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Building Enclosure Technology and Environment Council

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NATIONAL

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ENERGY EFFICIENCY AND DURABILITY OF BUILDINGS AT THE CROSSROADS

1. BACKGROUND

A few years ago, the American Institute of Architects (AIA) and the National Institute of Building Sciences (NIBS) agreed to work together to organize Building Enclosure Councils (BECs) in cities across the United States in an effort to encourage the exchange of technical information and know-how on the best practices of building enclosure design. As a result of that agreement, BECs, organized as committees of state or local components of the AIA, now exist in 21 U.S. cities. Further, a memorandum of understanding with the Canadian National BEC, executed at the 2008 AIA convention in Boston, provides for Canadian collaboration in the information exchange effort.

The first Building Enclosure Science and Technology (BEST 1) conference was hosted by BEC and AIA Minneapolis in June 2008. The conference, with the theme of “Energy Efficiency and Durability of Buildings at the Crossroads,” provided a wakeup call about both the deficiencies and the creative opportunities that lie ahead for the building design community in responding to a changing world in which buildings play a significant role in the use of energy (as well its impact on U.S. security, the balance of payments and the viability of the U.S. economy).

This paper is an outcome of BEST1, and it reflects the perceived need for the Building Enclosure Technology and Environment Council (BETEC) of NIBS to outline the current state of affairs. It is one thing to specify that buildings achieve certain efficiencies; it is quite another matter for that outcome to become a reality. This is where practitioners come in as they are the “doers” that make things happen. It is expected that through the BEC network a greater awareness of the technological successes achieved and lessons learned from failures in building system design can impact future designs and convert design intent into reality.

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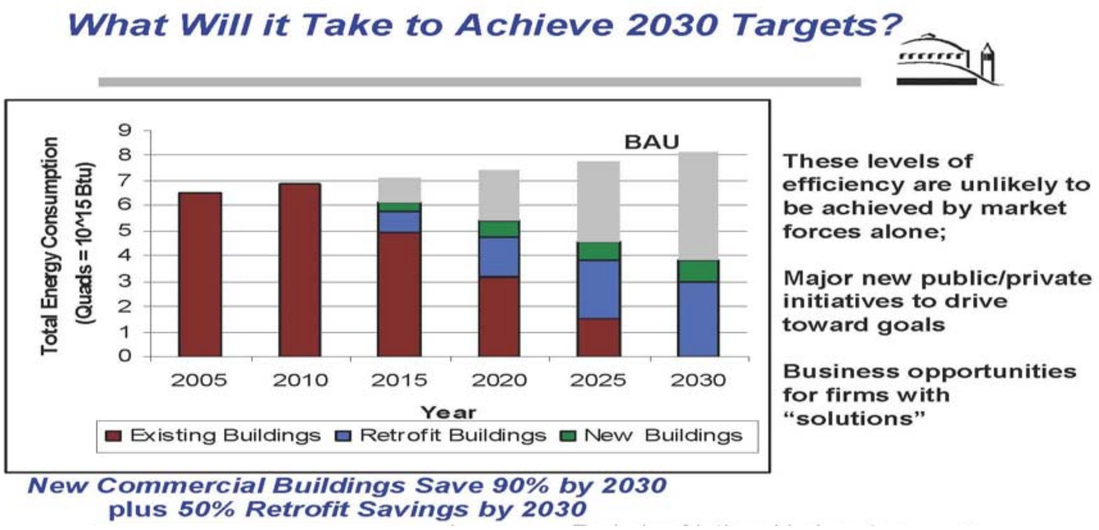
2. INTRODUCTION

The building industry is at a crossroads and the question is, where do we go from here. The "green" train has left the station but the tracks are still being built. At the far end there is an AIA commitment to achieving a 2030 carbon neutral future (and improvement in the existing building stock). At the beginning, just outside the station, there is a lot of good will but also a realization that the majority of existing highly inefficient buildings will be with us well beyond 2030. There is a chasm that must be bridged if that goal is to be achieved and there is confusion on how to accelerate the process of renewal.

All generally agree with the United Nations report that states:

> *The good news is we have got a huge source of alternative energy all around us. It is called energy conservation, and it is the lowest cost new source of energy that we have at hand. . . . Clearly saving energy is like finding it.*

Past successful programs for advanced building design reveal that only "a systems approach" will achieve energy-saving goals in the future. We are past selling magic new materials and miraculous one-issue solutions. Every building, old or new, needs to be treated as an organism in which every component is a piece of the puzzle. Quick-fix efforts devoted to only one or even several components in the building enclosure, at best, probably will not achieve sufficient energy savings and may actually cause other problems. Whether one changes only one component or rehabilitates the whole building, effective approaches require advice from experienced practitioners of all types. The green value of actions is determined by the resulting building performance, not by the perception that an action is green.



What Will it Take to Achieve 2030 Targets?

