

CHAPTER 17

ENERGY RESOURCES

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BUILDINGS and facilities of various types may be heated, ventilated, air conditioned, and refrigerated—using systems and equipment designed for that purpose and using the site energy forms commonly available—without concern for the original **energy resources** from whence those energy forms came. Since the energy used in buildings and facilities comprises a significant amount of the total energy used for all purposes, and since the use of this energy has an impact on energy resources, ASHRAE recognizes the “effect of its technology on the environment and natural resources to protect the welfare of posterity” (ASHRAE 1990).

Many governmental agencies regulate energy conservation legislation for obtaining building permits (Conover 1984). The application of specific values to building energy use situations has a considerable effect on the selection of HVAC&R systems and equipment and how they are applied.

CHARACTERISTICS OF ENERGY AND ENERGY RESOURCE FORMS

The HVAC&R industry deals with energy forms as they occur on or arrive at a building site. Generally, these forms are fossil fuels (natural gas, oil, and coal) and electricity. Solar energy and wind energy are also available at most sites, as is low-level geothermal energy (**energy source** for heat pumps). Direct-use (high-temperature) geothermal energy is available at some. These are the prime forms of energy used to power or heat the improvements on a site.

Forms of On-Site Energy

Fossil fuels and electricity are commodities that are usually metered or measured for payment by the facility owner or operator. On the other hand, solar or wind, each of which might be considered a dispersed energy form in its natural state (i.e., requiring neither central processing nor a distribution network) costs nothing for the commodity itself, but does incur cost for the means to make use of it. High-temperature geothermal energy, which is not universally available, may or may not be a sold commodity, depending on the particular locale and local regulations. [Chapter 32 of the ASHRAE Handbook—Applications](#) has more information on geothermal energy.

Some prime on-site energy forms require further processing or conversion into other forms more directly suited for the particular systems and equipment needed in a building or facility. For instance, natural gas or oil is burned in a boiler to produce steam or hot water, a form of thermal energy which is then distributed to various use points (such as heating coils in air-handling systems,

unit heaters, convectors, fin-tube elements, steam-powered cooling units, humidifiers, and kitchen equipment) throughout the building. Although electricity is not converted in form on-site, it is nevertheless used in a variety of ways, including lighting, running motors for fans and pumps, powering electronic equipment and office machinery, and space heating. While the methods and efficiencies with which these processes take place fall within the scope of the HVAC&R designer, the process by which a prime energy source arrives at a given facility site is not under direct control of the professional. On-site energy choices, if available, may be controlled by the designer based in part on the present and future availability of the associated resource commodities.

The basic energy source for heating may be natural gas, oil, coal, or electricity. Cooling may be produced by electricity, thermal energy, or natural gas. If electricity is generated on-site, the generator may be turned by an engine using natural gas or oil, or by a turbine using steam or gas directly.

The term **energy source** refers to on-site energy in the form in which it arrives at or occurs on a site (e.g., electricity, gas, oil, or coal). **Energy resource** refers to the raw energy, which (1) is extracted from the earth (wellhead or mine-mouth), (2) is used in the generation of the energy source delivered to a building site (coal used to generate electricity), or (3) occurs naturally and is available at a site (solar, wind, or geothermal energy).

Nonrenewable and Renewable Energy Resources

From the standpoint of energy conservation, energy resources may be classified in two broad categories: (1) nonrenewable (or discontinuous) resources, which have definite, although sometimes unknown, limitations; and (2) renewable (or continuous) resources, which can generally be freely used without depletion or have the potential to renew in a reasonable period. Resources used most in industrialized countries, both now and in the past, are nonrenewable (Gleeson 1951).

Nonrenewable resources of energy include

- Coal
- Crude oil
- Natural gas
- Uranium-235 (atomic energy)

Renewable resources of energy include

- Hydropower
- Solar
- Wind
- Earth heat (geothermal)
- Biomass (wood, wood wastes, and municipal solid waste)
- Tidal power

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- Ocean thermal
- Atmosphere or large body of water (as used by the heat pump)
- Crops (for alcohol production)

Characteristics of Fossil Fuels and Electricity

Most on-site energy for buildings in developed countries involves electricity and fossil fuels as the prime on-site energy sources. Both fossil fuels and electricity can be described in terms of their energy content (joules). This implies that the two energy forms are comparable and that an equivalence can be established. In reality, however, fossil fuels and electricity are only comparable in energy terms when they are used to generate heat. Fossil fuels, for example, cannot directly drive motors or energize light bulbs. Conversely, electricity gives off heat as a byproduct regardless of whether it is used for running a motor or lighting a light bulb, and regardless of whether that heat is needed. Thus, electricity and fossil fuels have different characteristics, uses, and capabilities aside from any differences relating to their derivation.

Beyond the building site, further differences between these energy forms may be observed, such as methods of extraction, transformation, transportation, and delivery, and the characteristics of the resource itself. Natural gas arrives at the site in virtually the same form in which it was extracted from the earth. Oil is processed (distilled) before arriving at the site; having been extracted as crude oil, it arrives at a given site as, for example, No. 2 oil or diesel fuel. Electricity is created (converted) from a different energy form, often a fossil fuel, which itself may first be converted to a thermal form. The total electricity conversion, or generation, process includes energy losses governed largely by the laws of thermodynamics.

Fuel cells, which are used only on a small scale, convert a fossil fuel to electricity by chemical means.

Fossil fuels undergo a conversion process by combustion (oxidation) and heat transfer to thermal energy in the form of steam or hot water. The conversion equipment used is a boiler or a furnace in lieu of a generator, and conversion usually occurs on a project site rather than off-site. (District heating is an exception.) Inefficiencies of the fossil fuel conversion occur on-site, while the inefficiencies of most electricity generation occur off-site, before the electricity arrives at the building site. (Cogeneration is an exception.)

SUSTAINABILITY

As the world has increased in population and developed technologically, the consequences of uncontrolled growth are being recognized: pollution, toxic waste creation, waste disposal, global climate change, ozone depletion, deforestation, and resource depletion. Continuation of current trends without implementation of mitigation strategies will adversely impact the ability of the earth's ecosystem to regenerate and remain viable for future generations.

The built environment contributes significantly to these effects, accounting for one-sixth of the world's fresh water use, one-quarter of its wood harvest, and two-fifths of its material and energy flows. Other impacts include air quality, transportation patterns, and watersheds. The resources required to serve this sector are considerable—and many of them are diminishing (Gottfried 1996).

The building industry's recognition of the impacts of its activities is changing the way it approaches the design, construction, operation, maintenance, reuse, and demolition of what it creates—namely, toward addressing the environmental and long-term economic consequences of its actions. While this **sustainable design ethic**—or **sustainability**—covers things beyond the purview of the heating, ventilating, air-conditioning (HVAC) industry alone, design for the efficient use of energy resources would certainly be a key element of any sustainable design, and it is certainly very much under the control of the HVAC designer.

The following section of this chapter provides guidance in achieving a sustainable design.

DESIGNING FOR EFFECTIVE ENERGY RESOURCE UTILIZATION

The preponderance of energy used in buildings is from nonrenewable energy resources, the cost of which historically has not included considerations of replenishment or environmental impact. As a result, energy use resulting from many building system designs has been based primarily upon economic considerations, which unfortunately are biased to encourage more rather than less use.

As these resources become less readily available and practitioners look toward the use of more exotic and replenishable sources, the need to operate buildings effectively using less energy becomes paramount. Extensive study since the mid-1970s has revealed that significant reductions in building energy use can be achieved by the application of some fundamental principles.

THE ENERGY ETHIC: RESOURCE CONSERVATION DESIGN PRINCIPLES

The basic approach to achieving an energy-efficient design is reducing loads (power), improving transport systems, and providing efficient components and “intelligent” controls. Design concepts applicable to successful energy-efficient design include understanding the relationship between *energy* and *power*, maintaining *simplicity*, using *self-imposed budgets*, and applying *energy-smart design practices*.

