MICROCOMPUTER ENERGY ANALYSIS STUDIES OF SELECTED BUILDING TYPES IN A HOT, HUMID CLIMATIC ZONE

Troy M. Mc Queen and John F. Leaver
School of Architecture, Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

The DOE-2 building energy analysis computer program has been used in both the design and analysis of new or retrofitted buildings. The combination of ease of use, economy, and the capability of producing a comprehensive thermal analysis has made this tool valuable to the design professional. Recent developments in the microcomputer area make it possible to employ hourly building energy analysis computer models, such as DOE-2, that were once available only through use of mainframe computers. A microcomputer version of the DOE-2 model is currently available for the study of design and analysis simulations of many building types. Several characteristic buildings emphasizing variations in housing, office/commercial, and school types are being studied. These building types form typical low-scale buildings that are found throughout the region. The discovery of the effects of shape, orientation, mass, and other architectonic elements on energy conservation form a major concern of the survey. A DOE-2 program version adapted for use on a microcomputer demonstrating similar modeling capabilities to the mainframe version is the primary analytical tool used in this study. DOE-2 simulates the heating and cooling loads and the energy consumed by both the primary plant and secondary HVAC energy sources.

INTRODUCTION

Numerous buildings exist in South Louisiana that are poorly designed to satisfy today's need for energy conservation. A set of unique retrofit applications are required to solve the problems generated by the variety of structural and building systems that have been used over the past fifty years in this region. At times during this period some consideration has been given to daylighting and the use of natural ventilation; however, most of these buildings, as they are currently used, do not meet conditions necessary to produce a high level of energy efficiency.

A study was initiated to delineate the potential for energy conservation by considering characteristic buildings and systems found in the region by construction date (decades). From a catalog of existing structures and selected building components, systems of these prototypical units will be investigated to determine the appropriate retrofit strategies for selected building types in a distinctive climatic zone. A building energy analysis program, DOE-2, was selected as the primary analytical tool to be run on a microcomputer. Results of a series of computer runs will be reviewed and serve as a base for comparative studies. Final evaluations to discover both the potentials and limitations of these retrofit strategies on actual buildings will include aesthetic values, technical considerations, and economic factors. Of primary concern is the development of reduced life cycle cost retrofit techniques.

DOE-2 PROGRAM

The DOE-2 building energy analysis computer program can perform the tasks of design and analysis of energy efficient buildings for both existing as well as new structures. What makes this flexible tool ideal for use by architects and engineers is its ease of use, economy, and comprehensive analysis capabilities. This program will determine hourly heating and cooling loads and provide as an output a detailed summary of peak loads. Two libraries, one for typical component construction and the other for weather data, are contained in the program. DOE-2 simulates the HVAC system and the operation of the building energy plant. The economic characteristics of a project are found through a life cycle cost analysis subprogram. The four main sections of the program include: LOADS, SYSTEMS, PLANT, and ECONOMICS.

One translation subprogram (BDL) and these four simulation subprograms are executed in sequence. Each of the four simulations feeds input into the next subprogram. The purpose of each of the subprogram components is as follows:

BDL. The Building Design Language translator reads the flexibly formatted input data and translates it into a format useful to each of the subprogram simulations.

LOADS. Based on ASHRAE algorithms, this subprogram uses the weighting-factor loads calculating method to account for the storage effects of the building elements. Both sensible and latent components of the hourly heating and cooling loads are calculated for each building space (zone). Ambient conditions are provided for use of an appropriate weather tape. LOADS responds to weather and solar conditions, the time delay heat transfer of building components, and the effects of building shade on solar radiation. Information inputs to LOADS includes: building location; thermal zone size; types of construction for walls, roof, and floor; internal loads with schedules; infiltration rates; and domestic (service) hot water use. Reports available from this subprogram include peak space and building loads, by source, and hourly data for a number of variables.

