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NEW BUILDING TECHNOLOGIES AND BUILDING ENERGY STANDARDS IN THE UNITED STATES

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Some new and emerging technologies that may affect building energy consumption are reviewed in this paper. We also describe a brief impacts analysis that evaluates the sensitivity of a simulation model to changes in broad categories of building equipment and materials. The analysis results permit direct comparisons of the effect of changes in energy efficiency to these building components.

Potential barriers to the use of some new building products are also discussed. The barriers, inherent in the current building energy standards, result partly from the structure of the standards and the procedures used to determine building compliance with those standards. We propose several methods for overcoming these barriers and encouraging the accommodation of new technologies within the standards.

INTRODUCTION

The commercial buildings sector is one of the largest end users of energy in the United States. In 1960, commercial buildings consumed approximately 4.9×10^9 GJ (4.7 quads) of primary energy. This same sector consumed an estimated 1.2×10^{10} GJ (11.8 quads) of primary energy in 1986, for an average annual growth of 3.6% (1). The 1.2×10^{10} GJ accounted for 16% of the total energy consumed in the nation that year. Most of the increase since 1960 is the result of higher consumption of electricity for heating, cooling, and other building service end uses.

The environmental and economic benefits of even small increases in commercial building energy efficiency are enormous. For example, a 1% reduction in energy consumption would save almost 1.2×10^8 GJ (0.12 quad). Further, if this reduction were to result solely from lower total electricity

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consumption, the accompanying savings would be 1.8 billion U.S. dollars (based on an assumed price of $0.05/kWh for electricity).

Clearly, the commercial buildings sector offers a significant opportunity for substantial reductions in energy consumption.

Driven by the U.S. energy crisis of the 1970s, much of the work in building technologies over the last 10 years has focused on improving the energy efficiency of the nation's building stock. Consequently, new building envelope, equipment, and lighting technologies are being proposed, developed, and introduced at a rapid pace. These advances are moving the nation toward the goal of increasingly higher levels of energy efficiency in buildings.

Currently, building energy standards govern much of the new construction in the United States, and some form of building energy standard is in place in many of the states. These standards are generally based on some version of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) Standard 90. The intent of these standards is to improve the energy efficiency of new commercial buildings. For this improvement to be achieved, standards will have to rely increasingly on new technologies to reach the mandated levels of efficiency. Thus, current and future building energy standards must be able to accommodate the new technologies as they become commercially available.

In this paper, we first present an overview of new building envelope, equipment, lighting, and miscellaneous technologies. The overview provides only a sampling of the many new and innovative materials, equipment, and systems that offer the potential for significant energy savings. Next, we describe a simple methodology for evaluating their potential impacts. Our case study results suggest which technologies might have the greatest impact on building energy consumption. We then discuss barriers inherent in current U.S. building energy standards that potentially complicate or preclude the implementation of these new technologies. Our paper ends with several proposed methods for reducing or eliminating these barriers in future versions of building energy standards.

OVERVIEW OF NEW TECHNOLOGIES

In this section, we present a brief overview of some innovative building materials, equipment, and system designs that have achieved, or are nearing, commercialization. Many show potential for significant energy savings over current products. However, it is important to remember that no matter how promising a technology may appear from an energy-savings standpoint, it must also gain widespread acceptance by the building design and construction community. If it is not fully embraced and integrated into newly constructed buildings, the technology will not achieve its potential in energy savings.

Envelope Technologies

The building envelope separates and protects the occupants from the outdoor environment. On a summer day, the envelope helps to keep the indoor environment cool and comfortable, even when it is hot and humid outside. On a winter day, it helps to keep the indoors warm and snug despite the damp and frigid temperatures on the other side of the walls. Consequently, the envelope can be an important determinant of the overall energy consumption of a building.

Developments in envelope systems and materials have occurred in three main areas: glazing, insulation, and thermal mass. Some of the more recent advances in these areas are listed in Table 1. This list represents only a sampling of the many new products and ideas that have been, or may soon be, injected into the marketplace.

