WHOLE-BUILDING ENERGY TARGETS:
A METHODOLOGY FOR FUTURE PERFORMANCE-BASED STANDARDS

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ABSTRACT

Building energy simulation is playing an increasingly important role in the development and implementation of building energy codes and standards in the United States. This trend parallels a progression over the past 15 years from the use of largely prescriptive methods for encouraging energy-efficient building design to reliance on more performanceoriented approaches. A multiyear research project is currently under way to develop a methodology on which to base future energy performance standards for the design of new commercial buildings. This research effort, the Whole-Building Energy Targets project, is sponsored by the U.S. Department of Energy and is being conducted with the assistance of leading buildings-industry associations in the United States. The project, the technical approach under development (in particular its use of economic optimization), and additional potential applications of the methodology are described in this paper.

INTRODUCTION

How much energy should new, energy-efficient commercial buildings use? The U.S. Department of Energy (DOE) is sponsoring a research project designed to provide technically robust answers to that question, thereby providing a basis for true performance-based energy codes and standards for the design of new commercial buildings. The project is called ***Whole-Building Energy Targets***, reflecting the focus on the performance of entire buildings rather than on systems or components. Pacific Northwest Laboratory is leading the project for DOE, and several key technical and professional associations that serve the U.S. buildings industry are providing major assistance.

Performance-based approaches to regulation have several well-recognized advantages over prescriptive ones. Prescriptive measures tend to constrain choices more than necessary to achieve their intended purpose, while performance-based methods offer maximum flexibility. When applied to the buildings industry, which is traditionally slow to adopt new materials and methods, prescriptive requirements can further slow the rate of advancement in building practices. Performance-based building energy standards, in contrast, can provide positive incentives for designers to improvise and for owners to accept new energy-conserving technologies.

The objective of the Targets project is to develop ***a methodology*** for generating and checking compliance with energy performance targets; that is, the effort is seeking to develop the research basis for future performance standards rather than the standards themselves. The final products from the project will be 1) a fully developed and documented methodology for generating performance targets and 2) software that implements the methodology in a usable way, both for generating targets and for assessing compliance of building designs with those targets. The software will enable the Targets methodology to be demonstrated and tested. In addition, the Targets methodology will be useful for applications other than performance standards, such as advanced tools for building design, energy retrofit analysis, and the planning of building energy research.

In the United States, building energy standards are developed through a consensus process in which individuals with a broad array of interests and knowledge collaborate to create standards that can command widespread support throughout the industry. The Targets software is envisioned as an analytical kernel upon which the developers of building energy standards (and other potential users) can build. Before the Targets software can become fully useful to end users, it will need to be embedded in final application software and adapted to incorporate implementation judgements and an array of data and assumptions on which there is broad agreement. Final application software, therefore, needs to be developed as part of these other efforts. A structured design for the Targets software will facilitate refinement of the methodology and development of those specific applications.

BACKGROUND

The earliest building energy standard to gain widespread acceptance in the United States was ANSI/ASHRAE/IES Standard 90-75 (ASHRAE 1975), which was promulgated by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) in 1975. This national voluntary consensus standard was developed by ASHRAE based on work done by the U.S. National Bureau of Standards in response to needs voiced by building code officials for energy conservation standards. While Standard 90-75 does have performance elements, such as constraints based on overall thermal transfer values for walls and windows, it is predominantly a prescriptive standard whose requirements are based on professional judgement.

Standard 90, in its various revisions, has become the predominant reference and guide for energy-related design of buildings in the United States and has been adopted by most state and local governments as the basis for their building codes. Standard 90 was altered in relatively minor ways during its first revision (in 1980) and given major modifications for its second revision, leading to the release of ASHRAE/IES Standard 90.1-1989 in late 1989 (ASHRAE 1989). Several months before, the DOE had issued Interim Standards, which are functionally equivalent to ASHRAE's, for use on federal facilities (OFR 1990). Several years of research went into improving the technical basis of this second revision, much of which was funded by DOE. Most dramatically revised were those sections dealing with building envelope. Several thousand simulations were performed using the DOE-2 computer program to develop a simplified model of space-conditioning loads in exterior building zones (LBL 1984; Jones 1983; PNL 1983). This model forms the basis for the envelope requirements. The resulting model is sufficiently complex that a computer program was necessary for its implementation as part of the standard.

