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TITLE THE ULTIMATE IN BULDING ENERGY ANALYSIS: DOE-2 AND BLAST

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THE ULTIMATE IN BUILDING ENERGY ANALYSIS:

DOE-2 AND BLAST

by

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ABSTRACT

Many building energy analysis tools, ranging from the simplest to the most sophisticated, are applicable to the design of large commercial buildings. This paper focuses on two of the sophisticated, detailed, and most powerful of these tools: the DOE-2 and BLAST computer programs. DOE-2 and BLAST are generally classed as high-level, computer-dynamic methods that are based on hour-by-hour computation.

These tools are placed in the context of building energy analysis, and the motivation for their development is traced. The characteristics of DOE-2 and BLAST are discussed, with emphasis on their solar simulation features, and their capabilities are contrasted and related. Three case studies, illustrating typical applications of the programs to the retrofit of existing buildings and the design of new buildings, are presented: a passive solar retrofit of an office building, the use of DOE-2 as a predesign analysis tool, and the use of BLAST in a research and development application.

Future directions in research and development needs for high-level building energy analysis tools and the progress being made toward increased use of these tools are discussed.

I. INTRODUCTION

The design of energy-efficient, envelope-dominated (residential and small commercial) buildings has been studied for several years and is now fairly well understood. On the other hand, only recently have there been concerted efforts to design energy-efficient large commercial buildings that are internal load-dominated. The thermal behavior of large commercial buildings is more complex because of multizone interactions, the greater need for humidity control, and the dominance of cooling and lighting loads. The interaction of the building envelope; heating, ventilating, and air-conditioning (HVAC) system; and plant, under part-load conditions, makes it difficult to integrate hourly loads to determine annual energy consumption.

For passive solar heating, cooling, and lighting strategies in particular, architects and engineers who design large commercial buildings have not developed their intuition to the point where these complex interactions are understood. Therefore, their intuition generally cannot yet lead them to appropriate energy-efficient design strategies. As a consequence, sophisticated building energy analysis computer programs are necessary, particularly during the latter phases of design, to guide the designer's approach.

Although there are many sophisticated computer-dynamic tools available in the public and private domain, DOE-2 and BLAST are the two most widely used public-domain building energy analysis computer programs. The application of these programs to big building design, with particular emphasis on passive solar applications, is the subject of this paper.

First, DOE-2 and BLAST are related to the general building energy analysis context. Then, their characteristics are described, followed by presentation of three examples of their use in big building design. Finally, some future directions for these and similar high-level analysis tools are discussed.

II. THE BUILDING ENERGY ANALYSIS CONTEXT

In examining the building energy analysis context in which computer-dynamic tools such as DOE-2 and BLAST are applied, we see that it is the uses to which a building energy analysis is applied that determine which tools should be used and how they are used. This context has three dimensions:

- the type of building and its energy complexity;
- the type of application: existing buildings, new buildings, or research and development; and
- the phase in the design process.

Building Type: Loads Versus Energy Consumption

The first dimension is established because we are dealing with large commercial buildings in which HVAC system interactions and plant part-load operation have a significant influence on the energy consumption of the building. In fact, the energy consumption follows the occupancy/operational patterns and is generally not proportional to the envelope loads. Furthermore, traditional design has been based only on peak load conditions characterized by winter and summer design days.

In contrast, the design of energy-efficient buildings requires that loads be integrated throughout the year, taking into account the dynamics of transient operation and the control and part-load operation of the HVAC system and plant. Consequently, to determine accurately the annual energy consumption of a proposed design, the analysis tool must model the dynamics of transient operation and the operation and control of the HVAC system and plant.

Type of Application: How Do We Use a Building Energy Analysis?

A building energy analysis may be used for the retrofit of an existing building, the design of a new building, or for research and development leading to improved building designs or design tools. Analysis of existing buildings may be used in an energy audit to determine base-case energy consumption characteristics by end-use category, and then to identify cost-effective energy conservation opportunities (ECOs). Similar analyses are used to determine cost-effective passive and active solar retrofits. Although the more obvious first-cut ECOs can be identified by examination or by using very simple analysis tools, the less obvious but still important ECOs usually require careful analysis of coupled effects using computer-dynamic methods. For example, as lighting and cooling energy use are reduced, heating may become more important. Rretrofits cannot be studied independently and in isolation; their effect on the operation of the whole building system must be assessed.

In new building design, high-level computer-dynamic tools can be used from the predesign through the construction document phases, as discussed below. Bear in mind that coupled systems effects must be considered, especially in schematic design and design development. For example, the interaction of a proposed passive solar strategy with the operation of the HVAC system may completely alter or nullify the intended effect of the passive solar strategy. Consequently, appropriate tools that accurately model these often complex and counter-intuitive interactions, should be used where these effects significantly affect the intended use of the building energy analysis.

For research and development work, analysis tools are used in energy transfer studies and for strategy, concept, and component performance assessments. In such cases, specialized tools are required that accurately model the details of complex energy flows and nonstandard components or system configurations. Such specialized and detailed characteristics are normally found only in computer-dynamic tools such as DOE-2 and BLAST.

The Design Process

A representation of the building design process is shown in Fig. 1. Note that in the predesign phase the tasks are to establish the base-case energy goals and budget, to identify the energy problem and its characteristics, and to identify potential energy-efficient and solar design approaches. Although computer-dynamic tools may be used in this phase (see the predesign analysis case study described in Section IV), they are usually cumbersome and expensive. Very simple tools that can be used quickly, easily, and inexpensively are best; great detail and sophistication are not required.

In conceptual and schematic design, inappropriate approaches must be eliminated and a few appropriate alternative strategies need to be evaluated. One or two schematic designs are then selected for detailed evaluation. During these phases, computer-dynamic tools such as DOE-2 and BLAST can be used effectively, but again they are often more difficult to apply than simple methods. However, where coupled-effects and/or HVAC system and load interactions are significant, the tools selected must accurately take such effects into account.

Computer-dynamic tools are most appropriate in the design development and construction document phases when the tasks are to optimize and refine the design and to check the design against the established energy budget. Parametric studies used to select final design parameters are easily accomplished using such tools as DOE-2 and BLAST.

Available Building Energy Analysis Methods

Building energy analysis methods are often classified as single-measure, multiple-measure, and computer-dynamic [1]. Single-measure methods include the Modified Degree-Day Method and the Equivalent Full-Load Hours Method. The Modified Degree-Day Method is restricted to single-zone, envelope-dominated structures; the Equivalent Full-Load Hours Method is highly empirical and has not been validated. Neither is applicable to large commercial buildings.

