Whole-Building Energy Targets "A" Prototype, Initial Version

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Foreword

This report is one in a series describing research activities that are part of the Pacific Northwest Laboratory's Building Systems Program conducted for the U.S. Department of Energy (DOE). The goal of the program is to improve energy-related decision-making during all phases of the building life cycle by considering interactions between building systems. This whole-building approach underlies the research conducted by the program.

The objectives of the Building Systems Program are

- to identify and quantify the energy-related effects of the interactions between building components and systems, and develop the scientific and technical basis on which private industry can rely to make improved energy-related system integration decisions during building design and construction
- to develop advanced, intelligent computer-based technologies for energy-efficient building design and operation (including construction and commissioning).

The lead laboratory for this program is the Pacific Northwest Laboratory. Expertise and resources from industry, academia, other government entities, and other DOE laboratories are used in planning, reviewing, and conducting research activities. Cooperative efforts with other organizations are an integral component of the program.

This report documents an initial version of prototype software for generating whole-building energy targets for commercial buildings. This software and the methodology it implements have potential applications to energy standards and guidelines, advanced building design tools, energy retrofit analysis, demand-side management programs, and the planning and assessment of building energy research.

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1.0 Introduction

The Whole-Building Energy Targets project, sponsored by the U.S. Department of Energy (DOE), is developing a methodology for generating energy performance targets for commercial buildings. The methodology and implementing software have potential applications to energy standards and guidelines, advanced building design tools, energy retrofit analysis, demand-side management programs, and the planning and assessment of building energy research.

Pacific Northwest Laboratory (PNL) is conducting the Targets project with assistance from three leading building-industry associations--the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE); the Illuminating Engineering Society of North America (IES); and the American Institute of Architects/Association of Collegiate Schools of Architecture (AIA/ACSA) Council on Architectural Research. The project's objective is to develop a methodology to generate energy performance targets for design, check the compliance of commercial-building designs with those targets, and evaluate design alternatives. Two previous phases of the project have been completed--Phase 1 Planning and Phase 2 Concept Development. The current phase is called Phase 3 System Development. Key elements of the technical approach are that targets will be based on space functions (i.e., the collection of activities and corresponding areas within a building) rather than building types, generated using economic optimization methods, and custom-generated for specific building projects.

Pacific Northwest Laboratory is developing computer software, referred to as the "Targets software," that implements this methodology. The Targets software will enable the methodology to be demonstrated and tested and is intended to provide the basis for final computer applications incorporating the methodology. The initial version of the Targets "A" prototype, the first working prototype from the Whole-Building Energy Targets project, was completed in May 1993.

Section 2 of this report provides an overview of the Targets software. Section 3 discusses the functional capabilities and limitations in the initial version of the software's first working prototype. Section 4 describes options for further software development.

2.0 Overview

The Targets "A" prototype is the first of three planned versions of the Targets software. A phased development approach has been planned to provide intermediate products, which will permit early testing of the methodology and review by the building industry. The "A" prototype is considered a developmental prototype--its principal purpose is to enable the project team to test the approach and refine requirements for later versions of the software. The two later versions that are planned, currently called the "B prototype" and the "final implementation," will provide enhanced capabilities and improved performance. These software products will provide a unique analytical capability and will be capable of being imbedded within final software useful for the applications listed in the introduction.

2.1 Definition of a Target

A target is a measure of acceptable energy performance, which can be used throughout the design process as a benchmark for assessing the energy efficiency of a building design. The term "design energy target" is used to emphasize that the target is intended for use in design comparisons and not as a predictor of the absolute value of energy performance for a building once it is operating. The difficulty in correctly anticipating, at the time of building design, all of the important operational conditions that will occur in the actual building makes such predictions inaccurate.

Targets are usually defined in terms of annual energy use or annual energy cost, normalized on a floor-area basis; i.e., thousand British thermal units per year per square foot (kBtu/[yr·ft²]) or dollars per year per square foot (\$/[yr·ft²]). Defining a target in terms of energy cost provides designers greater flexibility because they can trade freely between cost components in the energy bill when demonstrating compliance. For example, use of a measure that significantly reduces peak electrical demand charges but that resulted in a slight increase in electrical consumption would be discouraged under an energy target but may be encouraged under an energy cost target.

