Whole Buildings

An Integrating R&D and Policy Framework for the 21st Century

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Union of Concerned Scientists

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Contents

Figures

Tables

Executive Summary

Rather than isolated collections of components, buildings are integrated systems that interact with their environments. Through effective energy use, "whole" buildings levy the smallest possible environmental impact, while enhancing their users' comfort and productivity. The federal government can shape consumer demand for whole buildings through coordinating its building-related activities into a "whole building policy."

This report argues for an integrated approach to federal government building programs: a comprehensive "whole buildings" umbrella concept that ties the building and its components together into one unified package and encompasses all real-world physical and economic elements with which the building interacts or on which it depends. The same framework can bridge all federal agencies involved in building research in a coordinated manner within government, as well as with outside agencies and organizations, both nongovernmental and industrial, treating all as one unified package of complementary and supporting activities. The result will be greater building energy efficiency and occupant productivity, reduced impact of buildings on the environment, and greater economic efficiency, transferability and value of building R&D programs.

The message presented in this report is clear: to minimize duplication and fragmentation of effort, and to maximize potential returns for both the industry and for society at large, there is a strong need and a clear obligation for enhanced and long term stable federal agency funding for building R&D. The programs must be coordinated within and between agencies, as well as with the building industry, under a "whole building" conceptual umbrella.

The purpose of this report is to foster a concept whose time has definitely come, and thereby to urge its widespread adoption by government, industry, and the private sector in order to capitalize on the great potential benefits of integrated R&D to support integrated buildings. This is because this report does not invent the "whole buildings" concept, nor does it propose a structure that is not already at least partly in place, both within and outside of the federal government. It reemerged perhaps ten years ago in the manner in which the US Department of Energy coordinates its building research, and is being adopted in a much more comprehensive present reorientation of DOE buildings research today. It emerged in recommendations by the American Institute of Architects, also nearly ten years ago. And it is emerging in the definition of R&D tasks internationally, within the International Energy Agency building R&D activities.

What is needed is a market transformation that transfers all facets of "whole buildings" to common practice, in order to capitalize on their benefits. This can only occur as the result of a new appreciation for those benefits, and a market demand by those who "want" those benefits. This report notes that such a market "pull" for the transformation can result in part from a better appreciation of the role of buildings not just as economic elements, but as factors which help to shape the efficiency of our economy and the quality of our environment.

Buildings place dominant demands on the US use of natural and energy resources and are responsible for a very large share of US environmental emissions. Buildings account for a $222 billion annual energy bill, while using 36% of the nation's energy resources directly, 40% when one takes into account energy used in construction and demolition, and possibly over 50% when all of the energy-related factors are included that are necessary to serve buildings and their occupants. Buildings consume 66% of the nation's use of electricity, thereby tying up the output of 2/3 of all of the nation's electric power plants. This direct and indirect use of energy accounts for 35% of US carbon emissions, 47% of the nation's emission of SO_2, and 22% of Nitrogen Oxides. A major proportion of the flow of raw materials into the US economy goes into the construction of buildings, while the amount of those resources converted annually to construction and demolition waste rivals the US burden of municipal garbage.

Any attempt to reduce the flow of resources, to reduce waste, to reduce energy use (including dependence on foreign sources of energy), and to reduce environmental emissions to meet more stringent US standards or to live up to our '97 Kyoto promises, must look hard at the accessible and economic opportunities afforded by buildings. Similarly, no conversion of US practices and economy to a path leading to long-range sustainability can be accomplished with buildings constructed today that place a 50 to 100 year burden of excessive and inappropriate energy and resource demand on the future.

In fiscal year 1998, the Federal Government will spend approximately $476 million on buildings R&D and related technology programs. Funding for the few "whole buildings" programs that exist is insignificant in comparison to the breadth of building-related programs in general. With relatively scant funding directed toward specific integrated, "whole building" R&D programs, it is clear that the potential economic and environmental benefits of addressing building performance as a function of integrated systems are going unrealized.

"Whole buildings" is a better policy and one that will affect change. It must be elevated to a high level of administrative responsibility and respect. "Whole buildings" must secure a mandate simultaneously from the Federal government, the industry, and private sector research centers to coordinate, enhance, supplement, complement, and fill in gaps that are still barriers to systems integration in research and practice. It is deserving of its own clearly identified programmatic mission, supported by sufficient appropriations. To accomplish this will require a true federal/industry partnership, coordinated nationally in a structure yet to be defined.

This report concludes by presenting five policy criteria, with accompanying specific recommendations, to promote the adoption, successful introduction, and continuing effectiveness of a national "whole buildings" R&D program:

- Establish the "whole building" framework as a cornerstone of policy.
- Fund collaborative, fundamental and applied efforts in "whole building" R&D.
- Support accurate estimation and verification efforts.
- Embrace training and education.
- Stimulate demand through awareness.

Whole Buildings

An Integrating R&D and Policy Framework for the 21st Century

By Donald W. Aitken

This UCS report, along with a previously published condensed version[1], argues for an integrated approach to federal building programs: a comprehensive "whole buildings" umbrella concept that ties the building and its components together into one unified package and encompasses all real-world physical and economic elements with which the building interacts or on which it depends. (Please see the sidebar "Whole Buildings," for a functional definition of this concept.)[2] The same framework can bridge all federal agencies involved in building research in a coordinated manner within government, as well as with outside agencies and organizations, both NGO and industrial, treating all as one unified package of complementary and supporting activities. The result will be greater building energy efficiency and occupant productivity, reduced impact of buildings on the economy and environment, and greater economic efficiency, transferability and value of building R&D programs.

The purpose of this report is to foster a concept whose time has definitely come, and thereby to urge its widespread adoption by government, industry, and the private sector in order to capitalize on the great potential benefits of integrated R&D to support integrated buildings. This is because this report certainly does not invent the "whole buildings" concept, nor does it propose a structure that is not already at least partly in place, both within and outside of the federal government. It reemerged perhaps ten years ago in the manner in which the US Department of Energy (DOE) coordinates its building research, and is being adopted in a much more comprehensive present reorientation of DOE buildings research today. It emerged in recommendations by the American Institute of Architects, also nearly ten years ago. And it is emerging in the definition of R&D tasks internationally, within the International Energy Agency building R&D activities.

This would mean, for example, that building materials, components and energy systems are to be developed for application in optimal combination with each other. And that package, in turn, is optimized for energy efficiency and the use of locally available renewable energy resources (such as solar), as these affect design approaches and material and component selection. All of this would be cast within an economic and environmental "lifetime costing" framework that recognizes the costs and impacts of buildings from the production of the building materials prior to construction to reuse of those same materials following demolition. And these considerations, in turn, need now to be cast in view of the longer range necessity to accomplish environmental and resource sustainability. The supporting R&D, therefore, seeks to advance efficiency, energy, and component technologies that each contribute to the greatest physical and economic lifetime good of the building in a world in which structure, components, environments, and sustainability are inextricably linked in constant interactive modes. Therefore, no R&D program exists in isolation either from any others, or from the whole result. It should be a condition that research of one type will advance the potential performance of the whole, and enhance the benefits of all other research programs. Turning this realization into a national strategy is the challenging next step to completeness that is the thesis of this report.

Technical advances that have already led to better building performance and to more flexible or efficient responses by individual building components are already available today, but generally underutilized. A major barrier that must be overcome, therefore, is the market failure that presently impedes the adoption and application of good knowledge and components now available. Market transformations stimulated by government research are occurring, such as spectrally selective window glass and electronic ballasts to operate fluorescent lamps that themselves have better color and energy performance. And the ratio of economic benefits to government expenditures for these programs can be spectacular, such as the 400:1 return for DOE's combined expenditure to develop, demonstrate and support the early marketing of low-emissivity windows, electronic ballasts and high-efficiency supermarket refrigeration systems.[3] But what is needed is a market transformation that transfers all facets of "whole buildings" in view of their interactive and lifetime benefits. This can only occur as the result of a new appreciation for those benefits, and a market demand by those who "want" those benefits. R&D without market development cannot advance a good idea.

But equally important are the questions: who is going to be responsible for "whole building" R&D, and how is this to be coordinated so that building R&D does not remain fragmented or duplicative, and how can the activities of federal and private research efforts be defined in the context of a truly national strategy and fit into a coherent national program? In addition, why is federal government involvement and support so absolutely necessary to building research in general and to whole building research in particular?

The Renewable Energy Policy Project (REPP)[4] responded to the request of the members of the Passive Solar Industries Council (PSIC) to commission the present report, as a start toward answering these questions. The PSIC is a consortium of architects, builders, designers, building materials and product manufacturers, consultants, educators, engineers, utility companies and organizations, and individuals, with diverse but related interests who have come together because no other group was positioned to represent "whole buildings" in the trades and field. To pave the way for the present work, the PSIC commissioned a companion piece, "Overview of the Building Technologies Programs in the Federal Sector," a work that provides a snapshot of the various current federal buildings programs.[5] It shows how things are, while this report details how things should be.

To address this challenge, this report first reviews the hugely important and badly underrated role of buildings as an element in the US economy, to overcome the general view that buildings are mere containers within which to conduct our social and economic activities, with no major intrinsic impact on the outcome of those activities or on the economy. Almost everything else in the economy appears to be more interesting and important than energy economics, and certainly more so than building energy economics.

As a result, this report also builds the case for a long term and stable federal presence in building R&D. That is, such a presence will be shown to be necessary to provide the backbone and nervous system integration of "whole building" R&D, even while the flesh and blood elements are gradually improved by individual research centers and laboratories, and supplied as the result of market transformations. This report is therefore being written for members of Congress, federal and state policy makers, policy advocates in the private sector including those representing the building trades, energy efficiency industries, renewable energy industries, and non-governmental organizations (such as the author's own) that advocate responsible coordinated and long range federal R&D policy.

This report then steps back to describe what building energy systems actually do, to further refine the concept of "whole buildings" R&D. This is followed by a brief review of the emergence (or reemergence) of a "whole buildings" perspective in major solar and efficiency R&D programs, both past and present, so that we can see that we can build on what has already been started, making the proposed task easier.

Whole Buildings

The "whole building" concept can be defined in various ways, depending on the assumed boundaries. An evolving building-centered definition is that it represents a method of siting, design, equipment and material selection, financing, construction, and long term operation that takes into account the complex nature of buildings and user requirements, and treats the overall building as an integrated system of interacting components. In a 1992 Symposium the American Institute of Architects expanded this to "total building performance," to include resource and materials selection, their use and transformation in the manufacturing and building process, and extending to the concerns of building occupancy, maintenance, remodeling and re-use. The impact of materials choices on resource availability, the environmental impact of the building construction, and the potential for re-use of building materials after demolition extends this even further. And, of course, the need for today's choices to help put the United States on a path of resource and environmental sustainability is now recognized as an important policy driver.

The aim of this report is in part to assure the transition to low energy buildings as a new national norm for the 21st century (see the sidebar "What's in a Name?"). The energy saving and resultant cost-saving benefits are fundamentally important policy drivers. But an appropriate set of definitional boundaries also includes site-specific environmental energy resources, such as solar energy; the toxicity of materials used in construction and operation of the buildings and all of its components; environmental emissions resulting from direct energy use in the building, indirectly from purchased energy, or embodied in materials and equipment choices; and the relationships of these choices to national energy efficiency and emissions reduction strategies, as well as to the health and well being of building occupants.

The economic implications and trade-offs of various design, material and component choices in view of maximizing the benefits to the economy at large, such as promoting local products and labor, defines another set of variables that interact with all other choices. So does the promotion of the productivity and satisfaction of building occupants through design and material choices, which in turn is reflected in both quality and quantity of labor output, and which significantly influences the economic return to the building owner and user employer, often producing the dominant "payback" returns.

It is the usually unspecified scope of boundaries being considered that leads to the often-unclear concept of "lifetime costing." A "whole buildings" framework can bind all of these considerations into a single concept, so that each and every decision that affects the building can ultimately be examined at whatever level of specificity is desired, including its dependence on, or interaction with, every other decision. Building R&D programs should also be cast within this grand synthesis, to reveal the value of that research, to enhance complementary research and to avoid duplicative research.

A "whole buildings" approach requires participation by all stakeholders in the design and building process, including material and equipment manufacturers; designers, builders and developers; building trades and code officials; and end users. And the use of "whole buildings" approaches fosters earlier adoption of innovative technologies and systems by reducing first costs, ensuring full integration with building design and construction practices, demonstrating that innovations successfully meet or exceed end user needs, and expanding both the direct and societal value of the finished integrated product. Thus does continuing building technology research contribute to an ever-improving final integrated design and product. In a "whole buildings" perspective no one type of research can a-priori be assumed to be more important than another. It is the synthesis of all that determines the value of each.

This report concludes by casting suggested elements of such a whole buildings R&D perspective, many of which are already being offered in federal R&D plans, in the framework of a set of principles—an adapted "vision statement." These encompass the necessary ingredients for recasting US building R&D into a more productive and potentially more rewarding framework, for securing the necessary expertise in the building industry, and for stimulating the necessary public demand for the resulting benefits. Some discussion is also offered as to how this national strategy might be coordinated.

The message presented in this report is clear: to minimize duplication and fragmentation of effort, and to maximize potential returns for both the industry and for society at large, there is a strong need and a clear obligation for enhanced and reliable federal agency funding in building R&D, but the programs must be coordinated within and between agencies, as well as with the building industry, under a "whole building" conceptual umbrella.