The multiple-measure methods include the Bin and Modified Bin Methods [1] and graphical methods such as Energy Graphics [2]. Although the Modified Bin Method includes HVAC system and plant effects and can be sufficiently accurate, it is limited in flexibility and detail and is time-consuming and tedious if done by hand. Energy Graphics appears to have considerable promise for application to the early design phase, but is not yet well established or validated.

Finally, the computer-dynamic category includes many public and private-domain computer programs, covering a wide range of applications [3]. The key capabilities of high-level tools such as DOE-2 and BLAST are in the hour-by-hour simulation of the dynamics of transient operation throughout the year and their detailed simulation of the operation and control of the HVAC system and plant. Table 1 lists the significant capabilities of these high-level programs for application to large commercial building analysis and design. In many cases the detailed accounting of the effects listed is quite significant.

III. THE PUBLIC DOMAIN PROGRAMS DOE-2 AND BLAST

The DOE-2 and BLAST building energy anaysis computer programs were developed by the US Government to provide fast and easy-to-use, yet detailed and comprehensive, programs for commercial and residential builoings. Both programs have been validated and documented in varying degrees. Both have the basic structural features of loads, HVAC system, primary energy plant equipment, and economics subprograms.

DOE-2

Sponsored by the US Department of Energy, Office of the Assistant Secretary for Conservation and Renewable Energy, the DOE-2 computer program has been under development since 1977 [4]. Lawrence Berkeley Laboratory (LBL) has been the lead laboratory in the DOE-2 development effort, with assistance from the Los Alamos National Laboratory; Argonne National Laboratory provided assistance during the first two years of the project. DOE-2 is a detailed hour-by-hour program that uses hourly weather data as input. A key feature of DOE-2 is its input processor, which uses a Building Description Language (BDL) that allows the user to describe the building and its operation in architectural and engineering terminology. BDL simplifies the input process by allowing the user to default most input quantities. BDL also screens the input for errors and inconsistencies.

The DOE-2 LOADS program is based largely on ASHRAE algorithms and uses the weighting factor loads calculative method. Details of the building construction, shading, zone configurations, and internal load schedules may be entered by the user. During early design phases when such details are not known, extensive use of default values may be made. Both peak and hourly loads are calculated.

Some 23 HVAC systems are simulated in the DOE-2 SYSTEMS program. Features include modeling of control strategies, economizer cycles, exhaust air heat recovery, and operation of the supply and return fans.

The PLANT program simulates the operation of the primary energy supply and conversion equipment including boilers, chillers, cooling towers, and electrical generators. An active solar system simulator [5], which is based on the structure of the TRNSYS program [6], includes both preconnected and user-assembled solar heating and cooling systems. Energy storage and heat recovery equipment are also modeled in PLANT. Accurate simulation of the part-load performance of all plant equipment is a key feature of the PLANT program; output includes hourly, monthly, and annual energy consumption by end-use category.

Extensive documentation is available for DOE-2 including a Users Guide [7], Sample Run Book [8], and Reference Manual [4]. The Program Manual describing all program algorithms in detail for earlier versions of DOE-2 is being replaced by an Engineers Manual that is in preparation.

A comprehensive validation program for DOE-2 is nearly complete. This program has included line-by-line coding checks, as well as comparisons with other building energy analysis program results and comparisons with metered building data [9].

DOE-2 is available at LBL and at several computer service bureaus. It runs on CDC and IBM mainframe computer systems.

Various passive solar capabilities have recently been added to DOE-2 [10], including direct gain, thermal storage wall (vented and unvented), and sunspace systems (see Table 2). Some of these features are still being tested and are expected to be available in the near future. Note that because of the weighting factor methodology used to calculate loads, which does not compute wall surface temperatures, comfort conditions cannot be determined accurately by DOE-2. Also, night-ventilative-cooling accuracy and flexibility is limited because of the weighting factor approach used. Additional passive solar cooling and daylighting capabilities are to be added to DOE-2 in the near future.

BLAST

The BLAST building energy analysis computer program was developed by the US Army Construction Engineering Research Laboratory (CERL) with recent assistance from LBL [11]. BLAST is also a detailed hour-by-hour computer program using hourly weather data as input. Like DOE-2, BLAST has a user-oriented input language with default and input screening capabilities. The latest version available to the public is BLAST 3.0.

In contrast to DOE-2, BLAST uses a thermal balance approach to calculate building loads. Consequently, BLAST calculates wall surface temperatures allowing the determination of mean radiant temperatures and comfort conditions.

BLAST simulates a wide variety of HVAC systems, their operating and control systems, fan systems, and economizer cycles and exhaust air heat recovery. It uses computed space loads, weather data, and user inputs describing the air-handling system to calculate hot and chilled water, steam, gas, and electric demands on the air-handling system. Similarly, the BLAST PLANT program simulates the part-load operation of primary energy equipment. Its active solar simulator models a standard, preconnected liquid solar heating and cooling system. PLANT output is similar to that of DOE-2.

Documentation for BLAST consists of a Users Manual [11] and an Input Booklet [12] that contain data input forms for all BLAST instructions. Limited validation data for the BLAST program have been published [13].

Like DOE-2, BLAST is available only on mainframe CDC and IBM computers at a number of Department of Defense installations and computer service bureaus.

Because of its thermal balance loads calculative procedure, BLAST has more extensive and flexible passive solar heating and cooling capabilities [14] (Table 3) than DOE-2. For direct-gain heating applications, BLAST accurately simulates the distribution of solar gains on internal surfaces on an hour-by-hour basis and accounts for solar gains transmitted from exterior to interior zones. It accounts for the dynamic conductive and convective coupling among zones using a simultaneous solution technique. Attached surfaces and reveals, detached body shading surfaces, and moveable insulation can be modeled. Control is provided by a schedule, energy flow, or temperature difference.

Thermal mass may be included as part of the zone structure or may be added internal to the zone. Thermal storage walls, with or without thermocirculation are modeled, including the venting of the storage wall to the outside, driven by stack-effect natural convection within the storage wall air channel.

A first-order daylighting algorithm, as well as direct forced ventilative cooling, is included in BLAST. A roof pond heating/cooling model is to be added as an update to BLAST 3.0.