2.2 Purpose of "A" Prototype

The purpose of the "A" prototype is to serve as a bridge from the conceptual description of the Targets software, developed in the previous phase of the project, to actual functioning software, thereby serving a proof-of-concept function. In addition to its role in enabling demonstration and testing of the methodology, the "A" prototype is designed to provide preliminary answers to some key questions:

- Is developing targets using the proposed method computationally feasible?
- Do the resulting targets possess the desired characteristics; e.g., are they reasonable, cost-effective, and unbiased?
- How should different energy sources be treated using the methodology to avoid artificial bias that may favor one energy source over another?

- How should the space-function concept be implemented; e.g., at what level of detail and with what level of tailoring for anticipated building uses?
- What are the data requirements of the target-setting process?
- What limitations exist in the availability of necessary input data?
- What methods should be employed in the economic optimization process?
- How should the software be designed?

A key technical challenge to the feasibility of the methodology that has been defined for generating targets relates to economic optimization. Economic optimization is defined in this report as an automated process that selects combinations of energy efficiency features with the lowest overall life-cycle costs; i.e., when construction costs and costs that occur over time, such as for energy, are considered. In the "A" prototype, some measures such as those relating to lighting, are optimized for each space function. For most, however, the measures were assumed to apply uniformly to the entire building.

The task of developing this optimization capability is technically difficult because 1) the optimization must work effectively for any commercial building defined by the user and 2) the optimization must execute quickly enough to be used by designers to generate custom targets (at least for the final implementation). The need for an early testbed for developing this optimization capability was a major consideration in formulating the development strategy for the project and in defining the requirements for the "A" prototype.

3.0 Functional Description

In this section, the capabilities of the Targets "A" prototype are described, as are the limitations of the current version.

3.1 Targets Software Process

Figure 3.1 illustrates the basic process employed by the Targets software. The user enters a description of a building project using interactive screens within the Targets prototype. This description, labeled "Building Program" in Figure 3.1, is then passed to a set of analytical routines. These routines, labeled "Target-Setting Module," employ a two-step process to generate a target.

Figure 3.1. Inputs and Outputs of Target-Setting Process

The routines first make modifications to the building description based on a set of rules related to energy-efficient building design. For example, a rule may require the inclusion of a capability for 100% outside air economizer operation in compatible heating, ventilating, and air-conditioning (HVAC) systems. Second, an external energy-simulation program simulates the building description to which a series of different energy efficiency measures (EEMs) have been added in various combinations. This process is designed to find the combination of features that lead to the lowest life-cycle cost after accounting for interactions among the various measures. The special version of the building description containing these optimal energy efficiency features determines the target. The user can view the results from this target-setting process by viewing or printing one or more reports, represented by the box labeled "Targets Reports" in Figure 3.1.

3.2 Required User Inputs

In general, the information the user must provide to the Targets software to generate a target is a subset of the information routinely compiled at the beginning of a building project, commonly referred to as the "architectural program" or "building program." This information is listed under the box labeled "Building Program" in Figure 3.2. The list includes activities and corresponding spaces to be accommodated in the building and some basic information about the context; e.g., climate and energy prices. Also required is some information about building massing; i.e., number of floors, overall building dimensions, and orientation. While typical building geometries could be assumed in the absence of user input, the project team felt that this information was usually dictated by the building program or by site constraints and that it was usually known at a predesign stage when the software might first be used.

Information in the building program serves to define not only the building services and activities that will require energy but also the constraints in the building context that affect how efficiently those services can be provided. This user-entered information is supplemented by information stored in the prototype's databases, such as climate data and regional energy prices. The resulting target is based on both the collection of space functions in the building and certain attributes of the building itself.

Figure 3.2. Elements of Building Program Used in Generating Targets

In the "A" prototype, a major shortcut has been taken to simplify development. Rather than entering information from the building program, the user enters a description of the building design. The "A" prototype, in effect, infers the building program from the description of the building design, as suggested by the light connecting lines in Figure 3.3.