Energy and Power

From the standpoint of economics, more energy-efficient systems need not be more expensive than less efficient systems; quite the opposite is true. This observation results from the simple relationship between energy and power in which power is simply the time rate of energy use (or, conversely, energy is power times time). Power, in turn, describes the size of something. For example, power terms such as watt or kilowatt might be used in expressing the size of a motor, chiller, boiler, or transformer. Of course, the smaller something is, the less it costs; then, other things being equal, as the unit of a smaller size operates over time, it consumes less energy. Thus, in designing for energy efficiency, the first objective is always to reduce the power required to the bare minimum necessary to provide the desired performance—starting with the building's heating and cooling loads (a power term, in kW) and working through the various systems and subsystems.

Simplicity

Complex designs to save energy will seldom function in the manner intended unless the systems are continually managed and operated by technically skilled individuals. Experience in designing energy-efficient systems has shown that achieving energy-efficient performance over a long period of time with a complex system is seldom achievable; further, when these complex systems are operated by minimally skilled individuals, not only are energy efficiencies not achieved but performance suffers as well. The majority of the techniques discussed subsequently can be implemented with a high degree of simplicity.

Self-Imposed Budgets

Just as an engineer must work to a cost budget with most designs, self-imposed power budgets can be similarly helpful in achieving an energy-efficient design. Examples of some budgets that designers have set for themselves for office buildings in a typical midwestern or northeastern temperate climate are

Installed lighting (overall)	14 W/m ²
Space sensible cooling	63 W/m ²
Space heating load	47 W/m ²

Fan system pressure	1 kPa
Air circulation rates	5 L/(s·m ²)
Electric power (overall)	48 W/m ²
Thermal power (overall)	95 W/m ²
Hydronic system pressure	210 kPa
Water chiller (water cooled)	0.17 kW/kW cooling
Chilled water system auxiliaries	0.04 kW/kW cooling
Unitary air-conditioning systems	0.28 kW/kW cooling
Annual electric energy	580 MJ/(m ² ·yr)
Annual thermal energy	205 kJ/(m ² ·yr·K·day)

Then, as the building and its systems are designed, all decisions become interactive as the result of each subsystem's power or energy performance being continually compared to the "budget."

THE ENERGY-EFFICIENT DESIGN PROCESS

Energy efficiency should be considered at the beginning of the building design process because energy-efficient features are most easily and effectively incorporated at that time. Active participation of all members of the design team—including owner, architect, engineer, and often the contractor—should be sought early in the design process. Consider building attributes such as building function, form, orientation, window/wall ratio, and HVAC system types early as each has major energy implications.

Address a building's energy requirements in the following sequence:

1. **Minimize the impact of the building's functional requirements** by analyzing how the building relates to its external environment. Advocate changes in building form, aspect ratio, and other attributes that reduce, redistribute, or delay (shift) loads. The load calculation should be interactive so that the impact of those factors can be seen immediately.
2. **Minimize loads** by analyzing the external and internal loads imposed on the building energy-using subsystems, both for peak-load and part-load conditions.
3. **Maximize subsystem efficiency** by analyzing the diversified energy and power requirements of each energy-using subsystem serving the building's functional requirements. Consider static and dynamic efficiencies of energy conversion and energy transport subsystems, and consider opportunities to reclaim, redistribute, and store energy for later use.
4. **Study alternate ways to integrate subsystems** into the building by considering both power and time components of energy use. Identify, evaluate, and design each of these components to control overall design energy consumption. The following should be considered when integrating major building subsystems:
 - Address more than one problem at time when developing design solutions, and make maximum use of building components incorporated for nonenergy reasons (e.g., windows, structural mass).
 - Examine design solutions that consider time (i.e., *when* the energy use takes place) since sufficient energy may already be present from the environment (e.g., solar heat, night cooling) or from internal equipment (e.g., lights, computers) but available at times different from when needed. Thus, active (e.g., heat pumps with water tanks) and passive (e.g., building mass) storage techniques may be considered.
 - Examine design solutions that consider the anticipated use of space. For example, in large but relatively unoccupied spaces, task or zone lighting may be considered. Transporting excess energy (light and heat) from locations of production and availability to locations of need may be considered instead of purchasing additional energy.
 - Never reject waste energy at temperatures usable for space conditioning or other practical purposes without calculating the economic benefit of energy recovery or treatment for reuse.

- Consider or advocate design solutions that provide more comfortable surface temperatures or increase the availability of controlled daylight in buildings where human occupancy is a primary function.
- Use easily understood design solutions as they have a greater probability of use by building operators and occupants.
- Where the functional requirements of a building are known to be likely to change over time, design the installed environmental system to adapt to meet those changes that can be anticipated as well as to provide flexibility in meeting future changes in use, occupancy, or other functions.

BUILDING ENERGY USE ELEMENTS

Envelope

- Control thermal conductivity through the use of insulation (including movable insulation), thermal mass, and/or phase change thermal storage at levels that minimize net heating and cooling loads on a time-integrated (annual) basis.
- Minimize unintentional or uncontrolled thermal bridges, and consider them in energy-related calculations because they can radically alter the conductivity of a building envelope. Examples include wall studs, balconies, ledges, and extensions of building slabs.
- Minimize infiltration so that it approaches zero. (An exception is when infiltration provides the sole means of ventilation such as in small residential units.) This effort will minimize fan energy consumption in pressurized buildings during occupied periods and minimize heat loss (or unwanted heat gain in warm climates) during unoccupied periods. An additional benefit of a tight envelope in warm humid climates is that it improves indoor air quality. Infiltration should be reduced through design details that enhance the fit and integrity of building envelope joints in ways that may be readily achieved during construction. This includes infiltration control by caulking, weatherstripping, vestibule doors, and/or revolving doors—with construction meeting accepted specifications.
- Consider operable windows to allow occupant-controlled ventilation. If this is done, the design of the building's mechanical system must be carefully executed to minimize unnecessary HVAC energy consumption, and building operators and occupants should be cautioned about how operable windows may be improperly used.
- Strive to maintain occupant radiant comfort regardless of whether the building envelope is designed to be a static or dynamic membrane. Opaque surfaces should be designed so that the average inside surface temperatures remain within 3 K of room temperature in the coldest anticipated weather (i.e., winter design conditions) and so that the coldest inside surface will remain within 14 K of room temperature (but always above the indoor dew point). In a building with time-varying internal heat generation, consider thermal mass for controlling radiant comfort. In the perimeter zone, thermal mass is more effective when it is positioned inside the envelope's insulation.
- Effective control of solar radiation is critical to the design of energy-efficient buildings due to the high level of internal heat production already present in most commercial buildings. In some climates, lighting energy consumption savings due to daylighting techniques can be greater than the heating and cooling energy penalties that result from additional glazed surface area required, provided that the building envelope is properly designed for daylighting and that lighting controls are installed and used. (In other climates, such net savings may not be realized.) Daylighting designs are most effective if direct solar beam radiation is not allowed to cause glare in building spaces.
- Design the transparent portions of the building envelope to prevent solar radiant gain above that necessary for effective daylighting

and solar heating. On south-facing facades, the use of low shading coefficients is generally not as effective as external physical shading devices in achieving this balance. Low-emissivity, high-visible-transmittance glazings may be considered for effective control of radiant heat gains and losses. For shading control, designers may consider the judicious use of vegetation to block excess gain year-round or seasonally, depending on the plant species chosen.