While retaining many prescriptive elements, Standard 90.1-1989 makes a significant stride in the direction of performance standards. The revisions are significant for their incorporation of computers and simulation both in establishing the technical basis for the standard and as a tool for its implementation. Standard 90.1-1989 sets an additional new precedent in that it begins to treat buildings as thermally interactive systems. In Standard 90.1-1989, the design of one element or system in a building can affect the requirements for another. For example, walls in a building with large process equipment loads may be permitted to have higher thermal conductance than walls in buildings without such loads.

Performance-based energy standards necessarily require performance simulation in their implementation: it is not possible to bench-test a building as can be done with an automobile. Beginning with the its earliest version, Standard 90 has contained a whole-building performance compliance option. Although this option was rarely used at first, we have some evidence that it has seen increasing use as building energy simulation has gradually gained acceptance and become easier and less costly to perform. However, use of this compliance option currently involves added effort on the part of the user because it requires performance that is at least equivalent to designs complying fully with all prescriptive requirements. To demonstrate compliance, a user must develop a simulation input description for the design, modify the input description so that it complies with the prescriptive requirements, and then perform simulations for both versions. The desire to lessen this compliance burden and make the whole-building performance compliance path a more attractive option was a major impetus for initiating the Whole-Building Energy Targets project.

LIMITATIONS OF THE CURRENT WHOLE-BUILDING PERFORMANCE PATH

In addition to its cumbersome nature, the current performance path (based on equivalency in energy performance to a building meeting the prescriptive requirements) has other deficiencies. To keep a prescriptive standard manageable in size and complexity, simplification is necessary. In many cases, requirements must be set for average conditions, and significant variations between buildings that affect how they use energy must go unaddressed. This includes ignoring significant interactions that take place between building systems. For example, the envelope requirements in Standard 90.1-1989 draw on a set of assumptions that are most appropriate for office buildings. Yet the model is used in setting requirements for warehouses, churches, and hospitals as well as office buildings. Many differences, such as occupancy densities, operation schedules, and the needs for windows, were necessarily ignored in order to create a manageable standard.

In addition, Standard 90.1-1989 does not have an explicit economic basis for its requirements. Evaluations were conducted in research for the revised standard to assess the cost-effectiveness of various requirements. However, cost-effectiveness criteria were not used directly in establishing requirements, nor is the standard designed to be responsive to cost variations with location, such as those for utility rates. Electric rates vary quite widely across the United States; for example, rates in high-cost regions are as much as five time greater than rates in low-cost regions. As a result, the standard is not capable of providing accurate signals to building designers on the levels of energy efficiency that are most cost-effective.

Figure 1 illustrates the consequences of one simplification that is present in Standard 90.1-1989. Space-conditioning-related annual energy savings resulting from the substitution of a more energy-efficient electric lighting system are shown for a typical 4,500-square-meter (50,000-square-foot), 3-story office building designed to minimally comply with Standard 90.1-1989. The results, generated using the DOE-2.1D computer program, are shown for four different HVAC system types commonly used in the United States. The direct energy savings from the lighting efficiency improvement, which would be measured at the lighting circuit, were defined as 1.0. The left bar in each pair shows additional energy savings seen at the whole-building level in a hot climate--Lake Charles, Louisiana. Both cooling and fan energy use were decreased by the reduction in heat rejected from the lights, and these were offset only slightly by increases in heating energy use. Whole-building energy savings were on average 60% greater than the direct lighting-system savings. The right bar in each pair shows additional energy savings (or energy penalty) seen at the whole-building level in a cold climate--Madison, Wisconsin. For two of the four HVAC system types, the direct energy savings from the lights were partially offset by the increased energy use for heating, in excess of the decreased energy use for cooling.

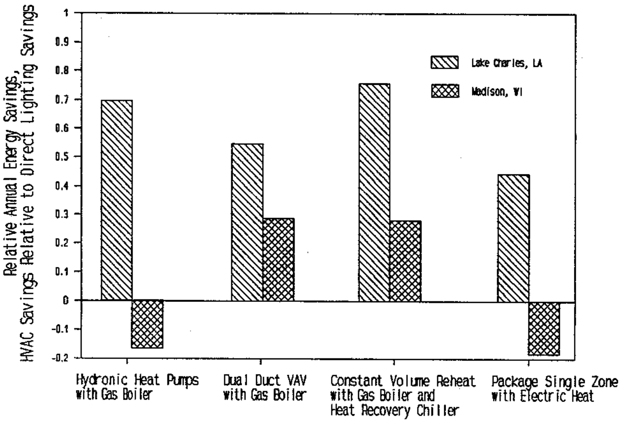

Figure 1. Space-conditioning-related impacts of a unitary improvement in electric lighting efficiency in a hot and a cold U.S. climate. The data were generated using DOE-2.1D for a 4,500-square-meter office building and four different HVAC systems.