Buildings and the US Economy

Our economic well-being depends on reliable, affordable supplies of energy. Our environmental well-being—from improving urban air quality to abating the risk of global warming—requires a mix of energy sources that emits less carbon dioxide and other pollutants than today's mix does. Our national security requires secure supplies of oil or alternatives to it, as well as prevention of nuclear proliferation. And for reasons of economy, environment, security, and stature as a world power alike, the United State must maintain its leadership in the science and technology of energy supply and use.[6]

It is this author's opinion that US energy policy is a consistently underrated element of US economic planning. We are more concerned with the short term or first cost of energy than with understanding the economic implications of energy choices in view of other economic variables, such as environmental impacts and benefits, or employment implications deriving from the resource choice itself, or implications of these choices on long term issues of sustainability. And, within that, buildings remain the most underrated aspect of energy economics, and the most unexploited opportunity for improving the efficiency of energy economics. The following sketches the basis for this argument.

The Significant Energy Use and Environmental Impacts of Buildings. Table 1 shows the primary energy use in quads[7] for the three primary energy-using sectors of the US economy from 1973–1997.[8] It demonstrates that while energy use in the buildings sector[9] increased from 24.1 quads in 1973 to 33.7 quads in 1997, the percentage share of total US primary energy used by buildings also increased,

TABLE 1
Primary Energy Use: 1973–1997 (quads)

	1973	1986	1990	1995	1997
Buildings	24.1	26.9	29.4	32.1	33.7
Industry	31.5	26.6	32.1	34.5	32.6
Transportation	18.6	20.8	22.6	24.1	25.5
Total	74.3	74.3	84.2	90.6	91.8

from 32.4% in 1973 to 36% in 1997, a figure which includes 66% of total US electricity consumption.[10] The consumption of electricity in the commercial sector doubled in the last sixteen years, and is expected to increase by another 150% by 2030.[11]

The authors of Worldwatch Paper #124 (1995) go further by noting that buildings consume "at least 40% of the world's energy" when one takes into account the fuels and power needed for construction.[12] And, in an analysis performed for the American Institute of Architects (AIA), Randall Croxton, architect of the "whole building" New York City renovations for the national headquarters of the National Audubon Society and of the Natural Resources Defense Council, determined that if one includes the energy to construct the infrastructure that is required to operate, service and maintain buildings it is possible to account for over 50% of US primary energy consumed directly or indirectly to serve the total needs of all the buildings in the United States. [13]

Table 2 reveals values of the primary energy used by the buildings sector for 1990 and 1997, disaggregated into fossil fuel and electricity supply.[14] A further disaggregation of EIA values for 1995 shows 67% of building primary energy from electricity

TABLE 2
Energy Use in the Buildings Sector (quads)

End-Use/Fuel	1990	1997
Residential:		
Electricity	10.2	11.9
Fossil	6.5	7.2
Subtotal	16.7	19.1
Commercial:		
Electricity	9.4	10.6
Fossil	3.8	4.0
Subtotal	13.2	14.6
Sector Total:		
Electricity	19.7	22.5
Fossil	10.2	11.2
Total	29.9	33.7

(21.9 quads—EIA and the "Five Laboratories" figures are determined slightly differently), 25% (8.2 quads) from natural gas, 6% (2 quads) from oil, 0.3% (0.1 quad) from coal, and 2% (0.6 quads) from renewables, with the listed renewables only showing a measurable impact as "site renewable energy consumption." Of those building "site" consumption figures for renewables, the 1995 figures show 95% (0.57 quads) from biomass, 3.33% (0.02 quads) from solar, and 1.67% (0.01 quads) from direct end-use of geothermal heating.[15]

In addition to being significant users of the nation's primary energy resources, buildings are responsible in a major way for the nation's atmospheric emissions. Table 3 shows the carbon emissions from buildings in 1990 and 1997—CO_2 is the major "greenhouse gas" resulting from fossil fuel burning, and implicated in human contributions to global climate change and warming. In 1995 buildings accounted for 35% of US carbon emissions (11.3% directly from on-site use of fossil fuels, and 23% indirectly from building use of electricity), 47% of the nation's emissions of SO2, and 22% of Nitrogen Oxides, along with contributions to Carbon Monoxide, Volatile Organic Compounds, and other compounds. In addition, on the global scale about 40% of the flow of raw materials into economies each year goes into the construction of buildings, while, in the United States in 1995 between 32 and 42 million tons of those resources were converted to construction and demolition waste, an amount roughly equivalent to the total US burden of municipal garbage.[16]

The short summary of these statistics is that buildings place dominant demands on the US use of natural resources and energy resources and are responsible for a very large share of US environmental emissions. Any attempt to reduce the flow of resources, to reduce waste, to reduce energy use (including dependence on foreign sources of energy), and to reduce environmental emissions to meet more stringent US standards or to live up to our '97 Kyoto promises, must look hard at the accessible and economic opportunities afforded by buildings.

For example, in 1995 64% of the energy used in buildings was for the sum of space heating and cooling, water heating, and lighting,[17] all of which can be reduced in major ways by "whole building" design that reduces each of these in part through the selection of advanced efficiency technologies and in part by optimizing their interactions through design and building material selection. In addition, these same end uses are attractive candidates for the direct use of solar and other environmental energies, as well as for optimized interactive contributions with all other building energy systems.

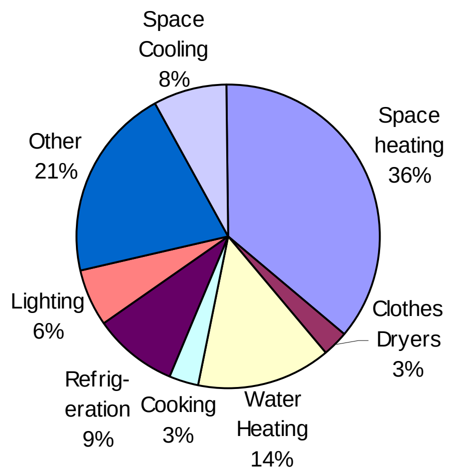
Figure 1 reveals the end-use splits for energy services in residential buildings, and Figure 2 reveals the same for commercial buildings.[18]

It is the flow of resources, though, from construction to demolition, which adds yet another dimension to the necessity for "whole building" design.

TABLE 3
Carbon Emissions in the Buildings Sector (MtC)

End-Use/Fuel	1990	1997
Residential:		
Electricity	162	183
Fossil	91	102
Subtotal	253	285
Commercial:		
Electricity	150	163
Fossil	59	62
Subtotal	209	225
Sector Total:		
Electricity	312	346
Fossil	150	164
Total	462	511

Figure 1: Residential Building Energy End-Use



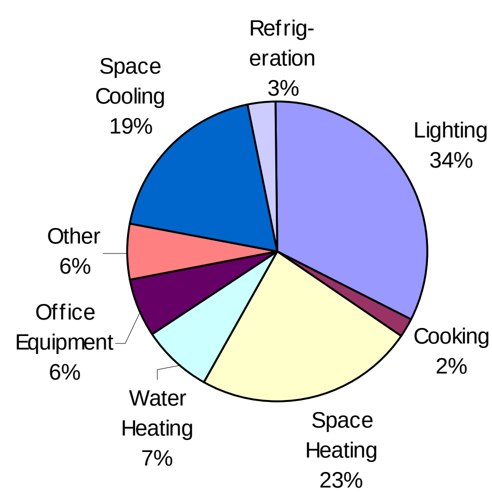
This same flow of resources and production of waste consumes large quantities of energy and contributes to the degradation of resources and the environment. Therefore, an appropriate "whole building" analysis must look beyond just the structure itself and include minimizing these other impacts, through careful selection of building materials and their interactions, more efficient and less wasteful construction methods, and complete "cradle to grave" life cycle analysis of the building. And any policy aimed at accomplishing long-term energy, resource and environmental sustainability in the United States must also address these implications of building construction, use, and demolition.

The Relative Value of Energy Use in Buildings to the US Economy. What is the significance of the residual (measurable) impact of energy, and in particular of building energy use, on the US economy? In 1995 direct expenditures in the United States for energy were $531.6 billion.[19] While this is certainly a significant amount, it only represents 7% of the US GDP for that year. Of that, primary energy use in buildings cost $221.9 billion, or about 42% of total US energy expenditures for that same year, a figure that amounts to only about 3% of US GDP. There was little relative change to these figures for 1997. And we don't export or import buildings, as we do automobiles and other goods (although we certainly do export and import our advanced building technologies), so we do not see buildings as important contributors to US competitiveness in the global economy. As a consequence, energy use in buildings doesn't have the readily apparent economic drivers that stimulate much political interest, let alone aggressive federal programs.

It should now be apparent that buildings must not be thought as mere containers within which to conduct our economic activities, but rather that they have a significant direct and indirect impact on the outcome of those other activities. Our economic analyses are superficially addressed at building first costs and operating costs. But we spend, on the average, 23 hours of each day in buildings and in the built environment.[20] Buildings play a significant role in shaping the attitudes and influencing the quality of the activities of all of those who live and work in them.

The Significance of "External" Building Energy Economics. Energy economics generally involves comparing costs of British Thermal Units (Btu) at the wellhead, or by the barrel, or costs of kilowatt hours at the electric utility busbar, and completely ignores the efficiency of those dollars spent to deliver the desired energy services. That is, which kinds of energy expenditures deliver the greatest benefit to the US economy? Analysis has shown repeatedly that the US GDP receives a considerably greater boost for expenditures on energy efficiency

Figure 2: Commercial and Industrial Building Energy End-Use



and for domestic supplies, for example, than for imported supplies.

But within those boundaries, which types of energy expenditures create the greatest number of new jobs, and how important should that be in making energy resource decisions? Analysis has also shown that investments in energy efficiency and for renewable energy resources yield a greater return to the US economy from enhanced employment opportunities than investments in domestic fossil fuel resources or nuclear generation.[21]

And which types of energy expenditures provide the greatest reduction in costs to mitigate energy-related environmental destruction and to reduce medical costs accruing from human health problems related to energy production and use? Again, expenditures on energy efficiency and renewable energy resources simultaneously reduce these pathological impacts and costs.

But these are all *externalities*, and hence not figured into the normal equation of energy economics. And yet US citizens and businesses actually pay for these costs, so they are certainly not "external" to US economics—"Externalities are not external to society."[22]

Equally significant is the failure to recognize the relative inequity of building energy economics in comparison with the economic value of those who work, buy or learn in buildings. For example, it costs an employer or building owner anywhere from 72 to 100 times as much per square foot of conditioned space to pay for the employee as it does to pay for the energy to condition and light the space for that employee.[23] An action that improves the quality of that space, such as natural daylight illumination, natural ventilation, locally controllable thermal and lighting settings, etc., and which yields even a 1% improvement in employee productivity or reduction in employee absenteeism, provides benefits equal to saving from 70% to 100% of the cost of energy. That, in turn, can often yield a payback of well within one year for expenditures to reduce building energy use, but with the payback resulting from factors other than energy savings.

Experience is accumulating to demonstrate that low energy and daylit building designs reduce employee absenteeism, increase retail sales, and improve the performance of students in schools, and that these improvements tend to be more like 5% to 15%, rather than just 1%. Over a ten-year building life a 10% improvement in employee productivity can be equal in value to the building owner as the entire first cost of the building. And over a forty-year building life a 10% improvement in employee productivity can be worth four times the entire first cost of the building (which by then is only 2% of the costs of owning and operating the building and supporting the employees inside it).[24] These kinds of paybacks are of great importance to employers, store owners, and parents, and must be taken into account in the evaluation of "whole building" benefits to society. (Please see the sidebar "The Bottom Line.")[25]

What Energy Saving Targets and Benefits Are Reasonable or Attainable for Buildings by 2010? In a 1997 Draft of "A Strategic Plan,[26] The US Department of Energy, Office of Building Technology, State and Community Programs, noted that if the 17 million houses and 10 billion square feet of new commercial and industrial buildings yet to be built by the year 2010 could achieve their technical potential of 50% energy savings over current practices (a figure entirely possible and often cost-effectively achieved today using readily available building technologies and design techniques), and if the remaining 76 million houses and 5 million commercial buildings were improved to reduce their energy use by 20% (also readily and cost-effectively achievable today), up to 10 quads of energy could be saved by 2010.

Achieving that technical potential would reduce building energy consumption by one-third, and be equivalent to releasing about 11% of the total US consumption of energy today into other more economically productive energy end-use sectors, while saving $60 billion *annually* in direct energy costs, and bringing the buildings sector down to the 1990 level of carbon emissions. (What is $60 billion/year? Support for about 2.5 million new jobs, or construction costs for approximately 100,000 new schools or 600 major new hospitals, or 1/5 of the projected cost to repair and restore the nation's highways, or about 60 times the present annual US DOE budget for its entire energy efficiency and renewable energy programs.)

The Bottom Line

Quantifiable evidence for the economic impact of productivity gains from placing employees or customers or students in more attractive surroundings is beginning to find its way into the literature. The following summarizes just five of those examples.