Table 1. New Envelope Technologies

Technology	Development
Radiant Barrier Systems (2,3)	Radiation control coatings or films can be added to the external surfaces of the envelope to reflect incident solar radiation. They can also be used on the interior surfaces to limit the amount of thermal energy leaving a structure.
Advanced Low-e Coatings (2,4,5)	Rapid progress is being made in window coatings that have high transmittance of solar radiation in the visible range and high reflectance in the UV and infrared ranges. Selective coatings can also be tailored to the specific application.
High-R Windows (2,5)	Windows now being designed have almost the same thermal resistance as an equivalent section of insulated wall.
Advanced Insulation and Anti-Infiltration Methods (2,5)	New insulations being developed are capable of producing R-20/inch. Anti-infiltration methods limit the amount of unconditioned air that enters the building envelope.
Switchable-e Glazing (2)	Glazings are being produced in which the amount of transmitted light can be controlled electronically. These can be automatically or manually controlled to respond to varying occupant needs and outdoor conditions.

Equipment Technologies

The primary energy consumer in a commercial building is usually the HVAC system. This system is responsible for maintaining a comfortable and healthful indoor environment for the building's occupants. Temperature control through heating or cooling, along with moisture and contaminant control through ventilation and filtration, are primary HVAC system functions.

Advances in equipment technology cover a broad spectrum. At one end, designers are implementing incremental changes to existing designs, providing modest increases in efficiency. This type of change is very important because of the market acceptance already enjoyed by most of these systems. At the other end of the spectrum, researchers are proposing novel systems, cycles, and working fluids that, in some cases, offer substantial potential for improvements in energy efficiency. Of course, these suffer from the drawback that they are not yet proven in the field.

Some of the improved and innovative equipment designs are listed in Table 2. Again, this list provides only a small sample of the many developments that have been, or are, taking place.

Table 2. New Equipment Technologies

Technology	Development
Advanced Oil-Fired Furnaces (2)	Many incremental advances offer potential for significantly increasing the efficiency of oil-fired furnaces. These include progress in direct venting, oil atomization, low-firing-rate burners, and performance-enhancing control.
High-Efficiency Gas-Fired Furnaces (7)	Efficiencies of small gas-fired furnaces have increased above 95%. Much current research focuses on material development for handling the resulting slightly corrosive fluids.
Variable-Speed Compressors and Fans (2,8)	Compressor capacity modulation and fan speed modulation are now practical because relatively inexpensive, highly efficient inverters and electronically commutated motors have been developed.
New Absorption and Refrigeration Fluids (2,8)	Because of future phase-outs of chlorofluorocarbons (CFCs), refrigeration fluid research has enjoyed a renaissance. New refrigeration fluids, such as various nonazeotropic refrigerant mixtures (NARMs), and refrigeration cycles more closely optimized to the working fluid have been introduced.
Advanced Heat Pump Concepts (1,2,9)	New and modified cycles include gas-fired absorption, ejector-coupled, braun linear, ground-coupled, advanced rankine, and open-cycle heat pumps.
Dessicant/Hybrid Cooling (2)	The system that uses process or equipment waste heat to regenerate a desiccant cooling system makes desiccant systems feasible alternatives to heat pumps.
Advanced Absorption Chillers (2)	New absorption chillers can produce the low temperatures necessary for ice-slurry district heating systems.
Airfoil Fan Designs (1)	Fan blade designs being developed exhibit efficiencies that are 25% to 40% greater than those of conventional fan blade shapes.
High-Efficiency Office Equipment (5)	The internal loads of buildings can be reduced by improving the efficiency of common office equipment. Countries like Japan are encouraging this by making laptop computers the new "office workstation."

Lighting Technologies

Lighting is thought to be the single largest end use of electricity in the commercial buildings sector. In 1985, it was estimated that lighting was responsible for 36% of all commercial electrical consumption (5).

Developments in lighting center on increasing the efficacy of the lamps (lumens/watt) and the efficiency of ballasts and luminaries. Most of these improvements have been incremental, with small but steady improvements introduced over time. However, several new lighting technologies proposed in recent years show significant potential for saving energy Significant progress has also been made in the control of lighting to make it more responsive to auxiliary sources (daylight) as well as occupant patterns.

A sample of new developments in lighting technologies is listed in Table 3. Included are a number of technologies that are already commercialized yet not widely implemented.

