Building Technologies

Technology Description

Building equipment

Energy use in buildings depends on equipment to transform fuel or electricity into end-use services such as delivered heat or cooling, light, fresh air, vertical transport, cleaning of clothes or dishes, and information processing. There are energy-saving opportunities within individual pieces of equipment – as well as at the system level – through proper sizing, reduced distribution and standby losses, heat recovery and storage, and optimal control.

Building envelope

The building envelope is the interface between the interior of a building and the outdoor environment. In most buildings, the envelope – along with the outdoor weather – is the primary determinant of the amount of energy used to heat, cool, and ventilate. A more energy-efficient envelope means lower energy use in a building and lower greenhouse gas emissions. The envelope concept can be extended to that of the "building fabric," which includes the interior partitions, ceilings, and floors. Interior elements and surfaces can be used to store, release, control, and distribute energy, thereby further increasing the overall efficiency of the buildings.

Whole building integration

Whole building integration uses data from design (together with sensed data) to automatically configure controls and commission (i.e., start-up and check out) and operate buildings. Control systems use advanced, robust techniques and are based on smaller, less expensive, and much more abundant sensors. These data ensure optimal building performance by enabling control of building systems in an integrated manner and continuously recommissioning them using automated tools that detect and diagnose performance anomalies and degradation. Whole building integration systems optimize operation across building systems, inform and implement energy purchasing, guide maintenance activities, document and report building performance, and optimally coordinate on-site energy generation with building energy demand and the electric power grid, while ensuring that occupant needs for comfort, health, and safety were met at the lowest possible cost.

System Concepts

Building equipment

- Major categories of end-use equipment include heating, cooling, and hot water; ventilation and thermal distribution; lighting; home appliances; miscellaneous (process equipment and consumer products); and on-site energy and power.
- Key components vary by type of equipment, but some crosscutting opportunities for efficiency include improved materials, efficient low-emissions combustion and heat transfer, advanced refrigerants and cycles, electrodeless and solid-state lighting, smart sensors and controls, improved small-power supplies, variable-capacity systems, reduction of thermal and electrical standby losses, cogeneration based on modular fuel cells and microturbines, and utilization of waste heat from fuel cells and microturbines.

Building envelope

- Control of envelope characteristics provides control over the flow of heat, air, moisture, and light into the building. These flows and the interior energy and environmental loads determine the size and energy use of HVAC and distribution systems.

- Materials for exterior walls, roofs, foundations, windows, doors, interior partition walls, ceilings, and floors that can impact future energy use include insulation with innovative formula foams and vacuum panels; optical control coatings for windows and roofs; and thermal storage materials, including lightweight heat-storage systems.

Whole building integration

- The system consists of design tools, automated diagnostics, interoperable control-system components, abundant wireless sensors and controls, and highly integrated operation of energy-using and producing systems.
- These components would work together to collect data, configure controls, monitor operations, optimize control, and correct out-of-range conditions that contribute to poor building performance. Whole building integration would ensure that essential information – especially the design intent and construction implementation data – would be preserved and shared across many applications throughout the lifetime of the building.
- Equipment and system performance records would be stored as part of a networked building performance knowledge base, which would grow over time and provide feedback to designers, equipment manufacturers, and building operators and owners.
- Optimally integrate on-site power production with building energy needs and the electric-power grid by applying intelligent control to building cooling, heating, and power.

Representative Technologies

Building equipment

- Residential gas-fired absorption heat pumps, centrifugal chillers, desiccant preconditioners for treating ventilation air, heat-pump water heaters, proton exchange membrane fuel cells, heat pump water heaters, solid-state lighting, and lighting controls.
- Specialized HVAC (heating, ventilating, and air-conditioning) systems for research laboratories, server/data systems, and other buildings housing high-technology processes.

Building envelope

- *Superinsulation*: Vacuum powder-filled, gas-filled, and vacuum fiber-filled panels; structurally reinforced beaded vacuum panels; and switchable evacuated panels with insulating values more than four times those of the best currently available materials should soon be available for niche markets. High-thermal-resistant foam insulations with acceptable ozone depletion and global warming characteristics should allow for continued use of this highly desirable thermal insulation.
- *Advanced window systems*: Krypton-filled, triple-glazed, low-E windows; electrochromic glazing; and hybrid electrochromic/photovoltaic films and coatings should provide improved lighting and thermal control of fenestration systems. Advanced techniques for integration, control, and distribution of daylight should significantly reduce the need for electric lighting in buildings. Self-drying wall and roof designs should allow for improved insulation levels and increase the lifetimes for these components. More durable high-reflectance coatings should allow better control of solar heat on building surfaces.
- *Advanced thermal storage materials*: Dry phase-change materials and encapsulated materials should allow significant load distribution over the full diurnal cycle and significant load reduction when used with passive solar systems.