Figure 3.3. Description of Building Design as Primary User Input in "A" Prototype

3.3 Demonstrating Compliance

Using building design rather than building program input enables the prototype to be used to demonstrate and test the processes for both target-setting and compliance. At the same time, it has enabled substantial detailed work associated with simplified project input to be deferred until the next prototype. Figure 3.4 illustrates the target-setting and compliance process as implemented in the Targets "A" prototype.

Using the Targets methodology, an energy guideline can be developed that has a single requirement--whole-building energy performance as good as or better than the target. This guideline will leave the designer with considerable flexibility while providing reasonable assurance that the fundamental objective of acceptable energy efficiency will be achieved.

Figure 3.4. Process for Generating Targets and Demonstrating Compliance

3.4 Description of Target-Setting Process

The Targets "A" prototype contains a set of databases used in the process of generating targets. These databases, shown at the top of Figure 3.5, cover the following four major areas:

- specification of EEMs to be evaluated in the economic optimization process
- rules (i.e., constraints) that ensure 1) the target is both energy-efficient and appropriate for the project and 2) the target and proposed design are analyzed consistently
- costs associated with the EEMs used in the optimization
- economic criteria used in evaluating performance.

The prototype user can modify information in many of these databases. Screens have been developed to enable user modification to facilitate testing and prototype review. Information contained in the final Targets software databases will require thorough industry review before the resulting targets will have real practical value. If the software is used as part of a sanctioned program (e.g., an energy standard), control will need to be imposed on some of the information in these databases.

Figure 3.5. Prototype Databases and the Two-Step Target-Setting Process

Figure 3.6 illustrates the economic optimization process. In the "A" prototype, a simplified energy simulation program, ASEAM Version 3.0, is used (Fireovid 1991). This program executes many times during the target-setting process. Each iteration of the target-setting process (and execution of the external simulation program) produces an evaluation of the life-cycle cost associated with a specific combination of energy efficiency features. ASEAM was selected for use with this first prototype because it executes quickly and is in the public domain. A full-featured hourly simulation program [e.g., DOE-2 (LBL 1989) or BLAST (BLAST Support Office 1991)] is planned to be used with later versions of the Targets software. Ultimately, it will be desirable for the software to be usable with a variety of simulation programs.

Because the life-cycle cost evaluations are performed based on the output of the simulation program, all interactions between measures are accounted for in these evaluations. Thus, buildings are treated as systems rather than collections of components—an approach with major advantages in encouraging future design of highly efficient buildings.

Figure 3.6. Relationship of the External Simulation Program with Prototype Software

3.5 Additional Reports

The Targets software identifies cost-effective sets of EEMs as a by-product of generating each target, making the target-setting process self-documenting. The specific set of measures on which a target is based can be inspected from within the software. In the "A" prototype, these measures and other by-products of the target-setting process can be viewed through reports. One report provides a line-by-line comparison of the descriptors that differ between the proposed design and the building description used to generate the corresponding target. Information on the sets of economically optimal building features is the key to additional potential applications of the Targets software, such as design tools, research planning, and prescriptive elements of building energy standards.

3.6 Summary of "A" Prototype Technical Characteristics and Capabilities

Some important technical characteristics and capabilities of the Targets "A" prototype initial version are summarized in the following list.

- computer platform - The prototype is designed to run on computers with Intel 80386 (or higher) processors (at least 4 megabytes of RAM) and DOS Version 5.0 (Microsoft 1991). The software requires approximately 5 megabytes of hard-disk space.
- software development environment - FoxPro Version 2.0 is used (Fox Software 1991). FoxPro is a database tool providing a fourth generation software development environment, screen generators and other program development aids, and powerful database functions. FoxPro is expected to provide the option of portability to other operating systems if it is used as the basis for later versions of the Targets software. FoxPro produces executable code; therefore, FoxPro does not need to be present on a computer to run the "A" Prototype.
- energy analysis engine - ASEAM Version 3.0, a public domain energy analysis program based on the ASHRAE-Modified Bin Method, is used. ASEAM is written in BASIC, although a C-language version is under development.
- user interface - The prototype has a character-based, data-driven interface that uses a mouse.
- types of buildings - The prototype can be used for commercial buildings with up to 15 spatial/functional elements (i.e., combinations of space functions and orientations). Initial testing has been restricted to a simple office building model, although the methodology will be applicable to the full range of commercial building types.
- locations - Climate and cost data for 46 Weather Year for Energy Calculations locations in the lower 48 states are included (Crow 1983).
- optimization variables - The prototype is capable of using the following decision variables: wall insulation; roof insulation; glass type; glass thermal, solar, and visible-light transmission; window-to-wall ratio; electric lighting efficiency; controls for daylight utilization; HVAC distribution type; and heating and cooling plant types and efficiencies.
- optimization approach - The prototype employs a variation on exhaustive enumeration in which all decision variables are discretized and can be evaluated in sequence and/or in combination.
- databases - Information in the following areas is stored in the prototype and used in the target-setting process: climate, energy prices, initial costs of EEMs, and constraints on EEMs and other energy-related features.

