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Long-Term Vision of the Built Environment in the United States

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I. Overview

Over the next 50 to 100 years in the United States the building sector will continue to be an important component of energy use, driven by the inexorable forces of population and economic growth, punctuated by continued urbanization. While the building types themselves may be heterogenous, they will likely share many common components, each of which will be individually shaped, and in some cases radically so, by the advancement of technology. Current research and development programs, both public and private, portray an ambitious array of visionary opportunities in this regard.[3]

If current research concepts become fully developed, future building systems will automatically operate and maintain themselves. The buildings' electronic sensors and data structure will support start-up, operation, maintenance, and monitor needed building repairs or renovation. The buildings' internal components, including their human occupants, will all be part of a balanced, fully integrated, and highly efficient building system. The buildings, themselves, will become part of a larger, integrated power and resource grid, with localized energy and environmental management systems and controls.

This "vision" of the future of the built environment, if extended beyond the U.S., may be able to achieve significant reductions of world energy consumption in this sector, particularly in the more developed regions, and especially the U.S. and OECD countries.[4] A 50 percent reduction in energy consumption is achievable in new construction today, at little or no incremental cost in residential buildings, and at about a 10-15 percent cost premium in commercial buildings. Looking further out into the future, say 50 to 100 years, it is likely that new construction will see "net-zero" energy consuming buildings, or even net energy producing buildings.

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[3] *DOE Research and Development Portfolio, Energy Resources*; Vol 1 of 4; February 2000; http://www.osti.gov/portfolio/

[4] *Powerful Partnerships*; Report of the Panel on International Cooperation in Energy Research, Development, and Deployment; Presidents Committee of Advisors on Science and Technology; (PCAST II); June 1999; Chapter 4, p 8

II. Buildings Sector In the United States

In the U.S., the buildings sector is defined to include both residential and commercial buildings. Residential building construction includes single-family, multi-family, and "manufactured" housing. Commercial building construction includes buildings used for commercial purposes, including retail and wholesale trade, and other non-industrial activities, such as offices, restaurants, hospitals, schools, warehouses, and others. Current emphasis in Federal research and development (R&D) in the buildings sector ranges from improvements to the building envelope (i.e., walls, vents, and windows, foundations), to the building equipment used for heating and cooling the space or for providing building services like lighting and appliances, to methods for integrating all of these components, through "whole building" integrated design techniques.[5]

III. Current Situation for the Building Sector in the United States

In 1999, the United States consumed roughly 96 quadrillion Btus (101 exajoules) of primary energy.[6] The Nation's 100 million households and 4.6 million commercial buildings consumed 36 percent or 35 quads (37 exajoules) of this total. Buildings also used two-thirds of all electricity consumed nationally.[7] More than $230 billion is currently spent each year in the United States to provide heating, cooling, lighting and related energy services for buildings. Even if the energy efficiency of the building sector components (envelope, equipment, and system integration) were to improve significantly, it is expected that overall sector energy consumption will still increase, as more buildings are constructed, more space per capita is provided, and more energy is consumed by growing economic activities associated with buildings. Energy production associated with this energy use in buildings is a major source of acid rain, smog, and greenhouse gas emissions in the United States, representing 35 percent of carbon dioxide emissions, 47 percent of sulfur dioxide emissions, and 22 percent of nitrogen oxide emissions.

