1.2 BUILDINGS

1.2.1 BUILDING EQUIPMENT, APPLIANCES, AND LIGHTING

Technology Description

A school in North Carolina features daylighting, state-of-the-art lighting controls, and an energy management system, allowing individual teachers to select optimum lighting levels for each room.

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. (The effects of passive and related systems are discussed in other profiles.) 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. Another promising opportunity lies in multifunction devices ranging from heat pumps, which provide both refrigeration and hot water, to an office appliance that serves as a networked printer, copier, scanner, and paperless fax machine.

System Concepts

- 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.

Representative Technologies

- 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.

Technology Status/Applications

- 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.

Current Research, Development, and Demonstration

RD&D Goals

- By 2008, for distributed electricity generation technologies (including microturbines), enable a portfolio of equipment that show an average 25% increase in efficiency.
- By 2008, for solid-state lighting in general illumination applications, develop equipment with luminous efficacy of 79 lumens per watt (LPW); and for laboratory devices, by 2025, luminous efficacy of 200 LPW.
- By 2025, develop and demonstrate marketable and advanced energy systems that can achieve "net-zero" energy use in new residential and commercial buildings through a 70% reduction in building energy use.
- By 2030, enable the integrations of all aspects of the building envelope, equipment, and appliances with on-site micro-cogeneration and zero-emission technologies.

RD&D Activities

- Most Federal R&D on building equipment is performed by DOE.
- International funding is less relevant than state activities such as currently ongoing in California, New York, and other states. This research is synergistic with and complements the DOE research.

Recent Progress

- 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.

Commercialization and Deployment Activities

- 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 three-year payback or better and amenities are maintained; technologies with payback of four to eight-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.

Market Context

- 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.

1.2.2 BUILDING ENVELOPE (INSULATION, WALLS, ROOF)

Technology Description

National laboratory exhibits show the benefits of energy-efficient building envelope design (left). This home in Atlanta, Georgia, (right) will use 58% less energy for heating and 53% less energy for cooling than a home of comparable size without energy-efficient design.

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.

System Concepts

- 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.

Representative Technologies

- *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.

Technology Status/Applications

- 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.

Current Research, Development, and Demonstration

RD&D Goals

- By 2008, demonstrate dynamic solar control windows (electrochromics) in commercial buildings; and, by 2010, demonstrate windows with R10 insulation performance for homes.
- By 2025, the program goal is to develop marketable and advanced energy systems capable of achieving "net-zero" energy use in new residential and commercial buildings.
- The long-term goal is to achieve a 30% decrease in the average envelope thermal load of existing residential buildings and a 66% decrease in the average thermal load of new buildings.

RD&D Challenges

- Foam insulations that retain high thermal resistance while using blowing agents with zero ozone depletion potential and negligible global warming effect.
- Self-drying wall and roof designs to avoid moisture problems such as materials degradation.
- Electrochromic window films and electrochromic/photovoltaic hybrid window films to control energy flows and generate electricity on site.
- Techniques to distribute and control daylight to reduce electrical energy use for artificial lighting.
- Advanced durable cost-effective superinsulations to reduce heating/cooling loads.
- Self-calibrating multifunction microsensors for monitoring building equipment performance and air-quality monitoring.
- Thermal storage materials: Typically, thermal storage in building components is achieved with heavyweight materials such as masonry. Advanced thermal-storage materials need to be lightweight to integrate with elements similar to drywall, floor, and ceiling panels.
- Scaling electrochromic window technology to commercial-scale window applications.

RD&D Activities

- Key agencies doing building envelope R&D are DOE, National Institute for Standards and Technology, several state agencies, and other institutions such as the Florida Solar Energy Center.

Recent Progress

- 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.

Commercialization and Deployment Activities

- 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.

Market Context

- 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.

1.2.3 WHOLE BUILDING INTEGRATION

Technology Description

Energy-management system field tests at the Zion National Park Visitor Center (top) and the Bighorn Home Improvement Center complex in Silverthorne, Colorado (bottom), DOE High Performance Buildings Program.

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

- 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

- 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 Status/Applications

- 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 Research, Development, and Demonstration

RD&D Goals

- Developing fully and seamlessly integrated building design tools that support all aspects of design and provide rapid analysis of problems.
- Development of automatic operation of buildings systems that require little operator attention.
- Utilizing highly efficient combined cooling, heating, and power systems that use waste heat from small-scale, on-site, electricity generation to provide heating and cooling for the buildings, as well as exporting excess electricity to the grid.