Lighting

Lighting is both a major energy end use in commercial buildings (especially office buildings) and a major contributor to internal loads by increasing cooling loads and decreasing heating loads. Therefore, it is important to produce (or advocate) a design that meets the lighting functional criteria of the space as well as one that minimizes energy use. The *IESNA Lighting Handbook* (IESNA 2000) recommends illuminance levels for visual tasks and surrounding lighted areas. Principles of energy-conserving design within that context are described as follows:

- Energy use is determined by the lighting load (demand power) and its duration of use (time). Minimize the actual demand load rather than just the apparent connected load. Control the load rather than just area switching, if switching may adversely affect the quality of the luminous environment.
- Consider daylighting along with the proper use of controls to reduce costs of electric lighting. Design should be sensitive to window glare, sudden changes in luminances, and general user acceptance of daylighting controls. Window treatment (blinds, drapes, and shades) and glazing should be carefully selected to control direct solar penetration and luminance extremes while still maintaining the view and daylight penetration.
- Design the lighting system so that illumination required for tasks is primarily limited to the location of the task and comes from a direction that minimizes direct glare and veiling reflections on the task. When the design concept is based on nonuniform illuminance, walls should be a light to medium color or otherwise illuminated to provide visual comfort. In densely occupied work spaces, uniform distribution of general lighting may be most appropriate. Where necessary, provide supplementary task illumination. General ambient illumination should not be lower than a third of the luminance required for the task; this will help maintain visually comfortable luminance ratios.
- Use local task lighting to accommodate the need for higher lighting levels due to task visual difficulty, glare, intermittently changing requirements, or individual visual differences (poor or aging eyesight).
- Group similar activities so that high illuminance or special lighting for particular tasks can be localized in certain rooms or areas, and so that less efficient fixtures required for critical glare control do not have to be installed uniformly when they are only required sparsely.
- Use lighting controls throughout so lighting is available when and where it is needed, but not wasted during those times when tasks being performed are less critical or spaces are not fully occupied. Also consider user acceptance of control strategies to maximize energy saving.
- Limit use of lower efficiency lamps (such as incandescent) to those applications where their color, lumens, or distribution characteristics cannot be duplicated by other sources. Due to their lower efficiency, limit the use of extended service incandescent lamps to those applications where fixtures are difficult to reach and/or maintenance costs for replacing lamps would be excessive.
- Continue carrying through the lighting design process as the building's interior design is occurring. Reduced light absorption may be achieved by using lighter finishes, particularly on ceilings, walls, and partitions.

Other Loads

- Minimize the thermal impact of equipment and appliances on HVAC systems by the use of hoods, radiation shields, or other confining techniques, and by using controls to ensure that such equipment is turned off when not needed. In addition, locate, where practical, major heat-generating equipment where it can balance other heat losses. Computer centers or kitchen areas usually have separate, dedicated HVAC equipment. In addition, consider heat recovery for this equipment.
- Use storage techniques to level or distribute loads that vary on a time or spatial basis to allow operation of a device at maximum (often full-load) efficiency.

HVAC System Design

- Consider separate HVAC systems to serve areas expected to operate on widely differing operating schedules or design conditions. For instance, systems serving office areas should generally be separate from those serving retail areas.
- Arrange systems so that spaces with relatively constant and weather-independent loads are served with systems separate from those serving perimeter spaces. Areas with special temperature or humidity requirements, such as computer rooms, should be served by systems separate from those serving areas that require comfort heating and cooling only. Alternatively, these areas may be served by supplementary or auxiliary systems.
- Sequence the supply of zone cooling and heating to prevent the simultaneous operation of heating and cooling systems for the same space to the extent possible. Where this is not possible due to ventilation, humidity control, or air circulation requirements, reduce air quantities as much as possible before incorporating reheating, recooling, or mixing hot and cold airstreams. As an example, if reheat is necessary to provide dehumidification and prevent overcooling, *only* the ventilation air need be so treated rather than the entire recirculated air quantity. Finally, reset the supply air temperature up to the extent possible to reduce reheating, recooling, or mixing losses.
- Provide controls to allow operation in an occupied mode and an unoccupied mode. In the occupied mode, controls may provide for a gradually changing control point as system demands change from cooling to heating. In the unoccupied mode, ventilation and exhaust systems should be shut off if possible, and comfort heating and cooling systems should be shut off except to maintain space conditions ready for the next occupancy cycle.
- In geographical areas where diurnal temperature swings and humidity levels permit, consider the judicious coupling of air distribution and building structural mass to allow nighttime cooling to reduce the requirement for daytime mechanical cooling.
- High ventilation rates, where required for special applications, can impose enormous heating and cooling loads on HVAC equipment. In these cases, consider recirculation of filtered and cleaned air to the extent possible rather than 100% outside air. Also, consider preheating outside air with reclaimed heat from other sources.

HVAC Equipment Selection

- To allow for HVAC equipment operation at the highest efficiencies, match conversion devices to load increments, and sequence the operation of modules. Oversized or large-scale systems should never serve small seasonal loads (e.g., a large heating boiler serving a summer service water-heated load). Include specific low-load units and auxiliaries where prolonged use at minimal capacities is expected.
- Select the most efficient (or highest COP) equipment practical at both design and reduced capacity (part-load) operating conditions.

- In the selection of large power devices such as chillers (including their auxiliary energy burdens), seriously consider life-cycle purchasing techniques.
- Keep fluid temperatures for heating equipment devices as low as practical and for cooling equipment as high as practical, while still meeting loads and minimizing flow quantities.

Energy Transport Systems

Energy should be transported by the most energy-efficient means possible. The following options are listed in order of efficiency from the lowest energy transport burden (most efficient) to the highest (least efficient):

1. Electric wire or fuel pipe
2. Two-phase fluid pipe (steam or refrigerant)
3. Single-phase liquid/fluid pipe (water, glycol, etc.)
4. Air duct

Select a distribution system that complements other parameters such as control strategies, storage capabilities, conversion efficiency, and utilization efficiency.

The following are specific design techniques that may be applied to thermal energy transport systems:

Steam Systems

- Include provisions for seasonal or non-use shutdown.
- Minimize the venting of steam and ingestion of air with the design directed toward full-vapor performance.
- Avoid subcooling, if practical.
- Return condensate to boilers or source devices at the highest possible temperature.

Hydronic Systems

- Minimize flow quantity by designing for the maximum practical temperature range (Δt).
- Vary flow quantity with load where possible.
- Design for the lowest practical pressure rise (or drop).
- Provide OPERATING and IDLE control modes.
- When locating equipment, identify the critical pressure path and size runs for the minimum reasonable pressure drop.

Air Systems

- Minimize airflow by careful load analysis and an effective distribution system. If the application allows, the supply air quantity should vary with the sensible load (i.e., VAV systems). Hold the fan pressure requirement to the lowest practical value and avoid using fan pressure as a source for control power.
- Provide NORMAL and IDLE control modes for the fan systems as well as the psychrometric systems.
- Keep duct runs as short as possible, and keep runs on the critical pressure path sized for minimum practical pressure drop.

Power Distribution

- Size transformers and generating units as close as possible to the actual anticipated load (i.e., avoid oversizing to minimize fixed thermal losses).
- Consider distribution of electric power at the highest practical voltage and load selection at the maximum power factor consistent with safety.
- Consider tenant submetering in commercial and multifamily buildings as a cost-effective energy conservation measure. (A large portion of energy use in tenant facilities occurs simply because there is no economic incentive to conserve.)

Domestic Hot Water Systems

- Choose shower heads that provide and maintain user comfort and energy savings. They should not have removable flow-restricting inserts to meet flow limitation requirements.

- Consider point-of-use water heaters where their use will reduce energy consumption and annual energy cost.
- Consider using storage facilitate heat recovery when the heat to be recovered is out of phase with the demand for hot water or when energy use for water heating can be shifted to take advantage of off-peak rates.

Controls

- A well-designed digital control system provides information to managers and operators as well as to the data processor that serves as the intelligent controller. Include the energy saving concepts discussed previously throughout the operating sequences and control logic. However, energy conservation should not be sought at the expense of inadequate performance; in a well-designed system, these two parameters are compatible.

ON-SITE ENERGY/ENERGY RESOURCE RELATIONSHIPS

An HVAC&R designer sooner or later must consider the use of one or more forms of prime energy. Most likely, these would be fossil fuels and electricity, although installations are sometimes designed using a single energy source (e.g., only a fossil fuel or only electricity).