IV. Population Trends, Globally and in Developed Regions

In the most recent version of the *World Population Prospects*, the United Nations, Department of Economic and Social Affairs, Population Division, projects population

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[5] *DOE Research and Development Portfolio, Energy Resources*; Vol 1 of 4; February 2000; http://www.osti.gov/portfolio/; pp. 233-257

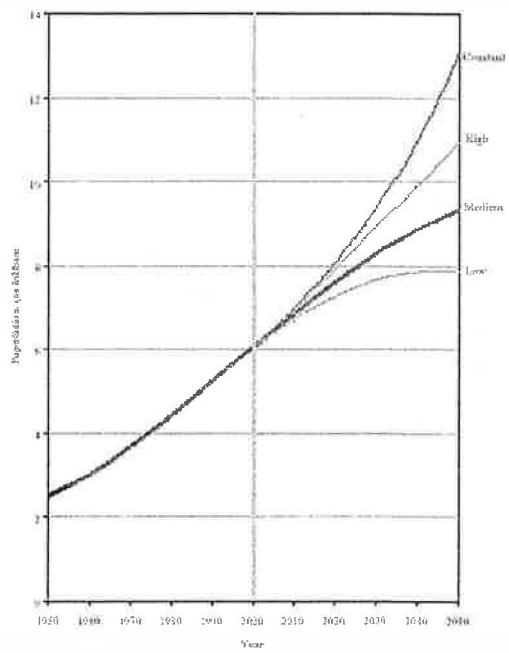
[6] Conversion factor from quadrillion (10^{15}) BTU to 10^{18} joules (or one exajoule) is 1.055.

[7] Energy Information Administration (EIA); *Annual Energy Outlook, 2001*; DOE/EIA-0383(2001) (Washington, DC, December 2000); Tables A-1 & A-2

growth and trends through 2050.[8] The key findings from the *2000 Revision* describe the primary global drivers expected to influence the building sector of the future.

World population reached 6.1 billion people in mid-2000 and is currently growing at an annual rate of 1.2 per cent, adding 77 million people per year. Six countries account for half of this annual growth: India for 21 per cent; China for 12 per cent; Pakistan for 5 per cent; Nigeria for 4 per cent; Bangladesh for 4 per cent; and Indonesia for 3 per cent. By 2050, world population is expected to rise to between 7.9 billion (low variant) and 10.9 billion (high variant), with the medium variant 9.3 billion (see Figure 1).

Figure 1. Estimated and Projected population of the world by projection variant, 1950-2050



The population of the more developed regions (MDRs), currently at 1.2 billion, is anticipated to change little during the next 50 years, because fertility levels are expected to remain below replacement levels (2.1 children per woman). In fact, by mid-century the populations of 39 countries are projected to be smaller than today, such as Japan and Germany, 14 per cent smaller; Italy and Hungary, 25 per cent smaller; and the Russian Federation, Georgia and Ukraine, between 28 to 40 per cent smaller.

The population of the less developed regions (LDRs) is projected to rise steadily from 4.9 billion people in 2000, to 8.2 billion in 2050 (medium variant), or approximately 90 percent of total world population. This projection assumes continuing declines in fertility. In the absence of such declines (constant variant), the population of less developed regions would reach 11.9 billion instead of the projected 8.2 billion. Particularly rapid growth is expected among the group of 48 countries classified as least developed. Their population is expected to nearly triple between 2000 and 2050, passing from 658 million to 1.8 billion, despite the fact that their fertility is projected to decline markedly in the future.

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[8] *World Population Prospects, The 2000 Revision, Highlights*; Population Division, Department of Economic and Social Affairs, United Nations, Draft, 28 February 2001; ESA/P/WP.165, http://www.undp.org/popin/; page *v*

The difference between the projected population in 2050, according to the *2000 Revision* (9.3 billion), and that projected in the *1998 Revision* (8.9 billion), is 413 million people. Higher future fertility levels projected for the 16 developing countries, whose fertility has not yet shown signs of a sustained decline, are responsible for 59 per cent of that difference. The somewhat higher recent fertility estimated in the *2000 Revision* for several populous countries (e.g., Bangladesh, India and Nigeria) accounts for a further 32 per cent of that difference.

For 1995-2000, life expectancy at birth in the more developed regions is estimated to be 75 years. In the less developed regions, life expectancy was nearly 12 years lower, at 63 years. By 2050 the less developed regions are expected to attain a life expectancy of 75 years, whereas in the more developed regions the projected level is 82 years. This suggests that the population in general will live longer, and that the age gap between more developed and less developed regions will narrow.