- The West Bend Mutual Insurance Company constructed a new 150,000 square foot facility in West Bend Wisconsin with important energy saving features based on integration of shell, interior design, and heating and cooling system design, along with “environmentally responsive workstations” that gave employees control over their own temperature and airflow. The result was a 40 percent reduction in energy consumption and a measured increase of 16 percent in claim-processing productivity, with the bulk of the productivity improvement reported to result from employee appreciation of the building design and systems.
- The best documented and most amazing commercial example is that of Lockheed Missiles and Space Company, which moved 2,700 engineers and support people from an existing building to a new 600,000 square foot facility in Sunnyvale, California, that had been designed for energy efficiency, daylighting, and acoustical and visual comfort. The $2 million extra first-cost was paid back in just four years from energy savings of $500,000 per year, but a measured reduction of 15% in absenteeism by employees who loved their new offices is reported to have actually paid back all costs to Lockheed in the first year. And evidence of a 15% increase in engineering productivity apparently improved their competitive position in winning contracts to the extent that profits generated by the increased productivity are said to have bought the entire building ($50 million) in two years.
- In the 1980’s the Bullocks Department store chain purchased a building in San Jose, California and replaced about one quarter of the roof with translucent tensile fabric that gave very nice daylighting to the merchandise below it. They soon found the sales in that section increased by 15%, regardless of what merchandise was moved into that area, because of the pleasantness of the experience.
- Wal-Mart, one of the nation’s largest department store chains, built its first “Eco-Mart” in Lawrence, Kansas, in 1993, along lines of energy efficiency and sustainability. The latter included the use of sustainably harvested timber and a building shell designed so that it could be later reused for a multi-family housing complex. Due to financial constraints only half of the store was subsequently skylit. Experience then showed the same lesson learned by the Bullocks store in San Jose: sales in the daylit half of the store were significantly higher than in the rest of the store, and also higher than for the same departments in other stores. Wal-Mart has since built two more “Eco-Mart” stores, capitalizing on lessons learned from the first one, with fully integrated architecture, lighting and mechanical systems.
- Two studies of three daylit schools in Johnstone County, North Carolina revealed that the extra costs for the daylighting features, less the savings from downsized mechanical systems resulting from a more efficient building and an integrated design, added a net of about 1% to the total cost of the building (but the buildings themselves came in 5% under budget). The documented energy use showed a one to three-year payback on first costs from energy savings of 22% to 64% compared to typical schools in the same county. But the most important feature was the performance improvement of 5% to 14% by students in the daylit schools on End-Of-Grade and California Achievement Tests compared to students in non-daylit schools in the same County. How important is this “bottom line? Well, how important is it to parents of students in school to know that their children are learning to their potential? And how important is it to have our future leaders be better learners and better educated? This is perhaps the most significant, and least quantifiable, of “external building economics.”

The DOE "Technical Potential" scenario is not fantasy. The 50% energy savings target for new residential and commercial buildings represents what is actually being achieved and documented today, usually at little to no extra cost, in all building types and in all US climates. (Please see the sidebar on "What We Can Accomplish Today With Whole Building Design.")[27] The problem, of course, is that only a handful of such buildings are being designed by a few architects in response to the demand of a few enlightened clients.

This illustrates that the challenge is one of overcoming barriers, a task that will never be accomplished without a new policy that circumvents those barriers by the very nature of the new policy, and which places building technology R&D on an equal footing with technology transformation and market development. That is what is being proposed in this report. This will be greatly facilitated by the continuing development of new and better components, technologies, and design tools, to make the job easier, the tools more accessible, and the results even better.

In the same 1997 Draft Strategic Plan, the US Department of Energy set what they feel to be "realistic" targets in view of the magnitude of the remaining barriers to rapid and widespread deployment of efficiency and renewable energy applications in buildings, reducing their ambitions to just 2 quads of energy saved by the year 2010, and 5 quads by 2020. On the basis of additional reputable studies, a fairly near-term consensus target appears to be emerging among the experts of an achievable goal of about 2 quads of energy savings in buildings by 2010.[28]

In their March 1998 Draft Strategic Plan, the US Department of Energy, Office of Building Technology, State and Community Programs, noted that the 2 Quad goal would still mean "…reducing energy use by 50% in 4.6 million new homes, and 5.6 billion square feet of new commercial floor space, and by reducing energy by 20% in 16.4 million existing homes and 7.9 billion square feet of existing commercial floor space."[29] This would yield $70 billion (even more schools, hospitals, roads, etc.) in cumulative savings, and defray the primary energy equivalent of about 37,000 MW of coal-fired power plants.[30] (This is equivalent to being able to shut down about 60 major 600 MW coal-fired power plants.).

But will this very modest objective be achieved in practice? And couldn't we do much better, since we already know how, and since many of the efficiency and solar technologies to achieve a more aggressive target are presently available and well proven in practice? It is ironic to note that this same target was set 20 years ago by DOE, and should have been achieved by now, but it wasn't. This illustrates the critical nature of addressing the market barriers that prevent realization of these goals, market barriers that must be removed as part of a national "whole buildings" strategy. For example, as noted in the March '98 Draft Strategic Plan,[24] these include

- *"…a lack of reliable and verifiable information*
- *mixed price signals between building owners and tenants*
- *code barriers to adoption of new technologies*
- *the length of the replacement cycle of building components and materials"*

An even more fundamental barrier to the adoption of building energy-saving measures was noted in the report *Energy Innovations*: "…relatively low energy prices that give consumers no motivation to find the lowest-cost technology."[31]

Perhaps an answer to this lies in combining reliable and stable long-term building R&D funding with aggressive campaigns of market development, education, information outreach, and demonstration. Perhaps it also lies in a major way in the exercise of leadership by the federal government. And, as the thesis of this report puts forward, it may well lie in the redefinition of the framework for all of these activities into a set of goals and activities integrated and synthesized around the concept of fostering whole building objectives. All three of these objectives are contained in the Strategic Plan for the "Buildings for the 21st Century" policy umbrella currently under development by DOE, suggesting an important role for the federal government in resteering national building energy strategy. But will that be sufficient?

What We Can Accomplish Today with "Whole Building" Design

- The "Way Station," a 30,000 ft^2 mental health facility in Frederick, Maryland, which opened in 1991, utilized a fully integrated design process to achieve a "climate responsive" building. (See the sidebar "What's in a Name?") The result was a building combining energy efficiency with passive solar energy that cost no more than a conventional building without these measures, but which reduces energy use by 66% and saves $38,000 a year.

- The University of Central Florida's Solar Energy Center, completed in 1995 in Cocoa Beach, is a 45,000 ft^2 daylit building combining offices, classrooms, visitor center and auditorium, that reduces energy use by 40% and electricity use by 75%. It saves $29,000 per year with a simple cost payback of 7.5 years on the added costs of the efficiency measures, except that the cost of the building *with* those measures was average for conventional buildings of that type without such measures.

- The Union of Concerned Scientists redesigned a 30,000 ft^2 six-story building under construction in 1994 adjacent to Harvard Square in Cambridge, Massachusetts, for its own national headquarters, while only increasing building costs by $1 per ft^2. Under stringent conditions because of the advanced stage of the building design, they still achieved an energy saving for heating and cooling the entire building of 30% to 50% compared to comparable new buildings in the area. The two UCS office floors were fully daylit, outfitted at a cost that was *less* than the outfitting costs of the other non-daylit floors in the same building, while reducing energy use for lighting on those floors by a *measured* amount of 80%, a figure low enough to be met by the output of a small rooftop photovoltaic system.

- In 1983 a magazine publisher well known in the West, Sunset Magazine, built a new office building, "Willow West," in Menlo Park, California, that reduced energy use by close to 80% compared to the stringent California building efficiency standards. There was no added cost, since the direct-coupled ground-water cooling system was so much less expensive than compressor chilling, offsetting all costs for the daylighting hardware and controls which also facilitated an economic downsizing of the ground coupled system.

- A tract builder in Reno, Nevada, Neuffer Construction, built over 400 passive solar tract homes in a ten year period, culminating in the early 1990's with a tract design that needed no cooling and which reduced heating costs by 50% from passive solar, in addition to even lower costs from energy efficiency measures. The total extra cost for these homes was about 1% of the sales price, leading to a condition in which utility incentives for the solar features could satisfy all utility requirements for rate-based savings in comparison with new natural gas service. The low energy costs provided for enhanced mortgage financing, causing the builder to estimate that the potential buyer market for his homes was increased by about 30%.

- A development of 23 $70,000 rowhouses was constructed in 1984 in North Philadelphia, combining energy efficiency with passive solar design. The reduction in energy use was 63% at no added cost, since the measures did not add any cost to the construction.

- A 2,530 ft^2 two-story 5-bedroom factory-built colonial house was constructed in 1995 in Falmouth Maine, featuring energy efficiency, passive solar, and a rooftop solar-electric system. It was built for $35,000 *less* than comparable custom homes in the area without these features, while reducing energy use by 82%.

- A 3,000 ft^2 custom home was constructed in Stevens Point Wisconsin for the same cost as other custom homes in the area, but the efficiency and passive solar design features reduced the heating energy use of the home in that harsh climate by 70%.

- Pacific Gas and Electric's ACT^2 program (Advanced Customer Technology Test for Maximum Energy Efficiency) integrated up to 27 energy efficiency measures and advanced technologies. Energy savings with favorable cost/benefit ratios for the utility ranged from 42% to 64% in their commercial projects, and 52% to 54% in their residential projects.

Why Should the Federal Government Be Involved in "Whole Building" Research and Support?

It is not just a question of figuring out how to develop and implement a "whole buildings" R&D program. As discussed above, public acceptance of the fruits of R&D is also necessary to produce real market transformations before any effects can be felt by society at large, which means that R&D and market development must always go hand in hand. And it will also be necessary to determine whether this work should be primarily conducted by private or public agencies and organizations. This goes to the heart of defining "public goods" research, as well as to recognizing that the fragmented nature of the buildings industry requires a steady hand on the research helm by some agency or structure other than itself. The buildings industry is both structurally incapable and economically unmotivated to take responsibility for the required level of research and strategic coordination that can yield major societal economic and environmental benefits.

In 1995 163,000 architects in the United States contributed to the work of almost 4 million construction workers in 130,600 commercial building companies, with perhaps close to 300,000 additional individual contractors (without payrolls). And about 90% of the homes constructed were not custom designed, but rather designed in-house by development companies. Decisions were made by hundreds of thousands of architects, hundreds of thousands of builders, and an even greater number of engineers, plumbers, electricians, and purchasers. They were largely individual decisions, made in an entirely decentralized framework. There is no natural coordination of this kind of activity. The fragmentation is intrinsic to the business, resulting in part from the mostly local nature of the building activity. So how can the building industry be expected to pull itself together into a coordinated "whole buildings" policy framework that produces low energy and healthy buildings? And why would it even want to, unless it can be shown that there is something in it for them?

All participants in the building industry are constrained by public safety codes, and many by building energy standards. This is government stepping in to set boundary conditions that yield benefits to the public. It does not hurt competition, for it is required of all. A deeper government involvement in fostering innovation and reorientation within the building industry is therefore a natural follow-up to this.

But should the "hand at the helm" be the federal government? This question is left open and revisited in the final policy portion of this report. It is undeniable, though, that the federal government will have to play the dominant role in defining and supporting whole buildings research, even if that research is coordinated with the private sector and across the multitude of dimensions embodied in the definition of "whole buildings" by another agency or structure. There is simply no other agency or structure that could support the multi-faceted research that this will continue to require. And this will require increased funding beyond today's levels of federal building support.[32] But what will stimulate Federal Government interest in defining and conducting a long-term stable "whole buildings" research effort? And what will stimulate Congress to provide the equally stable and long-term funding for that effort?

It was earlier noted in this report that energy use in buildings doesn't have the strong economic drivers that stimulate much political interest, let alone aggressive federal programs. But from the standpoint of protecting the financial interests of its citizens, this should really not be the case. The 1995 annual energy bill of $531.6 billion spread over 99.1 million households suggests a national energy bill of over $5,300 per household, or on the order of $2,100 for every citizen of this country.[33] And it is the citizens who pay for this, both directly to the utility company and at the gas pump, or indirectly in the embodied energy costs of all goods and services consumed.

Citizens only see the direct energy bills that they pay. Still, the 1995 national residential energy bill was $1,291 per household,[34] which hit directly at the home pocketbook. Citizens, often with help from the Federal government, can indeed do something about this. For example, the Federal Government can reward the low-income homeowners with over $1,000 of weatherization assistance, which has reduced the energy bills of 4.4 million US homes through 1995 by 20–25%.[35] And it can reward homebuyers in seven states now with mortgage cost-reductions from pilot home energy rating systems (HERS), and with more expected to participate in a national program in FY '98.[36]

An additional reason for the Federal Government to stand up and take notice of the economic value of the building sector is that the 1995 value of new construction was $396.5 billion, representing 5.5% of US Gross Domestic Product.[37] Including the $250 billion spent on building renovation raises this to $646 billion, over 8% of 1995 GDP. And taking into account the value of material and equipment suppliers, the buildings sector can probably account for 10% of GDP.[38] This is a hugely important industry.

But there are much more fundamental drivers beyond mere economic self-interest for the Federal Government to provide reliable and stable "whole buildings" research support. The PCAST report on "Federal Energy Research and Development for the Challenges of the 21st Century" noted that "Public sector R&D funding has the responsibility for addressing needs and opportunities where the potential benefits to society warrant a greater investment that the prospective returns to the private sector can elicit."[39] And a strong case can be made for the constitutional obligation of the Federal Government to support research that affects the health, welfare and safety of citizens, which buildings most certainly do.

Do we see evidence of this need for Federally supported "public goods" research in the building industry? Definitely yes. It has been estimated that the US construction industry spends between 0.2%[40] and 0.39%[41] of sales on R&D, while US homebuilding spends 0.25%[42] of sales on research. US contractors spend 0.00125% of sales on research while Japanese contractors spend over 300 times that much (still only 0.4% of sales).[43] This is to be contrasted with a US industry average R&D investment of 3.5% of sales, and international industry average expenditure on R&D at a rate of 4.3% of sales. So US buildings research is seriously underfunded by the buildings industry.