Solar energy normally impinges on the site (and on the facilities to be put there), so it has an impact on the energy consumption of the facility. The designer must account for this impact and may have to decide whether to make active use of solar energy. Other naturally occurring and distributed renewable forms such as wind power and earth heat (if available) might also be considered.

The designer should be aware of the relationship between on-site energy sources and raw energy resources—including how these resources are used and what they are used for. The relationship between energy sources and energy resources involves two parts: (1) quantifying the energy resource units expended and (2) considering the societal impact of the depletion of one energy resource (caused by on-site energy use) with respect to others. The following two sections describe those parts in more specific terms.

Quantifiable Relationships

As on-site energy sources are consumed, a corresponding amount of resources are consumed to produce that on-site energy. For instance, for every volume of No. 2 oil consumed by a boiler at a building site, some greater volume of crude oil is extracted from the earth. On leaving the well, the crude oil is transported and processed into its final form, perhaps stored, and then transported to the site where it will be used.

Even though gas requires no significant processing, it is transported, often over long distances, to reach its final destination, which causes some energy loss. Electricity may have as its raw energy resource a fossil fuel, uranium, or an elevated body of water (hydroelectric generating plant).

Data to assist in determining the amount of resource use per delivered on-site energy source unit are available. In the United States, data are available from entities within the U.S. Department of Energy and from the agencies and associations listed at the end of this chapter.

A **resource utilization factor** (RUF) is the ratio of resources consumed to energy delivered (for each form of energy) to a building site. Specific RUFs may be determined for various energy sources normally consumed on-site, including nonrenewable sources such as coal, gas, oil, and electricity, and renewable sources such as solar, geothermal, waste, and wood energy. With electricity, which may derive from several resources depending on the particular fuel mix of the generating stations in the region served, the overall RUF is the weighted combination of individual factors applicable to electricity and a particular energy resource. Grumman (1984) gives specific formulas for calculating RUFs.

While a designer is usually not required to determine the amount of energy resources attributable to a given building or building site for its design or operation, this information may be helpful when assessing the long-range availability of energy for a building or the building's impact on energy resources. Factors or fuel-quantity-to-energy resource ratios or factors are often used, which suggests that energy resources are of concern to the HVAC&R industry.

Intangible Relationships

Energy resources should not simply be converted into common energy units [e.g., gigajoule] because the commonality gives a misleading picture of the equivalence of these resources. Other differences and limitations of each of the resources defy easy quantification but are nonetheless real. For instance, electricity that arrives and is used on a site can be generated from coal, oil, natural gas, uranium, or hydropower. The end result is the same: electricity at x kV, y Hz. However, is a megajoule of electricity generated by hydropower equal in societal impact to that same megajoule generated by coal, by uranium, by domestic oil, or by imported oil?

Intangible factors such as safety, environmental acceptability, availability, and national interest also are affected in different ways by the consumption of each resource. Heiman (1984) proposes a procedure for weighting the following intangible factors:

National/Global Considerations

- Balance of trade
- Environmental impacts
- International policy
- Employment
- Minority employment
- Availability of supply
- Alternative uses
- National defense
- Domestic policy
- Effect on capital markets

Local Considerations

- Exterior environmental impact—air
- Exterior environmental impact—solid waste
- Exterior environmental impact—water resources

- Local employment
- Local balance of trade
- Use of distribution infrastructure
- Local energy independence
- Land use
- Exterior safety

Site Considerations

- Reliability of supply
- Indoor air quality
- Aesthetics
- Interior safety
- Anticipated changes in energy resource prices

SUMMARY

In designing HVAC&R systems, the need to address immediate issues such as economics, performance, and space constraints often prevents designers from fully considering the energy resources affected. Today's energy resources are less certain because of issues such as availability, safety, national interest, environmental concerns, and the world political situation. As a result, the reliability, economics, and continuity of many common energy resources over the potential life of a building being designed are unclear. For this reason, the designer of building energy systems must consider the energy resources on which the long-term operation of the building will depend. If the continued viability of those resources is reason for concern, the design should provide for, account for, or address such an eventuality.

OVERVIEW OF GLOBAL ENERGY RESOURCES

WORLD ENERGY RESOURCES

Production

Energy production trends for the world, by leading producers and world areas, from 1989 to 1998, are shown in [Figure 1](#). World primary energy production, following essentially no increase in the

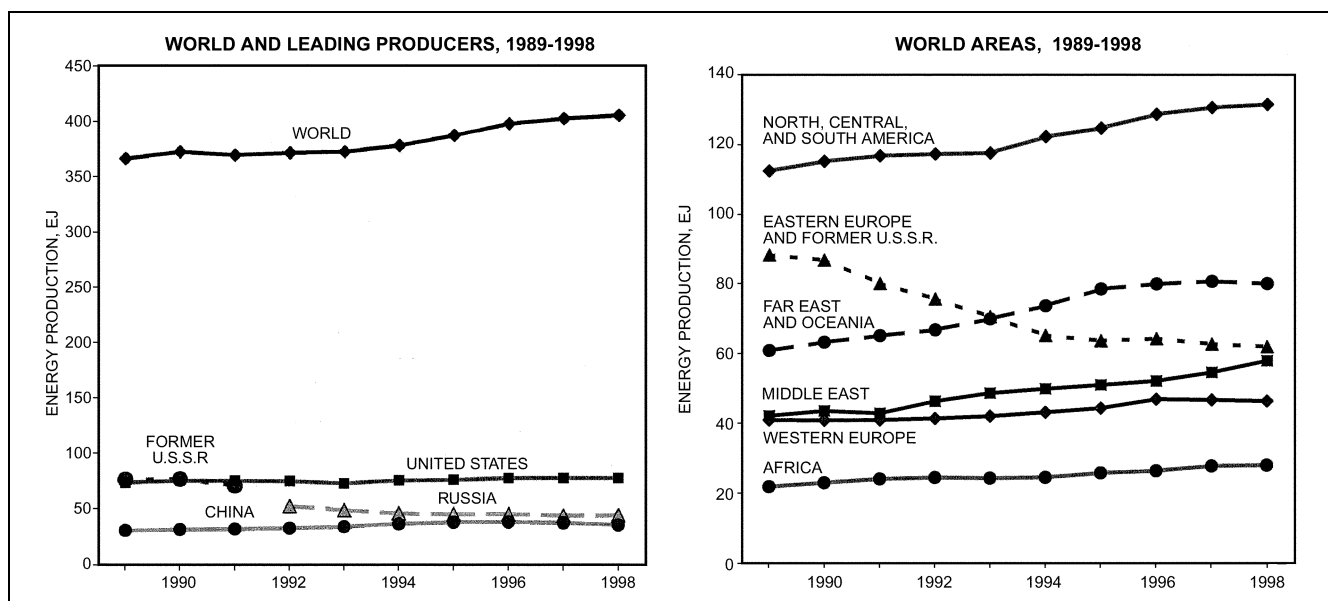


Fig. 1 World Primary Energy Production
(Basis: Energy Information Administration/Annual Energy Review 1999)