V. Urbanization Trends

In a recent publication focused on urbanization[9], the United Nations evaluated the growth and trends of urbanization. Several key findings from the *1999 Revision* describe the urbanization drivers influencing the buildings sector.

Virtually all the population growth expected during 2000-2030 will be concentrated in the urban areas of the world. During that period the urban population is expected to increase by 2 billion persons, the same number that will be added to the whole population of the world. In terms of population size, there are 2.9 billion inhabitants in urban areas today and 4.9 billion are expected in 2030, whereas the world has 6.1 billion inhabitants and is expected to have 8.1 billion by 2030.

Most of the population increase expected during 2000-2030 will be absorbed by the urban areas of the less developed regions, whose population will likely rise from 1.9 billion in 2000 to 3.9 billion in 2030. The urban population of the more developed regions, by contrast, is expected to increase slowly, passing from 0.9 billion in 2000 to 1 billion in 2030.

The rapid increase of the world's urban population, coupled with the slowing growth of the rural population, has led to a major redistribution of the population. Thus, whereas in 1950, 30 per cent of the world population lived in urban areas, by 2000 the proportion of urban dwellers had risen to 47 per cent and it is expected to reach 60 per cent by 2030 (see figure 2).

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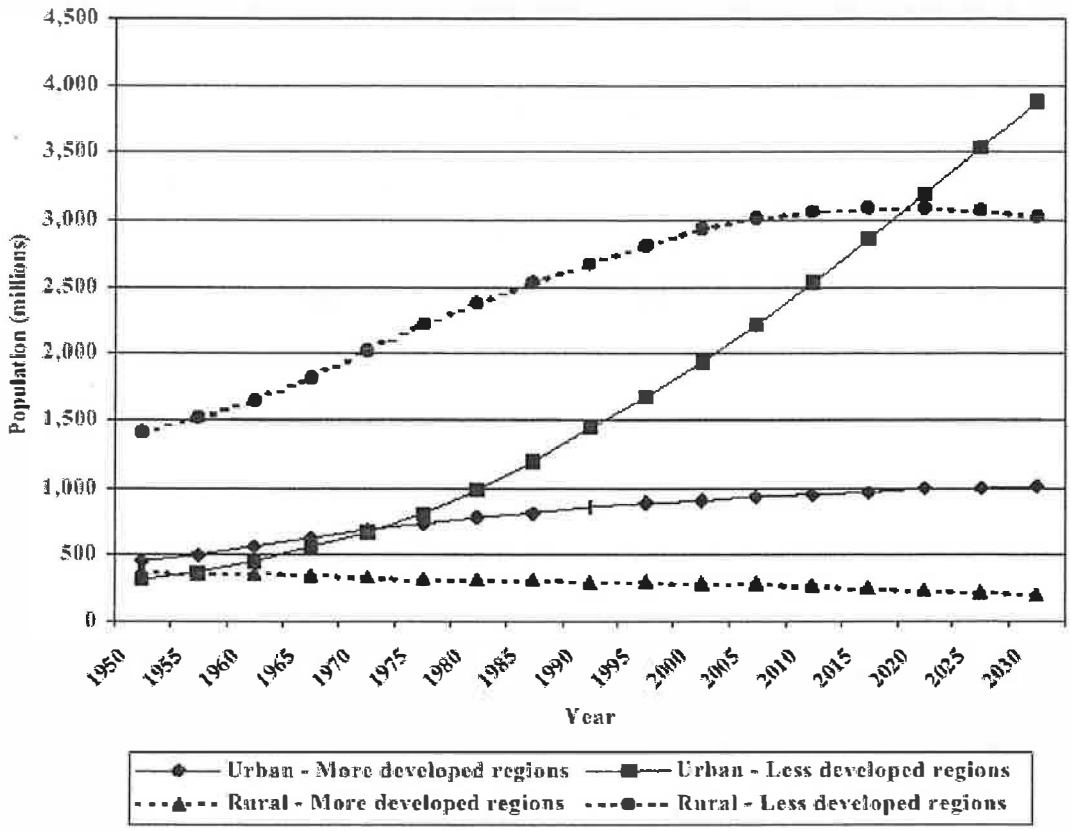
[9] *World Urbanization Prospects, The 1999 Revision, Key Findings*; United Nations Population Information Network (POPIN), Population Division, Department of Economic and Social Affairs, United Nations, http://www.undp.org/popin/; pp 1-2