It is not necessary to appeal only to the Federal Government's altruistic responsibilities, though, to argue for support of "public goods" research, especially in buildings. A 1995 report by the Council of Economic Advisors (CEA) noted that while returns from privately funded R&D are generally 20% to 30%, "social" returns can be 50% or higher (and this includes energy and environmental benefits).[44]

DOE has published estimated net present value (1996) benefits of $28 billion from just five of the myriads of technologies supported with $8 billion in energy-efficiency R&D expenditures from 1978 through FY 1994, including a reduction in annual carbon emissions of 16 million Metric tons.[45] Three of those technologies relate directly to whole building performance (building design software, electronic ballasts, and low-emissivity windows), with the greatest return on DOE investment ('96 net present value of $11 billion) from DOE's support for building design software.[46]

So where does the Federal Government stand now in its building research efforts? What is being proposed in this report to consolidate, expand, and assure this mission for the future? And where should the "whole buildings" coordination be housed? To address these questions, this report first steps back to clarify what buildings actually do (hence, the basis of their "wholeness"), and then to show the historical emergence of a whole buildings descriptive perspective.

What Buildings Do, And Why They Do It

Why does a Building Need Energy Inputs? A conventional building constantly interacts through its skin and windows and ventilation system with the ever-changing outside world. Those portions of the heating and cooling comfort and lighting needs of the building occupants that are not provided by the building's natural response at any moment are provided by energy-driven thermal and lighting systems installed in the building. The extra energy resource needs of its occupants, such as power for computers, must also be provided.

A building is, therefore, by definition, a "whole" physical object, and it also behaves as a "whole" dynamic system, both internally and in the larger coordinate system that includes its direct and induced interactions with the natural world. But a building doesn't actually care what temperature it is, or whether it is light or dark inside. The function, of course, is to provide for the comfort and productivity of its occupants.

Building heating goes back centuries, beginning by orientation and design to capture the sun's heat, supplemented by wood in fireplaces. That was followed by wood in stoves, and then to wood, coal and later oil in central furnaces. Today natural gas and electricity are the preferred choices for providing heat. The comfort and efficiency of heating was dramatically improved by the introduction of insulation. But through the late 1800s the lighting and cooling functions of buildings had to be provided by careful design of the building itself, using shading, natural ventilation, and daylight.

The advent of electrical lighting technologies and compressor cooling devices allowed buildings to be sealed off from direct interaction with the immediate environment, with all internal needs assured by thermostatic control and light switches. This change began to transform the building market in the late '40s and early '50s.

The result of this is that a building now uses energy to counteract its own intrinsic response to environmental changes. The internal thermal needs are basically met by heating and cooling systems that mitigate the natural response of the building: as the building loses heat in winter, heat must be reintroduced to maintain a comfortable temperature for the occupants, or as the building absorbs excessive heat in summer it must be rejected to maintain comfort. The building's internal lighting systems compensate for inadequate natural lighting, while shades and blinds compensate for glare or local overheating. And the heat from the bodies of the occupants, from all of the lights, and from all of the energy-using devices (computers, copy machines, etc.) can add additional loads to the building's cooling system. All of this energy-consuming compensation for the natural pathology of buildings goes on constantly and simultaneously.

What is often forgotten is that the productivity of the building occupants, which defines their economic value to the owners of commercial buildings, or the sales of products, which define the economic benefits to store owners, or the performance of children in school, which yields delayed economic benefits to all of society, are not determined merely by being warm enough, or cool enough, or having a sufficient quantity of light. It is increasingly understood that the quality of the space enhances all of these benefits. (Please see the Sidebar "The Bottom Line"). And it is also becoming understood that the perceived quality of the space derives in part from the user's ability to have personal control over the comfort and lighting conditions, from the use of high quality electronic lighting components, and from the ability to enjoy fresh air and to work, buy or study by natural light.

One of the great gifts of passive solar buildings, daylit buildings, and energy efficient "climate responsive" buildings to the US economy is that the very design practices which deliver their great energy efficiency improvements also yield the very conditions that enhance the pleasurableness of the space and the performance or productivity of their users. (Please see the sidebar "What's in a Name?")

How Can These Inputs Be Reduced from Within the Building? That all of these activities actually interact through physical feedback has led to energy saving approaches, such as energy management system (EMS) computers that constantly analyze sensor inputs to reveal the state of each energy system, and that seek to optimize that state and minimize its adverse interactions. In this sense, an EMS seeks to manage a building's functions as a single "whole" system of functions.

Important research over the years has led to components that have dramatically reduced both the energy demand of buildings and the magnitude of internal energy-consuming interactions within them. These include more efficient windows, more efficient heating and cooling components and systems, more efficient lamps and light fixtures, and more sensible and sensitive interior design for enhanced productivity.

Equally important has been the result of both research and experience that now enables designers to select materials and to design building envelopes, windows, and interiors that respond naturally to provide the comfort requirements of their occupants, so that a building will be warm when desired, or stay cool when desired, and with often sufficient illumination from natural light, delivered in glare-free environments.

What's in a Name?

Often people are referring to "whole building" perspectives while using other more common terminology, such as "passive solar buildings ", or "climate responsive buildings," or "climate adapted buildings," or "low energy buildings." Each of these, however, is a subset of the larger "whole building" concept.

Nevertheless each of these sometimes alternative descriptions carries considerable meaning in the accomplishment of a "whole buildings' perspective. "Passive solar" is worth its own Sidebar in this brief. "Climate responsive" and "climate adapted" are actually synonymous. They refer to the ability of the building, through the interaction with the climate of its exterior and interior design and its structural materials, to respond in ways which are consistent with the comfort, lighting and productivity needs of the occupants. As discussed in this brief, this relegates heating, cooling and lighting systems to secondary or back-up roles.

This not only saves a great deal of energy, it also allows for economic downsizing of heating and cooling equipment, with the resultant savings applied, for example, to better glass, greater insulation, or the more massive exposed interior surfaces which together help to yield the desired performance of the building. In some fortunate circumstances, these economic trade-offs can even balance one another out, leading to no, or very little, impact on the overall budget for the building construction. At the very least the increase in performance of the building is gained with a much smaller proportionate increase in building cost, accelerating the cost-payback of those extra expenses.

The descriptive "low energy buildings" is perhaps closer to the ultimate aim. For example the program under which the new building design tool, Energy 10, was developed by the National Renewable Energy Laboratory (NREL) in concert with the Passive Solar Industries Council (PSIC), and which features 16 interacting energy, solar and technology variables in its extremely user-friendly decision-making guidance to the user, is called "Designing Low Energy Buildings" (DLEB).

But it is the thesis of this report that, while attaining "low energy buildings" is one of the goals, it is still not adequately inclusive. (See the Sidebar "Whole Buildings" for aspects that go beyond energy.) So the convention that is adopted throughout this report is to formulate the more encompassing framework "whole buildings."

In this case, the building's own mechanical and lighting systems become back-ups, "touching up" conditions only when necessary, or over much reduced ranges of demand, or for less frequent or shorter times. And energy management is largely regulated locally, for example with locally responsive lighting controls, supported by locally controllable heating and cooling systems to meet the needs and wishes of each user when environmental thermal and illumination resources and fresh air through open windows do not deliver sufficient comfort.

This has proven to be a much more certain way to accomplish energy efficiency than to try to force an efficient result through the mere use of efficient components and "smart" central energy management systems. That is, too often we put "smart" brains into architecturally "dumb" buildings, leading to energy reductions that are far less than those that could be delivered by buildings that are designed and assembled to respond in more comfortable ways internally to changing conditions outside.

How Can These Inputs Be Reduced from Outside the Building? Designing buildings to respond compatibly to the natural environment also means to provide opportunities by design for the building to utilize environmental resources directly. This includes a host of possible design integrations of "passive" energy gain or heating impact mitigation measures, such as passive solar heating for residences and small commercial office buildings, solar air preheating through ventilated building skins on commercial buildings, solar water heating, natural cooling, and daylighting. (Please see the sidebar "Passive Solar Buildings.")

And it includes a portfolio of possible natural cooling techniques, starting as simply but powerfully with shade from carefully located trees and light colored or otherwise heat-rejecting exterior surface coatings, and including exterior building-integrated shading elements, natural cooling ventilation (either fan-forced or through operable windows), or by nighttime flushing of heat accumulated and stored during the day in building interior mass elements, and by evaporative cooling assist. New building component technologies are greatly enhancing these results, including window coatings to cut out unwanted heat gains in hot climates while still letting in natural light.

Ground coupled heat pumps that utilize the natural thermal capacity of the earth, or sometimes of ground water, can further lower energy costs and demands for heating and cooling. And daylighting (which uses solar energy for its light, rather than heating, value) is a profound resource both for diminishing the direct (illumination) and indirect (cooling) energy demands of lighting and for enhancing the quality of the space and improving the productivity of its users.

And lastly, exciting developments in building-integrated photovoltaics enable building components to generate electricity, so that residences and small commercial buildings can now utilize the significant surface areas available even after dedicating some of them for passive solar or solar water heating. This, in turn, can contribute toward the 50% energy-saving goal for all new buildings, while the buildings themselves contribute economic value to the utility grid as "distributed utility" generators and peak-load shaving resources during the daytime. Site-specific electricity generation has also been shown to reduce wear and tear on the electricity delivery infrastructure, adding to the lifetime of its components, and saving the utilities money from lengthened replacement and maintenance schedules.

Larger commercial buildings can use building-integrated PV shading devices in synergy with daylighting control requirements, with the electricity generated delivered to the building's internal distribution panel to reduce and manage peak load demands and charges caused by the other building systems. PV skylights, shingles and roofing tiles, and PV glass curtain wall components, are now also on the market. Transparent PV windows are well along in the laboratory.

The description of these new technology options for reducing building energy use by capitalizing on available environmental resources at the building site also reinforces the need to take a "whole building" perspective in the application of multiple energy-saving strategies. This is because passive solar heating can deliver up to six times more energy per square foot of area, and solar water heating can deliver up to three times more energy per square foot, than solar electricity.[47] An evolving federal and public excitement for "solar roofs" must be tempered by careful analyses to utilize building components in such synergy that the greatest energy and cost saving potential is realized by the design.

This means that buildings should be designed to utilize the thermal energy potential of solar energy first, and then to seek to meet the desired fraction of electricity needs through solar electric devices second. (This is set by a combination of costs and available unshaded surface area.) Experience has shown that a careful integration of passive solar and daylighting into buildings, however, can usually leave ample space for the production of electricity by solar energy as well. This condition need not cause design incompatibilities, but only provided that both heat and electricity from the sun are simultaneous design goals right from the start. And new products just coming on the market today integrate the two functions of electricity production and water or air heating into single devices, which further reduces the building surface area that is required.

How Can a "Whole Building" Framework Improve on This? So what, then, does a "whole building" perspective and approach add to all of these advances already in place, or emerging? Consider an analogy: an optimal (let alone functioning) human organism cannot be assembled in a manufacturing plant from blood, bone and tissue, and the complexity of the assembly instructions in the DNA and genes will apparently take the best computers in the world at least ten more years just to document (the human "genome" project). One can then appreciate that the

PASSIVE SOLAR BUILDINGS

The concept of "Passive Solar Buildings" deserves its own attention, both from its inherent linking of internal building performance and comfort to external solar energy resources, and from its great historical importance in driving the early evolution of a "whole buildings" perspective. In addition, the industries and policy makers involved today in moving passive solar buildings into the mainstream of U.S. design and construction practices are also the leaders of the move to unify building description and R&D into the all-encompassing "whole buildings" framework.

In its most elemental form, "passive solar" describes a building that

- gains and distributes its energy from the sun either as heat or as light or both without resorting to mechanical means for collection and distribution, and that
- serves the three functions of collection, storage, and distribution. (These functions can be accomplished with various degrees of complexity, and singly or in combination.)

But while this is the generally-accepted working definition of passive solar, it necessarily goes hand-in-hand with the requirement that the building

- stays naturally cooled during hot seasons through proper shading, natural ventilation, and a choice of building materials that can store heat in the winter and allow for its avoidance or dissipation in the summer.

Properly designed passive solar buildings are therefore more comfortable and utilize less energy in both summer and winter. A properly designed passive solar building also features careful interior design, to provide for physical thermal and visual comfort of the occupants throughout the interior.

One of the most important aspects of passive solar buildings is their dependence on appropriate building technologies and the related industries that make these technologies available to designers and builders.

As R&D on passive solar components improves their performance, or as new technologies are introduced which can expand the capabilities of building elements to deliver efficiency and comfort, the spectrum of possible designs and the value of the "whole building" end result continue to expand.

Recent and emerging successes from the laboratory to the field include, for example,

- coated glass that is spectrally selective, or switchable glass that can be either clear or opaque;
- concrete and brick materials with better thermal and structural properties;
- wood windows and doors with inherently sound thermal performance and longer lifetimes;
- better insulating materials to improve thermal performance and construction convenience;
- high reflectance acoustical tiles to promote daylight penetration deeper into the interior of buildings; and even
- solar electric cells mounted in conventional building skin elements or incorporated within the window glass itself.

Passive solar strategies reduce building loads, and therefore make other applications of renewables more feasible. A home designed for passive thermal heating and energy efficiency therefore can get by with a much smaller solar electric system that can still deliver a significant fraction of home electricity requirements.