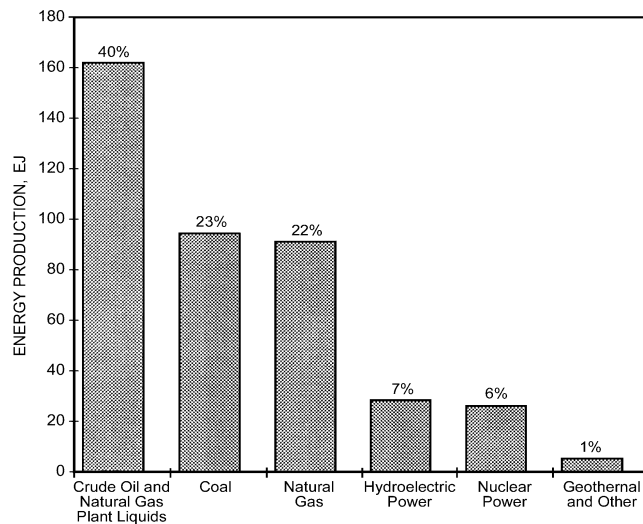


Fig. 2 World Primary Energy Production by Resource: 1998

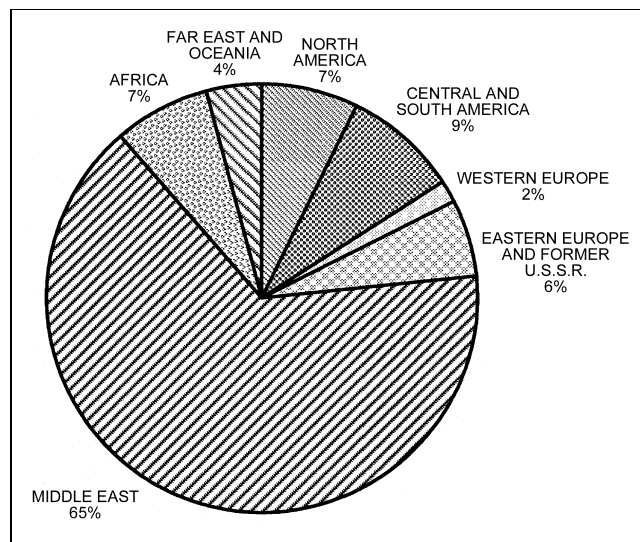


Fig. 3 World Crude Oil Reserves: January 1, 1999
(Basis: *Oil and Gas Journal*)

early 1990s, has risen subsequently at about 1.7% per year. The largest total energy producers in 1998 were the United States (20%), Russia (11%), and China (9%). Saudi Arabia (5%+) was the world's fourth largest producer. Together these producers accounted for almost half of the world's energy. Total world energy production by resource type is shown in [Figure 2](#).

Crude Oil. World crude oil production was 10.7×10^6 m³ per day in 1999—up 18% since 1973. The biggest crude oil producers in 1999 were the eight nations comprising the Organization of Petroleum Exporting Countries (OPEC) at 42% (including Saudi Arabia at 12%+), Russia (9%), and the United States (9%). Oil production declined most noticeably since 1992 in Russia (20%) and in the United States (17%). The other primary non-OPEC producers were China, Mexico, Norway, the United Kingdom, and Canada.

Natural Gas. World production reached 2.3×10^{12} m³ in 1998—up 15% from the 1989 level. The biggest producers in 1998 were Russia (25%) and the United States (23%).

Coal. At 4.5×10^9 Mg in 1998, coal production was lower by 0.3% than in 1989 and comprised 23% of the world's energy

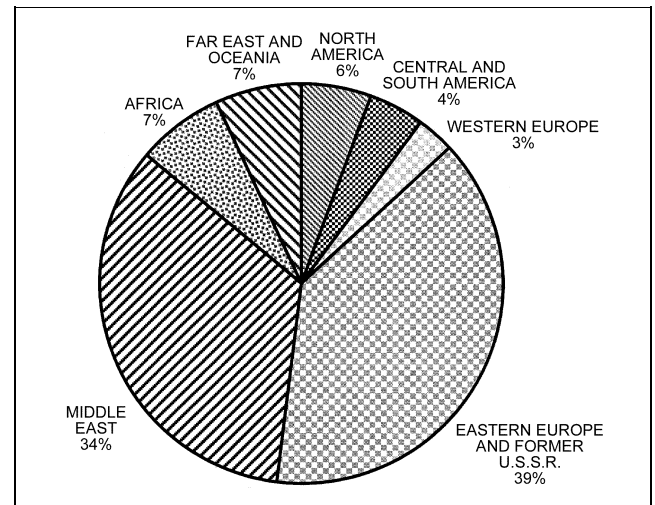


Fig. 4 World Natural Gas Reserves: January 1, 1999
(Basis: *Oil and Gas Journal*)

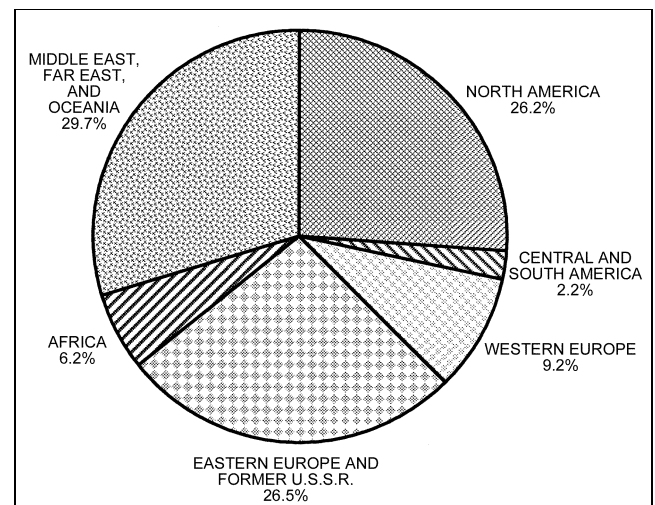


Fig. 5 World Recoverable Coal Reserves: December 31, 1996 and January 1, 1999 (U.S. Only)
(Basis: Energy Information Administration)

production. The leading producers of coal were China (27%), the United States (22%), India (7%), Russia (5%+), Germany (5%), and Poland (4%).

Reserves

On January 1, 1999, the estimated world reserves of crude oil and gas were distributed by world region as shown in [Figures 3](#) and [4](#). Saudi Arabia was estimated to have 39% of the Middle Eastern crude oil reserves. Iraq, the United Arab Emirates, Kuwait, and Iran were each estimated to have more crude oil reserves than any world region outside the Middle East. Outside the Middle East, the biggest reserves were estimated to be in Venezuela, Russia, and Mexico. The country with the largest gas reserves by far was Russia.

World coal reserves as of January 1, 1996, are shown by world area in [Figure 5](#) (note that the U.S. data are as of January 1, 1999). The countries with the most plentiful reserves, as a percent of total, were Russia (16%), the United States (25%), China (12%), and Australia (9%).

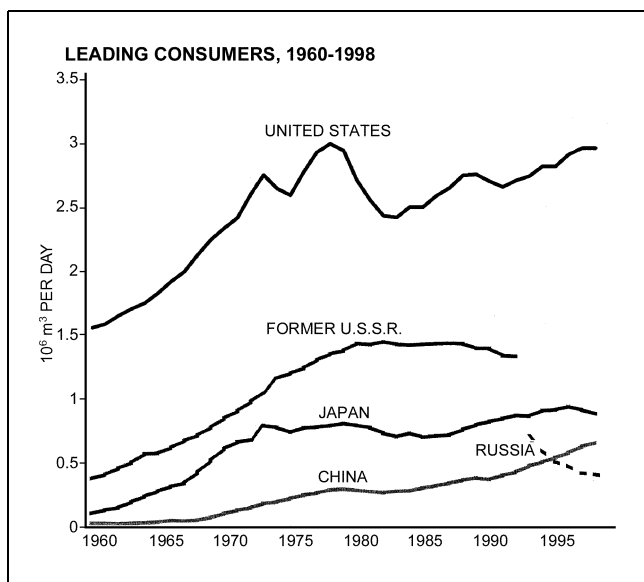


Fig. 6 World Petroleum Consumption: 1960-1998

(Basis: Energy Information Administration/Annual Energy Review 1999)

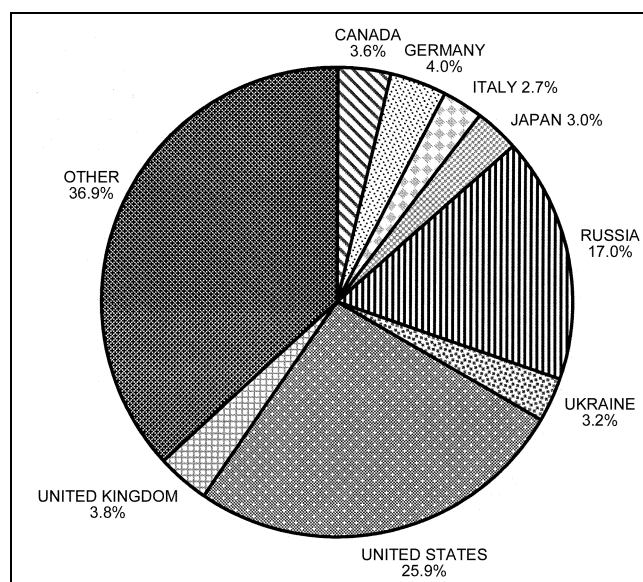


Fig. 7 World Natural Gas Consumption: 1998

(Basis: Energy Information Administration)

Consumption

Data on world energy consumption are available only by type of resource rather than by total energy consumed.