Figure 1 illustrates that the impact of improving lighting-fixture efficiency differs significantly when examined at the whole-building level versus when examined at the lighting-fixture level. Current lighting power allowances in Standard 90 account for the nature of activities within each building but not for the characteristics of the building itself. The graph in Figure 1 suggests that more stringent efficiency standards for electric lighting might be more economically justified for buildings in hot climates than for those in cold ones. Implicit in this interpretation is the assumption that more energy-efficient systems (but capable of equivalent performance) could be obtained at higher initial costs. However, other sources of variation between buildings, such as hours of operation or utility rates, could offset or contribute to the disparities.

Figure 2 shows simulated cooling energy use for the same medium-sized office building and HVAC systems as in Figure 1 in both a hot and a mild U.S. climate. Again, the results were generated using DOE-2.1D. Figure 2 shows cooling loads that are roughly three times as large in the hot climate--Lake Charles, Louisiana--as in the mild climate--Seattle, Washington. These data suggest that increased efficiency of cooling equipment would yield approximately three times the energy savings in Lake Charles as in Seattle. In fact, according to utility representatives, commercial electric rates are roughly twice as high in Lake Charles as in Seattle, leading to a roughly six-fold difference in economic benefit from increased cooling-equipment efficiencies between the two climates.

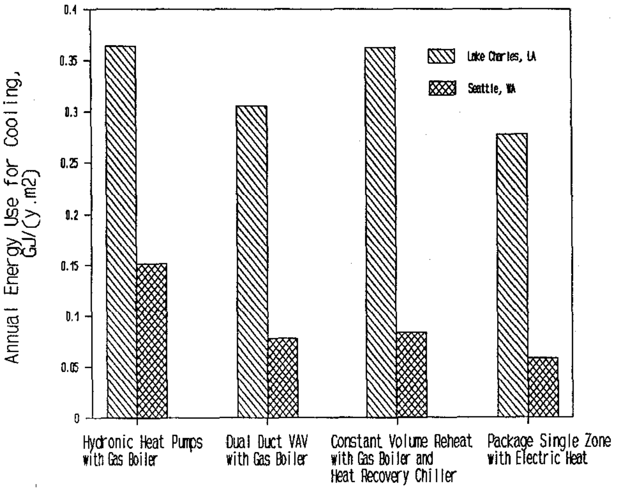

Figure 2. Comparison of cooling-system energy use for a 4,500-square-meter office building in a hot and a mild U.S. climate. The data were generated using DOE-2.1D and four different HVAC systems.

In existing U.S. energy standards, minimum efficiency requirements for cooling equipment are constant across all locations. These data suggest that if the required minimum equipment efficiencies are based on an appropriate balance between first costs and energy savings over time in Lake Charles, they require expenditures that are not cost-justified in Seattle. Conversely, if they are appropriate for Seattle, they leave substantial potential cost-effective energy savings unrealized in Lake Charles. The consensus process by which energy standards are developed in the United States is responsive to well-founded opposition. The process tends to limit the stringency of prescriptive requirements to efficiency levels that are cost-effective virtually everywhere, thereby limiting the success that a standard with this structure can ultimately have in promoting energy efficiency.

Some people think that Standard 90.1-1989 is already too complex. The technical limitations that we have identified may be unavoidable, given the need for simplicity and ease of use. In contrast, a whole-building energy performance standard, in concept, requires only that the performance equal or surpass a stipulated level. A performance standard could, therefore, be made technically robust without necessarily overburdening the user. The approach that has been developed for the Whole-Building Energy Targets project is intended to improve the technical foundation for future performance-based energy standards and, eventually, to encourage the creation of a more energy-efficient building stock.