The ability to identify those technologies during the design phase and to know that the best interactive mix of technologies is being adopted depends upon design tools that are both easy to use and sophisticated in their hidden abilities to simulate interactions and results. These are currently being developed by the U.S. DOE, by private sources, and by the industries themselves.

All of these technologies and more are being developed and introduced by the spectrum of members of the national "Passive Solar Industries Council", and supported by the government and organizational and consulting members of the PSIC. But while major developments have greatly enhanced the performance of passive solar and "whole buildings", the opportunity for continued improvement is significant. Past and present successes only underscore the need for continued and reliable R&D on building technologies.

expanding opportunity afforded by the increasing number of energy saving components and design approaches for buildings also compounds the complexity of interrelationships. As a result, there is no guarantee that a designer will have the wisdom to select these in optimal combination. That is, both the availability of, and interactions between, environmental energies, energy efficient devices, other building energy using and supporting measures, the very materials from which the building is constructed, and the workings of the US economy, lend a complexity that can even lead to inappropriate strategies in the final design from ignorance of the importance of their interactions.

A sure way to guarantee such an unfortunate result is to select components or design elements one by one according to their individual capacity to save energy, rather than to appraise the performance of the combination of all of these potential measures in their actual interactive roles. This is incredibly difficult—well beyond the capacity of any one designer, and demanding the kinds of design tools that are just now beginning to emerge (e.g., Energy 10), but are still in their infancy. Yet it is this very integrated approach that is necessary to assure optimal performance by the whole building in the sum of its interacting internal and external functions.

The Emergence of a "Whole Building" R&D Framework

Evolving Recognition of the Concept, and its Link to Solar Energy In 1989, in a report prepared for the AIA/ASCA Research Council, Donald Watson, FAIA, identified as a longer-term initiative to improve the climate for innovation (in the United State building industry), the need for a "whole systems" innovation in building.[48] That report went on to identify an "Applied R&D" need that was identified to be crosscutting between the public sector and the private sector, arising from "Lack of 'whole-systems integration and innovation in building."[49]

In 1992 the AIA/ACSA Council on Architectural Research held a Symposium entitled "Architectural and Building Research Needs and Opportunities in the 1990s." Editor Watson's Foreword to the Proceedings of that event stressed an expanded concept of "total building performance" to include the building within the context of its larger societal demands and impacts.[50] Watson further revealed in a 1997 publication that "passive solar" was always considered to be an explicit component of the AIA's emerging "whole systems" design concept:[51]

> *In sum, passive solar/climate responsive/ energy-efficient design concepts and technologies provide a simple and straight-forward way to assure that all buildings are designed with integrated architectural, mechanical engineering and lighting systems that improve the total quality of the building, its interior and surrounding landscape and environment.*

The inseparable relationship between passive solar and energy efficiency in buildings had been firmly established as Federal policy in The Energy Policy Act of 1992 (EPAct), when "standards" referred to in the Act were required to "…contain energy saving and renewable energy specifications."[52]

EPAct was also the origin of the Home Energy Rating System (HERS), which included the explicit instructions to "…provide that rating systems take into account local climate conditions and…solar energy collected on-site…."[53] As noted and footnoted earlier, seven states have DOE pilot programs to identify barriers to energy efficiency financing.

This policy was echoed two years later when President Clinton issued Executive Order 12902 on March 8, 1994. In that, in his instructions to federal agencies to achieve a 30% reduction in energy use in federal facilities by 2005 (relative to a 1985 baseline) the President admonished:[54]

> *Each agency involved in the construction of a new facility that is to be either owned or leased to the Federal Government shall: (1) design and construct such facility to minimize the life cycle cost of the facility by utilizing energy efficiency, …or solar or other renewable energy technologies;…and (4) utilize passive solar design and adopt active solar technologies where they are cost-effective.*

This, unfortunately, leaves both "cost-effective" and "life cycle" completely undefined, but the implication is certainly there that a building's "cost" is more than just the construction cost.

The Evolution of a "Whole Buildings" Perspective Within Federal R&D. Listing passive solar and energy efficiency in the same pronouncement does not necessarily imply a "whole building" integration of the two into federal R&D programs. Many elements of the passive solar research program of the late 1970s and very early 1980s, however, conducted by the US DOE under the able direction of Dr. Fred Morse, contained elements that would seem today to define integrated building design, even though that office of DOE was divided into separate efficiency and renewable energy program arms. Although that integrated perspective waned in the intervening years, DOE has resuscitated the concept with programs including the following.

The DOE-industry collaborative residential program, "Building America," is described as taking a systems engineering (whole building) approach to the design, construction and sale of buildings. Its purpose to foster "a systems engineering approach" so that "decisions previously made independently can quickly be made with consideration for the entire design, manufacturing, and construction process…"[55] certainly describes a framework appropriate to the application of a "whole buildings" program as well.

The "Exemplary Buildings Program," which is within DOE's Building America Program, is described by DOE as a design-oriented program that combines better design with the use of passive solar, energy efficiency, and renewable energy technologies. Again we see some of the kind of integration necessary for a "whole buildings" perspective. But it is not yet sufficient.

The present DOE effort with the clearest mandate to pursue "whole building" goals is the "Buildings for the 21st Century" umbrella strategy being developed to integrate design, advanced materials and equipment, and construction strategies within a single whole buildings framework. The objective of that strategy is "…to instill a whole new way of thinking about buildings… from a 'whole building' or systems engineering perspective…."[56] In a later draft Strategic Plan the "systems engineering perspective" element is explained as "Systems integration research and development …analyzes building components and systems and integrates them so that the overall building performance is greater than the sum of its parts."[57]

This has been confirmed throughout developments of this strategy framework. On December 4–5, 1996, 112 leaders in building policy and research were invited to an opening meeting of the Buildings for the 21st Century activity to "…help accelerate the adoption of the whole buildings or systems integration approach…."[58] The 31 who responded and were in attendance included public, private, nonprofit and community leaders, joined by 20 staff members from the US Department of Energy and four of its national laboratories. A follow-up meeting was held in March, 1997. In these two meetings, the "priority items" identified for Buildings for the 21st Century were to "…advance the concept and practice of a Whole Building approach to the design, siting, construction, operation, maintenance, upgrade, and disposal of buildings." Included was the all-important parallel activity "marketing the whole building approach." And a priority of this plan was to "Create an over arching whole building energy R&D plan for the United States."[59]

The Draft "Synthesis Action Plan" under Buildings for the 21st Century included, as a goal of the Education and Training Program, "The goal of this area is to foster the acceptance of the whole buildings concept…" and under the Public Awareness Campaign "The goal is to…increase the demand for sustainable buildings," thereby extending the strategy framework out in time.[60]

The US EPA Energy Star Buildings Program describes itself as "…a five stage implementation strategy that takes advantage of building system interactions…."[61] An aim of this strategy is to downsize HVAC components through accurate analysis of the combined effect of the strategies, to reduce first costs and energy costs. So here, too, we see some elements of a "whole buildings" approach, and a considerable conceptual and functional advance from the earlier EPA "Green Lights" program.

The EPA Energy Star Buildings Program is also a good example of federal inter-agency cooperation, since this is a joint program with the DOE. EPA does the marketing and DOE does the technical evaluation. So all of this is a start, but all of the pieces cited in this report do not constitute an integrated federal "whole buildings" program. They are at best very modestly funded, if at all, and the Buildings for the

21st Century framework has been developing plans for two years.

The Evolution of a "Whole Buildings" Framework in International R&D. "Whole building" research has also emerged internationally, in several of the tasks of the International Energy Agency (IEA). For example, Task 13 (completed in 1994), "Advanced Solar Low Energy Buildings," encompassed at least the integration of energy efficiency and the application of renewable energy to single-family and multi-family residential buildings.[62] IEA Task 20 (to be completed in 1998), "Solar Energy in Building Renovation," adopted the aim of exploring concepts "…from the perspective of their impact on building thermal performance, visual comfort, environmental impact, and economic performance."[63]

Probably the closest IEA Task for promoting R&D with a "whole buildings" perspective is Task 23 (1997–2002), "Optimization of Solar Energy Use in Large Buildings," where[64]

> *The main objective…is to ensure the most appropriate use of solar energy in each specific building project, for the purpose of optimizing the use of solar energy…by enabling the building designers to carry out trade-off analyses between the need for and potential use of energy conservation, daylighting, passive solar, active solar, and photovoltaic technologies in systematic design processes. In addition, the objective of the Task is to ensure that the buildings promote sustainable development. This is done by including considerations of other resource use and of local and global environmental impact in the trade-off analyses to be carried out.*

TABLE 4
Appropriations for Federal Building Technologies Programs by Category (in millions of $)

Category	Fiscal Year 1996	Fiscal Year 1997	Fiscal Year 1998
Systems and Design	34.6	34.9	34.6
Components	52.2	51.2	53.0
Equipment	101.3	102.0	107.1
Complementary Programs	209.4	229.5	240.8
Federal Coordinating Programs*	18.3	19.8	19.8
Safety, Health, and Loss Reduction	20.3	20.6	21.1
TOTALS	436.1	458.0	476.4

* This figure does not include the billions spent annually by GSA through the Federal Buildings Fund on the construction and operation of federal facilities. These activities, however, are not R&D or technology development related per se.

Federal Buildings R&D and "Whole Buildings"

Where We Are Now. A remarkably useful and comprehensive "Overview of the Building Technologies Programs in the Federal Sector," which examines seven of the major Federal building technologies programs by category, has recently been prepared and submitted to the Passive Solar Industries Council.[65] The following comments are extracted from that review, as is the summary Table 4 included in this report. Lengthier program descriptions, organized by the federal agencies that administer the programs, were provided to the PSIC in a companion report.[66]

> *In fiscal year 1998, the Federal Government will spend approximately $476 million on buildings R&D and related technology programs. The largest proportion of that investment (roughly 50 percent) was directed toward complementary, non-R&D programs such as weatherization and community development and programs to improve market adoption of new technologies. [$125 million of the $240 .8 million in FY '98 spent on complementary areas will go to the weatherization of low-income and elderly households.] Building equipment, systems and design, and building components programs received a much smaller share of federal investment (roughly 22, 7 and 11 percent, respectively). Programs aimed specifically at energy consumption in buildings are an even smaller subset of these groups. R&D*

programs to develop more energy efficient building materials, equipment, and design receive minimal funding when compared with basic science and engineering programs or in comparison with complementary programs such as the Weatherization Assistance Program.…

The vast majority of programs address buildings as components rather than as integrated systems. Funding for the few whole buildings programs that exist is insignificant in comparison to the breadth of building-related programs in general. With relatively scant funding directed toward specific integrated, whole building R&D programs, it is clear that the potential economic and environmental benefits of addressing building performance as a function of integrated systems are going unrealized.

It is actually not possible to ascribe any particular amount of funding toward federally supported "whole buildings" programs identified in Hochanadel's analysis. And the fine Buildings for the 21st Century framework, an unfunded idea since late 1996, still does not identify or direct any specific funding toward accomplishing the "whole building" coordination that it proposes. (But, in all fairness, it did provide helpful guidance to DOE FY 2000 budget requests.) This demonstrates that "whole buildings" is still seen only as an abstract concept, rather than as a concrete program element deserving of support in its own right. The following addresses this inadequacy.

Where We Need to Go. Certainly a major importance of "whole buildings" will be to serve as a coordinating framework for streamlining the multitude of federal buildings programs and for building a bridge to cooperative and complementary buildings R&D programs by the industry and private sector. But this in itself, along with the needed formalism to define an R&D framework within the all-encompassing "whole buildings" scope, is a program element in its own right.

If "whole buildings" is to affect change, it must be elevated to a high level of administrative responsibility and respect. "Whole buildings" must secure a mandate simultaneously from the Federal government, the industry, and private sector research centers to coordinate, enhance, supplement, complement, and fill in gaps that are still barriers to systems integration in research and practice. It is deserving of its own clearly identified programmatic mission, supported by sufficient appropriations. It must have a staff, budget and structure, but less centralized and more distributed in the field as support for existing buildings R&D structures, aiding in the coordination of their missions with the work of others.

"Whole buildings" needs to establish goals, with timetables and benchmarks. It needs to begin its work of structural reorganization, synthesis and coordination of the nation's buildings R&D strategies, bridging Federal, State, industry and other private sector activities, and placing present research in the context of a sustainable future. It needs to fold applied research together with the essential elements of marketing and market transformation, training and education, and stimulated awareness of the central importance of buildings to our economy, environment and personal well being.

It is a thesis of this report that no substantive advances will be made in any of these directions without the emergence of "whole buildings" by common consent as a program that is essential to all others, and the official establishment of that program—somewhere. Paraphrasing Hochanadel's observation presented earlier, the potential economic and environmental benefits awaiting as rewards from addressing building performance as a function of integrated systems will go unclaimed until we do so.

Elements of a "Whole Buildings" National R&D Strategy

Some Framing Assumptions. Describing an important need and obvious benefits does not produce change. Something as inherently complex as "whole buildings" can actually *increase* resistance to change. Change can be "pushed" by regulation or an Executive Order. Even better, though, is to "pull" change with enough examples to show that what is being sold is a better mousetrap that more people value and want, and to accompany this with very careful and targeted information outreach, and market development and stimulation.

The building industry resists change simply because it has little economic incentive to make changes that don't relate directly to increased sales. As mentioned earlier in this report, the most promising circumvention of these barriers is to generate demand for better buildings, and that can only come from experience that can be seen and replicated, and from educating buyers to the astonishing benefits of low energy, solar and daylit buildings.