Petroleum. The consumption trends of the leading consumers from 1960 to 1998 are depicted in Figure 6. In 1998, the United States consumed far more than any other country—26% of world consumption and 40% of the consumption of Organization for Economic Cooperation and Development (OECD) countries. By contrast, Japan, the second largest consumer among OECD countries, consumed just 7.5% of the world total and 12% of that of the OECD countries. Of the non-OECD countries, Russia and China were the biggest consumers (3% and 6%, respectively, of world consumption).

Natural Gas. Transport pipelines notwithstanding, this energy resource tends to be consumed close to the site of production; and indeed, in 1998 the two biggest natural gas producers were also the two biggest consumers. Figure 7 depicts natural gas consumption by the leading consumer countries as a percentage of world consumption. Of the major consumers, the United States consumed more than it produced (114%), and the former U.S.S.R. consumed less (67%). Germany and the United Kingdom, the third and fourth largest consumers, produced very little. Canadian consumption was 49% of its production. World consumption of natural gas increased 55% between 1980 and 1998, with the three major gas-consuming states of the former U.S.S.R. (Russia, Ukraine, and Uzbekistan) up 35% and the United States up 7%. After the United States and Russia, no single country consumed more than 5% of the world total.

Coal. Here, the three largest producers were also the three largest consumers. Figure 8 depicts the percentage of world consumption by the leading consumers during 1998. Since 1980, world coal consumption has increased 21%, with most of that increase in the early 1980s. Over the same period, consumption by China increased 93%, the United States 48%, India 185%, and Japan 43%. Significant drops occurred in Germany, Poland, and Russia.

Electricity. Figure 9 shows the world's electricity generation by energy resource in 1998. Figure 10 shows installed capacity for the same resources at the beginning of 1998. Both net generation and installed capacity were dominated by the United States (26%+ and 25%, respectively). Comparable figures for the next largest are

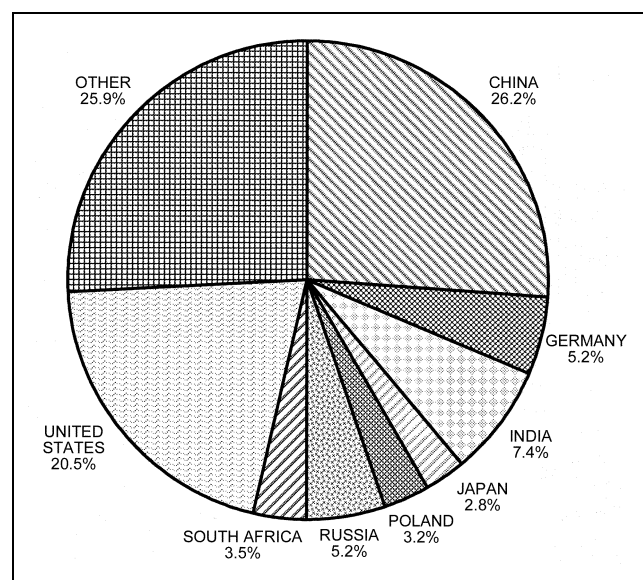


Fig. 8 World Coal Consumption: 1998

(Basis: Energy Information Administration)

China (8% for both), Japan (7% and 7+%), and Russia (6% and 7%). China, which has grown almost four times in net electric generating capacity since 1980, has surpassed Japan in the last few years.

Electricity generated by hydroelectric means increased in the world by 47% between 1980 and 1998, with the largest increase occurring in Central and South America. The top countries for hydroelectric generation in 1998 were the United States, Canada, and Brazil—collectively accounting for 37% of the world total quantity of electricity generated by that means.

Total world electricity generation from nuclear resources increased 239% between 1980 and 1998, with higher-than-average increases occurring in the Far East/Oceania, Western Europe, and Africa. The top-generating countries in 1998 were the United States (27% of world total), China (8%), and Japan (7%).

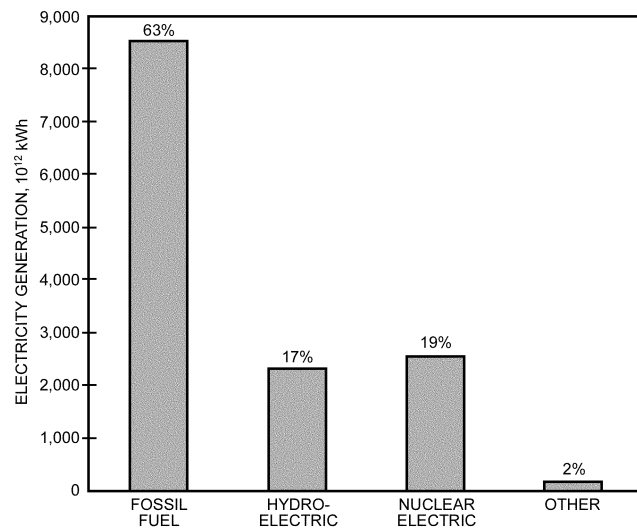


Fig. 9 World Electricity Generation by Resource: 1998

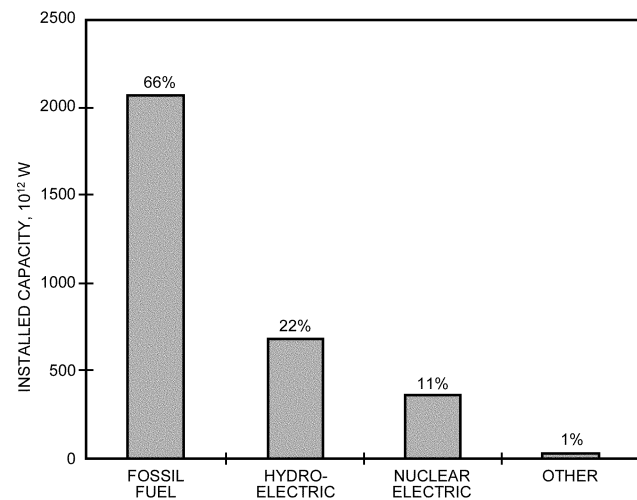


Fig. 10 World Installed Electricity Generation Capacity by Resource: January 1, 1998

Per Capita. Figure 11 compares the per capita commercial energy consumption of selected developed countries for 1998. As is apparent, the per capita energy consumption in cold-climate countries tends to be highest; also, the level in more developed countries is vastly different from that in less developed countries and differs considerably even among the more developed countries.