3.7 Conceptual Description of Targets "A" Prototype

Figure 3.7 provides a conceptual view of the information processing performed by the "A" prototype software. This view is useful for understanding how the Targets methodology has been implemented in software and for reviewing the status of the various functional elements of the software. Each of the elements is described below.

- building description input screens - The majority of building description input screens that exist within ASEAM 3.0 were replicated in the "A" prototype using the FoxPro language. Sometimes

Figure 3.7. Conceptual View of Targets "A" Prototype Software

it was necessary to depart from the original screen designs to provide additional input fields required to support Targets functionality. Information about the building design entered by the user is stored in a FoxPro database under "BUILDING" in the database schema, which is shown at a very high level in Figure 3.7.

- building analysis input screens - The building analysis input screens address two functions: definition of data necessary for the target-generation process and specification of the type of analysis to be performed. Information in the following four major areas must be defined for targets to be generated: 1) energy efficiency features to be optimized, 2) constraints to be used in the target-setting and compliance processes, 3) information related to location (e.g., climate and energy costs), and 4) economic parameters for computing life-cycle costs.
- building analysis algorithm: Case generator is the term that was used for the software routines that control the economic optimization process. Based on user input, the case generator determines which EEMs are to be analyzed and in what combinations and sequence they are to be analyzed.
- ASEAM input file generator - The ASEAM input file generator develops an ASEAM input file for each case (i.e., building description) selected for analysis by the case generator. The file generation process converts the building description from its stored form in the database into an ASCII input file used by ASEAM. The generation process also performs consistency checks to ensure that this operation is performed correctly.
- ASEAM 3.0 - The "A" prototype was designed to use the ASEAM program without modification. While developing the "A" prototype, a deficiency in reporting HVAC system capacities was identified, and The Fleming Group (authors of the ASEAM program) was engaged to modify this reporting feature. Except for this relatively minor modification, the ASEAM program has been implemented as is. No significant program deficiencies were found that may diminish the program's appropriateness as the basis for the initial prototype.
- ASEAM output file extractor - The output file extractor retrieves specific data from the ASEAM output files for each simulation in order to identify the most cost-effective energy features. These data include energy consumption for electricity and natural gas and capacities for various HVAC equipment. ASEAM determines the capacities for HVAC equipment based on load calculations that it performs automatically.
- building analysis algorithm: economics - The economics module uses present-value life-cycle economics to combine annual energy use and various costs associated with energy efficiency features to determine a total owning and operating cost for each set of features. The total owning and operating cost is associated with the corresponding combination of features and stored in the Targets database.
- building analysis output reports - Several tabular reports are provided in the "A" prototype. These reports show the performance of a proposed design and the corresponding target and compare the energy efficiency features on which the target is based with the features in the user's design. Several graphic reports have been added to the prototype to make output results easier to understand.

3.8 Sample Input and Output Screens

Several input and output screens from the "A" prototype are shown below to provide a sense of the "look and feel" of the "A" prototype user interface.

3.8.1 OPEN Screen

Figure 3.8 shows the OPEN screen, which allows the user to open records stored in the prototype's databases. The screen is accessed by clicking with a mouse on the top menu bar. The various locations where data are available are shown in the scrolling window at the bottom of the screen. Information in these records can be reviewed and edited by clicking with a mouse on the desired record and then on the Open record button at the right.