Table 3. New Lighting Technologies

Technology	Development
Daylighting and Advanced Lighting Controls (2,5,10)	Increasing attention is being given to using natural illumination from the sun (daylighting). This can be done automatically with sensors that reduce artificial lighting levels in response to daylight. Occupant sensors for lighting control can also save significant amounts of energy.
Isotopically Enriched Fluorescent (2)	The efficiency of fluorescent lamps can be increased by adding mercury-196.
Surface Wave Fluorescent (2)	This advanced fluorescent design reduces losses that result from radiation entrapment.
Advanced Phosphor Materials (1,2)	New types of phosphor coatings on the interior surfaces of fluorescent lamps are enhancing their performance. An improved phosphor coating can increase the efficacy of the lamp by 10% to 20%.
Electrodeless High-Intensity Discharge (2,10)	Today's high-intensity discharge (HID) lamps offer high efficacy but at a correspondingly high initial cost. Future generations of HID show potential for higher efficacies at lower cost.
Electronic Ballasts (1)	Electronic ballasts now being designed offer substantial improvements in efficiency over their traditional magnetic counterparts. They also increase the efficacy of the lamps by permitting operation at higher frequency. Electronic ballasts permit lamps to be operated over a range in intensity for further potential savings.
High-Efficiency Luminaries (10,11)	Improvements in luminaries raise the overall efficiency of the lighting system by increasing the amount of light that enters the space.

Miscellaneous Technologies

In addition to the advances just described, a number of other new technologies may have significant impacts on the ways in which buildings consume energy. These systems (or concepts) do not fit neatly into any of the categories discussed previously. However, they show the promise for changing the ways in which buildings are designed and operated.

Many of the concepts described here are not entirely new; some have been in use for decades. However, new developments in computing power, sensors, and materials have significantly enhanced the economic feasibility of previously unattractive concepts. This, combined with an increasing interest in occupant comfort and concern over indoor air quality, has spurred innovation in novel building technologies.

An overview of some of these miscellaneous building technologies is provided in Table 4.

Table 4. Miscellaneous Building Technologies

Technology	Development
Advanced HVAC Controls (1,5,12)	Because of the increased computing power of building energy management systems, many advanced control and operation techniques can now be implemented in buildings. These include adaptive and optimal control, demand-controlled lighting and ventilation, and HVAC system diagnostics.
Thermal Storage (1,13,14)	Both diurnal and seasonal thermal storage techniques have been shown to save energy. Diurnal storage has traditionally been associated with peak shaving. However, more efficient equipment sizing, nighttime equipment operation, and thermal storage in the building structure all can save energy. Seasonal thermal storage techniques such as aquifer thermal energy storage can also provide significant savings under the appropriate conditions.
Renewable Energy Technologies (15)	Although renewable energy technologies do not necessarily save energy, they do reduce the demand for nonrenewable energy sources. Ultra-efficient photovoltaics and superconducting ceramics are making solar and wind energy more attractive alternatives to fossil and nuclear power.
Task Conditioning (16)	Increasing concern over occupant comfort has prompted recent developments in task conditioning. Providing each occupant with the ability to control temperature, ventilation, and lighting levels may be the next stage in the evolution of building environments. Reducing ambient levels of lighting, temperature, and air conditioning may result in a net energy savings.
Water Loop Heat Pump Systems (17)	Systems such as the water loop heat pump (WLHP) show the advantage of taking an overall integrated approach to system design. In this case, the WLHP system often acts as simply a transfer mechanism where energy is transferred from locations where it is not needed (cooled spaces) to locations where it is (heated spaces).
District Heating and Cooling (2,18)	District heating and cooling have been used for a long time. However, advances in distribution, reduced emissions technologies, and more encompassing planning processes have made the improved efficiencies of these systems more attractive.

IMPACTS OF NEW BUILDING TECHNOLOGIES

One of the more difficult tasks in assessing any new technology is to estimate its potential impacts. Of particular interest here are the impacts related to building energy. The key question is: If a new technology is implemented in a building, what will be the difference in energy consumption?

This question is important for several reasons. First, when a new technology (for example, a heat pump) is introduced, claims about its efficiency or energy savings potential are usually made. To put these claims in some perspective, it is useful to know what effect the technology will have on the total energy consumption of a building. Second, if the total building energy savings are known for a variety of different technologies, then a mechanism exists for comparing them. Without such a mechanism, a designer will not know if 5% more efficient lights will save more total energy than a 5% more efficient boiler.

To gain a greater understanding of what technology improvements might mean in terms of energy consumption, we used a five-zone Building Analysis Model (19) to do a brief impacts analysis. This model had been used extensively during the development of ASHRAE Standard 90.1 (20), and it is currently being used in the development of the revised California Energy Standard for 1991. We have configured the model to be minimally compliant with Standard 90.1. As such, the model is hoped to be somewhat representative of current construction. The model is shown schematically in Figure 1.