IV. HOW ARE DOE-2 AND BLAST USED FOR BUILDING ENERGY ANALYSIS? THREE CASE STUDIES.

The flexibility and power of DOE-2 and BLAST as analysis tools applied in various phases of the design process will be illustrated by three case studies.

The Passive Solar Retrofit of an Office Building.

One of the projects in the Passive Solar Commercial Buildings Program, sponsored by DOE, was the retrofit of a six-story office building at Carnegie-Mellon University (CMU) in Pittsburgh, Pennsylvania. This building, the administration building for CMU, was very energy-inefficient as it was constructed and as it is now operated. The objective of the redesign study was to characterize the energy use of the existing building and to identify a series of cost-effective passive solar, or other, retrofits that could be implemented by the University. The Los Alamos National Laboratory assisted the Center for Building Sciences at CMU and its consultants by running DOE-2 in the retrofit analysis. The objective of the Los Alamos involvement was to run DOE-2 independent of, and as a check against, the analysis of the energy consultant on the project, Enercorp of Washington, DC. The Los Alamos results and conclusions were compared with those of Enercorp, whose analysis was constrained by a tight architectural/engineering (A/E) budget. The Los Alamos study was not so constrained and consequently was more thorough.

First, a detailed DOE-2 analysis of the existing building energy consumption was made and then a set of obvious energy conservation modifications (increased insulation, reduced lighting levels, and night HVAC system shutdown) was assessed by both Enercorp and Los Alamos. Then a series of six passive solar retrofits to the "modified" building, specified by CMU, was assessed using DOE-2. These retrofit options are listed in Table 4. The runs were based on independent assumptions and interpretations of the as-built drawings and field data gathered from CMU personnel by Enercorp and Los Alamos. However, Los Alamos had the benefit of more recent field data from the building.

Several differences between the Enercorp and Los Alamos modeling assumptions for the existing building and, therefore, for all subsequent runs, should be noted. Whereas Enercorp modeled a single Variable Air Volume (VAV) system for the building core and basement, Los Alamos used two constant volume systems, one for each of these areas. Furthermore, Los Alamos assumed the mechanical room to be conditioned with a heating and ventilation unit whereas Enercorp assumed this area to be unconditioned. Both analyses used two-pipe fan coil units for the perimeter zone. Also, Enercorp scheduled the lights on more infrequently and specified a greater portion of the heat from lights going directly to the space than did Los Alamos. Enercorp allowed DOE-2 to size the HVAC air flow rates, whereas Los Alamos used the fan capacities given on the as-built drawings. A few other differences in assumptions for zone conditioning, thermostat setpoints, heating/cooling equipment availability schedules, and number of zones occurred. These differences in input assumptions are typical of the interpretations of different users when analyzing the same building; this represents the "user effect."

Figure 2 shows the results of these runs expressed in energy end use quantities (at the building site, including steam generation and distribution losses for the CMU central steam plant) and broken down by heating, cooling, lighting, and miscellaneous energy use categories. Although the sensitivity of results to the input differences listed above was not determined, it is noteworthy that the total energy use of the existing building is only slightly over 12 per cent different for the two analyses. However, the differences in the heating, cooling, and lighting categories are greater

Also shown in Fig. 2 are the results of the six passive retrofit scenarios. Because of the HVAC modeling differences in the two sets of analyses, the Los Alamos results show significantly less effect from the passive retrofits that address the building loads (a maximum of 8 per cent energy reduction from the base-case modifications compared with 24 per cent). Therefore, how the building is modeled with a tool such as DOE-2, especially with regard to the HVAC system, can significantly affect the energy reduction potential of passive solar retrofits.

Because of the low effectiveness of the passive solar retrofits, Los Alamos further analyzed a series of basic energy conservation scenarios that emphasized HVAC system modifications. The results of these runs, which include one passive solar scenario, are shown in Fig. 3 in terms of both energy and cost reduction; note the significant energy savings predicted.

The Use of DOE-2 in a Predesign Analysis

As part of the preparation of design criteria before A/E selection for new building design, an in-house predesign energy study was conducted on the proposed Stable Isotopes Laboratory to be located at Los Alamos. This 8,000 ft^2 laboratory/office building was analyzed to determine a target energy budget, an approximate end-use breakdown so that the energy problem could be determined, and energy cost savings expected from several proposed generic energy-saving opportunities that might be appropriate to consider in the later phases of design.

Because no details of the building construction were known, only data dictated by the building program and Laboratory or DOE standards were available. Therefore, the proposed building was modeled as a five-zone "shoebox" using a greatly simplified input file structure for DOE-2 developed at Los Alamos. First, a base case conventional building was analyzed, followed by a series of HVAC systems, lighting, and building envelope alternatives. The results of this energy programming analysis set a target energy budget of 96,000 Btu/ft^2-yr, exclusive of process energy, using a combination of VAV and constant volume HVAC systems.

The results of the comparison between the conventional and energy-conservative base-case buildings are shown in the energy end use category charts of Fig. 4. Note the significant energy reduction resulting from a proper selection of the HVAC system. The 10-yr accrued energy cost results of a set of envelope or architectural modifications to the energy-conservative base case are shown in Fig. 5. Because this building is internal-load dominated, the envelope improvements have little effect on the accrued energy costs. Consequently, passive solar options for the building envelope will not warrant much consideration in later phases of design. On the other hand, Fig. 6 shows that several engineering options, mainly lighting reduction and HVAC system and plant variations, significantly affect the energy costs. These results strongly suggest that engineering options be given greatest consideration in the later phases of design as they represent the best opportunities for energy reduction. This type of information is most important to the A/E design team and should be included in the design criteria report.

This example illustrates the flexibility and value of a tool such as DOE-2 for a fairly quick and simple analysis of a building in the predesign phase. Such a simplified analysis is done using a simplified input file in which the vast majority of input variables are defaulted by DOE-2.

<u>The Use of BLAST to Study Convective Heat Transfer Mechanisms Within Thermal Zones</u>

Although BLAST has also been used for passive solar retrofit and predesign studies of commercial buildings, it is more appropriate than DOE-2 for studies of the effect of detailed energy transfer mechanisms within and among zones of a building. The results of such studies are used not only to develop heat transfer and passive solar mechanism models for BLAST, DOE-2, and other building energy analysis tools, but to aid in assessing and understanding which mechanisms are important and which are not under a variety of conditions for different building types. A recent LBL study of the characterization of convective heat transfer on the inside surfaces of a space will be described to illustrate this kind of analysis.