These levels of efficiency are unlikely to be achieved by market forces alone;

Major new public/private initiatives to drive toward goals

Business opportunities for firms with "solutions"

New Commercial Buildings Save 90% by 2030 plus 50% Retrofit Savings by 2030

Figure 1 Simulation of U.S. commercial sector building energy use from 2010 to 2030, contrasting "business as usual" scenario (top progression) with a strategy that reduces energy use in all new buildings by 90% compared to current intensity (new building use shown in green) and retrofits and renovates all existing stock (blue) by 2030 to reduce end use intensity by 50%

compared to current use. Reprinted with permission from the Department of Energy's Lawrence Berkley National Laboratory.

Although the process for assessing the success of energy-saving approaches is essentially the same for houses as for large office buildings, the need for mock-up and commissioning tests and the involvement of the full design team in review of energy-saving elements is emphasized for large office buildings. This paper describes both the current status of building enclosure design and how large potential energy savings can be achieved through the integrated design of new buildings and the rehabilitation of existing buildings. Included are comments concerning the interrelationship of energy efficiency, building durability, and the quality of the indoor environment.

The building community is at the crossroads, not because we lack knowledge and industrial know-how (those we have in abundance), but rather because our vision of buildings has ceased to be valid. The stakes are high. We need a new vision that will improve building energy efficiency, extend the building lifecycle, and improve economic competitiveness by putting savings from energy efficiency to more productive uses. Nevertheless, this vision cannot be achieved without broad acceptance by the entire design and construction community including building owners, investors, and financiers.

To set the stage, the following topics will be addressed briefly:

- Our carbon footprint – the scope of current building energy use
- Past changes in design practices and use of energy
- The current approach to design of the opaque portion of building enclosures
- Fenestration and its potential for minimizing or maximizing solar gains
- Rehabilitation of existing buildings
- New building design

3. OUR CARBON FOOTPRINT

Whether one agrees with the direct link between CO_2 increases in the atmosphere and global climate change or not, our carbon footprint is a convenient measure of how we use energy, whatever its source. Energy security is another priority, which has even greater precedence in the minds of some.

Reported statistics concerning carbon footprints vary because some researchers include the embodied energy in materials and transportation whereas others consider only the part that relates to the energy use of the physical building and its occupancy. That having been said, one author claims that the average carbon footprint per person in the United States is 33 lb/day, in California is 18 lb/day, and in the city of Los Angeles is 8.5 lb/day. These numbers are cited only to demonstrate how much the carbon footprint can reflect both climate and occupancy. Most of the carbon dioxide produced in buildings (30- 50%) results from the use of energy for space heating and cooling, for appliances (up to 20%), and for water heating and lights (10% each). The total CO_2 emissions from buildings, transportation, and industry in the United States are currently estimated to be the same level as those of China.

What about energy sources? Coal is plentiful in the United States, but coal consumption results in emissions levels two to three times higher than those produced by other fuels. Carbon capture and sequestration can reduce carbon dioxide by 70% making coal a major transitional energy source (including its transformation into liquid fuel), but these measures require heavy investments and are not yet proven at a scale that would begin to address the emissions envisioned in the future. Wind harvesting can be used only in limited locations and only in conjunction with other base load energy sources. Photovoltaic (PV) energy, although still expensive, has a bright future but it requires improvements in the electric grid and significantly reduced costs. The current electric grid has a low efficiency. A future economy involving a large number of plug-in cars and thousands of PV installations would require a smart distributed grid.

This brief overview of energy sources illustrates the dilemma. Many proposed “energy solutions” result in equal or greater carbon emissions (coal, coal to liquid, tar sands). It is also evident that efforts to achieve energy security and potential man-induced climate change are coupled and proposed solutions will need to have a positive impact on both. If supported effectively, such solutions could create a win-win situation for market-driven technologies.

Thinking that changes in the supply side of energy -- involving any mix of coal, nuclear, ethanol from corn, oil sands, coal to liquid transformation, or even hydrogen -- will fill our future energy needs may lead us to an expensive dead end. Pushing one technological solution is a traditional way of increasing the energy supply without considering the demand side. We need to realize that the potential for reducing building energy use is widely underestimated and is the key to reducing overall energy demand. In effect, by pursuing an aggressive energy efficiency campaign dealing with both new and existing buildings, it may be possible to reduce the demand side to a level at which many expensive alternative energy sources will not be needed.

If we consider the passive energy savings measures available today to rehabilitate old buildings as well as those energy efficiency measures now available for new buildings, the picture is optimistic. However, if alternate energy supplies are to be sufficient to meet the nation’s growing needs, we need to initiate broad programs for the “energy upgrading” of most of our existing buildings and enact high energy efficiency standards for new buildings.

Figure 2, developed with poetic license, represents the potential impact of several supply side perspectives compared with one massive demand side option.