A fine distinction needs to be made here between "policy" and R&D, and between "strategy" and just better program management. This report is arguing for the introduction of a new "policy" of "whole buildings" that both transcends and encompasses existing national buildings policy and R&D simultaneously, while bridging from government to the private sector, and from the present to the principles of future sustainability. It argues for a national "strategy" that can be the underpinnings of that policy, incorporating a synthesis of the integrated way buildings work, and featuring a proper elevation of buildings R&D to a position commensurate with their great and underappreciated contributions to the US economy.

But this report has chosen to focus on the R&D element of both policy and strategy, since those are the programs most clearly identifiable and funded today, in both public and private sectors. The importance of this concluding section, however, is to underscore that in a "whole buildings" perspective the definition of R&D itself extends well beyond the laboratory to encompass the ancillary activities, such as training and education and market transformation, that carry the R&D out of the laboratory and into productive contributions to society.

In the following, generic action points are first offered, which collectively are designed to take us from here to there—from the present state of fragmented policy and programs to a synthesized and coordinated "whole buildings" policy framework. Each is then followed by a sampling of recommendations to begin to move us along that path. But first we consider what that framework might be.

Who Should Be at the "Whole Buildings" R&D Helm? Where will the central direction—the nerve center—of this grand "whole buildings" synthesis activity even be housed? There is no question that the US Department of Energy is, and will continue to be, the centrally important agency for the conduct of buildings R&D in its own laboratories, in contracts to other organizations and institutions, and through partnerships with sectors of the building industry. And DOE has already defined the goals for a major synthesis framework for building R&D programs, Buildings for the 21st Century, that encompasses a national scope, including a "national marketing program" and work with the finance and insurance industries.

But, as Hochanadel argues, "The need for an integrated focus on 'whole buildings' is mirrored by a need for an integrated, coordinated focus on the portfolio of federal building technologies programs."[67] Can one government entity "coordinate" the work of others? Certainly there are a number of committees and panels already charged with this responsibility. But Hochanadel questions the "…degree to which the efforts of groups such as the National Science and Technology Council's (NSTC) Committee on Construction and Building or the Building Environment and Thermal Envelope Council (BETEC) can be translated to concrete program direction for the numerous disaggregated federal buildings programs."[68] And this report proposes that this be far more than mere coordination of activities being carried out by others, since the entire "whole buildings" concept introduces new elements into R&D and all of the related finance and marketing programs that need to be framed within this larger concept.

Should this coordination, then, including a new in-house capability to conduct or supervise the bridging "whole building" R&D activities, come out of a structure established by an industrial coalition, since they will reap the rewards of the very programs that they coordinate? As both participants in the work and recipients of the benefits of that R&D, an industry-centered structure might facilitate more easily those R&D aspects that link and reduce the fragmentation of the diverse elements of itself. But how could such an entity then coordinate federal programs, if it is not one of them? And judging from the little R&D funding by the building industry to date, the federal government would still need to be the primary source of support for this new activity. The American public would also certainly reap the rewards of a coordinated federal program in buildings R&D, technology transfer, and marketing.

This report will not make a recommendation, although possible suggestions are put forth in the next section. But this report appeals for keeping an open mind on possibly creating and implementing such a new structure in order to assure an administrative framework that serves the widest possible public interest across all sectors, throughout the entire country, to the benefit of all stakeholders, and with maximum contribution toward elements of sustainability.

What Criteria Should Be Encompassed by a New "Whole Buildings" R&D Strategy? In the interest of brevity, but with the risk of possible oversimplification, the following five principles can represent a beginning set of policy criteria to promote the adoption, successful introduction, and continuing effectiveness of a national "whole buildings" R&D program.[69] After each is presented, recommendations are indeed offered which are representative of the kinds of policy actions that might come out of each of these framing principles.

***Policy Recommendation #1.* Establish the "Whole Building" framework as a cornerstone of policy.**

Description. "Whole building" design needs to be explicitly articulated and acknowledged as the *cornerstone* of any national building energy or sustainable design policy. This articulation needs to come from the highest possible levels of government, and include an acknowledgement of the importance of buildings R&D to furthering all aspects of US economy, education, environment, and quality of life. And since buildings constructed today have 50–100 year lives, a national "whole buildings" strategy must also recognize that buildings constructed today should embody the conditions for future sustainability in their design, operation, energy requirements, and maintenance, and in the potential reuse of their construction materials. This policy should represent a new mode of thinking about buildings.

Discussion. This recommendation is perhaps the most difficult to implement because it requires a fundamental change in the current mind set on federal buildings policy and R&D management. Furthermore, the change must be made from the top down. Currently, the scant programmatic focus that is given to addressing buildings as whole integrated systems is an after- thought or add-on. From the cabinet level on down, this orientation must be changed so that the "whole buildings" perspective is the locus from which all federal building policy and program direction emanates.

Several precedents at the federal level indicate that such a fundamental shift is possible.

Federal policy makers can be commended for recently establishing a programmatic model of the type of program and orientation that is needed. The newly created Partnership for Advancing Technology in Housing (PATH) program, administered by the Department of Housing and Urban Development, is an interagency collaborative with the private sector. PATH aims to improve the cost, quality, comfort, and environmental impacts of all new housing by the year 2010 by moving improved technologies into the marketplace.[70] The program is now in the process of formalizing its plan of action for achieving that goal. However, what is already apparent is that the PATH program will be the most holistic building program—both in terms of addressing buildings as whole, integrated systems and for its interagency/private sector strategy for achieving its goals. The program's one limitation is that it addresses only housing. It does not address commercial or institutional buildings.

The beginnings for the necessary change in focus also has a precedent at DOE. As already presented in this report, DOE's Office of Building Technology, State and Community Programs recently adopted the "Buildings for the 21st Century" umbrella philosophy to guide its building programs. While it is still too early to evaluate the success this program will have in making fundamental changes in actual R&D program perspectives and public policy, it potentially provides a foundation for making the whole buildings case to higher levels of the federal government.

To achieve the necessary change in perspective, an informal and/or ad hoc coalition of building industry interests (e.g., builders, architects, designers, engineers, financiers, realtors), and renewable energy and energy efficiency industry representatives should be established on the model of the Sustainable Energy Coalition. The coalition could be spearheaded by the Passive Solar Industries Council which in and of itself is already a coalition of diverse building interests with a whole buildings mission. The first priority of the coalition should be to implement a communications and advocacy campaign whose audience is the

Administration and Congress. The campaign should target these audiences from the top down. That is to say, the focus should begin at the highest levels of the Office of the President (and relevant bodies such as PCAST, the National Science and Technology Councils Committee on Construction and Buildings, etc.) and Congressional leadership and relevant committees.

In terms of Congress, the coalition should work with the House Renewable Energy Caucus to utilize existing relationships between advocates and law makers. As well, the Coalition should work with the leadership and members of the Interior and Energy and Water Appropriations Subcommittees in the House and Senate to make sure that these policy recommendations are implemented. In addition, the coalition should work with the Military Construction and Treasury, General Government, and Civil Service Appropriations Subcommittees in order to affect policy over spending on military and government construction projects and building operations. Likewise, the coalition and other advocates should focus on federal policy through the Senate Energy and Natural Resources Committee and the House Commerce and Science Committees.

The aim of the coalition's campaign should be the incorporation of the whole buildings focus in the mission statements, policies, and programmatic strategies of all federal buildings-related bodies, committees, and programs. This should be the first step of ongoing relationship-building activities. The coalition should then work with the Administration and Congress to ensure that this philosophy is followed up with concrete program direction. Finally, the coalition should work with the Administration and Congress to ensure that while federal programs recognize buildings as integrated systems, federal policy must also view R&D programs as integrated systems.

Policy Recommendation #2. **Fund collaborative, fundamental and applied efforts in "Whole Building" R&D.**

Description. The United States should support a coordinated, coherent program of fundamental and applied research in materials, components, design tools and monitoring techniques in the context of "whole building" performance. Research today is product specific and does not adequately address "whole building" performance and demonstration. New programs of R&D need to be defined and implemented that address "whole building" performance, in particular the interactive effects of all building technologies within the building and with the physical and economic environments that support them. New and emerging building technologies that facilitate better interactive performance are to be especially encouraged. And, as argued earlier in this report, a coordinating agency or entity needs to be defined and implemented that will facilitate both the conception and synthesis of whole building R&D across all public and private sectors, supported by new analytical tools that embrace the interactive roles of buildings as elements in the US economy, environment, and sustainable future. While this could be a new agency, it may well be better to empower an existing agency, given greater authority through the President's leadership, to provide more concrete program direction and review, and institutionalize the coordination between agencies.

Discussion. To meet this criterion requires a two-pronged strategy that addresses two major flaws in current federal buildings policy. The first is the current, minute level of funding for building systems integration R&D programs. The federal government currently underfunds both basic R&D (e.g., basic building physics studies) and applied research (e.g., development of analytical tools to facilitate better interactive performance) in the area of "whole buildings."[71] The second flaw in federal policy to be addressed is the lack of coordination of R&D activities and program direction among the myriad buildings-related programs.

As this report has already shown, the whole buildings approach is a powerful tool in the policy arsenal for achieving economic, environmental, and national security goals. To achieve this return on investment, the federal government has to take the leadership role and make the investment. The few federal programs that develop systems integration technologies (e.g., DOE's Best Practices program) or aim to create high performance buildings using a whole buildings perspective (e.g., DOE's Exemplary Buildings program, or EPA's Energy Star Homes program) receive scant funding. The term scant is used here in comparison to four benchmarks: the potential of these programs to reduce building energy costs and environmental degradation; the appropriateness of the federal role in this area as discussed earlier in this report; the comparison with other federal building component programs that take more of a "shot gun" approach; and the contribution of buildings/construction to annual gross domestic product.

The federal government should increase funding to research basic building physics, particularly the areas of thermal storage, perimeter daylighting, performance values of "green" materials, and convective airflow. Furthermore, the federal government should fund research which supports existing, voluntary, market driven, industry-based programs (e.g., the US Green Buildings Council's LEED Rating System and Edison Electric Institute's E-Seal program) that incorporate indoor air quality, water quality, consumer waste, passive solar, and whole building interaction. However, this support should be cooperative and supportive rather than being set up as competing programs.

The federal government must also provide adequate funding to programs that implement the "whole buildings" concept (e.g., EPA and DOE's Energy Star Homes) while ensuring that other new buildings-related initiatives (e.g., the Million Solar Roofs program) that receive funding adequately address the "whole buildings" perspective. Probably most important is the need for funding to be stable, i.e., multi-year and not so subject to the changing winds of partisan politics. Large fluctuations in the past have not only sent mixed messages to industry and markets, they also disrupt on-going R&D activities. The "buildings coalition" should conduct the advocacy activities to support funding for these programs.

To meet the other need, that of coordinating federal buildings R&D activity, some entity must be given responsibility for ensuring that a coordinated federal buildings R&D policy is implemented at the programmatic level. The federal government administers buildings R&D and related programs at numerous federal agencies ranging from DOE, NIST, HUD, GSA, EPA, DOD, and even Health and Human Services. Research is conducted by private sector companies on their products and materials, at national laboratories, at universities and by state energy offices across the country. These activities must be coordinated to avoid duplication and to ensure the cross pollination of research efforts. More importantly, these efforts must be coordinated to ensure that individual programs are organized by a "whole building" philosophy.

The federal entity chosen to coordinate federal buildings activities should have as its first task the responsibility for designing an overall, multi-year specific action plan that outlines federal buildings R&D strategy. This strategy would be the comprehensive blueprint for a coordinated, "whole buildings" based R&D agenda. The second step for the coordinating entity would then be to assign the various parts of the overall agenda to the federal agencies (or potentially in some cases to private researchers) who will have the responsibility for conducting them. While at first glance it appears that these assignments have already been made, they have not been done so through a coordinated federal strategy, nor framed within this integrated concept.

To assign responsibility for coordination to some federal entity will require that the Administration empower this entity with authority commensurate with its responsibility. In other words, federal programs must be accountable to the entity for carrying out the coordinated policy. This will necessitate a level of administration and oversight which cannot be achieved by a committee that meets only once a year and has no institutional resources of its own.

At the same time, this entity must incorporate input and representation of the various federal programs (e.g., NIST, DOE, EPA, HUD, US Army Corps of Engineers, GSA, etc.) as well as the private sector.[72] Existing bodies already incorporate this type of input while operating at a high level in the administration. Therefore, it should not be necessary to create a new institutional entity, but rather it will require empowering a standing entity so that federal programs are accountable to it.

For example, the Energy Research and Development Panel of PCAST recently released its report outlining recommendations of general policy and funding for a host of energy R&D programs. This type of activity could serve as the foundation for coordination of federal buildings policy and program direction. In this example, the President's Office of Science and Technology Policy could be charged with assessing the degree to which agencies meet the policy recommendations and program direction of PCAST. The Coalition and its individual members should be charged with working with the Administration to implement the integrating activities of the entity and to secure congressional acceptance of the concept.

The task of achieving these goals might at first glance appear to be impossible. Coordinating the large number of federal buildings programs would be no small task. However, one only has to look as far as the human genome project, to find a model for such an undertaking. The human genome project is undertaking a coordinated effort to map the genetic make-up of the human body. Research is being conducted by organizations worldwide. The World Health Organization is coordinating that research and collecting the fruits of individual research efforts. This is a monumental task that shows that coordination of massive research undertakings is possible.

Policy Recommendation #3. Support accurate estimation and verification efforts.