Whole building integration

- DOE is developing computer-based building commissioning and operation tools to improve the energy efficiency of "existing" buildings. It is also investing in the next generation of building-simulation programs that could be integrated into design tools.
- DOE, in collaboration with industry, also is developing and testing technologies for combined cooling, heating, and power; and wireless sensor and control systems for buildings.

Technology Applications

Building equipment

- Technology improvements during the past 20 years – through quality engineering, new materials, and better controls – have improved efficiencies in lighting and equipment by 15% to 75%, depending on the type of equipment. Efficiencies of compact fluorescent lamps are 70% better than incandescent lamps; refrigerator energy use has been reduced by more than three-quarters during the past 20 years; H-axis clothes washers are 50% more efficient than current minimum standards. Electronic equipment has achieved order-of-magnitude efficiency gains, at the microchip level, every two to three years.

Building envelope

- Building insulations have progressed from the 2-4 hr ºF ft^2/Btu/in. fibrous materials available before 1970 to foams reaching 7 hr ºF ft^2/Btu/in. Superinsulations of more than 25 ºF ft^2/Btu/in. will be available for niche markets soon. Improvements in window performance have been even more spectacular. In the 1970s, window thermal resistance was 1 to 2 ºF ft^2/Btu. Now, new windows have thermal resistance of up to 6 ºF ft^2/Btu (whole window performance). Windows are now widely available with selective coatings that reduce infrared transmittance without reducing visible transmittance. In addition, variable-transmittance windows under development will allow optimal control to minimize heating, cooling, and lighting loads.

Whole building integration

- Savings from improved operation and maintenance procedures could save more than 30% of the annual energy costs of existing commercial buildings, even in many of those buildings thought to be working properly by their owners/operators. These technologies would have very short paybacks, because they would ensure that technologies were performing as promised, for a fraction of the cost of the installed technology.
- Savings for new buildings could exceed 70%, using integration of building systems; and, with combined cooling, heating and power, buildings could become net electricity producers and distributed suppliers to the electric power grid.

Current Status

Building equipment

- Recent DOE-sponsored R&D, often with industry participation, includes an improved air-conditioning cycle to reduce oversizing and improve efficiency; a replacement for inefficient, high-temperature halogen up-lights (torchieres), which use only 25% of the power, last longer, and eliminate potential fire hazards; ozone-safe refrigerants, where supported R&D was directed toward lubrication materials problems associated with novel refrigerants and ground-source heat pumps.

Building envelope

- A DOE-sponsored RD&D partnership with the Polyisocyanurate Insulation Manufacturers Association, the National Roofing Contractors Association, the Society of the Plastics Industry, and Environmental Protection Agency (EPA) helped the industry find a replacement for chloroflurocarbons (CFCs) in polyisocyanurate foam insulation. This effort enabled the buildings industry to transition from CFC-11 to HCFC-141b by the deadline required by the Montreal protocol.
- Spectrally selective window glazings – which reduce solar heat gain and lower cooling loads – and high-performance insulating materials for demanding thermal applications are available.

Whole building integration

- Energy 10 models passive solar systems in buildings.
- DOE-2: international standard for whole building energy performance simulation has thousands of users. DOE released Energy Plus, new standard for building energy simulation and DOE-2 successor.
- The International Alliance for Interoperability is setting international standards for interoperability of computer tools and components for buildings.
- DOE-BESTEST is the basis for ANSI/ASHRAE Standard 140, Method of Test for the Evaluation of Building Energy Simulation Programs.