A detailed temperature dependent algorithm for natural convective flows over horizontal and vertical surfaces was added to a developmental version of BLAST to assess the importance of the detailed modeling of these processes compared with the use of the constant film-coefficient models now used in the program. BLAST was run using both types of models for a single-zone test building.

Figure 7 shows preliminary results from that study. The constant film coefficients ordinarily used in BLAST are shown in brackets at the surfaces of the zone; the temperature-dependent coefficients calculated by the detailed experimental algorithm are shown above them for sections of each surface. Note the considerable differences between the coefficients calculated for several of the surfaces, particularly along the south wall. These results show that the common assumption of constant convection coefficients is

Although this study is not yet complete and the sensitivity of the load and building energy consumption results to these varying parameters has not been fully assessed, this study shows that assuming these coefficients to be constants may lead to substantial errors in thermal load and air temperature calculations, and in the distribution of gains and losses among the building surfaces.

Because convective heat transfer is the weakest link in our understanding of energy transfers in buildings, and because such processes have not been studied in sufficient detail, the use of BLAST for such purposes is highly appropriate. Only with a program such as BLAST, where the interaction of these processes with the HVAC system and with other elements of the building envelope and lighting system can be studied in a fully coupled and dynamic manner, is this type of study appropriate.

V. FUTURE DIRECTIONS

There are two primary issues related to future directions in high-level building energy analysis computer program development and applications that need discussion. The first deals with development needs and directions for these programs, and the second deals with the progress that is being made toward increasing use of these programs.

Development Needs and Directions

The primary area of ongoing development for DOE-2 and BLAST is in the modification of these programs to improve their passive solar heating, cooling, and daylighting capabilities. Both DOE-2 and BLAST now incorporate several passive capabilities, primarily heating, and further development is under way [10,14]. The chief weakness is in passive cooling for BLAST and DOE-2 and also in daylighting for DOE-2. Both of these areas require additional research before accurate correlations and models can be developed, implemented, and tested in the programs.

A second area where these tools can be valuably developed and applied, and where there is great need in the A/E community, is in the use of DOE-2 and BLAST in parametric studies leading to the development of simplified design tools, particularly for use in early design phases. Part of this effort involves using the high-level programs to determine the range of applicability of existing simplified tools such as the SLR method [15] and Energy Graphics [2]. Indeed, the development of simplified correlational design tools should be based on the most complete, technically accurate and detailed, and validated tools used as references.

A third area is in the use of these tools, combined with regional economic analysis, in parametric studies for systems and concept assessment for passive solar and other energy-conserving strategies. In this manner, the general cost-effectiveness of experimental strategies, as applied to various building types, can be identified for the design community.

Finally, the existing versions of DOE-2 and BLAST, which use separate loads and systems programs wherein the variable temperature and system control strategies are not properly treated, should be revised and combined into a single research tool. The details of this tool are not known at this time, but at a minimum, the tool should include combined loads/systems simulation, full thermal balance loads capabilities, and full interzone coupling.

Progress Toward Increased Use

Over the past five years, DOE-2 and BLAST have undergone extensive development and revision, and only during the last two years have they been used in a stable production mode. During this time, many users have learned to use the programs and the "fear factor" of learning to use a new, sophisticated tool is gradually diminishing among building analysts and designers. The continued decrease in this fear factor with more education and wider use will in turn produce even more widespread use.

However, it has become evident that for DOE-2 or BLAST to be widely used by design professionals, considerably simplified input schemes, including graphical, need to be developed to reduce the cost and complexity of using the programs. The use of DOE-2 with simplified input files, as described above, is an example of what is needed.

Finally, DOE-2, BLAST, and other high-level analysis tools are so comprehensive, powerful, and sophisticated that most design professionals still will seldom find time or investment opportunity to learn their use, even with simplified input/output. Consequently, the small number of specialized building energy analysis firms that now exist will likely see significant growth over the next 10 years. With the expected continued increase in real fuel prices, coupled with new guidelines and standards being considered or developed by professional organizations and at various levels of government, the market for the services of such firms to the A/E industry and building developers is sure to increase.

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TABLE 1

CAPABILITIES OF HIGH-LEVEL COMPUTER-DYNAMIC TOOLS

1. Hour-by-Hour Weather

2. Dynamic Calculations

3. Detailed Loads

    - Building construction (including mass)
    - Shading
    - Multiple zones
    - Passive solar
    - Latent loads
    - Internal load schedules

4. Detailed Systems

    - Wide variety of HVAC systems
    - Control strategies
    - Economizer cycles
    - Exhaust air heat recovery
    - Fan operation

5. Detailed Plant

    - Wide variety of equipment (including solar, energy storage, heat recovery)
    - Accurate part-load performance
    - Load management

TABLE 2

DOE-2 PASSIVE SOLAR CAPABILITIES

1. Direct Gain and Large Thermal Mass

   - Custom Weighting Factors
   - Shading devices

2. Night Insulation

   - Controlled by schedule

3. Thermal Storage Walls

   - Vented and unvented
   - Masonry or water walls

4. Sunspaces

   - Attached sunspaces (convection and conduction through massive walls between zones)
   - Atriums
   - Buffer spaces

5. Forced Ventilative Cooling

TABLE 3

BLAST 3.0 PASSIVE SOLAR CAPABILITIES

1. Direct Gain and Large Thermal Mass

   - Multizone thermal balance (dynamic conductive and convective coupling)
   - Intersurface radiation
   - Proper distribution of solar radiation in interior surfaces
   - Shading devices

2. Night Insulation

   - Controlled by schedule, energy flow, or temperature difference

3. Thermal Storage Walls

   - Unvented or vented to exterior

4. Sunspaces

   - Attached sunspaces
   - Atriums
   - Buffer spaces

5. Forced Ventilative Cooling

6. Daylighting

7. Auxiliary System Control on Air and/or Mean Radiant Temperature

TABLE 4

WARNER HALL, CARNEGIE-MELLON UNIVERSITY

PASSIVE SOLAR RETROFIT OPTIONS CONSIDERED

A. Insulating Panels on All Windows

B. Insulating Panels South and East Windows, Reflective Film Applied to North and West Windows

C. Canvas Awning Shades

D. Water Wall on South and East Windows

E. Light Shelf on South and East Windows

F. Added Insulation

FIGURE CAPTIONS

1. Building design process schematic.

2. Comparison of energy use breakdown for several scenarios for Warner Hall, Carnegie-Mellon University.

3. Annual energy use and cost comparison of Los Alamos modifications analyzed for Warner Hall, Carnegie-Mellon University.