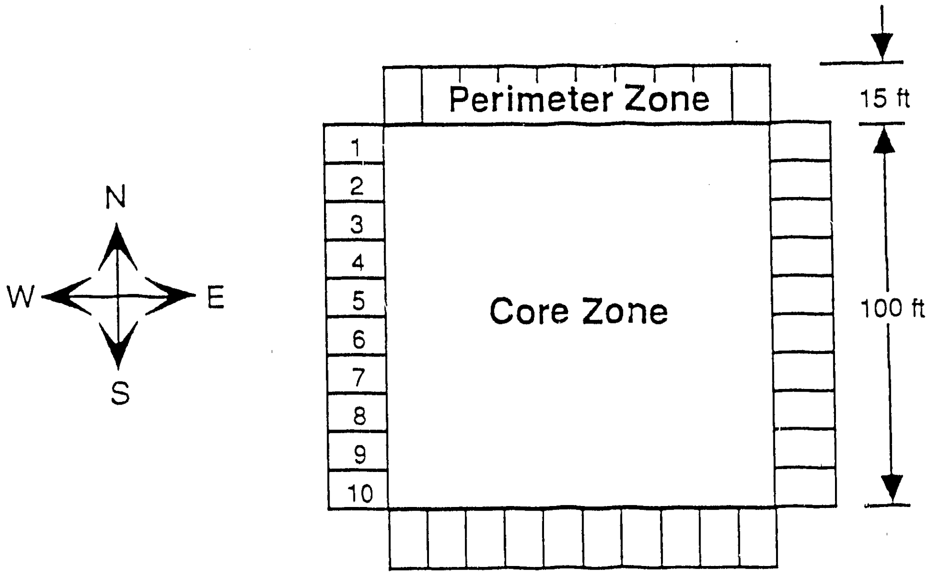

Figure 1. Building Analysis Model

We selected an office building type and used the schedules for occupancy, lighting, and other variables as documented in Chapter 13 of the current ASHRAE standard (20). The other major assumptions we used in modeling the building are as follows:

- Building facades are located parallel to the major compass headings.
- Each of the 40 perimeter zones is 4.6 m (15 ft) deep, 3.1 m (10 ft) wide, and 2.7 m (9 ft) high.
- A plenum is modeled above each zone; the five plenums are separated by *airwalls*. Each plenum is 1.2 m (4 ft) high, resulting in a 4.0-m (13-ft) floor-to-ceiling height.
- The perimeter zones are connected to the interior zone by 70% partitions and 30% airwalls. The end walls of the perimeter zones are adiabatic.
- Three floor surfaces are modeled for each zone--70% is connected to each plenum, 15% is raised concrete floor, and 15% is slab-on-grade.
- Two roof surfaces are modeled above each plenum--70% is connected to the zone above, and 30% is connected to outside air.
- The interior zone is square with an area of 930 m^2 (10,000 ft^2).
- The window-to-wall ratio is 0.30.

The specific envelope, equipment, and lighting parameters for the baseline case are specified in Table 5. We used these baseline parameters to develop an input file for DOE-2, a whole-building energy simulation program that estimates hourly energy consumption (21). The DOE-2 simulation also requires that a geographic location be specified in the input file. We decided to use

Table 5. Values of Selected DOE-2 Input Parameters

Input Parameter	Value
Internal Loads	
Equipment	0.14 W/m^2 (1.5 W/ft^2)
Lighting	0.16 W/m^2 (1.7 W/ft^2), recessed nonvented troffers
Envelope	
Wall Conductance	0.73 $W/m^2 \cdot °C$ (0.13 $Btu/h \cdot ft^2 \cdot °F$)
Roof Conductance	0.32 $W/m^2 \cdot °C$ (0.056 $Btu/h \cdot ft^2 \cdot °F$)
Floor Conductance	0.36 $W/m^2 \cdot °C$ (0.064 $Btu/h \cdot ft^2 \cdot °F$)
Window Conductance	3.27 $W/m^2 \cdot °C$ (0.58 $Btu/h \cdot ft^2 \cdot °F$)
Shading Coefficient	0.46
Equipment (Single-Zone Package)	
Cooling Coefficient of Performance (COP)	2.78
Gas-Fired Heating Annual Fuel Utilization Efficiency (AFUE)	78%

Washington, D.C., because its relatively severe summers and winters capture many of the features of other climates across the United States.

