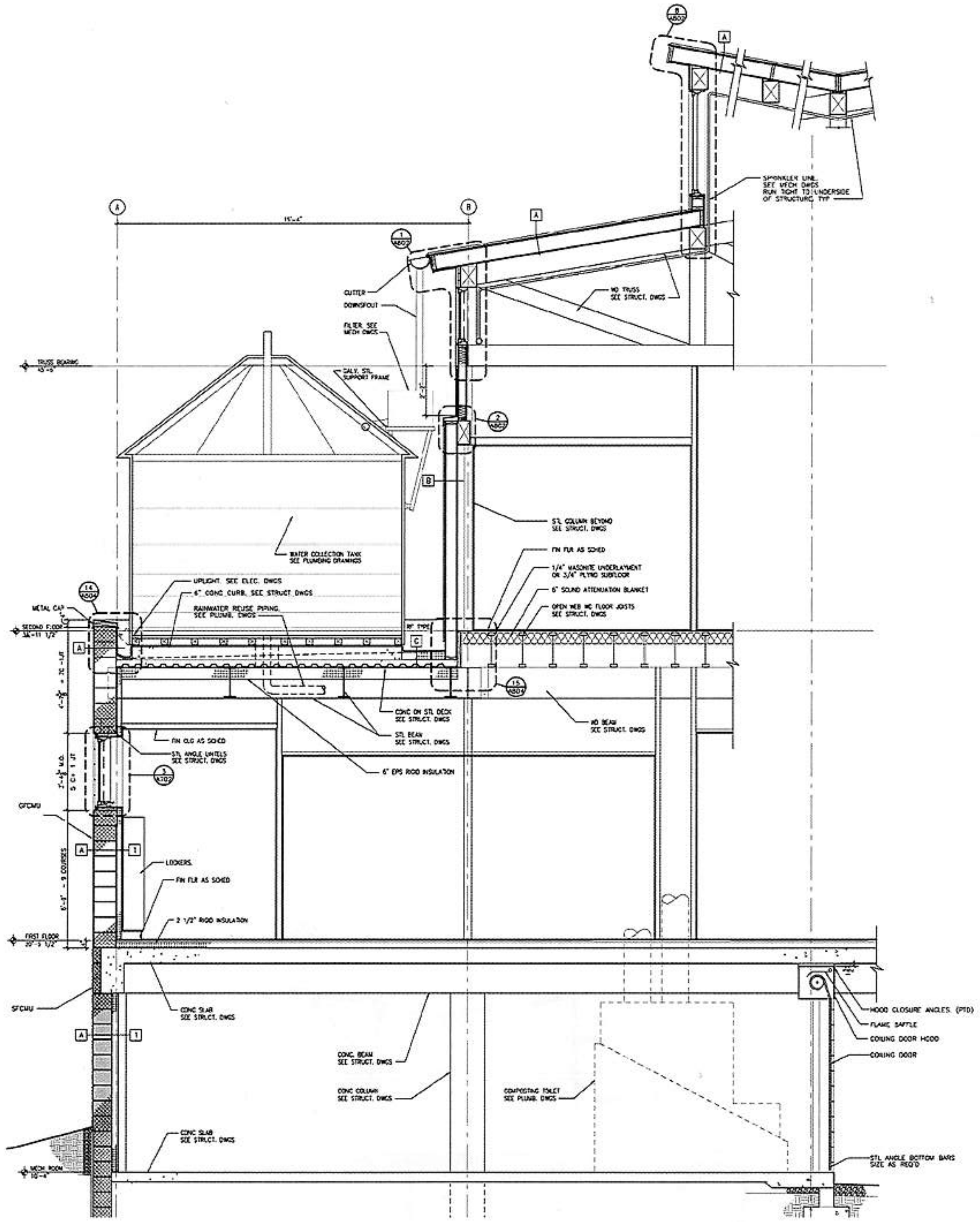


Fig. 2.12 *Section through the Philip Merrill Environmental Center developed during the construction documents phase. The water storage tanks, which are a signature element of the final design, have evolved from concept to buildable artifact. (© SmithGroup; used with permission.)*

Fig. 2.13 *North (inland) façade of the Philip Merrill Environmental Center showing the visual impact of rainwater collection intent and solution. Water conservation has informed this façade. (Photo © 2004 Walter Grondzik; all rights reserved.)*