APPROACH

The Targets project began with the goal of developing a set of whole-building energy performance targets whose immediate application would be in simplifying the use of the whole-building compliance path within the federal equivalent of Standard 90. Members representing ASHRAE, the Illuminating Engineering Society of North America (IES), and the American Institute of Architects (AIA) joined with PNL researchers to comprise the project team. Recognizing a much broader set of needs, the project team recommended a more extensive scope for the effort than initially proposed, a shift of focus to the methodology for generating targets rather than the targets themselves, and several new ideas for approaching the problem (Crawley et al. 1987). The principal characteristics of the recommended approach are 1) basing the performance targets on a detailed accounting of the spaces and functions within each building and 2) integrating the economics of improved building energy efficiency directly into the process for generating targets.

Space Function Basis

Space function--the combination of a function (or human activity) and the associated space within a building--will define the units on which targets will be based. Associated with each function are needs for thermal comfort, ventilation, illumination, services, and amenities. Some example functions are private offices, kitchens, operating rooms, lobbies, and corridors. Using space functions as the basis for defining expectations for energy performance is a significant departure from the traditional approach of using building types, e.g., office buildings and elementary schools. The differences among buildings of a given type and prevalence of multi-use buildings restrict the validity and usefulness of employing building types as the basis for targets.

The location of a space within a building also serves to define energy requirements. Interior office space will use energy differently than will space at the perimeter of a building, and a space with a southern exposure will use energy differently from one whose exposure faces north. By considering the location of spaces together with their associated functions, a detailed picture of the energy requirements for an individual building project can be established. The performance targets developed from this information will be project-specific, i.e., based on a specific combination of space functions. They will, therefore, be responsive to the specific requirements and circumstances that affect how little energy the specific building can cost-effectively be designed to use.

Constrained Economic Optimization

Many aspects of a building's energy-related design are constrained. The constraints include functional requirements, building codes, accepted building practices, the expectations of future occupants as expressed through rental markets, and other subjective factors. However, once these constraints have been identified, using economics as the basis for selecting from among the remaining energy-design options will lead to selections that are both acceptable and cost-effective. After the most glaring inefficiencies have been addressed in a building design, improving its energy efficiency entails incurring higher initial costs that will be repaid through energy savings over time.

The Targets methodology selects sets of energy-related features that minimize life-cycle energy-related costs based on simulated energy performance. The energy-related features provide the basis for the performance targets. By optimizing the important energy features based on the output from building energy simulations, any system interactions modeled in the simulations will automatically be accounted for in the sets of features and in the resulting targets. The largest technical challenge in the Targets project involves the integration of building energy simulation programs with an efficient, automated economic-optimization procedure.

The intent in using optimization as the basis for performance targets is not to force designers to optimize their building designs based on the economics of energy-efficiency investments; a performance standard can enforce only one thing--performance that meets a stipulated level. Optimization provides an objective method for determining levels of energy efficiency that can be achieved cost-effectively. The level of performance that is cost-effective depends on available energy-efficiency technologies, how much those technologies cost, and how well they perform in reducing energy costs.

Decision Variables. The wide range of buildings to which standards must apply and the interactive nature of building systems make it difficult to write simple prescriptive requirements that perform well in all cases, as has been illustrated in an earlier section. These same attributes make it challenging when cast as an optimization problem and solved using methods from the field of operations research.

A person schooled in optimization would characterize the Targets optimization as a ***mixed problem*** because it involves the optimization of both discrete and continuous ***decision variables*** (i.e., the variables whose values will be optimized in the process of solving the problem). The types of decision variables that must be addressed are shown below with an example of each:

- *binary variables* - e.g., a system either has a time clock that schedules its operation or it does not;
- *discrete variables* - e.g., the lights can be controlled by 1) a light switch, 2) an occupant sensor, or 3) a continuous dimming control for daylight utilization;
- *discrete-continuous variables* - e.g., equipment is available with rated seasonal efficiencies of 8.0, 9.0, 10.0, and 11.0;
- *continuous variables* - e.g., blown insulation can be added above the ceiling at any level between R-0 and R-40.

Constraints. Many of these decision variables will be subject to constraints on the values that they will be permitted to assume. Most are simple fixed limits, called ***bounding constraints***, but others may restrict the selection of certain options in combination. For example, dual duct and multizone HVAC systems may be prohibited from using air-side economizers because of control problems. Although preliminary constraints will be developed for purposes of demonstration and testing, the Targets software will contain the flexibility to enable application developers to implement the constraints that they determine are necessary. This will ensure that the selected set of energy-efficiency features underlying each target will be feasible and appropriate to each specific application.