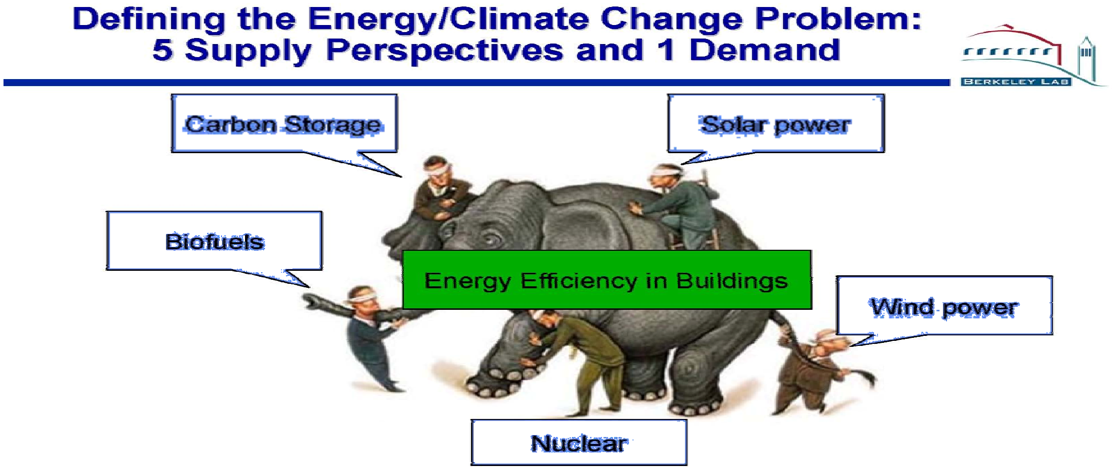


Figure 2 Conceptual balance of power between five supply side and one demand side options. Reprinted with permission from the Department of Energy's Lawrence Berkley National Laboratory.

While the media talk glibly about the use of renewable energy, they do not realize that this approach requires very efficient use of all energy from all sources. Renewable energy sources still represent only a drop in the bucket given the gross inefficiency of today's buildings. The construction and operation of buildings consumes 40% of the total energy used in the United States whereas the transportation sector uses only about two-thirds of the energy used by buildings (or 27% of total energy. Buildings also consume 68% of all electricity, which results in the production of 750 million tons of CO_2 (i.e., 38% of total U.S. production of carbon dioxide and 49% of U.S. production of SO_2).

Average energy use by commercial buildings in 1990 was 315 kWh /m^2 but it has declined steadily since that time, reaching 250 kWh /m^2 in 2002. Note, however, that this was equivalent to the energy use of commercial buildings in 1920 – in other words, a masonry building without insulation built nearly 100 years ago consumed as much energy as a shiny, glass-clad building constructed today!

This, of course, says nothing about the increase in energy-consuming functions of modern buildings. In contemporary office buildings, the office equipment and computers use 10% of total energy but lighting uses 28%. A layman, who accepts that in 1920 people also used lights (and probably less efficiently than now) and who understands that we now employ improved thermal insulation, thermal mass, air barriers and many other energy saving measures, understandably would be puzzled as to why we do not use much less energy than in the 1920s.

This is the energy situation in which we find ourselves. Some have proposed societal goals aimed at achieving carbon neutral new construction by 2030, but to see how this can be accomplished, we need to understand the changes in building construction that took place in the past 60 years.

4. REVIEW OF CHANGES IN BUILDING CONSTRUCTION AND THE ROLE OF BUILDING SCIENCE

Some changes that have occurred in residential construction are described below followed by identification of the corresponding changes in the construction of commercial and institutional buildings.

4.1 Control of Heat, Air, and Moisture Movement in Residential Walls

Prior to the 1930s, walls often were not insulated even though roofing felt was used as sheathing paper, walls were very leaky, but the use of building paper weather barriers, as distinct from roofing materials, soon became the rule. The building paper was placed on the external side of the wall sheathing to impede the movement of air and intrusion of rain behind the cladding while permitting some moisture to permeate to the outdoors. To improve thermal comfort, wall cavities were filled with insulation -- first using wood chips and other available natural materials, sometimes stabilized with lime, then shredded newsprint, and eventually mineral fiber and fiberglass batts.

Meanwhile, scientists observed that the presence of thermal insulation in the wood frame cavity lowered the temperature on the outer side of the cavity, leading to a higher potential for vapor condensation that, in turn, was found to be detrimental to the durability of the wall and the siding. Vapor barriers were introduced to reduce the flux of vapor coming from the warmer indoor environment and to alleviate condensation problems. A practical unit of permeance describing a typical and acceptable level of vapor flow retardation was introduced and named 1 perm (57 ng/m^2 s Pa).