4. Energy end-use breakdowns for Stable Isotopes Laboratory, Los Alamos National Laboratory.

5. Stable Isotopes Laboratory - architectural options.

6. Stable Isotopes Laboratory - engineering options.

7. Calculated and standard assumed convective coefficients in the BLAST program.

DESIGN PROCESS

PRE-DESIGN → CONCEPTUAL DESIGN → SCHEMATIC DESIGN → DESIGN DEVELOPMENT → CONSTRUCTION DOCUMENTS

	PRE-DESIGN	CONCEPTUAL DESIGN / SCHEMATIC DESIGN	DESIGN DEVELOPMENT	CONSTRUCTION DOCUMENTS
TASKS	• Energy Goals And Budget • Identify Energy Problem • Match Energy Sources to Needs • Identify Energy Saving Concepts	• Develop And Test Alternatives • Adjust Energy Budget • Select 1 or 2 Final Schematic Designs	• Select Final Design • Refine Final Design • Finalize Energy Budget	• Final Details • Contract Documents • BEPS
TOOLS	• Energy Use For Reference Building • Very Simplified Methods	• Rules of Thumb • Component Characterizer • Scale Models • Simplified Methods • Economic Analysis	• Full Dynamic Analysis Tool • Scale Models • Economic Analysis	• Full Dynamic Analysis Tool • Final LCC
	DOE-2 or BLAST Simplified Input	DOE-2 or BLAST Simplified Input	DOE-2 or BLAST	DOE-2 or BLAST

Fig. 1. Building design process schematic.

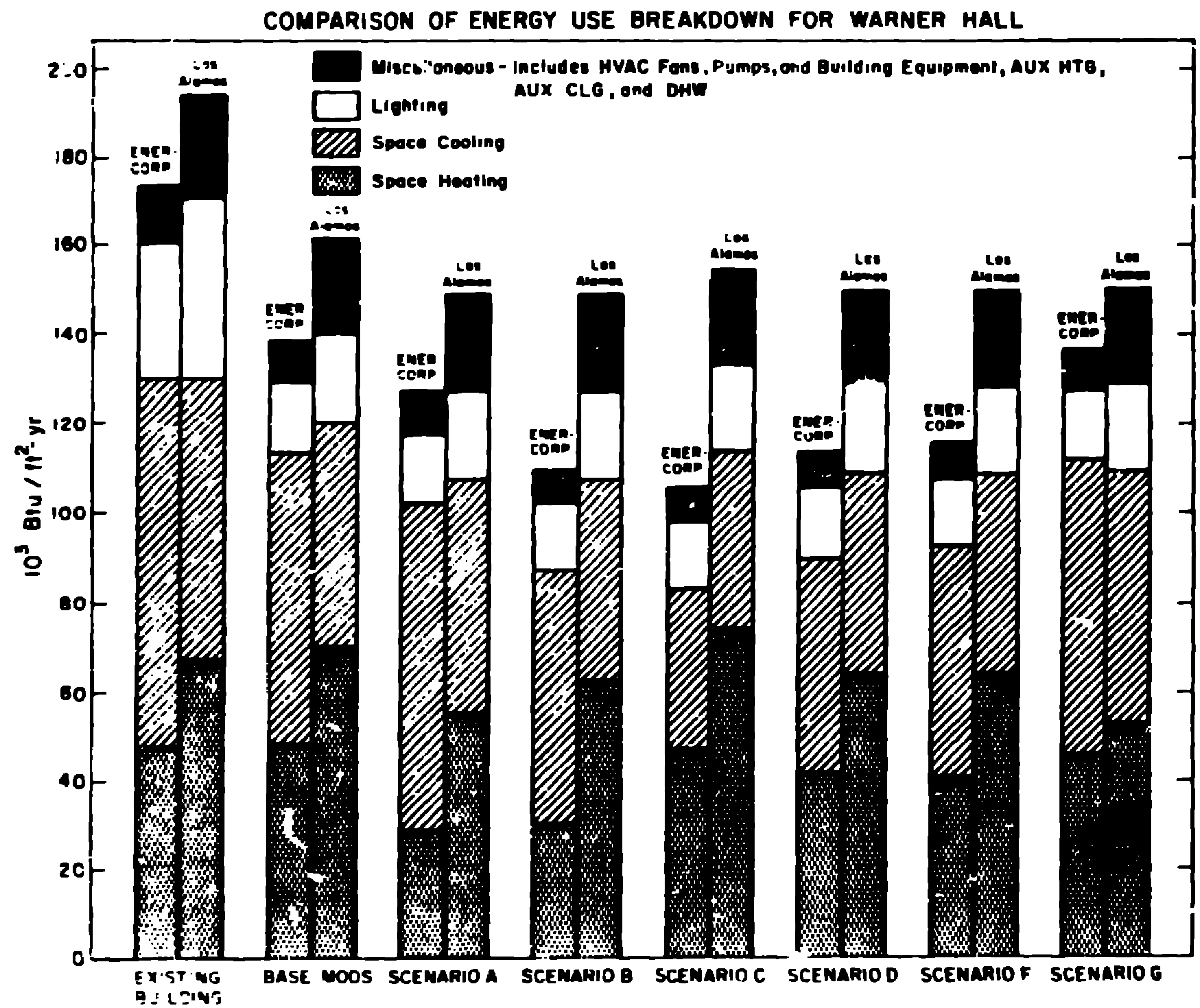

Fig. 7. Comparison of energy use breakdown for several scenarios for Warner Hall, Carnegie-Mellon University.