SYSTEMS. A number of HVAC systems can be simulated in this part of the program. This secondary HVAC simulation subprogram corrects the first approximations of the energy demands of a building that is produced by the LOADS subprogram. Input data for SYSTEMS include system type, size, spaces served, ventilation, air flow rates, control strategies, and fan characteristics. Modeling of control strategies, economizer cycles, exhaust air recovery and operation of the supply and return fans are possible. Output from this subprogram is a list of peak loads and heat extraction (or addition) rates.

PLANT. The operation of the primary energy supply and conversion equipment is simulated by this subprogram. PLANT calculates all fuel and electric energy demands of the overall system and the costs of these energy sources. Heat recovery and energy storage can be modeled also. An accurate simulation of the part load performance of all energy plant equipment is a key feature of this subprogram. Input data includes information about the capacity, number, first cost, and maintenance of the primary equipment located in the simulated building.

ECONOMICS. In this economic analysis subprogram, selected LOADS, SYSTEMS, and PLANT alternatives may be considered. The current value of the life cycle cost of the building, including the cost of fuel, equipment, operation, and maintenance, is calculated in this part of the program. For retrofits to an existing building, it can be used to determine the savings-to-investment statistics or to compare the cost of new building design proposals (1, 2, 3).

MAIN-FRAME COMPUTER VERSIONS

The DOE-2 program is available to run on a number of computers using FORTRAN language. DOE-2 was originated to provide analysis methods to assist building designers in reducing energy consumption and to furnish an evaluation tool for the Building Energy Performance Standard (BEPS). It has been in the developmental stage by the U.S. Department of Energy (DOE) for some time. The Building Energy Analysis Group at Lawrence Berkeley Laboratories (LBL) is performing research into the operations and continued development of DOE-2 (4).

DOE-2 VALIDATION

The validity of the DOE-2 computer program has been demonstrated through a number of studies. It has been concluded from these that DOE-2 can accurately model the hourly thermal behavior of a variety of building types, including commercial and residential buildings. The later versions of DOE-2 use custom weighting factors that are specific to the building being analyzed and can produce more accurate results. The degree of accuracy, however, depends more upon the quality of input data as a result of historical knowledge of the construction of the building and the system operation (5, 6, 7).

LATEST DOE-2 RELEASE: DOE-2.1C

The latest version of the DOE-2 program is DOE-2.1C. This version has been made available only recently and contains features that are not available in similar programs. Some of the new features are: daylighting, window and shade management, new shading options, a sunspace (atrium) model, and new HVAC system type (a powered induction unit). In the BDL, expert user control and direct interface with the operation in LOADS is possible through the use of an optional feature, Functional Values. Also, the user can control the frequency at which hourly report data are printed. Under LOADS, algorithms have been added to model the different forms of heat transfer than can occur between a sunspace or atrium and adjacent spaces. Conditional shading device control is now available. In the SYSTEMS subprogram air source heat pump enhancements have been added (8, 9, 10).

DOE-2 DOCUMENTATION

Documentation is available to complement the updated versions of DOE-2. Detailed discussions and instructions for using the new features and enhancements are provided for the 2.B and 2.C versions (8, 9, 10).

MICROCOMPUTER VERSION

Recently a full implementation of DOE-2 has become available for a microcomputer. Certain minimum system requirements for using this version are necessary. The micro version will provide printed reports.

A complete program package for the micro version includes the program diskette library, user's manual, software sentinel, and weather data diskette. Additional weather data diskettes are available for more than 200 sites; and in some cases, both TMY and TRY disks are available. With this software, DOE-2.1B can be run on a desktop computer. The micro version is the DOE-2.1B program ported to a personal computer. It is envisioned that as the LBL groups upgrades the DOE-2 program, updates for the micro will also be available that include enhancements.

Upon completion of a simulation run with the micro version results may be viewed on a CRT monitor, printer, or plotter. Two outputs are available: a "quick" graphics format or a "presentation" graphics format.

As a superset of the DOE-2.1 mainframe computer program, the micro version includes the following typical steps.