Figure 3.8. Targets "A" Prototype OPEN Screen

3.8.2 Target Compliance Report Screen

Figure 3.9 shows the Target Compliance Report screen, which provides a comparison between the target and the performance of the design. In the "A" prototype, the comparison is shown for both energy and energy cost.

Figure 3.9. Targets "A" Prototype Target Compliance Report Screen

3.8.3 Graph of Total Life-Cycle Costs for Wall and Roof R-Values

Figure 3.10 contains a mesh plot from the Targets "A" prototype showing data generated in the course of a target-setting run (although this graphing capability is not currently linked dynamically to the database). The graph shows the total life-cycle cost (i.e., construction costs plus energy costs over time) for various combinations of wall and roof assembly insulation levels (R-values). The low point in the graph's surface was selected as the basis for the performance target. The grid that defines this surface reflects the process employed in the initial prototype for finding the lowest-cost combination of features. A normal target-setting analysis employs many more optimization variables than this example and creates results that cannot be easily represented graphically.

Figure 3.10. Total Life-Cycle Costs for Various Combinations of Roof and Wall R-Values

4.0 Current Status and Planned Enhancements

4.1 Status of System Functionality

Because of resource limitations, not all of the functionality defined in the requirements specification for the Targets "A" prototype was successfully implemented in the initial version completed in May 1993. This section of the report reviews the status of the major elements of the Targets "A" prototype and identifies those aspects of the prototype that have not been completely implemented.

4.1.1 Building Description Input Screens

The major shortcomings in the initial version of the "A" prototype relative to planned functionality are in the building description input and building analysis input screens (see Figure 3.7). Developing these elements was much more time-consuming than anticipated. While all of the building description screens (approximately 40) are complete, the screen functions have not been fully debugged to work reliably. To test the functionality of the remainder of the system, these screens were bypassed in the testing process and building descriptions were input directly into the FoxPro database.

Two test buildings (an office and retail building) were defined for use with the prototype and test run using ASEAM. These building descriptions have not been transferred from ASEAM into the prototype's FoxPro databases. To date, all testing on the prototype has been done using a five-zone model originally developed as part of ASHRAE Special Project 41.

4.1.2 Building Analysis Input Screens

Similar problems were encountered in developing the building analysis input screens. While all screens were completed, some failed to work reliably as designed. Most problems were encountered in the most complex screens, particularly in the Optimization Decision Variable specification screen. This screen allows the user to determine which optimization decision variables will be used in the run, select what levels of each decision variable to use, and determine the sequence that will be employed in the optimization process. This complex screen was redesigned into four simple screens. The designs for these new screens were completed, but insufficient resources prevented screen rebuilding and testing. However, the underlying algorithms were successfully tested using FoxPro directly. The building description constraint capability was subjected to more limited testing, but functioned correctly in all cases tested.

4.1.3 Building Analysis Algorithm: Case Generator

All of the 13 optimization decision variables were tested and found to be functioning correctly when tested from the FoxPro database. However, the building analysis algorithm was tested using only up to three different decision variables at one time. This is a fairly limited test, but the algorithm appears to be operating correctly.

4.1.4 ASEAM Input File Generator

The ASEAM input file generator was a major source of difficulties during initial prototype testing. These difficulties are attributed to the large number of lines of data that are processed, complexities in the structure of these data (e.g., interdependencies in the data) and the lack of documentation of the ASEAM input file structure. These problems appear to have been surmounted. Procedures were developed to facilitate testing of the file generation process. The file generator performed correctly during fairly extensive testing of other system parts.

4.1.5 ASEAM 3.0

The "A" prototype uses the ASEAM 3.0 program with only minor modifications to enhance reporting capabilities for equipment sizes.

4.1.6 ASEAM Output File Extractor

The output file extractor is a small, fairly simple piece of code that deals with a very small amount of data relative to the data required by the input file generator. The output file extractor performed without error during fairly extensive testing of other system parts.