ANNUAL ENERGY USE AND COST COMPARISON OF LOS ALAMOS MODIFICATIONS FOR WARNER HALL

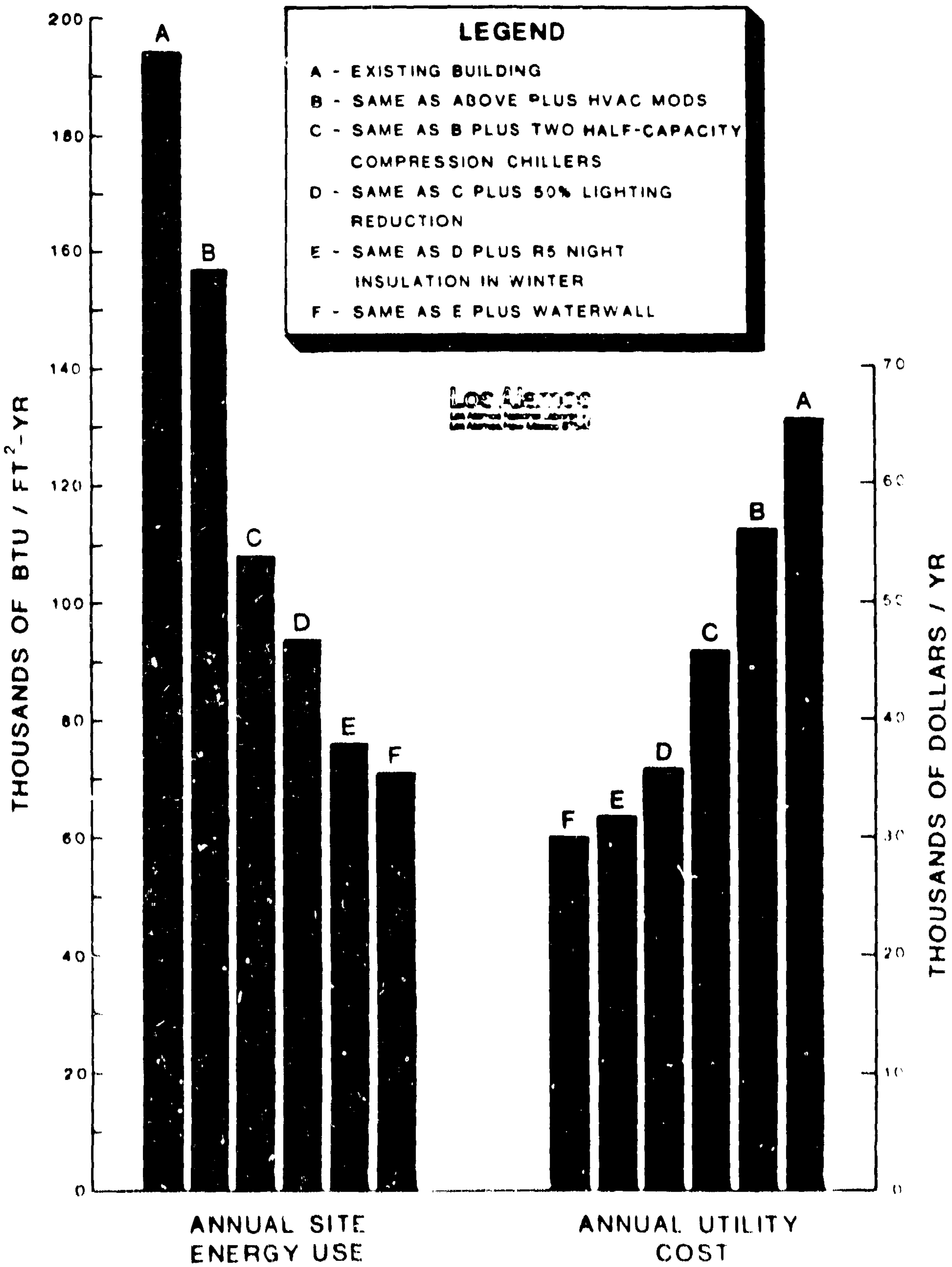

Fig. 3. Annual energy use and cost comparison of Los Alamos modifications analyzed for Warner Hall, Carnegie-Mellon

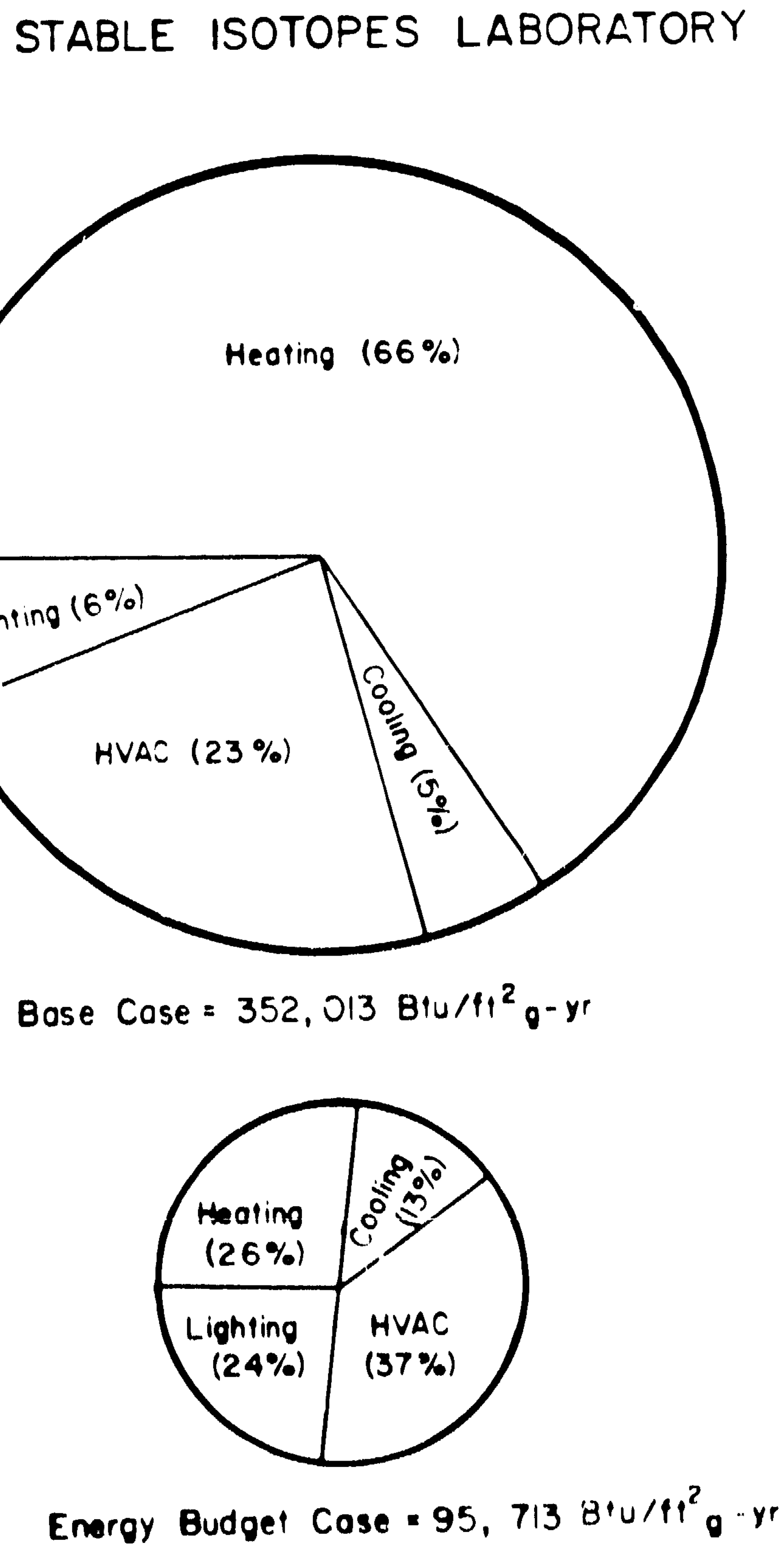

Fig. 4. Energy end-use breakdowns for Stable Isotopes Laboratory, Los Alamos National Laboratory.