Figure 2. Estimated and projected urban and rural populations of the more and less developed regions, 1950-2030



The process of urbanization is already well advanced in the more developed regions, where 76 per cent of the population lives in urban areas. Nevertheless, the concentration of population in cities is expected to continue so that, by 2030, 84 per cent of the inhabitants of more developed countries will be urban dwellers.

From another perspective, in the U.S., undeveloped land was converted to developed land during the 10-year period, 1982-1992, at a rate of 1.4 million acres (or 567,000

hectares) per year. During the following 5-year period, 1992-1997, the land conversion rate accelerated, increasing to 2.2 million acres (891,000 hectares) per year.[10]

In the U.S., as is the case in most countries in the more developed regions (MDR) of the world, increasing demand for appliances and space conditioning is likely to be a *less* important driver for future energy use than is increasing space per capita. Thus, in the MDR countries many of the more important opportunities for increased efficiency lie not with appliances and space conditioning, but in the areas of more efficient building design, major building renovations, and with the buildings' functions and equipment .

In the countries of the less developed regions (LDR) of the world, by contrast, increased space conditioning, followed by increased penetration of major appliances and other equipment, is likely to be the most important driver of future energy use. In such LDR countries the more significant opportunities present themselves in the areas of building equipment and appliance efficiency standards, and building construction standards.

VI. Projections for the Built Environment

Based on these projections and other studies[11,12], the future for the buildings sector globally will likely be one that sees increasing expansion, increasing urbanization, and increasing concentration of economic activities in urban areas, accompanied by increased intensity and use of energy consuming installed building equipment.

In the U.S., the future for the buildings sector will likely see similar trends, except characterized additionally by increasing land conversion, sometimes referred to as "urban sprawl," and rising building space per capita. The land area defined within the boundaries of Metropolitan Statistical Areas (MSAs) will expand, and economic activity will concentrate within these MSAs. Given these projections, the buildings sector in the U.S. will likely be characterized by strong expansion in commercial buildings and supporting service infrastructure, and modest expansion of housing, which in the U.S. will consist largely of two types, single-family units and large multi-family units.

Even though population and demographic research shows that the future urbanization and expansion of the built environment will be mostly concentrated in the less

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[10] U.S. Department of Agriculture, National Resources Conservation Service, *1997 National sources Inventory*, Revised December 2000

[11] *World Population Prospects, The 2000 Revision, Highlights*; Population Division, Department of Economic and Social Affairs, United Nations, Draft, 28 February 2001; ESA/P/WP.165; http://www.undp.org/popin/

[12] *Our Common Journey, A Transition Toward Sustainability*; National Research Council; National Academy Press; Washington, DC; 1999

developed regions of the world, the built environment of the more developed regions (MDR) remains an important opportunity for improved energy efficiency. More building energy per capita is consumed in the MDR countries, so efficiency improvements will continue to have leverage there. Also, technology advances and complementary policy innovations often arise first in MDR countries, providing a source for diffusing innovation elsewhere. Quite apart from these points, improved efficiency creates direct economic and environmental benefits for the affected consumers and producers.