Discussion. For optimally efficient buildings to proliferate, consumers, designers, builders and manufacturers must be able to estimate confidently and within acceptable real-world deviation limits "whole building" energy performance, and must have continued verification and demonstration that buildings designed and constructed according to whole building system conceptions are cost-effective across a variety of climates and building types in both new construction and retrofits. Software for this purpose must be developed that is fast, inexpensive to use, accurate, and which permits easy analysis of building envelope and component alternatives, including the effects of their interactions. Such software must also serve as design guidance tools, prioritizing strategies that, in interaction with other strategies, deliver the highest or most cost-effective return for the package. And these must be supplemented by objective well-documented case studies and demonstrations to validate computer models, to provide monitored data on actual building cost and performance, and to give confidence to both consumers and lending institutions. The software might also be licensed by the federal government to private software companies to market and sell, to help build the public/private bridge, and to bring to bear the great skills of private software developers.

Discussion. The type of information needs described here are crucial to win acceptance for "whole buildings" technologies and practices by consumers and lending institutions who are being asked to invest in efficiency and renewable energy. Therefore, it is critical that the federal government continue to support those existing programs that are developing and demonstrating prediction and verification tools and supplement them in areas that are currently not addressed.

DOE should continue to be the lead agency and provide supplemental support for these programs, requiring that it be funded to do so. In September of 1995, the Congressional Office of Technology Assessment, in its report "Renewing Our Energy Future" noted that building on the field performance data collected over a decade ago would have considerable value. OTA also recommended commercial demonstration for builders and users and the increased support to enable the *rapid* development of design tools.[73]

This could be achieved by accelerated DOE support for continued development of "Designing Low Energy Buildings/ENERGY-10" software to make it more robust and to include additional technologies. This software is a tool that allows building designers to measure the interactive and complex effects of energy consuming and saving measures and design options. A number of well known technologies (e.g., photovoltaics, natural ventilation, exhaust air heat recovery, evaporative cooling, and solar hot water heating) have yet to be incorporated into the software because of a lack of funding. DOE should also continue the Exemplary Buildings program, which is one of the few design-oriented demonstration programs currently in existence. Another area for continued federal programming is in the development of short-term energy measurement (STEM) tools. Additionally, the Home Energy Ratings Systems (HERS) Council Guidelines, developed in a strong industry-government partnership, should be considered to be one of the key measurement and verification tools.

Apart from the individual contributions to improving the nation's building stock, prediction and verification programs provide a foundation for other policy tools. For example, the HERS Guidelines developed by the HERS Council are now languishing "on the shelf." They should be the measurement and verification basis for any proposed federal tax cuts for building energy efficiency. The Coalition should work with DOE and the HERS Council, the Treasury Department and Internal Revenue Service, the Senate Finance Committee, and the House Ways and Means Committee to make this a reality.

Policy Recommendation #4. Embrace training and education.

Description. Individual, community, state and federal building decision makers must be introduced to the concepts and benefits of "whole building" policy, while architects, engineers, and building operators must be explicitly trained to understand how to pursue their trades in the context of whole building performance. At the very least this will require the introduction and widespread dissemination of user-friendly whole building design tools (see recommendation #3) that can lead decision makers and designers through optimal design selection on the basis of immediately available estimates of building performance that embrace all natural and mechanical system interactions. But the aim of this should be higher, with the goal of accomplishing a real market transformation by changing the very basis on which buildings are evaluated and decisions made.

Discussion. Hand-in-hand with efforts to integrate programs, fund activities, and develop the appropriate design, measurement and verification tools goes the need to train the building trades on the concept of "whole buildings" and the accurate, fast tools available to put the concept into practice. These training needs directly address the market transformation issue described earlier in this report. At present, typical US architectural and engineering education programs do not stress building technologies, materials, or components, let alone "whole building" energy performance and therefore cannot be considered to have a holistic perspective.

To address this need, DOE and other federal agencies must implement education, training, and technology transfer programs that will help to stimulate a transformation of the marketplace. In effect, these activities will move the technologies and practices developed through federally supported programs into the marketplace where the American public can reap their environmental, economic, and national security benefits.

DOE, EPA, and other agencies must look to industry/private models in continued support of combined national technical conferences. Organizations such as the Energy Efficient Buildings Association (EEBA) now open their conferences to similar organizations such as the HERS Council and PSIC in order to provide a broader picture for attendees. Similarly, the American Solar Energy Society's annual national conference, the annual Passive Solar Conference, the American Institute of Architect's Committee on the Environment, the American Society of Mechanical Engineers, and the Solar Energy Industries Association's Soltech conference now are combined every four years in a coordinated national conference that provides a forum for engineers, architects, industry members, and federal R&D professionals to share information and move the fruits of federal R&D into the consciousness of private practitioners. In addition, the federal government must practice what it preaches by providing design assistance, peer reviews and training for the design and operation of federal buildings.

Furthermore, DOE's national laboratories, along with the laboratories at the National Institute of Standards and Technology and the US Army Corps of Engineers, must be required to identify "users" or audiences for their research before beginning any project and then be encouraged to continue and enhance technology transfer programs and partnerships with private industry. The high level federal entity charged with coordinating federal buildings R&D should also be charged with evaluating the progress of agencies in fostering this cooperation. For example, federal agencies and laboratories could be evaluated based on the number of CRADAs and licensing agreements they transact.

Policy Recommendation #5. **Stimulate demand through awareness.**

Description. Since the supply of nonrenewable fuels is subsidized by the federal government, for whole building designs that integrate efficiency and renewable energy sources to compete fairly in the marketplace, consumer demand for these applications must be stimulated. Consumers (broadly defined as builders, building owners, homebuyers, lending institutions, and state and federal building managers) must be made aware of the documented and measurable benefits of energy and cost savings, quality of living and workplace, and resultant quality of life and productivity of employees, when housed in buildings designed according to "whole building" practices. Such a campaign must include sophisticated and pervasive marketing programs, imbedded into the very methods by which the building industry reaches its customers and delivers its services. These programs, too, must be assembled as a "system" of related market-development activities, rather than random "shot gun" programs which stand alone, and which may not be able to produce results by themselves.

Discussion. As with the previous recommendation, this policy recommendation addresses the need for federal policy to incorporate market transformation as an inherent accompaniment to R&D activities. It is safe to say that consumers, lenders, realtors, and in many cases builders are unaware of the cost effective building technologies that are currently available. The federal government has historically emphasized push strategies that attempt to "push" technologies out of the laboratories into the hands of industry who will commercialize and "sell" the new technologies. In the case of building technologies, the federal government must also adopt a pull strategy whereby consumers are educated on the availability and desirability of these technologies so that they begin to demand them in the marketplace.

DOE should be given the mandate and the funding to implement new public awareness campaigns. Consumers should be reached through targeted public service announcements and local events and demonstration programs (e.g., the American Solar Energy Society's National Tour of Solar Homes). Similarly, Congress should provide EPA with the support necessary to make Energy Star Homes a recognizable and desirable label in the minds of consumers. In addition, EPA should continue its efforts to gain the support of builders, realtors, appraisers, and financiers for their program.

While the federal government is somewhat limited in its ability to advertise and promote its own programs, nonprofit organizations and trade groups are not so constrained (except by lack of resources). The coalition described earlier should implement a public information campaign (in tandem with its campaign targeting the Administration and Congress) to make the case to consumers and to those with a role in building construction, finance, and operations. Funding for these activities could be obtained from government agencies, contributions from the coalition members, and from the philanthropic community. As is often the case, these activities are not without precedent. Groups such as the Sustainable Energy Coalition, the Safe Energy Communication Council, and the Communications Consortium have implemented similar campaigns covering other technologies.

Conclusion

This report has argued for an integrated approach to R&D with regard to buildings: a comprehensive "whole buildings" umbrella concept that ties the building and its components together into one unified package and encompasses all real-world physical and economic elements with which the building interacts or on which it depends. The same framework can bridge all federal agencies involved in building research in a coordinated manner within government, as well as with outside agencies and organizations, both NGO and industrial, treating all as one unified package of complementary and supporting activities. The result will be greater building energy efficiency and occupant productivity, reduced impact of buildings on the environment, and greater economic efficiency, transferability and value of building R&D programs.

Any attempt to reduce the flow of resources, to reduce waste, to reduce energy use (including dependence on foreign sources of energy), and to reduce environmental emissions to meet more stringent US standards or to live up to our '97 Kyoto promises, must look hard at the accessible and economic opportunities afforded by buildings. Similarly, no conversion of US practices and economy to a path leading to long-range sustainability can be accomplished with buildings constructed today that place a 50 to 100 year burden of excessive and inappropriate energy and resource demand on the future.

The purpose of this report is to foster a concept whose time has definitely come, and thereby to urge its widespread adoption by government, industry, and the private sector in order to capitalize on the great potential benefits of integrated R&D to support integrated buildings. In parallel there must be a market transformation that transfers all facets of "whole buildings" to common practice. This report has not invented the "whole buildings" concept, nor has it proposed a structure that is not already at least partly in place, both within and outside of the federal government.

"Whole buildings" is a better policy and one that will affect change. It must be elevated to a high level of administrative responsibility and respect. "Whole buildings" must secure a mandate simultaneously from the Federal government, the industry, and private sector research centers to coordinate, enhance, supplement, complement, and fill in gaps that are still barriers to systems integration in research and practice. It is deserving of its own clearly identified programmatic mission, supported by sufficient appropriations.

The message presented in this report is clear: to minimize duplication and fragmentation of effort, and to maximize potential returns for both the industry and for society at large, there is a strong need and a clear obligation for enhanced and long term stable federal agency funding for building R&D. The programs must be coordinated within and between agencies, as well as with the building industry, under a "whole building" conceptual umbrella.

A framework of principles under which such a "whole building" program might be conceived can be similar to the following set:

- Establish the "Whole Building" framework as a cornerstone of policy.
- Fund collaborative, fundamental and applied efforts in "Whole Building" R&D.
- Support accurate estimation and verification efforts.
- Embrace training and education.
- Stimulate demand through awareness.

REFERENCES

1 Aitken, Donald, "Putting it Together: Whole Buildings and a Whole Buildings Policy", Renewable Energy Policy Project (REPP) Research Report, September 1998, No. 5.

2 The AIA reference in this sidebar is "Architectural and Building Research Needs and Opportunities in the 1990s," Donald Watson, FAIA, Editor, *Symposium Proceedings: AIA/ACSA Council on Architectural Research,* Washington, D.C., October 4, 1992. The author of this brief would also like to thank Dr. Ren Anderson, Technology Manager, Building Energy Technology Program, National Renewable Energy Laboratory, for his helpful insights and suggestions on how to express this concept.

3 "Energy Innovations: A Prosperous Path to a Clean Environment," A report by the Alliance to Save Energy, the American Council for an Energy-Efficient Economy, the Natural Resources Defense Council, the Tellus Institute, and the Union of Concerned Scientists, June, 1997, p. 112.

4 The Renewable Energy Policy Project (REPP) was established under the direction of Alan Miller in August 1995 to accelerate the worldwide development and use of renewable energy technologies. REPP seeks to provide policy research support for the renewable energy community, and educate policymakers and energy professionals on the benefits of renewable energy.

5 Hochanadel, Joel, "Overview of the Building Technologies Programs in the Federal Sector," prepared for the Passive Solar Industries Council, 1511 K St., NW, Suite 600, Washington, D.C., 20005, February 20, 1998.

6 "Federal Energy Research and Development for the Challenges of the 21st Century," report of the Energy Research and Development Panel, The President's Committee of Advisors on Science and Technology (PCAST), September 30, 1997.

7 A Quad is one quadrillion British Thermal Units (Btu) of energy (a 1 with 15 zeros after it).

8 This table is adapted from "Scenarios of US Carbon Reductions," the Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, 1997, the so-called "Five Laboratory" Report, p. 2.14. The data are from the 1996 and 1997 energy use estimates of the Energy Information Agency (EIA).

9 The "buildings sector" is generally narrowly defined to represent only the actual buildings in service in the United States. Energy use of the building sector is either expressed as site energy used or primary energy required to deliver energy services to all buildings presently in service. Table 1 shows the latter.

10 Core Databook, US Department of Energy, Office of Building Technology, State and Community Programs, April 30, 1997.

11 Dr. Ren Anderson, Technology Manager, Building Energy Technology Program, National Renewable Energy Laboratory, private communication.

12 Roodman, David Malin, and Lenssen, Nicholas, A Building Revolution: How Ecology and Health Concerns Are Transforming Construction," Worldwatch Paper #124, March 1995, pp. 22–25.

13 Croxton, Randall, private communication.

14 "Scenarios of US Carbon Reductions," loc. cit., p. 3.2

15 Core Data Book, loc. cit.

16 *A Building Revolution: How Ecology and Health Concerns Are Transforming Construction,* loc. cit.

17 Core Data Book, loc. cit.

18 US Department of Energy, "A Strategic Plan for the Office of Building Technology, State and Community Programs," Draft Plan December 9, 1997. The footnote given in that reference is adapted to the following: the end-use splits represented in these charts differ from those reported in the EIA Annual Energy Outlook, 1997. These charts include data for industrial buildings which are not reported by EIA. In addition, energy for "District Services" (heating and cooling) and "Other Fuels" (heating), lumped by EIA under "other," is attributed to space conditioning. Finally, the statistical adjustment of 1.6 quads required for the Annual Energy Outlook to be consistent with the State Energy Data System has been deleted from "Other." Our gratitude is expressed to Sean C. McDonald, Senior Research Economist, Battelle Pacific Northwest Laboratory, for providing Figs. 1 and 2 for this report.