4.1.7 Building Analysis Algorithm: Economics

The economics module has been tested against hand calculations and appears to be working correctly. However, the original prototype requirements specification required the capability to use the following types of cost components in the objective function: energy, initial (i.e., construction), maintenance, replacement, and miscellaneous. Only the first two of these cost components have been tested, although testing of the remaining components is not expected to be difficult or to uncover major problems.

4.1.8 Building Analysis Output Reports

Of the four planned tabular output reports, only two (Energy Performance and Targets Compliance) are fully functional in the prototype's initial version. The Target-Setting Variable report worked correctly in a previous version, but developed a bug that prevents it from being viewed in the current version. The Near-Optimal Configurations report works, but requires revised headings and lacks a data-sort capability necessary to make the report useful. Correcting these problems is expected to require only minor effort.

A series of output graphs was added to the prototype to make output easier to understand than in its tabular form. These graphs can be accessed with a click of a mouse from within the prototype; however, they do not display data that is dynamically linked to the prototype (i.e., they display data from the prototype that has been manually formatted for graphing). Although establishing a dynamic link between prototype output and graphs is not difficult, this step was deferred because of insufficient available resources.

4.1.9 Summary

The initial version of the Targets "A" prototype contains the major features of the Targets methodology determined necessary to prove the feasibility and value of the approach for performance targets developed by the Targets project team. These features include an explicit economic foundation for the targets, support for a space-function basis, and the ability to generate targets for specific building projects. While building a limited working version of the Targets software, no major technical surprises were found. However, significant limitations in the user interface of the "A" prototype initial version make the intended demonstration and testing of the methodology difficult without further software enhancement.

4.2 Proposed Future Development

The three-phase plan for completion of the Targets project begun in 1991 contains two natural decision points—at the completion of the "A" prototype and at the initiation of work on the final implementation of the Targets software. Currently, there is uncertainty on future funding levels for the Building Systems Program and on the share of program funds that will be allocated for further work on the Targets project. Therefore, the following discussion attempts to outline options for future project development in only very general terms.

To provide the necessary foundation for further project development, additional work needs to be performed on the "A" prototype. This work will maximize the value of "A" as a developmental prototype and will use the prototype as an effective vehicle to better understand the problem of developing a software system for performance targets. Without this additional work, many of the lessons that can be learned from the initial software development effort will not be effectively captured. Follow-up work on the "A" prototype will be focused on correcting those features that currently prevent broad-based and effective testing, demonstration, and review of the prototype.

Once this follow-up work has been completed, the prototype will become an effective vehicle for addressing the outstanding technical issues that need to be understood before performance-based targets can be broadly applied. Significant outstanding technical questions remain in the following three general areas:

- user issues - What are the user interface and software design issues that need to be addressed to make the Targets software clear and understandable and acceptably easy to use?
- data and building/energy domain issues - What information needs to be compiled to ensure that the Targets software performs properly, and what impediments must be overcome to obtain adequate data? Further analysis is needed to assess the adequacy of current approaches to cost data, constraints, and the implementation approach for the space-function concept.
- optimization issues - What methods will be effective in enhancing the performance of the economic optimization process, which will be required for practical, broad-scale use of the capability to generate custom targets for specific buildings? The "A" prototype can serve as an effective testbed for development of an efficient system for optimization.

The current multiyear plan for the Targets project involves developing a Targets B prototype in the next phase. As currently envisioned, this prototype will focus on a new, easy-to-use user interface while providing incremental improvements in other system features; e.g., optimization procedures and EEM cost data. The B prototype has been envisioned as a developmental prototype, although it will be developed so as not to preclude early practical applications if suitable applications are identified.

Two alternative strategies for project development may warrant consideration. The three major options that have been identified for future development are summarized below:

1. Focus development of the B prototype on a specific practical, near-term application, such as using targets in a design tool or as part of a research planning and assessment model. This approach would provide a near-term application for the work, but would shift the project focus toward providing near-term practical value and away from refining the target-setting methodology.
2. Develop the B prototype through incremental enhancements to the "A" prototype, focusing effort on resolving outstanding technical impediments to final application. This strategy would retain the original focus on methodology development but would enable the development work on the final implementation to proceed at an earlier date than under either of the other strategies.
3. Develop the B prototype as envisioned in the original plan.

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