Effectively, the 1930’s-built house featured a paper-based water-resistive barrier (WRB) capable of changing from a water vapor retarder when dry to a breather when wet because the paper acted as a smart water vapor retarder that changed its vapor permeability with moisture content. However, this WRB did not eliminate the airflow through the wall. The air flow helped to dry the moisture that condensed on the cold side of the thermal insulation. There was also the large moisture buffer capability of sheathing planks, wood frame, and insulation. Interior finishes were largely wet applied plaster. Finally, the pace of construction was slow enough to allow the building to dry and settle before the final coat of plaster was applied.

Following World War II, wood boards were replaced by plywood panels in wall sheathing. During the 1970s wafer board, and subsequently oriented strand board (OSB), came to dominate the sheathing market. The use of paper-faced gypsum panels for the interior finish also emerged during this evolution to reduce construction time. Incidentally, use of “drywall” reduced the construction moisture load and the use of panel sheathing materials minimized air infiltration. The use of interior polyethylene vapor retarders continued this trend but also inhibited the ability of walls to dry to the interior, and moisture tolerance declined. Despite this use of materials that were progressively more susceptible to moisture, these materials performed adequately when properly used. Nevertheless, to perform adequately, drying capability to the outside was critical in this situation.

More recent increases in levels of thermal insulation have further reduced the drying capability of walls such that deficiencies, such as leaks at windows or cladding penetrations, may now result more easily in moisture-originated damage.

Recent acceptance of the concept of drain screen walls that allow rain water to be drained from the space behind the cladding has the potential to cause severe problems. When water is delivered behind the cladding (and often behind the exterior thermal insulation), a portion of it is retained on the drainage medium, both the surfaces of the cavity and the joints of panels. Despite the perceived ability of these walls to drain down to the flashing, water will evaporate and be redirected by reverse thermal gradients to the inside of the wall. To avoid this, one can use a WRB with high resistance to water vapor but this, in turn, will further reduce the drying ability from the inner wall.

In summary, the following major changes in wall design that reduce the moisture tolerance of residential walls dramatically have taken place over the past 60 years:

- Increased levels of thermal insulation,
- Increased level of water vapor resistance,
- Increased air tightness of the walls,
- Reduced ability of walls to dry,
- Reduced moisture buffering capability,
- Introduction of more moisture sensitive materials, and
- Allowing drainage from the wall-window interface to enter behind the cladding and exterior insulation.

4.2 The Beginning of High-Performance Housing in North America.

Prior to the 1970s when energy security became an issue, society was not very concerned about whole building performance. The oil supply crises in the early 1970s, however, forced society-wide discussion of long-term global energy security and supply and stimulated the introduction of energy conserving housing programs in Canada and the United States. These programs, in turn, affected the construction of conventional homes. Airtight building enclosures were needed which, in turn, required mechanical ventilation. High-efficiency heating devices were introduced that modified air flow patterns in buildings or eliminated the need for chimneys and this raised a new concern – the need for an air redistribution system within the house. At that point, interaction of the building enclosure with the heating, ventilation and air redistribution system in the occupied space became part of the builder's design framework and phrases such as "building as a system" were used to describe the approach taken.

In summary, today we have the technology to achieve reliable design of building enclosures to control heat, air, and moisture transport but we also realize that this can only be done if there is equal attention is paid to indoor environmental and HVAC considerations. Like the R2000 program in Canada, the Energy Star program of U.S. Environmental Protection Agency (EPA) and the Energy Efficiency Building Retrofit Program, a project of the Clinton Climate Initiative (CCI), are good examples of programs designed to reduce energy consumption in new and existing buildings by specifying performance requirements.

4.3 Changing the Scale – Commercial, Institutional, and Other Large Buildings

While residential building designs can be suitably replicated in similar climatic zones, large buildings are often unique designs. There are great functional differences between different building uses – office buildings, warehouses, laboratories, hospitals, etc. -- and their energy use reflects that diversity. However, the heat, air, and moisture transport physics remain the same for all structures.

Air flows (infiltration and exfiltration) are important to both energy efficiency and building durability. The specific aspect of air flow that relates to energy and durability is the moisturecarrying capability of air, which is much more significant than water vapor diffusion. Air movement also can drive rain penetration. Air movement occurs when there is connectivity between areas with different air pressures. There are many causes for air pressure differences (e.g., wind creating pressure on one side of a building and suction on the other side of the building). Vertical pressures (buoyancy effects) arise from temperature differences between indoor and outdoor spaces as well as within a building itself. The use of mechanical equipment such as local exhaust fans in bathrooms, kitchen fans, and heating and cooling equipment also can create pressure differences.

Air carries outdoor pollutants as well as those generated within the building enclosure. Mold spores from basements and attics and those growing on paper-clad drywall on the interior of walls can be carried into the living spaces. Consider one example: a typical office building might use a ceiling return plenum for air distribution systems. Steel stud exterior walls have internal interconnected cavities and the drywall finish typically ends at the level of the plenum. This condition provides excellent connectivity between those wall cavities and the ceiling space. In other words, many commercial buildings are designed with unlimited possibilities for air flow from any indoor space to any other space.