19 Ibid.

20 Miller, Burke "Buildings for a Sustainable America Case Studies," The American Solar Energy Society, 2400 Central Ave., G-1, Boulder, Colorado, 80301–2843, p. 3.

21 Many publications document this. Here is a sampling of them: "Solar, Jobs and California's Economic Recovery," A report of the Solarcal Council, January, 1983; "Jobs Benefits of Expanding Investment in Solar Energy," by Muller, Laitner, Miller and Zarsky, Solar Industry Journal, Vol. 3, Issue 4, 1992, p. 17; "Biofuels and Job Creation: Keeping Energy Expenditures Local Can Have Very Positive Economic Impacts," by Ed Wood and Jack Whittier, Biologue, Vol. 10, No. 1, Sept/Dec. 1992, p. 6; "Energy Efficiency and Job Creation: The Employment and Income Benefits from Investing in Energy Conserving Technologies," by Howard Geller, John DeCicco, and Skip Laitner, The American Council for an Energy-Efficient Economy, Washington, D.C., October, 1992; "Economic Impacts of a Photovoltaic Module Manufacturing Facility," Final Report, and "National Economic Impacts of Photovoltaic Systems Deployed Through the Year 2000," both reports for the US DOE, Photovoltaic Program, Office of Solar Energy Conversion, Office of Conservation and Renewable Energy, May 7, 1992; "Energy Investments for a Stronger Virginia Economy—Increasing Investment in Energy Efficiency and Renewable Energy," by Skip Laitner, Citizens Fund, Washington, D.C., February, 1991; "Energy Investments for a Stronger Louisiana Economy—The Benefits of a Least-Cost Energy Policy," Citizens Fund, Washington, D.C., May 1991; "Fueling Wisconsin's Economy With Renewable Energy," Proceedings of the 1995 Annual Conference of the American Solar Energy Society, Minneapolis, MN, July, 1995. A comprehensive argument is presented in "Jobs and the Environment—The Myth of a National Trade-Off," by E.B.Goodstein, a report to the Economic Policy Institute, Washington, D.C., 1994. Cost savings from energy efficiency and renewable energy that can be converted to increased job production were documented in "America's Energy Choices—Investing in a Strong Economy and a Clean Environment," by the Alliance to Save Energy, the American Council for an Energy-Efficient Economy, the Natural Resources Defense Council, and the Union of Concerned Scientists, 1991. These same four organizations were joined by the Tellus Institute in publishing an up-date of "America's Energy Choices," now called "Energy Innovations—A Prosperous Path to a Clean Environment," June, 1997 (a sampling of the jobs impact of this policy by sector is offered in Table 7-5, p. 151). Positive job impacts from shifting to renewable resources were also reported in "Powering the Midwest: Renewable Electricity for the Economy and the Environment," the Union of Concerned Scientists, 1993.

22 Morse, Fred, "Morse's Law."

23 Building energy use is roughly in the range of $1 to $1.50 per square foot per year, while employee salaries

are in the range of $100 to $150 per square foot of commercial space. A more precise national average for various building energy, repair and maintenance, and employee costs can be found in "Greening the Building and the Bottom Line: Increasing Productivity Through Energy-Efficient Design," by Joseph J. Romm, US Department of Energy, and William D. Browning, Rocky Mountain Institute (RMI Publications, Rocky Mountain Institute, Drawer 248, Old Snowmass, Colorado, 81654).

24 These figures are from early studies by the Government Services Administration (GSA) and IBM. They are reported with further discussion in "Case Study: Lockheed Building 157—An Innovative Deep Daylighting Design for Reducing Energy Consumption," by Lee S. Windheim et al., Leo Daly Associates, San Francisco.

25 Material in this sidebar on reported productivity and sales benefits is extracted from references 23 and 24, and from this author's personal knowledge (the Bullocks Store and Lockheed examples). The information on the energy performance of daylit schools in North Carolina is from "Energy Performance of Daylit Schools in North Carolina," Michael H. Nicklas and Gary B. Bailey, "Proceedings of the 21st National Passive Solar Conference, R. Campbell-Howe and B. Wilkins-Crowder, eds, American Solar Energy Society, Boulder, Colorado (April, 1996), p. 138. Information on the performance of students in daylit schools is from Michael H. Nicklas and Gary B. Bailey, Ibid., p. 133.

26 US Department of Energy, "A Strategic Plan for the Office of Building Technology, State and Community Programs," Draft Plan December 9, 1997. loc. cit.

27 The primary reference for the examples used in this sidebar is *Buildings for a Sustainable America Case Studies,* by Burke Miller, published by the American Solar Energy Society, Boulder, Colorado. The description of the UCS office building can be found in "The New UCS Energy Efficient Daylit Office Building in Cambridge, Mass." Donald Aitken and Howard Ris, Proceedings of the 20th National Passive Solar Conference, R. Campbell-Howe and B. Wilkins-Crowder, eds., The American Solar Energy Society, Boulder, Colorado (1995), p. 249, and also in "The Union of Concerned Scientists Walk Their Talk," by Donald W. Aitken and Howard Ris, *Solar Today,* Vol. 11, No. 2, March/April 1997, p. 28. The Willow West case study is this author's own work, and has not been published. The description of the Neuffer Construction passive solar subdivisions can be found in "Builder Experience With Low-Cost High-Value Passive Solar", Donald W. Aitken and Paul Neuffer, Proceedings of the 18th National Passive Solar Conference", S. M. Burley and M.B. Arden, eds., American Solar Energy Society, Boulder, Colorado (1993), p. 77.The descriptions of the ACT^2 projects were downloaded from the PG&E Web site, www.pge.com/customer_services /other/pec/act2/act2over.html

28 A major multi-organizational economic energy analysis, "Energy Innovations," derived a cost-saving "Innovation Path" target of 2.33 quads of building energy that could be saved by the year 2010, in comparison with a "Business as Usual" path, leading to a reduction in carbon emissions equivalent to 18.2 million metric tons. ["Energy Innovations: A Prosperous Path to a Clean Environment," June, 1997, published jointly by the Alliance to Save Energy, the American Council for an Energy-Efficient Economy, The Natural Resources Defense Council, the Tellus Institute, and the Union of Concerned Scientists. See, for example, Table 5-1, p. 115.] Their analysis included not only the adoption of cost-effective energy efficiency measures, but also a modest increase in the direct end-use of solar energy. And the "Five Laboratory" Report came up with a realistic goal of 1.9 quads of energy that could be saved in buildings by the year 2010 with just the application of improved efficiency measures. ["Scenarios of US Carbon Reductions," the Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, 1997, p. 2.14.]

29 US Department of Energy, "A Strategic Plan for the Office of Building Technology, State and Community Programs," Draft Plan March 13, 1998, p. 5.

30 This assumes about 32% efficiency and an 80% capacity factor for the plants.

31 "Energy Innovations: A Prosperous Path to a Clean Environment," loc. cit., p. 105.

32 The President's Committee of Advisors on Science and Technology (PCAST) recommended, for example, a doubling of the R&D budgets in real (constant) dollars for end-use efficiency and renewable energy technologies by FY, which will return these programs to the 1990 level of funding in constant dollars. loc. cit.

33 BTS Buildings Data Summary Sheets, April 30, 1997, loc. cit.

34 Ibid.

35 Ibid.

36 Hochanadel, Joel, Federal Buildings Program Review 1997, Draft October 23, 1997, loc. cit. The seven states are Alaska, Arkansas, California, Colorado, Mississippi, Vermont and Virginia.

37 BTS Buildings Data Summary Sheets, April 30, 1997, loc. cit.

38 US Department of Energy, "A Strategic Plan for the Office of Building Technology, State and Community Programs," Draft Plan December 9, 1997, loc. cit.

39 "Federal Energy Research and Development for the Challenges of the 21st Century," report of the Energy Research and Development Panel, The President's Committee of Advisors on Science and Technology, September 30, 1997. loc. cit., p. 13. This quote continued: "*Such needs and opportunities relate to public goods (such as the national-security benefits of limiting dependence on foreign oil), externalities (such as unpenalized and unregulated environmental impacts), and situations where lack of appropriability of the research results, or the structure of the market, or the size of the risk, or the scale of the investment, or the length of the time horizon before potential gains can be realized dilute incentives for firms to conduct R&D that would greatly benefit society as a whole…Needs for public-sector R&D can increase over time if the public-goods and externality challenges grow or if changing conditions shrink the incentives of firms to conduct some kinds of R&D that promise high returns to society.*"

40 Council on Competitiveness, 1992 estimate, noted in "Scenarios of US Carbon Reductions" (the "Five Laboratory" Report), loc. cit., p. 2.11.

41 Business Week, "R&D Scoreboard," June 28, 1993.

42 Asian Wall Street Weekly Journal, August 12, 1991, p. 10.

43 Ibid.

44 Council of Economic Advisors (CEA), "Supporting Research and Development to Promote Economic Growth: the Federal Government's Role (Washington, DC), October, 1995, as reported in "Scenarios of US Carbon Reductions" (the "Five Laboratory" Report), loc. cit., pp. 2.13–2.14.

45 "Scenarios of US Carbon Reductions" (the "Five Laboratory" Report), loc. cit., p. 2.14.

46 Ibid., Table 2.5, p. 2.15.

47 Photovoltaic systems on the market convert anywhere from 5%-8% (amorphous or other thin-film), or 10% to 15% (crystalline or polycrystalline) of the incident radiation into electricity, including the losses in the signal conditioning systems. Solar domestic water heaters can

operate at 45% efficiency, solar swimming pool heaters can reach 90% efficiency on warm days, and passive solar which, for example, just lets the sunshine come in through the windows, can be nearly 90% efficient in converting incident sunshine into heat inside the building.

48 Watson, Donald, "Opportunities to Improve the Process of Innovation in the United States Building Industry," a report for the AIA/ASCA Research Council, prepared for the AIA/ACSA Research Council under a subcontract supported by the US Department of Energy's Grant "Energy Research Program for the Profession of Architecture" 1988–1989, p.8. "*There is a need for 'whole-systems' innovation in building that seeks out opportunities when separate components, products and processes of design and construction are viewed together. Design and building concepts that efficiently utilize the entire building and its site for integrated heating, cooling, and daylighting…are examples of innovations that would not have been identified without a whole-systems approach to design and construction and life-cycle efficiency in building."*

49 Ibid., p. 9.

50 Watson, Donald, Ed., "Architectural and Building Research Needs and Opportunities in the 1990s," AIA/ACSA Council on Architectural Research, 1735 New York Ave., NW, Washington, DC, 20006, (published 1993), p. i. *"A second key idea that emerged from the Symposium is the concept of 'total building performance', in which designs are more broadly conceived than in conventional architectural practice to include resource and materials selection, their use and transformation in the manufacturing and building process and…extending to the concerns of building occupancy, maintenance, remodeling and re-use…."*

51 Watson, Donald, *Solar Energy for a Sustainable Future,* The American Solar Energy Society, Ch. 3, p. 35.

52 The Energy Policy Act of 1991, Public Law 102–486, Sec. 305(a)(2).

53 Ibid., Part 6, Sec. 271(b)(4).

54 The President—Executive Order 12902, "Energy Efficiency and Water Conservation at Federal Facilities," Part 3, Sec. 306, March 8, 1994, Federal Register 59, No. 47, March 10, 1994, pp. 11463–11471.

55 From the "Building America" Web Page, www.eren.doe.gov/buildings_america/over.html

56 Description extracted from the Buildings for the 21st Century Web page, www.eren.doe.gov/buildings/bldg21c.html "Looking at the building from a 'whole building' or systems engineering perspective, buildings will be viewed as integrated systems rather than a series of independent components…This 'whole building' perspective must also include advanced building technologies that incorporate solar and other forms of renewable energy…Buildings for the 21st Century will actively involve the buildings industry in expanding the adoption of whole building practices, accelerating the use of energy efficient and solar energy technologies and establishing the concepts of system engineering in all phases of building design, construction, financing, and operation…."

57 A Strategic Plan for the Office of Building Technology, State and Community Programs, U. S. Department of Energy, DRAFT, March 13, 1998.

58 Building for the 21st Century Web page, loc. cit..

59 Ibid.

60 Buildings for the 21st Century, Synthesis Action Plan, DRAFT, Feb. 25, 1997, p. 4.

61 Description extracted from the Buildings Program Web Page of the USEPA Energy Star Programs, www.epa.gov/appdstar/buildings

62 Description extracted from the IEA Tasks Web page, www.arch.vuw.a.c.nz/iea/research_tasks.html

63 Ibid.

64 Ibid.

65 Hochanadel, Joel R., "Overview of the Building Technologies Programs in the Federal Sector," Analytical Summary Edition, prepared for the Passive Solar Industries Council, Washington, D.C., February 20, 1998.

66 Ibid., Compendium Edition.

67 Ibid., Analytical Summary Edition.

68 Ibid.

69 In January of 1996 the Passive Solar Industries Council framed a draft "Vision Statement," encompassing "Five Principles," to secure "Passive Solar in America's Future." The material and discussion in this section is adapted from that document.

70 Hochanadel, Joel, "Overview of the Building Technologies Programs in the Federal Sector, Compendium Edition, loc. cit., pp. 45–46.

71 Ibid., Analytical Summary Edition—see discussion on pp. 17–18.

72 Ibid.

73 "Renewing Our Energy Future," US Congress, Office of Technology Assessment, OTA-ETI-614 (Washington, D.C., US Government Printing Office, September, 1995).