STABLE ISOTOPES LABORATORY ARCHITECTURAL OPTIONS

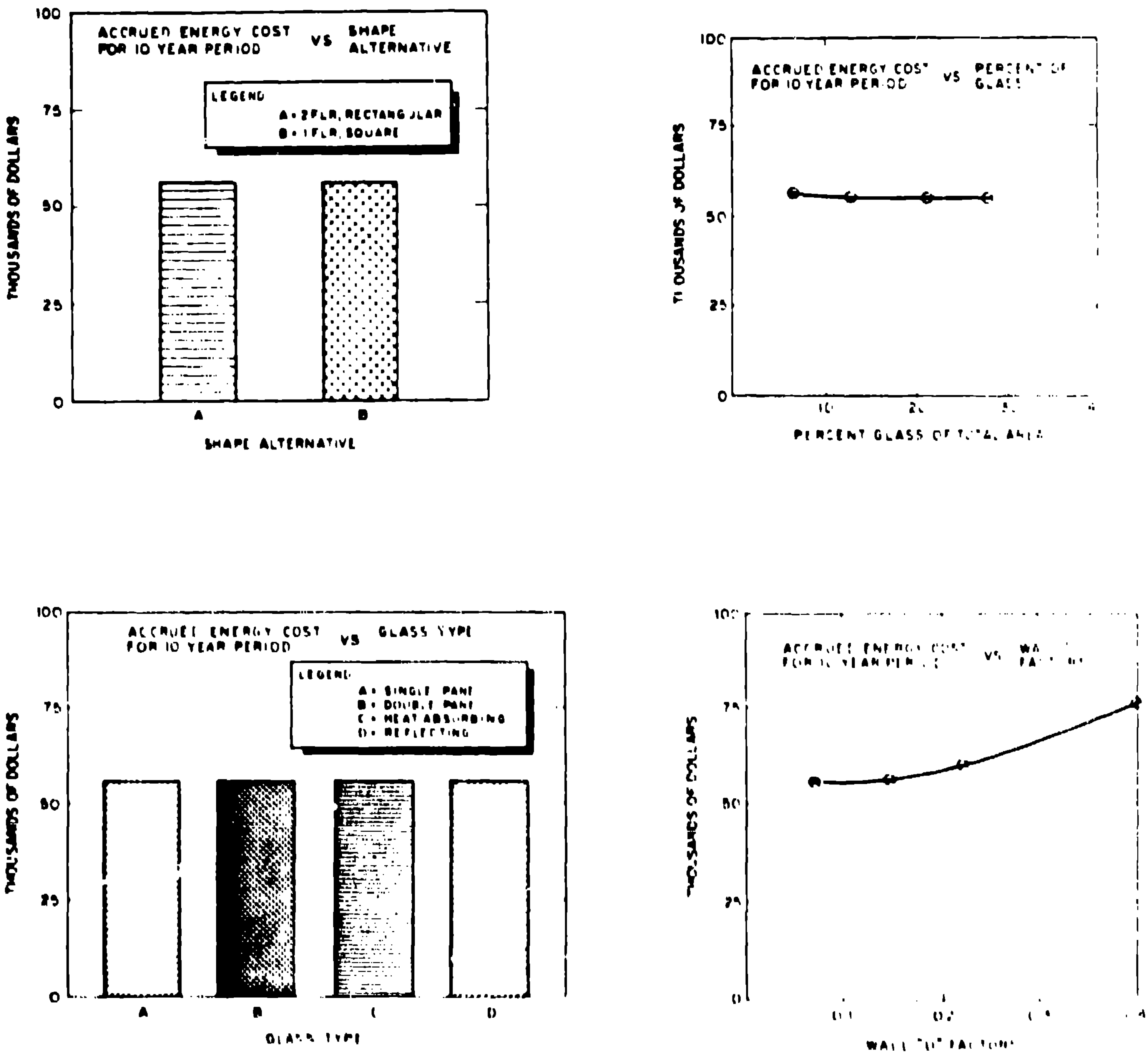

Fig. 5. Stable Isotopes Laboratory — architectural options.