In effect, an airtight building enclosure is needed for the following reasons:

- To reduce the amount of uncontrolled air flow through building cavities and its possible effects on the hygrothermal performance of the enclosure and, especially to reduce the risk of excess moisture being deposited in the construction.
- To reduce the amount of volatile organic compounds (VOCs), particulates, and mold spores carried from the outdoors or from construction materials into the indoor space.
- To reduce the amount of heating and cooling required by unconditioned air entry

4.4 The Need for Air Pressure Control in Buildings

As long as buildings were leaky and poorly insulated, the effect of HVAC systems on induced air pressure and on the durability of the enclosure was not significant. There was no need to understand air movements in the building other than to know that they provided a necessary supply of fresh air. This is not the situation today. Now we require well-insulated, airtight buildings in which the indoor environment contributes to livability. The key to achieving these goals is to appreciate that air pressure fields have an important effect on the performance of building enclosures; therefore, understanding air movements in buildings is a necessity. Air pressure differences, however small and difficult to measure, must be determined to establish the performance of the building as a system. This is probably one of the key reasons for a fundamental revision to many assumptions that have developed over the years. Air transport control is now recognized as the least understood issue in the design of building enclosures. While the need for air tightness is now well recognized, achieving it in practice is still a challenge. Rain penetration and the influence of air penetration remain the most important issues to be handled in building enclosure design.

Air barrier systems are required for the proper performance of building enclosures in all climates. Ensuring continuity of the air barrier plane over 100% of the exterior surface is a key requirement for air flow control by the building enclosure. Air barrier continuity must be checked both during the design review and (by commissioning) during construction.

5. WHERE ARE WE TODAY WITH THE OPAQUE PART OF THE BUILDING ENCLOSURE?

For technical people, every high-performance building – indeed every building – must address many different aspects of performance such as energy efficiency, durability, constructability, health and comfort of occupants (indoor environment), fire resistance, acoustics, and affordability. This statement, however, does not necessarily reflect public perceptions. In a 2007 survey, 41% of all respondents defined a “green building” as one with a specified percentage of green materials and 46% stated that “green buildings” must follow criteria established by a national program.

While the term “green buildings” has become a buzzword for environmentally driven impulses, a definition is needed for performing a cost-benefit analysis. To avoid ambiguity in the use of words like “green” or “sustainable,” the term “**high-performance building**” is preferred as it is defined in the Energy Policy Act of 2005 as follows:

> *The term “high performance building” means a building that integrates and optimizes all major high-performance building attributes, including energy efficiency, durability, life cycle performance, and occupant productivity.*

A consequence of this definition is that the concept of “green materials” must be abandoned in favor of “high performance assemblies.” For example, a bitumen-based self-adhering flashing would not meet the public perception of a “green material.” However, when properly applied, bitumen flashing tapes are key components in durable, airtight assemblies.

5.1 Evaluation of Systems, Not Materials

It is important to place emphasis on the performance of the building and built assemblies instead of merely on the materials used in those assemblies even though dealing with materials is easier. Building codes and standards always ascribe a specific function to a specific material because this is the only way that a prescriptive code can work. Water resistive barriers (WRBs), water vapor retarders, air barriers, thermal barriers (fire), and rain-screens are all items in which functions and materials are mentally coupled; however, a material (e.g., closed-cell spray foam) also can function as insulation, a rain-screen, a WRB, a water vapor retarder, and an air barrier.

The outcome of an architectural design is modified by interactions between different materials and the trades involved in installing them in an assembly. Architectural design and construction are holistic processes that involve highly specialized people from multiple disciplines, and an important issue is how they collaborate during this process. This aspect of design is so important that we stress the importance of mock-up evaluation and ongoing commissioning as separate activities in the construction process. This is to ensure that the design concept is constructible and that all the building trades learn how they must collaborate to achieve the intent of the design.

So far we have established that the future belongs to high-performance buildings. Let us now review the critical components of the matrix called, for simplicity, the “High-Performance Value” of a building.

5.2 Key Components of “High Performance Value” During the Design and Construction of Buildings

The key components of “High Performance Value” during the design and construction of buildings include:

1. Designing for durability.

2. Designing for energy efficiency and efficient use of materials in terms of
    a. Separating ventilation/air distribution and heating/cooling systems,
    b. Using instantaneous or integrated hot water systems,
    c. Increasing the use of day lighting technologies and controls,
    d. Improving the indoor environment (with view to occupant health and productivity),
    e. Achieving design flexibility (i.e., lower costs associated with space reconfigurations),
    f. Re-using of materials in building enclosure systems,
    g. Designing from cradle to grave (i.e., considering whether the existing components can be used in next-generation buildings).