VII. Other Considerations

In accord with the above view, the U.S. Energy Information Administration (EIA)[13] projects that the United States will add, between now and 2020, 28 million households and about 16 billion square feet (1.5 billion square meters) of commercial floor space. Once built, these homes and buildings could have longevities of 50 years or longer, so the impacts of buildings design, construction, and installed equipment decisions cast long shadows onto the future. Fully 30 percent of existing commercial floor space, and 40 percent of existing housing, were built prior to 1960.[14] Therefore, any effective strategy for addressing future energy use in the buildings sector must envision a portfolio of technologies and complementary policies that address not only new buildings and uses, but also existing buildings and uses, through retrofit and renovation.

Beyond the existing stock of buildings, it is conceivable that future buildings will become more durable and disaster resistant, adding decades to their longevity, perhaps up to as long a several hundred years. This notion would support, further, flexible concepts in design for interior space adaptability, for both commercial and residential construction.

Finally, one of the primary institutional challenges to achieving more efficiency in the buildings sector is the fragmentation of its industry. The building construction industry encompasses literally hundreds of thousands of independent businesses and millions of individual decision makers. Developers, designers, builders, utilities, engineers, and occupants pursue their own objectives, which often can make coordination of integrated system design and optimization challenging, at best.

One consequence of this fragmentation is that the building industry spends relatively little on R&D. R&D expenditures for the buildings industry as a whole are an order of magnitude less than the national average for other industries. Given the importance of current energy consumption, projected growth in the buildings sector, and the longevity

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[13] Energy Information Administration (EIA); *Annual Energy Outlook, 2001*; DOE/EIA-0383(2001) (Washington, DC, December 2000)

[14] United Nations Economic Commission for Europe; *Annual Bulletin of Housing and Building Statistics for Europe and North America 2000*, Dwellings by period of construction; (pdf file); http://www.unece.org/env/hs/bulletin/cnt2_e98.htm

of the built environment, investments in R&D in this area would appear to be important, given its potential and leverage on the future of buildings sector energy consumption and related environmental impacts.

VIII. Technology Opportunities

In addressing the challenges of the buildings future, there are many opportunities for technology advancement, which can reduce both energy consumption and material and resource flows associated with buildings. Although the future suggests heterogeneity of building types (commercial, service, detached home, apartment buildings), there are common genre of building components. These include: (a) the building envelope, including its walls, roofs, and fenestration components (windows, ventilation, day-lighting, etc.); (b) the building equipment, including heating, ventilation, and air handling and conditioning equipment; lighting; and standard appliances; and (c) the complement of functional equipment associated with a particular residential or economic activity.

Each component affords significant opportunities for efficiency improvement, which can be advanced by investment in research and technology development, and is being pursued by interested parties (manufacturers, research institutions, laboratories, etc.). It is further encouraged, in the U.S., by Federal leadership in novel areas of R&D, and by a set of complementary and supportive building efficiency policies and programs, including consumer information programs, such as efficiency testing and labeling of energy using components, building codes and construction standards, efficiency standards on certain residential appliances (see page 11), efficiency rating systems for homes, and partnerships with States, municipalities, and building owners and operators.

The greatest leverage for the future, however, may lie not so much with the individual buildings components, but with the integration of the components within a larger concept of "whole building" design, augmented by "intelligent" systems and equipment.

Whole Building Technologies

- Whole Building Design Tools: Energy-10
- Energy-efficient HVAC
- Ventilation
- Solar Technologies
- Energy-Efficient Building Equipment
  - Office Equipment
  - Lighting
  - Water Heaters
  - Appliances
- Window sizing and glazing

A. Whole Building Design

Looking at homes from a "whole building" design or integrated systems engineering perspective requires viewing the building and its components, and its functions, as integrated systems, rather than a series of independent components. This view can have significant effects, when it is incorporated into the early design, planning and building stages.