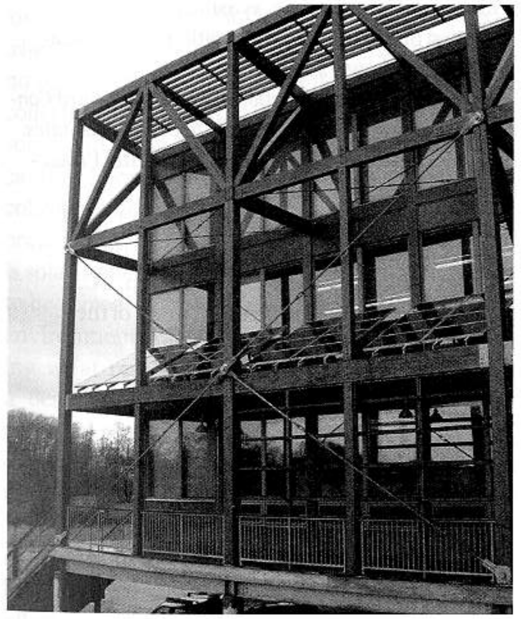


Fig. 2.14 *South (bay side) façade of the Philip Merrill Environmental Center showing PV panels, daylighting/solar apertures, and shading elements. Energy collection has informed this façade. (Photo © 2004 Walter Grondzik; all rights reserved.)*

Performance Data. Information available to date suggests substantial design team success in "pushing the envelope of green building"—particularly in the areas of material, water, and energy conservation:

- The building achieved a LEED Platinum rating.
- All wood was obtained from renewable resources; more than 50% of building materials were obtained from within a 300-mile (480-km) radius of the site.
- There is a projected 90% reduction in water use compared to that of a comparable (conventional) office building.
- There is a projected annual energy use of 350,000 kWh (90% electricity) with an anticipated contribution of 43,000 kWh equivalent from solar thermal systems and PV; plug loads account for roughly a third of the energy use, lighting another third, and climate control the remaining third.
- The project received a Grand Award, Building Team Project of the Year, from *Building Design & Construction* magazine in 2001.

- The building was named one of the AIA/COTE Top Ten Green Projects in 2001 (American Institute of Architects/Committee on the Environment).

FOR FURTHER INFORMATION

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CHAPTER 3

Sites and Resources

SITE ANALYSIS TYPICALLY PRECEDES SITE planning. The purpose of a site analysis is to understand the character of a given site. Such an analysis usually includes the collection of information on utility availability, noise sources, zoning, views, solar access, traffic and pedestrian patterns, climate, and the like. In some cases, long-term statistical data are available as an information resource (such as for climate, solar position, utility services); for other variables (such as noise, views, pedestrian circulation in an urban area) there is usually no existing database, and all information must be collected directly by the designer. To be useful and successful, a site analysis must do more than simply catalog information; it must place value on the collected information in the context of a proposed project and its design intent. For a given building, is solar radiation a desirable resource or a problem to be solved? Is wind a usable design element or an environmental force to be avoided? Understanding what resources are available for inclusion in a design solution, and what natural forces are potential problems to be mitigated by design, is the essence of site analysis—and a necessary precursor to green design.

A designer's early site-planning decisions will, at a later date, influence available options for a building's climate control and lighting systems and affect a building's overall consumption of energy. When the site is seen as a collection of resources (sun, wind, water, plants) and also as part of the environment we all share, buildings can greatly reduce dependence upon nonrenewable fuels. They can also do this without limiting the availability of local energy resources for neighboring buildings. In addition to saving energy, the use of on-site resources can create outdoor spaces that become especially pleasant to be in. Such spaces can direct winter sun to a glass wall while blocking the wind, or funnel summer breezes through shade to an open window. Site planning is greatly influenced by economic considerations, zoning regulations, and adjacent developments, all of which can interfere with the design of a site to utilize the sun, the sky, and the wind. Integration of all these concerns at the site-planning stage is the first step in adapting a building to its climate. This chapter looks briefly at some aspects of site-climate interactions.

3.1 CLIMATES

Climate is a long-term statistically derived picture of weather. Weather is what happened today or yesterday, while climate is what happened over the past 10, 15, or 20 years. Our most familiar names for climates describe their most severe season, as shown in Fig. 3.1. This is a convenient means of description, but it can be misleading for designers. "Cold" climates can have very hot, sometimes humid summer days; hot-arid climates can have bitterly cold winter conditions. Before designing buildings that will modify exterior conditions to provide indoor comfort, we should know when