STABLE ISOTOPES LABORATORY–ENGINEERING OPTIONS

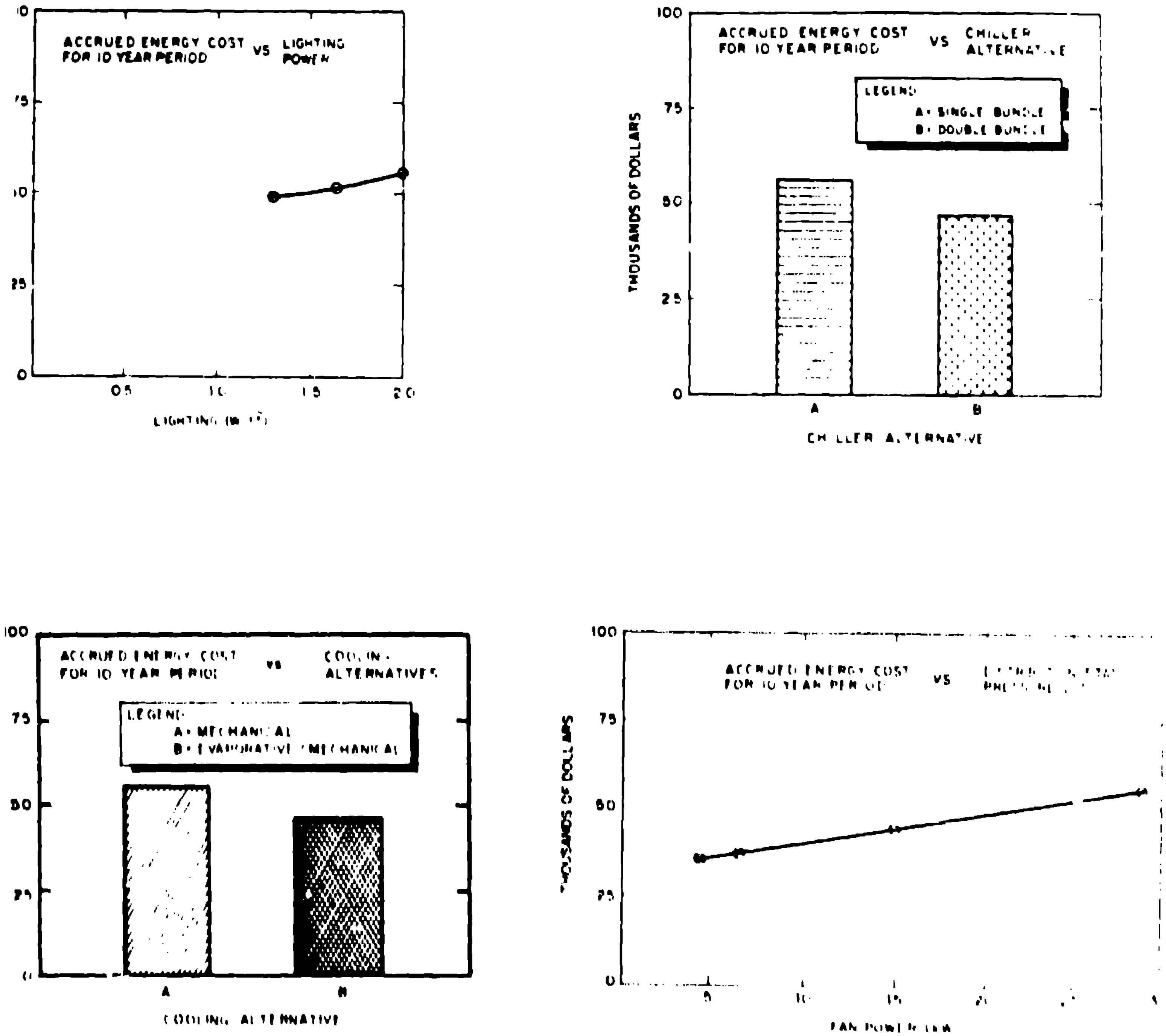

Fig. 6. Stable Isotopes Laboratory – engineering options.

CALCULATED AND <STANDARD ASSUMED> VALUES.

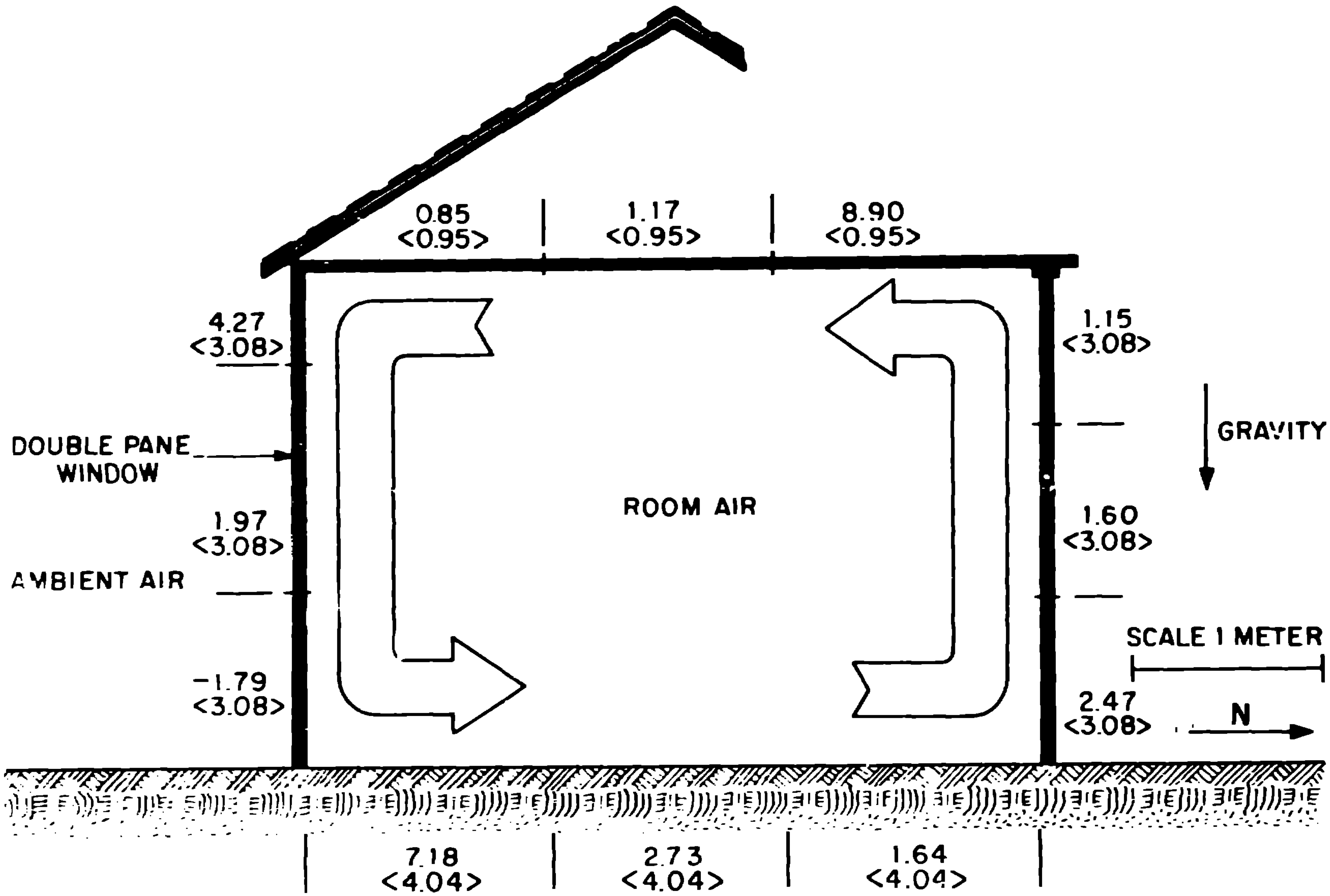

Fig. 7. Calculated and standard assumed convective coefficients in the BLAST program.