Technology History

- 1890s – First commercially available solar water heaters produced in southern California. Initial designs were roof-mounted tanks and later glazed tubular solar collectors in thermosiphon configuration. Several thousand systems were sold to homeowners.
- 1900s – Solar water-heating technology advanced to roughly its present design in 1908 when William J. Bailey of the Carnegie Steel Company, invented a collector with an insulated box and copper coils.
- 1940s – Bailey sold 4,000 units by the end of WWI, and a Florida businessperson who bought the patent rights sold nearly 60,000 units by 1941.
- 1950s – Industry virtually expires due to inability to compete against cheap and available natural gas and electric service.
- 1970s – The modern solar industry began in response to the OPEC oil embargo in 1973-74, with a number of federal and state incentives established to promote solar energy. President Jimmy Carter put solar water-heating panels on the White House. FAFCO, a California company specializing in solar pool heating; and Solaron, a Colorado company that specialized in solar space and water heating, became the first national solar manufacturers in the United States. In 1974, more than 20 companies started production of flat-plate solar collectors, most using active systems with antifreeze capabilities. Sales in 1979 were estimated at 50,000 systems. In Israel, Japan, and Australia, commercial markets and manufacturing had developed with fairly widespread use.
- 1980s – In 1980, the Solar Rating and Certification Corp (SRCC) was established for testing and certification of solar equipment to meet set standards. In 1984, the year before solar tax credits expired, an estimated 100,000-plus solar hot-water systems were sold. Incentives from the 1970s helped create the 150-business manufacturing industry for solar systems with more than $800 million in annual sales by 1985. When the tax credits expired in 1985, the industry declined significantly. During the Gulf War, sales again increased by about 10% to 20% to its peak level, more than 11,000 square feet per year (sq.ft./yr) in 1989 and 1990.
- 1990s – Solar water-heating collector manufacturing activity declined slightly, but has hovered around 6,000 to 8,000 sq.ft./yr. Today's industry represents the few strong survivors: More than 1.2 million buildings in the United States have solar water-heating systems, and 250,000 solar-heated swimming pools exist. Unglazed, low-temperature solar water heaters for swimming pools have been a real success story, with more than a doubling of growth in square footage of collectors shipped from 1995 to 2001.

Reference: American Solar Energy Society and Solar Energy Industry Association

Technology Future
Building equipment • Building equipment, appliances, and lighting systems currently on the market vary from 20% to 100% efficient (heat pumps can exceed this level by using "free" energy drawn from the environment). This efficiency range is narrower where cost-effective appliance standards have previously eliminated the least-efficient models. • The stock and energy intensity of homes are growing faster than the building stock itself, as manufacturers introduce – and consumers and businesses eagerly accept – new types of equipment, more sophisticated and automated technologies, and increased levels of end-use services. • The rapid turnover and growth of many types of building equipment – especially electronics for computing, control, communications, and entertainment – represent important opportunities to rapidly introduce new, efficient technologies and quickly propagate them throughout the stock. • The market success of most new equipment and appliance technologies is virtually ensured if the efficiency improvement has a 3-year payback or better and amenities are maintained; technologies with payback of 4 to 8-plus years also can succeed in the market, provided that they offer other customer-valued features (e.g., reliability, longer life, improved comfort or convenience, quiet operation, smaller size, lower pollution levels). • Applications extend to every segment of the residential and nonresidential sectors. Major government, institutional, and corporate buyers represent a special target group for voluntary early deployment of the best new technologies. • Building equipment and appliances represent an annual market in the United States, alone, of more than $200B, involving thousands of large and small companies. Certain technologies, such as office and home electronics, compete in global markets with little or no change in performance specifications. ***Building envelope*** • A critical challenge is to ensure that new homes and buildings are constructed with good thermal envelopes and windows when the technologies are most cost-effective to implement. • The market potential is significant for building owners taking some actions to improve building envelopes. Currently, 40% of residences are well insulated, 40% are adequately insulated, and 20% are poorly insulated. More than 40% of new window sales are of advanced types (low-E and gas-filled). In commercial buildings, more than 17% of all windows are advanced types. More than 70% of commercial buildings have roof insulation; somewhat fewer have insulated walls. • Building products are mostly commodity products. A number of companies produce them; and each has a diverse distribution system, including direct sales, contractors, retailers, and discount stores. Another critical challenge is improving the efficiency of retrofits of existing buildings. Retrofitting is seldom cost-effective on a stand-alone basis. New materials and techniques are required. • Many advanced envelope products are cost-competitive now, and new technologies will become so on an ongoing basis. There will be modest cost reductions over time as manufacturers compete. • Building structures represent an annual market in the United States of more than $70B/year and involve thousands of large and small product manufacturers and a large, diverse distribution system that plays a crucial role in product marketing. Exporting is not an important factor in the sales of most building structure products. ***Whole building integration*** • The future vision of buildings technologies is one of "net zero energy" buildings which use a combination of integrated electricity generation--such as photovoltaics--paired with energy efficiency and power controls, to create a building that on average during a year produces enough energy for all the energy demands within the building. • Design tools for energy efficiency are used by fewer than 2% of the professionals involved in the design, construction, and operation of commercial buildings in the United States. A larger fraction of commercial buildings have central building-control systems. Few diagnostic tools are available commercially beyond those used for air-balancing or integrated into equipment (e.g., Trane Intellipack