1. Set up procedures. Check hardware and system software configurations.
2. Materials library. The standard materials library can be modified or a unique library created.
3. Weather data. An hourly weather file must be available. The appropriate weather file must be copied from a weather diskette to the fixed disk.
4. BDL Input data file. The BDL file must be developed externally, using a word-processor or editor.
5. Identify errors in the BDL file. The BDL input processor subprogram performs a check on the user's input data and generates a "standard file." Error or warning messages are presented in the BDL output report.
6. Correct BDL file. A de-bugging procedure is necessary to correct any errors found in the file.
7. Execute the Building Simulator. After re-

moving the errors in the BDL input file, the Building Simulator is run, or it will be initiated automatically, if the BDL was successfully completed.

8. Results of a run. The File Manager is used to lable the results of a run.
9. Graphical Output. With the Graphics Post-Processor output from a run may be reviewed, plotted, or printed (11).

METHODOLOGY

An investigation of characteristic school buildings found in south Louisiana can serve to demonstrate the approach used in the study. This part of the study involves a two-phase process; the first is the implementation of DOE-2 to simulate the energy behavior on middle schools in a hot-humid climate. Building type and construction year are factors that form an energy context and historical reference for the study of design aesthetics. Buildings selected will represent a diversity of age, construction type, plan form, system type, and orientation. These case studies will formulate a data base from which a checklist appears of various building components exhibiting comparative high energy usage; strategies will be proposed and studied to determine their viability and cost effectiveness. Various techniques will emerge that can be cataloged to form a pattern of viable energy strategies. The second phase involves the in-depth study of each school using parametric studies to understand the integrated relationship of the factors involved with energy behavior within buildings. The study of the interactive nature of these building components will be performed to a more refined and detailed level concerning such issues as the energy effect of the building orientation and the plan form, or the energy effect of the orientation and the plan form on various wall types whether with or without windows, or the energy effect of scheduling masses of people in certain locations at certain time periods. These are just a few examples of the dynamic nature of the effect of building components and energy. From these parametric studies an interactive energy model for middle school buildings in a hot-humid climate can be constructed.

CASE-STUDY EXAMPLE: McKinley Middle Magnet School

The energy simulation of existing building types can demonstrate to architects and engineers viable energy retrofit strategies and directions that insure energy conserving design. Public operated middle schools were considered first because of the number of existing schools in the city/parish region. East Baton Rouge Parish (city-county) public school system has more than 100 school complexes. There are 19 high schools, 14 middle schools, and 67 elementary schools.

The purpose of the study is to propose appropriate low-cost retrofit strategies. A four-phase modeling procedure is being followed to accomplish the objectives of the study.

Phase One: The initial computer simulation of the existing building is being performed to determine the areas of highest energy usage. The overall computer loads need to be compared to the actual energy consumed by the buildings studied to determine the relative accuracy of the model. Most computer simulations fall within the 10 percent range of energy consumed. If the computer loads fall outside this range, additional study must be performed to correct the discrepancy.

Phase Two: Parametric simulation studies must be performed to determine the impact of individual components on the energy behavior. These parametric studies allow for the change in one variable at a time. The variables linked to the significant energy producing components are examined.

Phase Three: The changing of cumulative variables assists in the understanding of the dynamic behavior of energy within buildings. These cumulative variable changes can be compared to runs of the previous phases to determine their dynamic effect.

Phase Four: After these computer simulations have been performed, proposed low/high cost strategies can be illustrated. The library of appropriate strategies will be established representing the various contexts into which each proposal will fall.

Of the fourteen middle schools, McKinley Middle Magnet is a central city complex built in the early 1950s and has many characteristics of schools built in that decade (Fig. 1). The earlier use of this structure was for a high school. When the facility was outgrown by student population, a new high school was built nearby and the school became a middle school. The student population is about 1400. Site planning for energy conservation was obviously not a major consideration during the building design phases. Orientation of Building A, not air-conditioned initially, was a purely aesthetic concern. While the building was originally considered to be naturally ventilated, the southwestern exposure coincides with a maximum daily peak load during the months requiring cooling. Daylighting may have been a part of the preliminary design consideration, but its use has not been maximized in the present configuration. Little or no insulation was placed in the roof and wall elements of the structure. Some glazing has been replaced with a plastic glazing material. No effort has been made to seal windows or to manage ventilation. Both heating and cooling demands are increased by this lack of consideration of window glazing and frames. Classrooms on the southwest are overheated during all seasons--fall, winter, and spring. Cooling equipment for these areas were probably oversized, also.