RD&D Challenges

- Design tools: enhanced analytical capabilities, integration with the design environment, automated design and analysis capability, design databases, visualization, and high-level monitoring and reporting tools.
- Automated diagnostics: diagnosticians, plug-and-play capabilities, automated real-time purchasing, advanced data visualization, automated identification, and correction of the causes of operation problems.
- System interoperability and controls: integrated control networks; plug-and-play control components; adaptive, optimized, self-generating control algorithms; automatic configuration and commissioning of controls; and advanced control techniques.
- Sensors: wireless data acquisition, detection of materials properties, micro-scale sensors, microelectronic sensors, multiple-sensor arrays, protocols for using new sensors, new sensing technologies, order of magnitude lower-cost sensor systems, and ubiquitous use of sensors.
- Visualization: use of supercomputers, networked personal computer to provide distributed super-computer-level performance, advanced computational methods, and virtual reality systems to permit real-time visualization of designs and design changes, including lighting, thermal flows, and air quality.
- Buildings Combined Cooling, Heating, and Power: Technologies for reusing waste energy to provide net-electricity producing buildings.
- Early priorities include enhancing design-tool integration; developing automated diagnosticians; implementing remote data collection and visualization; developing combined cooling, heating, and power; and developing low-cost, wireless sensor, and control technology.
- Advanced building simulation tools to permit better design, construction, commissioning, and operation.

RD&D Activities

- DOE is funding work with the California Energy Commission, California Institute for Energy Efficiency, Honeywell, Johnson Controls, Siemens, Electric Power Research Institute, Southern California Edison, and Pacific Gas and Electric Company. International efforts include an effort funded by the European Union to develop adaptive control techniques for improving the thermal environment for JOULE IIICSEC.

Recent Progress

- Energy 10: models passive solar systems in buildings.
- DOE 2: international standard for whole building energy performance simulation has thousands of users worldwide.
- DOE released Energy Plus, the new standard for building energy simulation and successor to DOE-2.
- The International Alliance for Interoperability is setting international standards for interoperability of computer tools and components for buildings.

- DOE-BESTEST: basis for ANSI/ASHRAE Standard 140, *Method of Test for the Evaluation of Building Energy Simulation Programs.*

Commercialization and Deployment Activities

- 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).

Market Context

- 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.

1.2.4 URBAN HEAT ISLAND TECHNOLOGIES

Technology Description

Heat islands form as cities replace natural vegetation with pavement for roads, buildings, and other structures necessary to accommodate growing populations. These surfaces absorb – rather than reflect – the sun's heat, causing surface temperatures and overall ambient temperatures to rise. The displacement of trees and shrubs eliminates the natural cooling effects of shading and evapotranspiration. Further, urban form and anthropogenic sources of heat contribute to heat island formation. Measures to reduce urban heat islands include increasing vegetative cover, installing reflective roofs and pavements, and, potentially, using permeable pavements. Heat island mitigation measures can reduce ambient air temperatures in urban areas, thereby slowing the chemical formation of smog (ground-level ozone) and reducing cooling-season electricity demand for air conditioning. Associated with the decrease in air-conditioning use are reductions in associated air pollution and greenhouse gas emissions. In general, the larger the area implementing heat island reduction measures – and the longer, sunnier, and hotter the summer season – the more substantial the impacts on meteorology and air quality. Building level energy modeling as well as large-scale meteorological and air quality modeling can assist in understanding the effects of heat island reduction measures.

System Concepts

- Reduced temperatures reduce the need for summertime cooling energy. Reduced air-conditioning reduces power plant emissions, including greenhouse gas emissions and ozone precursors.
- Reduced temperatures decrease biogenic volatile organic compounds emissions and evaporative losses.
- Trees sequester carbon (particularly urban or suburban trees, which can sequester about 18 kg of carbon annually) and precipitate particulates and other airborne pollutants.
- Reduced ambient air temperature reduces photochemical reaction rates, which may reduce ozone production.

Representative Technologies

- Placing trees on the west-, south-, and east-facing sides of a building can significantly reduce cooling costs for a home or low-rise building during peak summertime demand. Simulations of energy savings benefits for Sacramento and Phoenix found that three mature trees around homes cut annual air-conditioning demand by 25%-40%.
- There are more than 1,000 Energy Star-labeled roof products, which include coatings and single-ply materials, tiles, shingles, and membranes. Energy savings in buildings with reflective roofs range as high as 32% during peak demand, with a summer average of 15%.
- Research regarding the impacts of cool pavements is in its infancy; and unlike roof products, many technical and institutional questions exist. To date, mechanisms for creating cool pavements include increasing solar reflectance or increasing permeability. Both asphalt and concrete products can be constructed to have higher reflectances. Higher albedos can reduce maximum pavement temperatures by about 10°F per 0.1 increase in albedo. In turn, air temperature could potentially be reduced by about 1°F if all pavement albedos were increased by 0.2. Complicating factors, though – such as the impact pavement reflectance may have on adjacent building heat gain – still need to be addressed. Permeable pavements using asphalt, concrete, or unbound materials including vegetation are becoming increasingly common. Their impacts on urban climates, though, have not been well researched.