The Objective Function. The parameter that an optimization procedure attempts to optimize (maximize or minimize) is called the ***objective function***. The primary objective function that the Targets optimization will minimize is the present value of life-cycle energy-related costs. This measure of total cost is made up of the initial cost of energy-related features, the present value of the energy costs that occur over the life of the feature, and the present value of affected maintenance and replacement costs. Figure 3 illustrates graphically the components and subelements of these components that comprise the objective function. In general, when there are nonlinearities, discontinuities, and interactions among these components, the optimization problem becomes more difficult to solve. For example, a utility rate schedule with a multiple-block rate that made annual energy costs a nonlinear function of lighting energy use would likely be more difficult to deal with in an optimization than one with a uniform rate.

Problem Scope. The wide range of buildings to which the Targets methodology will be applied further complicates the problem. For example, the optimization needs to perform well when applied to a church building in Seattle, Washington, and a hospital in Lake Charles, Louisiana, despite the vast differences between the two buildings in operation schedules, internal functions, climate, and energy prices. Figure 4 lists some important building and site characteristics that will change the context for the optimization. The Targets optimization procedure must be capable of solving a family of different problems, not just repeatedly solving the same problem with minor variations.

Execution Speed. The final challenging aspect of the Targets optimization relates to execution speed. Almost any optimization problem can be adequately addressed, given enough time and computational power. However, if the Targets software is to be successful in generating custom, building-specific performance targets as part of a standards compliance procedure, execution time must not be excessive (e.g., greater than 12 hours). The optimization techniques that are capable of solving this type of problem are, by nature, iterative. Because building energy simulations will be used to generate key components of the objective function, numerous simulations will be

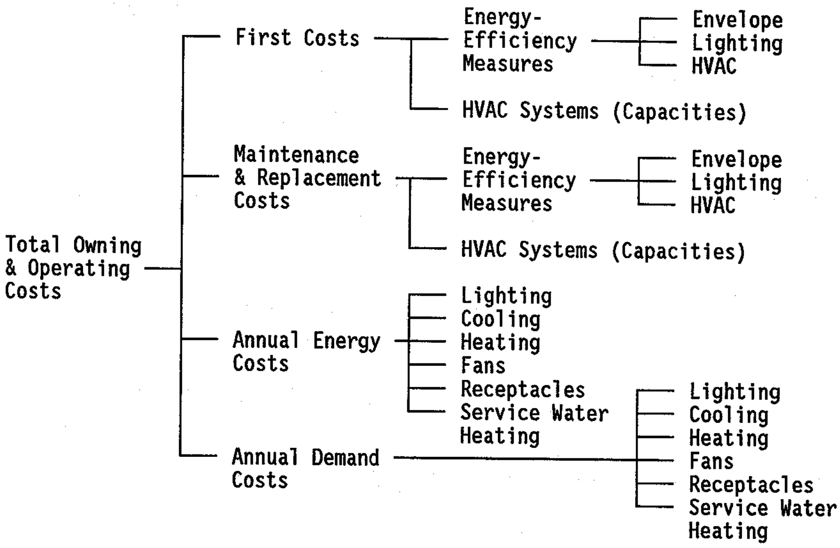

Figure 3. Components of the objective function for optimizations performed as part of the Targets software, with subelements of major cost components identified to the right. The Targets software will determine sets of energy-efficiency measures that will minimize the purchase value of total owning and operating costs.

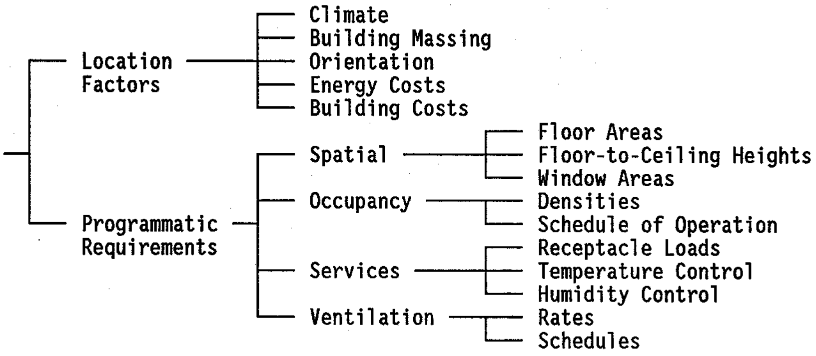

Figure 4. A hierarchical representation of the context variables over which the Targets optimization procedure must perform. These variables are defined by the user. The Targets optimization must be capable of performing effectively over any reasonable range of these variables.