3. Designing to be efficient enough to justify economic use of renewable resources in terms of
    a. Developing better tools for building enclosure performance evaluation and
    b. Improving control over inter-zonal and interstitial air flows.

4. Laboratory or field testing of mock-ups of building enclosures for commercial buildings.

5. Using the commissioning process as a part of the design and construction process (from design intent through the construction period and including some post occupancy tests) by
    a. Conducting a trouble shooting study of design drawings as the first step in commissioning,
    b. Testing air flows during construction,
    c. Testing air quality of occupied space after occupancy, and
    d. Verifying predicted energy performance parameters against actual building data.

Number one in the high-performance value matrix is the issue of durability (long-term performance). If one extends the service life of a building by, for example, 20% over that of typical construction, one reduces life-cycle costs. In this process, the direct savings of replacement and energy can provide multiple benefits to owners.

The second critical consideration is to increase all possible passive energy efficiency measures that lead to energy savings before progressing to active measures that address energy utilization. Passive measures often are neglected even though they offer the most value for the invested money. These measures include:

1. Simple building shape and mass placement that respects the climate (saves capital and energy),

2. Increased air tightness (cost little, saves lots),

3. Increased insulation values and reduced thermal bridging (costs but saves energy), and

4. Improved windows (increases capital cost but saves operating cost) or reduced window area (saves capital and operating costs but may limit daylight).

Economical solutions that can be applied to the supply side of the energy equation include use of:

1. Free pre-cooling with air distribution systems,
2. Solar air preconditioning,
3. Geothermal preconditioning, and
4. Solar hot water (often third party financed – leased).

More complex technical measures that can be employed include:

1. Radiant cooling,
2. Heat and energy recovery ventilators,
3. Diagnostics for malfunctioning systems or components in service,
4. Dedicated ventilation air systems,
5. Brushless DC motors,
6. Small centrifugal compressors, and
7. Micro-channel heat exchangers.

While these examples highlight some of the current solutions used in high-performance buildings, they also shine a spotlight on the bigger picture of progress needed. With a high level of thermal insulation in the enclosure and better windows, we would eliminate the need for perimeter heating. High-performance building enclosures also can change the HVAC and lighting systems needed, – that is, they can dramatically reduce thermal loads, and encourage the use of distributed HVAC systems while also reducing electric lighting demand by effectively using daylighting.

There also is a trend toward use of multifunctional building enclosures. Dynamic envelopes can be used to pre-heat or pre-cool indoor air and, by using filters and dehumidifiers, these enclosures can modify the indoor environment. Advances in glass and window technology permit the use of increased daylighting. With reduced thermal loads, several technologies previously discarded in research are becoming more economically viable. Coming back as significant improvements to the technology mix are use of the effects of thermal mass and phase change materials even though they are climate-dependent.

6. FENESTRATION IMPACTS ON BUILDING ENERGY CONSUMPTION

It is estimated that windows account for about 10% of total building energy use. The traditional view of the high negative energy impact of windows in buildings contrasts with the impressive progress in window technology and systems that has taken place in recent years.

6.1 Vision of Window Research -- Moving Windows from Energy Losers to Energy Suppliers

To achieve the goal of making windows energy suppliers in cold climates one, must reduce the overall U value (increase the R-value and improve the thermal performance) enough that the solar gain can exceed the heat loss.

Savings from Better Windows

Annual Heating Cost simulated for a heating climate

Single Glazed w/Storm, $1310

Double Glazed, $1218

Double w/Low-E, $1120

House with no windows, $1000

"SuperWindow", $960

Conclusion: Good windows outperform insulated walls in winter!

Figure 3 Simulated winter seasonal energy use of a house in Boston as windows are improved; note that the house with "super windows" with U < 0.15 has a lower winter heating bill than the same house without any windows so the windows are now net energy suppliers. Reprinted with permission from the Department of Energy's Lawrence Berkley National Laboratory.

This implies that windows with a high R-value and a moderate solar heat gain coefficient (SHGC) should be used in cold climates. In hot climates, the energy flows are dominated by solar gain which is highly variable depending upon climate, latitude, season, and orientation, and needs vary – i.e., cooling load controls vs daylight admittance and view vs glare control. Thus, in hot climates as well as in mixed climates, static control needs to be replaced by dynamic control of solar gain. This approach should drive design strategies and technology for the near term. In the more distant future, windows should become even greater net energy suppliers by becoming more fully integrated with photovoltaic capabilities.

Highly insulated window systems will employ such technologies as aerogels, vacuum glazing, low-E coatings, gas fill, and improved thermally resistive frames. Dynamic solar control may include conventional dynamic solar shading systems such as roller shades or blinds or can involve operation of a glazing layer with a reversible optical switch from high to low transmission. Suitable technologies include active electrochromic glazing (requires wiring) or passive thermochromic (reacting to glass temperature), photochromic (reacting to sunlight intensity), etc. Field tests with prototype electrochromic windows were started in 1999 and these technologies are now commercially available. The 2030 "ideal" window is expected to have an R10 insulating value and variable solar control and, in most climates, will provide a net winter energy gain and 80% saving in cooling.