UNITED STATES ENERGY USE

Per Capita Energy Consumption

Figure 12, which is based on EIA (1999), presents a capsule overview of past U.S. energy use intensity by relating the growth in per capita energy use since 1949 to population growth. The growth in per capita energy use has varied significantly from the population growth rate. The 1960s experienced a sharp increase in the per capita energy use growth rate, which leveled off during the 1970s due to higher energy prices and the emphasis on energy conservation. [No change in the intensity of energy use would result in a flat (horizontal) energy-per-capita curve]. In the early 1980s,

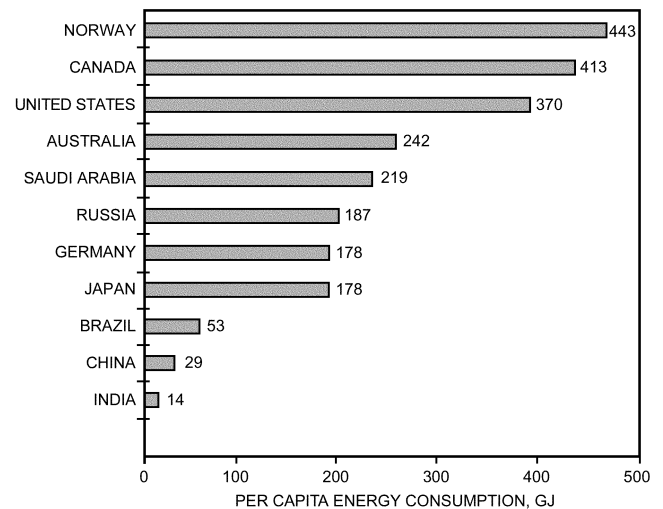


Fig. 11 Per Capita Energy Consumption by Selected Developed Countries in 1998

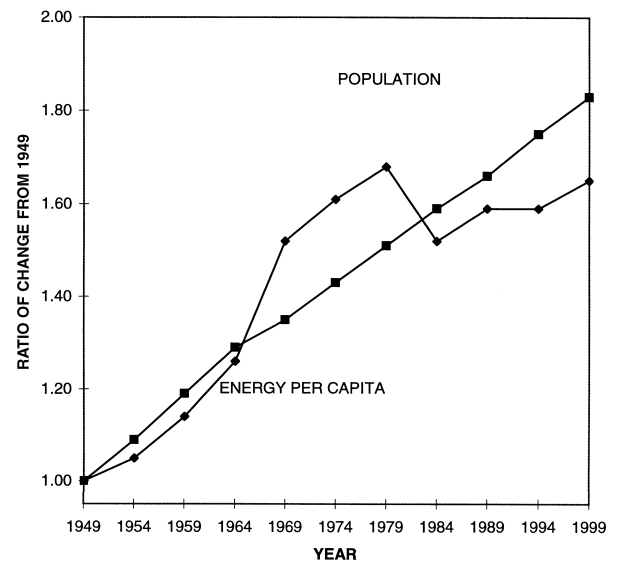


Fig. 12 Per Capita End-Use Energy Consumption Trends in the United States

however, a significant drop in the per capita energy use growth rate occurred as industrial output decreased, efficiency of use improved, and global economic pressures mounted. The period since the mid-1980s shows a resumption of per capita energy use growth at a rate at first paralleling that of the population.

The *Annual Energy Outlook* is the basic source of data for projecting the use of energy in the United States (EIA 2000). Figure 13 and Figure 14 are summaries of data from this source.

EIA (2000) presents forecasts of energy trends that are based on macroeconomic growth scenarios prepared by several outside sources. EIA has also added a low and a high world oil price scenario to its mid-growth economic scenario. Thus, the National Energy Modeling System (NEMS), which EIA uses for these forecasts, has yielded three scenarios. Figure 13 and Figure 14 present the baseline or reference case. It assumes average annual growth of the real gross domestic product (GDP) at 2.2%, of the labor force at 0.9%, and of productivity at 1.3%. The forecast, in order to be

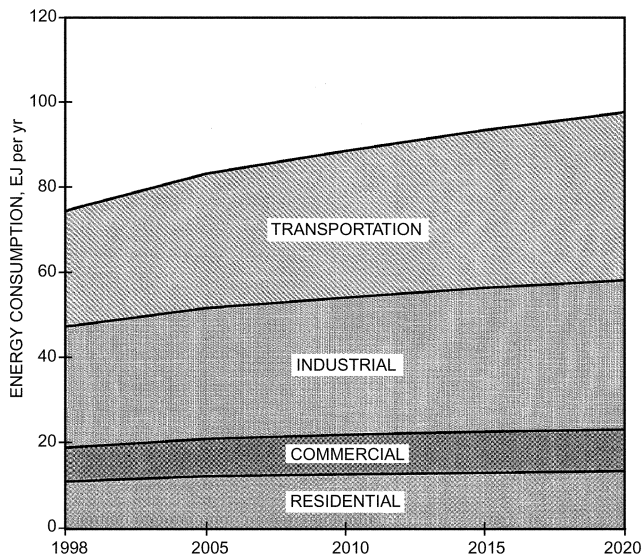


Fig. 13 Projected Total U.S. Energy Consumption by End-Use Sector

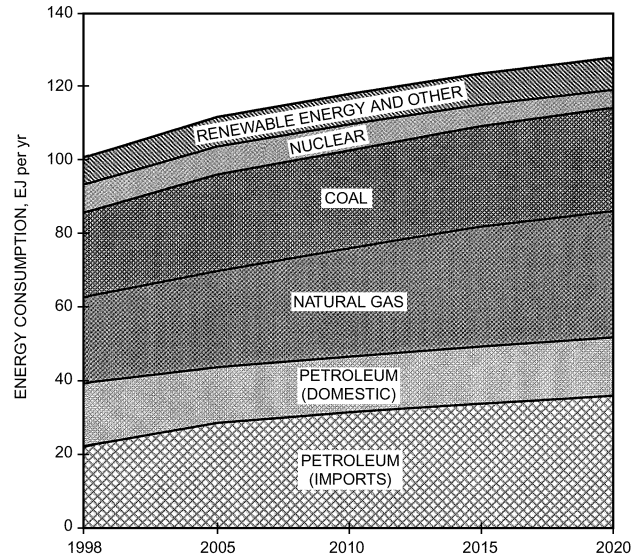


Fig. 14 Projected Total U.S. Energy Consumption by Resource

policy-neutral, also assumes that all federal, state, and local laws and regulations in effect as of July 1, 1999, remain unchanged through 2020.

Projected Overall Energy Consumption

Figure 13 shows energy use by end-use sector, with the major end-use sectors being residential, commercial, industrial, and transportation. HVAC&R engineers are primarily concerned with the first three sectors. Figure 14 shows energy consumption by type of resource. Figure 13 shows less total energy consumption than Figure 14 primarily because it excludes the thermodynamic losses of electricity generation and the processing and delivery burdens of various energy forms.

The following observations apply to the overall picture of projected energy use in the United States over the next two decades (Figures 13 and 14):