For instance, efficiency improvements that might be hard to justify on their own

accord may be seen in a different light when they result in a smaller heating and cooling loads, and smaller and cheaper systems for the home. At the same time, retrofitting an improved lighting system might lead to increases in heating requirements, which may partially offset the energy savings from the improved lighting. Synergies such as these are common in building designs, but are often overlooked, and difficult to assess and capture without advanced building modeling and design tools.

B. Intelligent Building Systems[15]

The process of designing, constructing, starting up, controlling, and maintaining building systems is complex. If done properly, the final product delivers comfort, safety, a healthy environment, and operates efficiently, at reasonable cost.

The key to managing this process of designing and operating buildings efficiently lies, in part, in the ability to monitor data and manage information, deliver it efficiently, and use it effectively for building design and operation.

Intelligent building systems (IBSs) will use data from design, together with sensed data, to automatically configure controls, commission (i.e., start up and check out) and operate buildings. Control systems can use advanced technologies and can be based on smaller, cheaper, and more abundant sensors than today.

Intelligent devices can use this wealth of data to ensure optimal building performance continuously by controlling building systems and continuously re-

Technologies for Intelligent Building Systems:

- Sophisticated user-friendly computer-based tools;
- Manufactured wall systems with integrated superinsulation and "superwindows" optimized for orientation, external temperature, and internal needs;
- Photovoltaic roof shingles with reflective roofing;
- Low-cost, high-performance solar water heaters and other advanced solar heating and cooling technologies;
- Advanced HVAC systems, where necessary;
- Strategic positioning of trees to reduce cooling costs, fuel cells providing low-carbon energy, and energy storage;
- Advanced high efficiency lighting systems actively operating with an array of daylighting and site/task strategies to optimize luminosity and reduce energy consumption;
- Smart technology to closely match energy and water supply for multifunctional and integrated appliances and buildings control systems, and automatic load modulation of heating and cooling systems in response to varying weather, environment and occupant demands;
- Improved sensors and controls, zoning and variable loading of the heating and cooling; and
- Healthful house construction that is radon resistant, non-allergenic, and makes use of recycled materials.

[15] Energy Efficiency and Renewable Network, U.S. Department of Energy, Buildings web site; http://www.eren.doe.gov/buildings/research_systems.html

commissioning them using automated tools that detect and diagnose performance anomalies and degradation.

Intelligent building systems can provide much more than today's rudimentary control. They can optimize operation across building systems, inform and implement energy purchasing, guide maintenance activities, and report building performance, while ensuring that occupant needs for comfort, health, and safety are met at lowest possible cost.[16]

IX. Leadership Role of Federal R&D

In the U.S., Federal leadership in R&D in the buildings area fills four needs. First, the Federal research planning provides a means to interact with and assist the many diverse parties within the buildings industry and associated interests and consumers, in coordinating R&D efforts, particularly in an industry where benefits of R&D investment are potentially large, but private investment in R&D is limited. Second, certain risky and costly research, which may be important to other aspects of technology advancement in this sector, might not occur at all, were it not for presence of Federal R&D leadership, due, in part, to the complexity of the research and, in part, to the fragmented nature of the buildings marketplace. Third, Federal R&D leadership provides industry with data, information, and objective analysis on new technologies and techniques, which help to reduce barriers to new technology adoption. Finally, the Federal Government has its own economic incentive to advance buildings research and technology, because of the savings from reduced energy costs incurred by the Government, which is the single largest consumer of buildings energy in the United States.[17]

Federal leadership in R&D alone, however, is unlikely to be sufficient without a full set of complementary and supporting technology and buildings efficiency policies and programs. This is why Federal efforts in the buildings sector also place emphasis on activities designed to encourage the deployment of new technologies through audits, education, training, and related efforts across the buildings community.

One example is the Energy Star® Program. This is a Federal Partnership between the U.S. Department of Energy (DOE) and the Environmental Protection Agency (EPA). It works with over 4,000 retailers. The primary objective is to increase, through efficiency markings on products, consumer awareness, interest, and desire for energy efficient products, such as appliances, lighting, windows, etc.