necessary to generate each target. The Targets software is intended for use on the personal computers and workstations that will be used in design offices in the near future. Execution times for the building energy simulation programs that we intend to use with the software may range from several seconds (for temperature bin-based simulations) to a significant fraction of an hour (for full-year hourly simulations). To meet reasonable user expectations for responsiveness, the optimization procedure will need to be made as efficient as possible, and the issue of precision will need to be examined. Fortunately, the validity and benefits of applying optimization to the energy-standards problem do not appear to depend on proof of optimality or extreme levels of precision. An optimization procedure capable of consistently determining highly cost-effective sets of features may be fully adequate for most applications.

PROJECT PLANS

The objectives for the Targets project, the technical approach, and the concept for incorporating the approach in software were developed during the first two phases of the project. We are now entering the third and final phase of the project, which will focus on resolving remaining technical issues and implementing the Targets methodology in software. Development of the software will take place as a sequence of three progressively more sophisticated software products, the third representing the final product of the Targets project. Brief descriptions of these three software products follow.

Prototype Using ASEAM

The first prototype will provide a usable, working version of the Targets methodology implemented as part of a temperature bin-based energy analysis program called ASEAM (A Simplified Energy Analysis Method) (ACEC/RMF 1987). ASEAM is a public-domain, DOS-based program for estimating the energy consumption of residential and simple commercial buildings, which has been developed with funding from DOE. ASEAM is currently in use by hundreds of engineers, federal energy managers, architects, university faculty members, and researchers in the United States.

The first Targets prototype will be capable of selecting economically optimal sets of building energy features for buildings containing up to 15 separate space functions. It will provide the capability to optimize a limited set of envelope, HVAC, and electric lighting system parameters. The prototype will enable users to modify economic parameters, building costs, energy prices, and optimization constraints. This prototype will be an add-on to the ASEAM program, and the current menu-driven user interface used by ASEAM will simply be extended to support the new Targets-related functionality. The focus of this initial development work will be on producing a simple working software implementation, which will enable demonstration and testing of the Targets methodology. The prototype may also be useful in demonstrating some of the additional applications that have been envisioned for the Targets methodology. This work was initiated in early 1991, and completion of the prototype is planned for late 1992.

Preliminary Targets Implementation

In the second part of this effort, we will produce a second version of the Targets software based on a new structured design with a more advanced (although not elaborate) user interface. This prototype will include most of the functionality envisioned for the final Targets software. However, the energy analyses will be performed using ASEAM, and those limitations in scope and technical rigor inherent in temperature bin-based methods will remain. This implementation will be developed for the computer environments expected to be most widely used by architects and engineers at the time of project completion.

During development of this second prototype, we plan to also investigate the treatment of electric lighting systems within the whole-building energy performance approach. Unlike building envelope and HVAC requirements, lighting system requirements (e.g., foot-candles of illumination on a work surface and color rendering index) are not valid inputs for current building energy analysis programs used in the United States. The user input for lighting systems is the power requirement, not the lighting requirement, because building energy analysis programs do not model lighting performance. For this reason, electric lighting systems pose unique problems to a methodology designed to link the requirements for each space to the amount of energy needed to meet those requirements.

Full Implementation of the Targets Methodology

In the final phase of development, we will build on the Preliminary Targets Implementation, replacing ASEAM with DOE-2 as the primary energy analysis program. We plan to accomplish this by using a neutral format for the representation of building and energy-performance data. This will open the Targets methodology to use with other energy analysis programs whose input and output files can be translated to the neutral format. The full implementation of the Targets methodology will be capable of dealing with a more extensive set of energy-efficiency options, which will require added sophistication in the areas of design constraints, building costs, and optimization. With the completion of this prototype, the methodology and implementing software will be complete and ready for use as a kernel in customized applications for specific buildings problems, such as building standards.

ADDITIONAL POTENTIAL APPLICATIONS OF THE METHODOLOGY

The Targets methodology and, in particular, its optimization capability, have a number of potentially valuable applications in addition to standards for which it was originally envisioned. Several of these are discussed briefly below.