System) and the recently announced air-conditioning diagnostic hand-held service tool by Honeywell (i.e. Honeywell HVAC Service Assistant). • The Department of Energy – in concert with the California Energy Commission – is testing a number of automated diagnostic tools and techniques with commercial building owners, operators, and service providers in an effort to promote commercial use. About 12 software vendors develop, support, and maintain energy design tools; most are small businesses. Another 15 to 20 building automation and control vendors exist in the marketplace – the major players include Johnson Controls, Honeywell, and Siemens. • Deployment involves four major aspects: seamless integration into existing building design and operation practices and platforms, lowering the cost of intelligent-building and enabling technologies, transforming markets to rapidly introduce new energy-efficient technologies, and a focus on conveying benefits that are desired in the marketplace (not only energy efficiency). • These technologies would apply to all buildings, but especially to existing commercial buildings and all new buildings. In addition, new technologies would be integrated into the building design and operation processes.

Source: National Renewable Energy Laboratory. *U.S. Climate Change Technology Program. Technology Options: For the Near and Long Term.* DOE/PI-0002. November 2003 (draft update, September 2005).

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Solar Buildings

Market Data

U.S. Installations (Thousands of Sq. Ft.)

Source: EIA, *Renewable Energy Annual 2004,* Table 38, REA 2003 Table 18 and Table 10; REA 2002, Table 18; REA 1997- 2000, Table 16; REA 1996, Table 18.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Annual													
Hot Water				755	765	595	463	373	367	274	423	511	452
Pool Heaters					6,787	7,528	7,201	8,141	7,863	10,797	11,073	10,800	13,634
Total Solar Thermal 1	18,283	19,166	11,164	6,763 7,136	7,162	7,759	7,396	8,046	7,857	10,349	11,004	10,926	14,114
Cumulative													
Hot Water				755	1,520	2,115	2,578	2,951	3,318	3,592	4,015	4,526	4,978
Pool Heaters				6,763	13,550	21,078	28,279	36,420	44,283	55,080	66,153	76,953	90,587
Total Solar Thermal 1	62,829	153,035	199,459	233,386	240,548	248,307	255,703	263,749	271,606	281,955	292,959	303,885	317,999

1. Domestic shipments - total shipments minus export shipments

U.S. Annual Shipments (Thousand Sq. Ft.)

Source: EIA, *Renewable Energy Annual 2003,* Table 11; and REA 1999, Table 11.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total	19,398	N/A	11,409	7,666	7,616	8,138	7,756	8,583	8,354	11,189	11,663	11,444	14,114
Imports		N/A	1,562	2,037	1,930	2,102	2,206	2,352	2,201	3,502	3,068	2,986	3,723
Exports	1,115	N/A	245	530	454	379	360	537	496	840	659	518	813

U.S. Shipments by Cell Type (Thousand sq. ft.)

Source: EIA *Annual Energy Review 2004,* Table 10.3; and *Renewable Energy Annual 2003,* Table 12.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Low-Temperature Collectors	12,233	N/A	3,645	6,813	6,821	7,524	7,292	8,152	7,948	10,919	11,126	10,877	13,608
Medium-Temperature Collectors	7,165	N/A	2,527	840	785	606	443	427	400	268	535	560	506
High-Temperature Collectors	N/A	N/A	5,237	13	10	7	21	4	5	2	2	7	0
Total	19,398	N/A	11,409	7,666	7,616	8,137	7,756	8,583	8,353	11,189	11,661	11,444	14,114