It can be argued that all of the parameters listed in Table 5 are important in characterizing the energy consumption of a building. However, the overall energy consequences of performance improvements in any one of them might be unclear. Such information would provide some perspective when evaluating the new technologies described in the previous section. The building energy analysis model just described and the idea of *sensitivity coefficients* defined below provide some useful insight into these issues.

The baseline building simulation model can be used as a basis for estimating potential impacts of small improvements in envelope, equipment, or lighting. This is done by independently varying each of the parameters in Table 5 and observing the resulting changes in building energy consumption.

To compare the energy impacts of changes to different parameters, the change in a given parameter can be normalized by its absolute magnitude. This produces a sensitivity coefficient, S_i, for parameter i, as shown by

$$S_i = \frac{\delta Energy}{\frac{\delta P_i}{P_{i,n}}}$$

where δEnergy is the change in total building energy consumption, δP_i is the change in building parameter i, and $P_{i,n}$ is the nominal value of the building parameter. Thus, for a selected set of nominal building parameters, using this definition of sensitivity coefficient lets us directly compare the sensitivity of each load (heating, cooling, total, and so on) to those parameters. Also, because the sensitivity coefficients of different parameters have the same units, their magnitudes can be directly compared.

Figure 2 provides a comparison of the sensitivity coefficients of the parameters listed in Table 5. The signs of the sensitivity coefficients have been adjusted so that the bars in Figure 2 represent the magnitudes of the sensitivity coefficient (a measure of the net energy savings) for an increase in performance of the indicated parameters. The results illustrated here indicate that performance increases to lighting have the greatest relative impact on total energy consumption. Performance increases in shading coefficient have the least impact on total energy consumption.

The generalizations that can be drawn from the data in Figure 2 are intuitive, though not necessarily obvious. Performance enhancements to devices that actually consume the energy in the building generally will result in the largest net energy savings. Performance enhancements to constituents that do not directly consume energy may still result in a net savings in energy. However, those savings are generally smaller in magnitude.