Design Guidance

The analytical capabilities inherent in the Targets methodology could help designers to design buildings that are more energy-efficient. Generating a set of energy-design features to provide a basis for a performance target and designing a building are related but different problems. An actual design problem is more constrained because a vast array of additional factors, many of them having little or nothing to do directly with energy, must be considered. The actual design problem may require information that is more concrete and detailed than is required for establishing targets. While a designer must select from among specific available products, a procedure for generating targets could be based on product and cost information that captures the range of available solutions and the corresponding cost trends rather than on information on specific products.

In spite of these differences, the designer may be interested in the selected set of energy-efficiency options underlying the target to provide a starting point for design. The Targets optimization procedure might also be employed to examine an energy-related subproblem within a design during an advanced phase of design. The process of performing an optimization may generate, as a byproduct, information that reveals relationships among energy-related features. These might be displayed graphically to enable designers to better understand which decisions are most important to the performance of the design. We envision that the Targets software could serve as one of many analytical kernels embedded within an advanced computer-based application that provides support for building designers.

Energy Retrofit Analysis

A major current use of the ASEAM program is in analyses to identify cost-effective measures for use in the energy retrofit of existing buildings. Because fewer options are possible when retrofitting existing buildings than when designing new ones, this application may be computationally easier than generating energy design targets. However, retrofit analysis involves the examination of concrete options and detailed costs, while a more generalized approach to options and their costs may be advantageous for generating performance targets. Therefore, data requirements may change between these applications. Because the ASEAM program is currently used largely in retrofit applications, we expect retrofit analysis to be one of the first practical applications of the Targets software.

A Research Tool for Studying System Interactions

Many energy-efficient technologies are found to interact with one another when their performance is examined at the whole-building level. The interactions can be complementary--meaning that the technologies work well in concert--or they can be antagonistic --meaning that each diminishes the economic viability of the other. For example, automatic lighting controls for daylight utilization are complementary with advanced glazings having high visible transmittance yet good solar heat-gain properties. The controls are antagonistic with highly efficient electric lights, because each tends to cancel the potential savings of the other. Full exploitation of new technologies such as electro-chromic glazing (glazing whose solar heat-gain and visible-light properties are directly controllable) in energy-efficient buildings will require understanding and careful attention to system interactions. With such glazings, the design of the fenestration may significantly affect the requirements and performance of the lighting and HVAC systems, creating interdependencies that complicate design and analysis. We believe that the capability to address multidimensional optimization problems available in the Targets software may be of significant value in understanding how to effectively exploit such technologies as part of efficient, integrated building systems.

Research and Development Planning and Assessment

A number of important questions that arise in planning and assessing research and development (R&D) programs are very difficult to address with current modeling capabilities. These include what impact a future technology is likely to have on energy use, what specific applications a future technology will be best suited for, and how low the price of a future technology will need to be for it to succeed in the marketplace.

With an optimization capability and building simulation models representing the building stock, these kinds of questions could be objectively addressed. For example, by performing optimizations for a range of representative buildings in a range of locations and noting the locations for which a new technology is incorporated into the optimized buildings, the extent and composition of the potential market for a new technology could be identified. Additional analyses could estimate the sensitivity of these results to initial costs and energy costs. The optimization capability might also assist those planning long lead-time R&D efforts to assess whether one candidate technology is likely to complement or eclipse the market opportunities for a second technology.

CONCLUSION

The Targets project is designed to improve the technical foundation and ease-of-use of performance-based energy standards in the United States. If the project is successful, it will increase the incentive for designers to adopt new, more energy-efficient technologies (e.g., advanced glazings, lighting, and equipment). Those adopting these new technologies will gain design flexibility (credit relative to the performance target), which can be utilized anywhere in the design (e.g., on greater window area, more dramatic lighting, soaring spaces). After new technologies are proven in actual buildings and accepted by the buildings industry, they will join the array of options used to define new target levels, thereby renewing the incentive for further innovation and early adoption of the latest energy technologies.

The development and refinement of building energy standards is necessarily a long-term evolutionary process. We hope that the Targets project will create an important building-block for realizing continued improvement. We hope to be able to report back at the next IBPSA conference with results that reveal how successful we have been in addressing the key technical challenges identified in this paper.

ACKNOWLEDGEMENT

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