In today's residential market, 95% of the windows sold are double-glazed and more than 50% have a low-E coating. Obviously this represents substantial progress from 1973 when single pane windows dominated sales with double glazing capturing only a small market share.

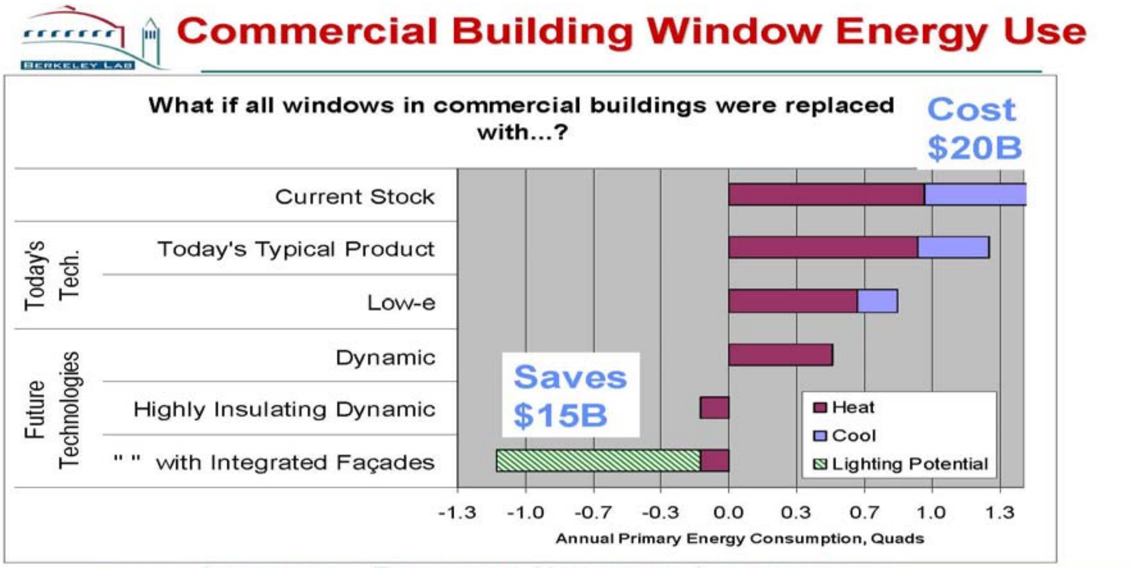


Figure 4 Current U.S. commercial window stock is responsible for about 1.4Q of energy use/yr at an annual cost to building owners of about $20 billion. Replacing all existing stock with improved technologies would have the impacts shown above. Integrated facades with daylight dimming have the potential to provide $15 billion per year in energy savings by offsetting some of the current use of electric lighting. Reprinted with permission from the Department of Energy's Lawrence Berkley National Laboratory.

The simple comparison shown in Figure 4 stresses the fact that today's cost-effective technology involving low emissivity coatings and gas fill is already an acceptable solution when the window to wall ratio is a reasonable percentage of the whole; however, it is not acceptable to build buildings with R-2 exteriors that are all glass! Nevertheless, we are dealing with a moving target -- with improved thermal insulation in walls, today's windows will again have a larger impact, but the continuing progress in window technology ensures that there will be viable solutions for the future. Research currently is addressing further reductions in heat transfer through glazing systems, low conductance spacers, and insulated frame systems and better methods for installing windows in walls.

6.2 Facade Performance Needs

Facade Performance Needs

- Comfort
- View/Privacy
- Security
- Acoustics
- Structure
- Recycled Materials

- Energy

- Daylight
- Aesthetics
- Weatherproof
- Cleaning
- Maintenance

Figure 5 A list of performance attributes to be considered in facade design.   Reprinted with permission from the Department of Energy's Lawrence Berkley National Laboratory.

Conventional means of energy reduction include modest sized windows with double glazing, spectrally selective glass, manually operated interior shading, and dimming lighting controls. Daylighting control systems must be integrated with the building enclosure, electric lighting, and HVAC controls. These integrated façade solutions have several functions – spectral control of transmitted radiation to reduce cooling loads and dynamic control of intensity and direction of solar radiation to further improve visual comfort and capture daylight savings. These control systems must consider comfort and satisfaction of occupants as these issues are related to human performance in the work environment. The economics of building occupancy indicates that the cost of maintenance, taxes, and energy is about 3% and rent is about 10%; the remaining 87% is the cost related to occupant salaries or productivity. The issues involved here are that advanced façades with lighting controls and smart shading devices that can provide control of glare, thermal comfort, and excellent energy efficiency.