Poor site planning, building design, and selection of materials and systems of construction all contribute to make this school complex a larger than average consumer of energy. While some low-cost energy conserving strategies may reduce operating cost, to achieve significant cost reductions more expensive systems must be considered. These should be planned and developed on a life cycle cost basis, and those strategies that produce early paybacks must be considered first priority.

An energy analysis program conducted by a private engineering firm indicates the energy use in the existing facilities at McKinley Middle Magnet School. For the classroom spaces lighting demands the greatest part of the existing budget (45 percent). As expected, the cooling system demands the other major part of the costs (about 39 percent). Priorities must be assigned to energy conservation projects within the city-parish region. These should be based on a consideration of the expected life cycle cost for modifications, especially those requiring large capital expenditures. Where possible, minor modifications should come from yearly operating budgets; however, as a financial crisis exists, even these may not be possible currently. As funds become available, a decision mechanism to determine the levels of priority for modifications must be in progress to assist the planners and decision makers.

The focus of the case study is the McKinley Middle Magnet School in Baton Rouge. The school is designed as a campus-type plan and the study involves the classroom building, A. A double-loaded corridor serves as the main circulation artery for the two-story, 29,000 square foot building (Fig. 2). The structural frame is reinforced concrete and internal partitions are hollow clay tile. The typical exterior wall contains approximately 60 percent glazing. The HVAC system is a two-pipe fan coil system with boilers, a cooling tower, and absorption chillers serving as the major plant components. The simulation model considered the external siting, the internal arrangement and scheduling for people, lights, and equipment, and divided the building into thirteen separate zones to monitor the enternal energy demands.

The initial simulation furnished insight as to which building components caused the greatest energy consumption and it established the base conditions upon which various strategies were tested. The data used for the comparison studies was generated by the three programs, LOADS, SYSTEMS, and PLANT output reports. The LOADS output data presents the yearly heating and cooling energy totals required by various building components to maintain human comfort. The portion of the SYSTEMS output data used consists of the total heating, cooling, and electrical energy. Heating energy is the sum of all heat energy delivered to the spaces for the year. Cooling energy is the sum of all energy extracted from the building for cooling for the entire year. Electrical energy consists of the total electric consumption including lights, secondary HVAC equipment, and fans. The total site energy is the portion of the output data used from the PLANT reports. It consists of the sum of fossil fuel and electric source energy to maintain the required demands.

BASE CONDITION

The thermal LOADS generated by the initial simulation yields a deceptively high cooling demand with the components illustrating the highest consumption as infiltration, glass solar, electric lighting, and glass conduction. Cooling loads dominated the heating load by three to one. Closer examination of the data revealed two and one-half summer months of intense solar gain and increased infiltration, and therefore an apparent increase in the need for cooling. External gains continued to be added while the internal gains for the same period were non-existent due to the closure of the school. It