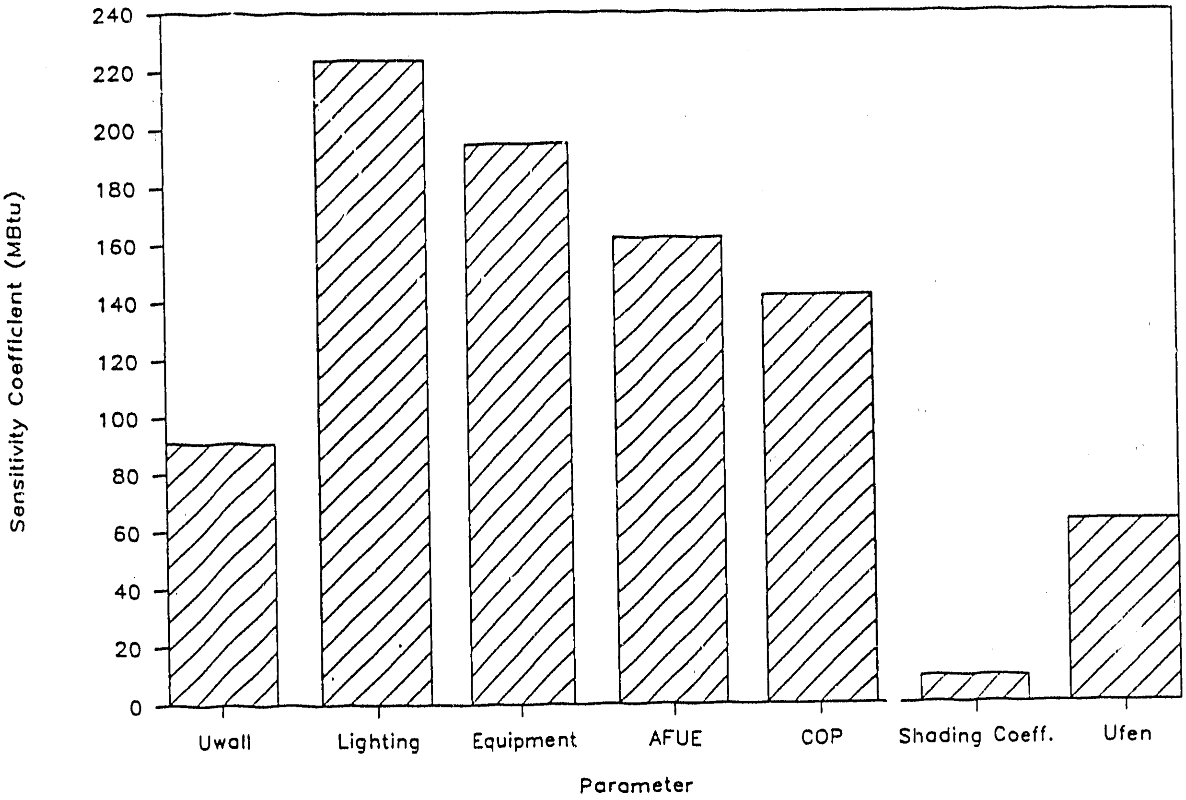

Figure 2. Sensitivity Coefficients for Key Building Parameters

POTENTIAL BARRIERS IN CURRENT BUILDING ENERGY STANDARDS

Building energy standards seek to promote the design and construction of energy-efficient buildings. The traditional method of regulating building design has been to provide a detailed set of prescriptive criteria for selecting, installing, and using the major construction materials and energy-consuming equipment. Early versions of the current U.S. building energy standards used this method. To provide the most generality, the criteria in the standards were based on overall thermal performance characteristics that could be quantified for each of the materials and equipment from which the designer could choose. Consequently, criteria limits were set for glazing and wall U-values, cooling equipment coefficients of performance, heating equipment thermal efficiencies, lighting power densities, and so forth.

Unfortunately, prescriptive requirements do not easily accommodate advances in technology. The criteria can be changed to reflect higher performance levels, but the selectivity of the criteria eventually becomes a hindrance in representing new technologies.

In the following paragraphs, we briefly discuss predecessors to the current U.S. building energy standards. Then, current methods used in the standards to deal with different building technologies are examined. Next, barriers to new technologies that may be encountered in energy standards are discussed.

Finally, examples of technologies that can or cannot be accommodated by existing energy standards for buildings are presented.

ASHRAE Standard 90-75 was the first energy conservation standard developed by ASHRAE. This standard and its revision, ASHRAE Standard 90A-1980, were designed as consensus standards for use as the basis for building energy codes. Both standards used prescriptive criteria to regulate the design and construction of new buildings. By 1987, all 50 states in the United States had enacted building energy conservation regulations, most of them based on Standard 90 (20).

The ASHRAE Standards Committee's recognition of advances in building component and equipment performance, as well as its desire to encourage innovative energy-conserving building designs, led to the development of ASHRAE/IES Standard 90.1-1989. This standard and the U.S. Department of Energy's federal-sector equivalent continue to use prescriptive criteria for building components. However, these standards also include alternative system performance or whole-building performance compliance paths. To understand how these current standards deal with new technologies, both of the alternative compliance paths must be examined.

The system performance path is available for lighting and building envelope system compliance calculations. For lighting, the procedure requires the calculation of a building-level lighting power allowance, which is the sum of allowances, based on activity type, for each of the building spaces. Adjustments are made to account for the impact of room dimensions on the use of lighting power in each space. The actual connected lighting power in the building, which can be adjusted with certain daylighting and advanced lighting control credits, must then be less than the lighting power allowance.

The envelope system performance path uses a complex set of regression equations that model the relationship between a set of envelope thermal parameters and perimeter zone heating and cooling loads. This set includes the overall conductances of the walls and windows, the heat capacity of the walls, the window-to-wall ratio for the building, and perimeter zone internal loads. The regression equations include location-specific climate terms. To achieve compliance, a combination of design envelope parameters must be selected that yields lower estimated heating and cooling loads than the criteria, which are calculated using the same equations and a predetermined compliance set of parameters. The procedure allows the designer to make discretionary tradeoffs in the performance levels of various envelope components.

For more innovative building concepts, designers are encouraged to use the whole-building performance approach. This approach involves the computer modeling of both the design building and a so-called prototype or reference building. The modeling must include hourly energy performance calculations. To achieve compliance, the designer must show that the proposed building performs better, on an annual basis, than the prototype building. The prototype building is defined to have floor space and occupancy identical to that of the design building, but with predetermined envelope, lighting, and HVAC equipment performances.