Optimizing the design of such systems can be challenging. The designer needs a range of building design tools that must:

- Allow integration strategies to be explored,
- Allow facade performance to be optimized,
- Make lighting tradeoffs between HVAC and the facade, and
- Explore commissioning and operational issues.

To this end, the designer has available a series of tools for characterizing and optimizing the properties of window systems that include the Window 5 software suite which includes IGDB (spectral glass data sources), OPTICS (window glass) and THERM (window frame), CGDB (complex glazing data base), and WINDOW (whole window). Other building design simulation tools include ENERGY PLUS and RADIANCE, COMFEN (whole building commercial), and RESFEN (whole building residential).

7. ENERGY SAVINGS THROUGH REHABILITATION OF EXISTING BUILDINGS AND IN THE DESIGN OF NEW BUILDINGS

In this section, we highlight potential energy savings in the rehabilitation of existing buildings and key elements in the design process of new buildings.

7.1 Energy Saving Opportunities in Existing Buildings

The rehabilitation process can be started with lighting. Energy use for lighting averages 12% of the total in residential occupancies and 28% in commercial buildings. Given the relatively small cost of fixtures, this may be the first item on the retrofit list. The next priority is the control of air flows. This will require that air barrier systems be installed in all new and existing buildings. There are many possible solutions such as:

1. An inexpensive but temporary solution that involves sealing all penetrations for AC, pipes, and ducts and placing two or three coats of lime-cement stucco or other trowel grade air barrier material on all leaky masonry block surfaces.

2. A more costly but more effective solution involves adding continuous exterior insulation integrated with an air barrier and possibly also improved windows.

The design community has learned from past weatherization programs that single actions (e.g., adding attic insulation, replacing windows, or even sealing of some holes in the building enclosure), while important, do not have a high impact and can lead to other problems if not holistically considered. The logical conclusion is that both a holistic approach and professional insight are necessary for these programs to be effective. The effective existing and emerging housing retrofit programs involve inspections by independent experts to assess the condition of a building, its equipment, and its airtightness. On that basis, a range of improvements of increasing complexity and cost are suggested that, if employed in part or fully, can be eligible for cost rebates to help offset the cost of the inspection/analysis and part of the cost of implementing the recommendations. Programs of this nature are proving to be effective because the advice provided is informed and the costs are partially recovered.

7.2 Energy Saving Opportunities During Design of New Buildings

The key message of this white paper is that every building is a system of interconnected assemblies and components and, thus, every change in aspect will affect other aspects of building performance as well. How does one evaluate the effect of those changes? Marshall McLuhan was quoted as saying: “Our Age of Anxiety is in great part the result of trying to do today’s job with yesterday tools.”

Architects and designers often do not have adequate tools for evaluating long-term performance of buildings. There nevertheless is one powerful tool that makes up for the lack of many artificial tools – the collective brain of a design team. We need to use it from the beginning to the end of the construction process. We postulate that a conceptual design should include:

1. A plan for design review that includes trouble shooting by experts in heat, air, and moisture control of buildings;
2. The inclusion of key elements in mock-up lab and field testing; and
3. Design intent for all systems included in the commissioning plan.

Mock-up testing and commissioning are likely to be done by an external agency. The proposal from such an agency or testing lab defining all details of the proposed work should be reviewed by the full design team before it is approved. Particular attention should be placed on commissioning during the construction phase. To better understand the benefits of the commissioning process, please consult one of the many recent publications on this topic (e.g., NIBS Guideline 3-2006, *Exterior Enclosure Technical Requirements for the Commissioning Process*).

Experience indicates that the building enclosure specialist (a nonstructural, technical professional whose job it is to work with different teams to find missing enclosure interface detail drawings, specify additional tests on test assemblies, etc.) who was employed by some architecture firms in the 1970s brought the expertise that we are now highlighting to these firms. Whether this function is internal or external is a moot point; we stress only the need for including such expertise during both the design and construction processes.

8. CONCLUSIONS

Society needs to build on the strength of existing knowledge. Building enclosures – their energy efficiency, durability and the indoor environment – are today at a cross-roads. On one hand, a large amount of knowledge and expertise is available; on the other hand, old approaches are not as valid as they once were. It is time to create a new vision because the stakes are high. We need this new vision to improve our energy efficiency, maintain energy security, and sustain the economy. Savings can be put back to more productive uses even though it will take time to realize full return on investment. Yet, this vision cannot be achieved without a mobilization and education of our society. Unless major public/private initiatives are developed, the strategy based on retrofitting existing buildings will not work. As was the case during World War II, we need society's bond to win a 21st century war – but this one is to save the planet.

We support launching and sustaining large-scale, long-term national programs that blend policy, economics, and technology in public/private partnerships. We support making energy performance visible by displaying performance, using devices that monitor energy use from buildings to grid. We support extensive participation of the media in unleashing public imagination in the support of different programs. Effectively, our proposal can be summarized as: **Think big, start small, and act now with the focus on how.**

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