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[16] *Federal Energy Research and Development for the Challenges of the Twenty-First Century*; Report of the Energy Research and Development Panel, Presidents Committee of Advisors on Science and Technology; (PCAST I); November 1997; Chapter 3, p. 11

[17] *DOE Research and Development Portfolio, Energy Resources*; Vol 1 of 4; February 2000; http://www.osti.gov/portfolio/

The U.S. government established a mandatory compliance program in the 1970s, requiring that certain types of new appliances bear an energy consumption and efficiency rating label, in order to help consumers compare energy use and efficiency among similar products. In 1980, the Federal Trade Commission's Appliance Labeling Rule became effective. It requires that EnergyGuide labels be placed on all new refrigerators, freezers, water heaters, dishwashers, clothes washers, room air conditioners, heat pumps, furnaces, and boilers. EnergyGuide labels are not required on kitchen ranges, microwave ovens, clothes dryers, on-demand water heaters, portable space heaters, and lights.

Appliance Standards
Contributed to $24B savings

- Refrigerators
- Freezers
- Ovens
- Dishwashers
- Clothes washers
- Clothes Dryers
- Central air conditioners
- Room air conditioners
- Heat pumps
- Water heaters
- Furnaces, and boilers

Finally, the buildings sector is an industry that has been slow to adopt new technologies, this may be understood, in part, because new and more efficient technologies may cost more, and this cost is paid by builders. The long-term costs of operation and maintenance, and their cost savings, are paid by others.

Many countries have recognized that codes and standards can be effective means for encouraging the adoption of new building technologies, and they have taken steps to implement them. Mandatory efficiency standards in the U.S., enacted at the national level for appliances and mass-produced equipment, and at the state level for buildings, is a primary reason energy efficiency has improved over the past two decades.

X. Concluding Vision

In conclusion, the building sector will continue to be an important component of energy use, driven by the forces of population and economic growth, punctuated by continued urbanization. While the building types themselves may be highly heterogenous, they all will likely share many common components, each of which will be individually shaped, and in some cases radically so, by the advancement of technology. Current research and development programs, both public and private, portray an ambitious array of visionary opportunities in this regard.[18]

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[18] *DOE Research and Development Portfolio, Energy Resources*; Vol 1 of 4; February 2000; http://www.osti.gov/portfolio/

The concept of whole building systems integration, however, may prove to offer the greatest opportunities for optimizing efficiency, reducing costs, and enhancing indoor environmental quality. Research on this front continues to make significant progress.

If current research concepts become fully developed, future building systems will automatically operate and maintain themselves. The buildings' electronic sensors and data structure will support start-up, operation, maintenance, and monitor needed building repairs or renovation. The buildings' internal components, including their human occupants, will all be part of a balanced, fully integrated, and highly efficient building system. The buildings, themselves, will become part of a larger, integrated power and resource grid, with localized energy and environmental management systems and controls.

This "vision" of the future of the built environment, if extended beyond the U.S., may be able to achieve significant reductions of world energy consumption in this sector, particularly in the more developed regions, and especially the U.S. and OECD countries.[19] A 50 percent reduction in energy consumption is achievable in new construction today, at little or no incremental cost in residential buildings, and at about a 10-15 percent cost premium in commercial buildings.

Looking further out into the future, say 50 to 100 years, it is likely that new construction will see "net-zero" energy consuming buildings, or even net energy producing buildings. This is especially true when considering the potential emergence of not only new smart building materials and systems, but also looking forward to renewable technology breakthroughs that could be integrated into structures to produce and store both thermal and electrical energy.

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[19] *Powerful Partnerships*; Report of the Panel on International Cooperation in Energy Research, Development, and Deployment; Presidents Committee of Advisors on Science and Technology; (PCAST II); June 1999; Chapter 4, p 8