Because building energy standards are intended to improve the energy efficiency of new buildings, they should permit the use of technologies that are energy-efficient. It is important that a program designed to improve energy efficiency does not itself create barriers to that goal.

Barriers to new technologies may occur in two ways--explicitly or implicitly. An explicit barrier would be one in which the standard specifically excludes a certain technology. Implicit barriers arise when the standard is either silent on or cannot accommodate the technology.

Explicit barriers are relatively rare in standards. When these barriers do exist, they are usually designed to discourage the use of an energy-inefficient technology such as electric resistance forced air heating systems. In this instance, the barrier may not preclude the use of the technology but, rather, may make it very difficult to use.

Implicit barriers may be more subtle and thus more difficult to recognize. A standard's silence on a specific technology may create a barrier situation. Standards usually deal specifically with building envelope components, lighting systems, service water heating, and HVAC equipment. In addressing these components, the standard will specify thermal and optical properties for the envelope, electric power requirements for the lighting, and efficiency ratings for the equipment and systems. As long as the new technology being considered can be described effectively using the parameters and properties contained in the standard, it can be accommodated. If the characteristics of the new technology differ from existing norms, a barrier may exist.

One example of a barrier that exists in current standards is the case of variable thermal resistance materials. Typically, standards will prescribe properties in terms of thermal resistance (R-value) or thermal transmittance (U-value). In all cases, the standard assumes constant thermal properties. When the thermal properties vary, the standard is unresponsive to the technology. Under a prescriptive approach to standards, the energy-saving value of variable thermal resistance materials is not recognized. A further barrier exists because few current energy simulation programs can simulate variable property materials. Thus, the performance path of compliance is also blocked to variable resistance materials. In general, envelope components with variable thermal or optical properties are implicitly barred by current standards.

A second example of a barrier is the case of aquifer thermal energy storage (ATES) systems used for space cooling. An ATES system takes advantage of winter chill to charge a groundwater aquifer, which is used as the storage container. In the summer, the chilled water is withdrawn and used for space cooling. Because conventional vapor compression chillers are not required, ATES systems can operate at very high COPs. The barrier that exists in the current standards is the absence of a recognized test method for rating ATES systems. Without a standardized test method, it is impossible to fairly compare the ATES system to conventional chillers. In addition, energy simulation programs do not currently support models that can adequately describe the performance of an ATES system. Thus, the ATES system is implicitly barred from current standards under both the prescriptive and performance paths to compliance.

Even though the standard may be silent on a technology, the result is not always a barrier to that technology. For example, many of the current developments in the lighting area can easily be accommodated by the standard. Why? Because the improvements in lighting technology will yield improvements in performance characteristics that are already considered by the standard. Any technology that improves the amount of light output for a given power input will tend to result in a lowering of the unit power density figure for a space. The standard currently recognizes this type of improvement in efficiency and thus presents no barrier to the technology.

CONCLUSIONS

As we have shown, advances in building technology will soon be bringing a myriad of new and potentially energy-saving materials, equipment, and systems to the marketplace. We have also seen that the energy impacts of these new technologies will vary--depending upon their application and the incremental increase in efficiency or effectiveness.

The magnitude of the impacts will also greatly depend on the degree to which these technologies are implemented. This, of course, means that the technologies must be cost-effective alternatives to current practice. However, there must also be a mechanism for incorporating them into the energy standards with which they must comply.

Thus, those who develop building energy standards must continually assess new technologies to ensure that they can be accommodated within the standards. In addition, methodologies must be developed for incorporating technologies that perform differently from those presently available.

Some of the ways in which this might be accomplished include

- developing new algorithms for energy simulation programs that describe the energy performance of the technology
- developing *equivalent* thermal parameters for components to allow comparison to existing components
- creating sections of the standard that specifically address new and emerging technologies
- providing incentive credits within the standard to encourage certain types of technologies.

The above mechanisms may provide a means for enabling new technologies to be incorporated into the standards. However, care must also be taken to ensure that by providing this *flexibility*, standards developers do not create loopholes that would allow incorporation of undesirable technologies as well. For this reason, buildings energy researchers must work toward finding a balance point at which energy standards can accommodate potentially energy-conserving technologies while still inhibiting the use of some of the less efficient ones.

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