U.S. Shipments of High-Temperature Collectors by Market Sector, and End Use (Thousands of Sq. Ft.)	Source: EIA, *Renewable Energy Annual 2003,* Table 18; REA 2002, Table 18; REA 1996, Table F9; REA 1997, 1999-2000, Table 16; and REA 1998, Table 19.									
	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Market Sector	0	0	0	0	0		0	0	0	0
Residential	1	7	7	18	0		1	2	7	0
Commercial	0	2	0	0	0		0	0	0	0
Industrial	9	0	0	2	4		1	0	0	0
Utility	3	0	0	1	0		0	0	0	0
Other	13	10	7	21	4		2	2	7	0
Total										
End Use	0	0	0	0	0		0	0	0	0
Pool Heating	0	7	7	18	0		0	0	0	0
Hot Water	0	0	0	0	0		0	0	0	0
Space Heating	1	0	0	0	0		0	0	0	0
Space Cooling	0	0	0	0	0		0	2	7	0
Combined Space and Water Heating	0	2	0	0	0		0	0	0	0
Process Heating	9	0	0	2	4		2	0	0	0
Electricity Generation	2	0	0	1	0		0	0	0	0
Other	13	10	7	21	4		2	2	7	0
Total	0	0	0	0	0		0	0	0	0

2000 data not published by EIA

U.S. Shipments of Medium- Temperature Collectors by Market Sector, and End Use (Thousands of Sq. Ft.)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Market Sector										
Residential	774	728	569	355	366		238	481	507	478
Commercial	51	50	35	70	59		23	69	44	0
Industrial	12	1	0	18	0		5	60	0	26
Utility	0	0	0	0			0	4	0	0
Other	3	7	2	0			1	1	2	3
Total	839	786	606	443	426		268	614	553	507
End Use										
Pool Heating	32	21	11	36	12		16	28	22	33
Hot Water	743	754	588	384	373		231	421	510	452
Space Heating	62	6	2	13	24		9	145	4	6
Space Cooling	0	0	0	0			0	0	0	0
Combined Space and Water Heating	2	2	3	8	16		12	15	16	16
Process Heating	0	1	0	0			0	4	0	0
Electricity Generation	0	0	0	0			0	0	0	0
Other	0	0	1	1			0	0	0	0
Total	839	784	605	442	427		268	614	553	507

Source: EIA, *Renewable Energy Annual 2003,* Table 18; REA 2002, Table 18; REA 1996, Table F9; REA 1997, 1999-2000, Table 16; and REA 1998, Table 19.

2000 data not published by EIA

U.S. Shipments of Low- Temperature Collectors by Market Sector, and End Use (Thousands of Sq. Ft.)	Source: EIA, *Renewable Energy Annual 2003,* Table 18; REA 2002, Table 18; REA 1996, Table F9; REA 1997, 1999-2000, Table 16; and REA 1998, Table 19.									
	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Market Sector										
Residential	6,192	6,146	6,791	6,810	7,408		9,885	10,519	9,993	12,386
Commercial	552	625	726	429	726		987	524	813	1,178
Industrial	69	51	7	44	18		12	2	71	44
Utility	0	0	0	0	0		0	0	0	0
Other	0	0	0	2	0		34	0	0	0
Total	6,813	6,822	7,524	7,285	8,152		10,919	11,046	10,877	13,608
End Use										
Pool Heating	6,731	6,766	7,517	7,164	8,129		10,782	11,045	10,778	13,600
Hot Water	11	4	0	60	0		42	1	0	0
Space Heating	70	51	7	53	18		61	0	65	8
Space Cooling	0	0	0	0	0		0	0	0	0
Combined Space and Water Heating										0
Process Heating	0	0	0	0	5		34	0	34	0
Electricity Generation	0	0	0	0	0		0	0	0	0
Other	0	0	0	0	0		0	0	0	0
Total	6,813	6,821	7,524	7,285	8,152		10,919	11,046	10,877	13,608

2000 data not published by EIA

Technology Performance

Energy Production	Source: Arthur D. Little, *Review of FY 2001 Office of Power Technology's Solar Buildings Program Planning Unit Summary*, December 1999.								
	1980	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Energy Savings									
DHW (kWh/yr)					2,750				
Pool Heater (therms/yr)					1,600				

Cost	Source: Hot-Water Heater data from Arthur D. Little, *Water-Heating Situation Analysis*, November 1996, page 53, and Pool-Heater data from Ken Sheinkopf, *Solar Today,* Nov/Dec 1997, pp. 22-25.								
	1980	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Capital Cost* ($/System)									
Domestic Hot-Water Heater					1,900 - 2,500				
Pool Heater					3,300 - 4,000				
O&M ($/System-yr)									
Domestic Hot-Water Heater					25 - 30				
Pool Heater					0				

* Costs represent a range of technologies, with the lower bounds representing advanced technologies, such as a low-cost polymer integral collector for domestic hot-water heaters, which are expected to become commercially available after 2010.

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