- Although a major issue in energy markets is carbon emissions, impacts of programs to reduce them are not reflected in these forecasts because no specific policies for carbon reductions have been enacted.
- Given the above premise, carbon emissions from energy use will increase by an average of 1.3% per year through 2020 due to rising energy demand, declining nuclear power generation, improvements in efficiency, and slow growth in the use of renewable sources. The 2020 level of carbon emissions will thus be almost 33% higher than the 1998 levels.
- Though average crude oil prices are expected to remain low over the next several years, unanticipated changes in supply or political events could change that scenario.
- The wellhead price of natural gas is expected to increase at an average annual rate of 1.7% up to 2020, reflecting exploration and production improvements balanced by greater demand.
- The price of coal, on the other hand, is expected to decline by 28% over the same period as a result of better productivity, more low-cost western coal production, and competitive labor pressures.
- Ongoing changes in the financial structure of the electricity industry and resulting cost reductions due to increased competition are reflected. Transitions to retail competitive pricing have been assumed in areas where legislation has been enacted, and stranded cost recovery will be phased out by 2008.
- Electricity prices will decline an average of 19% per megajoule between 1997 and 2020 due to lower operating, maintenance, and administrative costs resulting from industry restructuring.
- More than half of the nuclear electricity generating capacity existing in 1998 will be retired by 2020 as operating licenses expire with no new plants having been built.
- Offsetting this decline, electricity generation from both coal and natural gas is projected to increase significantly, with the share of natural gas in 2020 more than doubling the 1998 level.
- Electricity generation using renewable sources (which includes cogenerators) will increase by only 0.5% per year, held back in large measure by the fact that electric industry restructuring tends to favor natural gas over renewables or coal.
- Petroleum consumption will grow by 1.3% annually, led by the transportation sector, which is where most of it (70%) is used.
- The share of petroleum consumption met by net imports will reach 64% in 2020. (This is up from 52% in 1998.) Over this period, U.S. crude oil production will decline at an annual rate of 0.8%, with declining resources overshadowing improvements in exploration and processing technologies.
- Natural gas consumption will increase by 1.8% per year, with demand increases in all sectors and led by its use for electricity generation.
- Coal consumption will increase at an average annual rate of 0.9%. Most of it (90%) will be used for electricity generation, but its share for that purpose will decline by 2020.
- Consumption of renewable energy (including using ethanol in gasoline) will increase by only 0.8% per year, however, with about 60% going toward electricity generation.
- Electricity demand will grow by 1.4% annually, with efficiency gains offset by growth in the use of new electricity-using equipment.
- Total energy demand in the commercial and residential sectors will grow at 0.9% and 0.8% per year, respectively. This results from greater use of computers, telecommunications, and other office appliances, but it is offset by somewhat improved building and building equipment efficiencies.
- Energy use by the transportation sector will grow at an average of 1.7% per year, with variations from this average very dependent on prevailing fuel prices.
- Per capita energy use will remain stable through 2020 as overall efficiency gains offset higher per capita demand.

- Total energy use per dollar of gross domestic product (energy intensity), however, will continue to fall at an average rate of about 1.1% per year through 2020.

Outlook Summary

In general, the following key issues will dominate energy matters in the next two decades:

- Rising dependency of the United States on imported oil
- Expected retirement of more than half of the existing nuclear power plants
- Role of technology developments, including energy conservation and energy efficiency as alternatives to energy production
- Deregulation of the utility industry and the growth of independent power producers
- Dealing with the increasing rate of carbon emissions, especially in light of international agreements with, and moral pressure from, others of the global community
- Growth of population, coupled with the shift of “baby boomers” into retirement

ENERGY RESOURCE PLANNING

The energy supplier (or suppliers) in a particular jurisdiction must plan for the future energy needs of that jurisdiction. For competitive energy markets where these decisions do not have high societal costs, these plans are made by the energy suppliers as part of their business. These decisions are not revealed to governmental authorities or the public more than is absolutely necessary, because significant competitive advantages could be gained by knowledge of a competitor's future plans. For electricity (and to a lesser extent natural gas) significant societal issues are involved in energy resource planning decisions, and these decisions cannot be made by energy suppliers without approval by many different groups and entities. These issues include:

- Reliability, which is affected by the diversity of supply sources available. This would include the number of geographic supply sources and pipelines in the case of gas and would include the percentage of generation from various fuel sources in the case of electricity. Due consideration should be given to the projected future supply and reliability of energy resources, including the possibility of supply disruption due to natural or political events, and to the likelihood of future supply shortages, which could reduce reliability.
- Reserve margins, or the ratio of total supply sources to expected peak supply source needs. Reserve levels that are too high result in the waste of resources, higher environmental costs, and possibly poor financial health of the energy suppliers. Reserves that are too low result in volatile and very high peak energy prices and reduced reliability.
- The production and transmission of energy often requires governmental cooperation to condemn private property for use in energy production and transmission facilities. The construction and maintenance of this property are also regulated due to wetlands, prevention of toxic waste releases, and other environmental issues.

Integrated Resource Planning

Integrated resource planning (IRP) is a process commonly used for the planning of significant new energy facilities. The steps in this planning process include: (1) forecasting the amount of new resources needed and (2) determining the type of resource to be provided and who will provide this resource. Traditionally, the local utility provider forecasts the future needs of a given energy resource, then either builds the necessary facility with the approval of regulators or uses a standard offer bid to determine

what non-utility provider (or the utility itself) would provide the new energy resource. However, with increasing deregulation of energy providers, a single energy provider may no longer be responsible for maintaining an adequate supply. This forecasting task may be provided by a regulatory body, or it could be by a consensus decision of the various competing energy suppliers, with oversight and approval of regulators.

Supplying new energy resources through either a standard bid process by a supplier or traditional utility regulation will usually result in the selection of the lowest cost supply option, without regard for environmental costs or other societal needs. IRP allows for the choice of a greater variety of resource options and allows environmental costs and other indirect costs to society to be given greater consideration.

IRP addresses a wider population of stakeholders than do most other planning processes. Many regulatory agencies involve the public in the formulation and review of integrated resource plans. Customers, environmentalists, and other public interest groups are often prominent in these proceedings.

Prior to the deregulation of energy suppliers, **demand-side management** (DSM) was a common option for providing new energy resources, especially for electricity. These are actions taken to reduce the demand for energy, rather than increase the supply of energy. DSM is desirable because the environmental costs of DSM are almost always lower than the environmental costs of building new energy facilities. However, several factors have caused a decline in the number of DSM programs:

- Lower cost supply options, especially for natural gas-fired generation, make it more difficult to implement DSM options that do not result in higher total costs.
- Building and equipment codes and standards are a highly efficient form of DSM, providing reduced energy use with much lower administrative costs than programs that reward the installation of more efficient equipment at a single site. However, they are more subtle than traditional DSM programs and may not always be recognized as a form of DSM.
- The opening of markets to competing suppliers makes it more difficult to administer and implement DSM programs. However, they are still possible if the regulators wish to continue them, and set appropriate rules and regulations for the energy market to allow the implementation of DSM programs.

Many participants in IRP processes may be interested in only one aspect of the process. For example, the energy industry's main interest may be cost minimization, while environmentalists may want to minimize pollutant emissions and prevent environmental damage from the construction of energy facilities. Participation by all affected interest groups helps provide the best overall solution for society, including the indirect costs and benefits from these energy resource decisions.

TRADABLE EMISSION CREDITS

Increasingly, quotas and limits apply to the emissions of various pollutants. These currently include sulphur dioxide (SO₂) and nitrogen oxides (NO_x) but may someday include carbon dioxide (CO₂). Often a market-based system of **tradable credits** is used with these quotas. A company is given the right to produce a given level of emissions and it earns a credit, which can be sold to others, if it produces fewer emissions than that level. If one company can reduce its emissions at a lower cost than another, it can do so and sell the emissions credit to the second company and earn a profit from its pollution control efforts. To date, this type of activity has largely involved large industrial plants, but it can also involve commercial buildings with on-site emissions, such as generation equipment or gas engine-driven cooling.

Designers must be aware of any regulations concerning pollutant emissions; failure to comply with these regulations may result in civil or criminal penalties for designers or their clients. However, designers should understand the options available under these regulations. The purchase or sale of emissions credits may allow reduced construction or building operations costs if the equipment can “overcomply” at a lower cost than the cost of another source of emissions to comply, or vice versa. In some cases, documentation of energy savings beyond what codes and regulations require can result in receiving emissions credits that may be sold later.

AGENCIES AND ASSOCIATIONS IN THE UNITED STATES

American Gas Association (AGA), Arlington, VA
 American Petroleum Institute (API), Washington, D.C.
 Bureau of Mines, Department of Interior, Washington, D.C.
 Council on Environmental Quality (CEQ), Washington, D.C.
 Edison Electric Institute (EEI), Washington, D.C.
 Electric Power Research Institute (EPRI), Palo Alto, CA
 Energy Information Administration (EIA), Washington, D.C.
 Gas Research Institute (GRI), Chicago, IL
 National Coal Association (NCA), Washington, D.C.
 North American Electric Reliability Council (NAERC), Princeton, NJ
 Organization of Petroleum Exporting Countries (OPEC), Vienna, Austria
 United States Green Building Council (USGBC), San Francisco, CA

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