Technology Status/Applications

- Nationally, there are numerous tree-planting programs and greening efforts aimed to meet various objectives including stormwater management, heat island reduction, and beautification. Because vegetation – particularly planting deciduous trees around buildings – can reduce air-conditioning demand, some utilities run shade-tree programs. Further, some communities have implemented shade-tree ordinances that range from planting trees along streets to requiring parking-lot developers shade 50% of paved areas 15 years after development.
- Some communities are installing alternative-pavement parking lots and alleys – mainly using porous pavement technologies. White-topping is also becoming increasingly popular, particularly in intersections.

Current Research, Development, and Demonstration

RD&D Goals
- Improved understanding and quantification of the impacts heat island reduction measures have on local meteorology, energy use and expenditures, greenhouse gas emissions, and air quality.
- Specific products include a GIS application that predicts heat island outcomes from different development scenarios (e.g., benefits from large-scale tree planting), and cool materials for roofs and pavements.

RD&D Challenges
- Better understand interaction between meteorological, land surface, and emission-specific parameters in baseline and modified modeling scenarios.
- Determine albedo and emissivity levels of city surfaces.

RD&D Activities
- The Department of Energy's Lawrence Berkeley National Lab Heat Island group has conducted research on the impact heat island reduction strategies have on local meterology, air quality, and energy demand. Currently, LBNL is working with Oak Ridge National Laboratory, the California Energy Commission, and other stakeholders to develop cool residential roofing products.
- The Environmental Protection Agency (EPA), which established the Heat Island Reduction Initiative (HIRI), works with community groups, public officials, industry representatives, researchers, and others to identify opportunities to implement heat island strategies. HIRI previously supported research. Currently, the program translates research into outreach materials, tools, and guidance that provide communities with information to develop programs, policies, codes, and ordinances to implement heat island reduction strategies.
- Oak Ridge National Laboratory and the Florida Solar Energy Center conduct research on cool-roof applications.
- Penn State and other North American universities are conducting research on green roof technologies, including their impacts on energy consumption, stormwater management, water quality, surface and air temperatures, and pollution removal.
- The USDA Forest Service develops methods and models to quantify carbon storage and sequestration, building energy-use effects, and air pollution removal by urban forests at the local to national scale.
- The Forest Service conducts analyses in numerous cities, and national assessments to quantify the effects of urban forests on carbon storage and sequestration, building energy use, and air pollution removal.
- A few cities and states (e.g., Chicago, California, and Georgia) have incorporated reflective roofs into their energy codes. Many utilities (e.g., Austin Energy, Florida Power and Light, Xcel Energy) have reflective-roof incentive programs. Reflective roofs are given credit in several environmental rating programs, including the U.S. Green Building Council's LEED (Leadership in Energy and Environmental Design) rating system. Many cool-roofing membranes and coatings are available, and these products are mainly used for commercial or flat roofs. Cool-tile and metal roofing products are also available, and these are used for residential roofs. Research is currently being conducted to develop additional cool-roof products for the residential market, for example, cool asphalt shingles.

Recent Progress

- EPA and DOE demonstrated the impact of cool roofs on building energy use; EPA developed the Energy Star Roof Products program.
- ASTM and ASHRAE standards have been developed, and prototype cool-roofing materials have been developed.
- The Cool Roof Rating Council was organized and several state and air-quality management districts have adopted heat-island-reduction measures.

Commercialization and Deployment Activities

- Reflective roofing and paving technologies may be broadly applicable to U.S. cities, but benefits will vary.
- Some cities and states require use of cool roofs, and many existing efforts support their installation (e.g., Philadelphia's Cool Homes program), thus increasing the demand and deployment of these products.

Market Context

- Heat island reduction strategies including urban reforestation, rooftop gardens, reflective roofs, and alternative pavements have been implemented in many cities including Los Angeles, Sacramento, Salt Lake City, Houston, Tucson, Chicago, Miami, and Atlanta – interest is growing.
- Nationally, reflective roofing materials probably comprise less than 10% of the roofing market; and asphalt is the most common pavement surface.