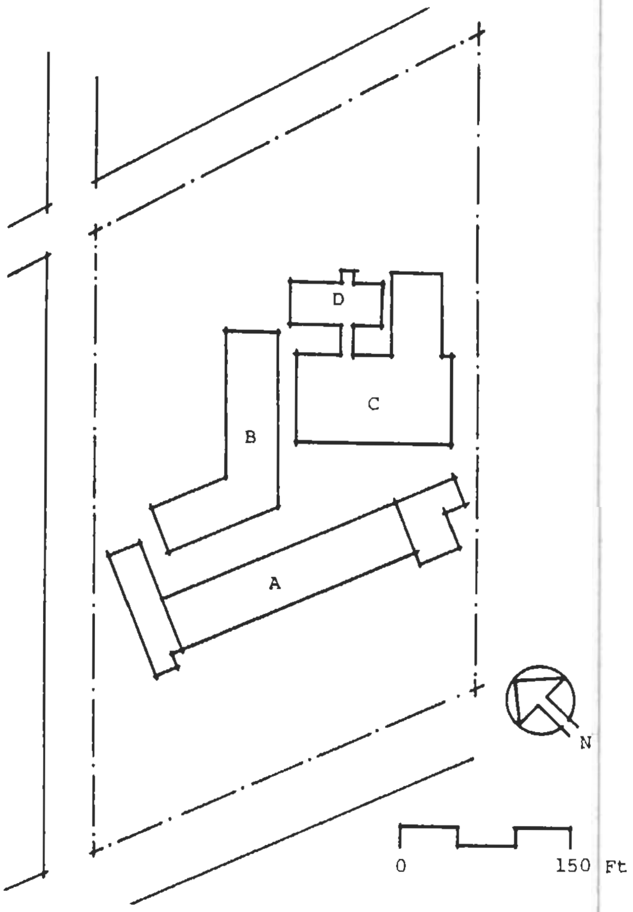
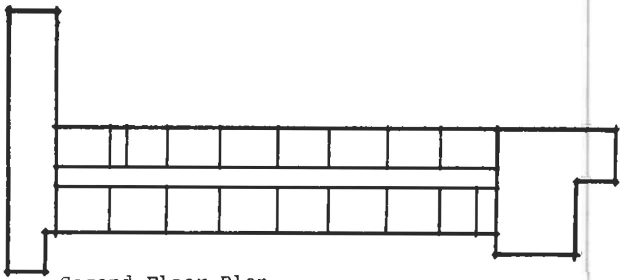
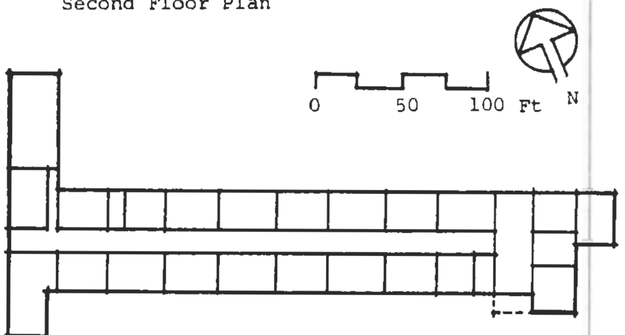


Fig. 1. Campus plan.



Second Floor Plan



First Floor Plan

Fig. 2. Building A, floor plans.

should be noted that this occurred in all the parametric LOADS simulated. This factor was corrected at the SYSTEMS level and the energy consumers in the descending order were electric lighting (658 MBtu), cooling (399 MBtu), and heating (272 MBtu). Total site energy consumed was 1490 MBtu, with a 51.3 KBtu/sq-ft gross area (Fig. 3).

The following strategies were undertaken to reduce the energy consumed and to determine what percentage could be affected (Fig. 4).

LIGHTING

Electric energy was the dominate user at the SYSTEMS level and electric lights contributed about 49.4 percent of energy supplied at the PLANT level. The electric light level was decreased from 4 to 2.7 watts per square foot. Due to the extensive exterior glazing, the loss in the lighting level appeared to have a minimal effect on lighting levels. The results revealed a minimal effect on the thermal LOADS, about 4 percent overall savings with an increase of 6.4 percent in the heating load and a decrease of 7.2 percent in the cooling load. At the SYSTEMS level the heating energy dominated the cooling energy (320 MBtu to 305 MBtu), while the electrical energy dropped 24 percent from 658 MBtu to 505 MBtu. Thus an overall savings at the site was about 12 percent with a 45.4 KBtu/sq-ft-yr gross area.

INFILTRATION

The 1.0 air change per hour appears to be a conservative estimate as both 0.5 and 1.5 air changes per hour were modeled. Tightening the building envelope produced a 27.4 percent LOADS reduction, while at the 1.5 air change rate an increase of 13.3 percent was incurred. SYSTEMS reveals a savings of 12.2 percent in heating and 26.9 percent, with an increase of 2.8 percent for electrical energy. Reducing infiltration from 1.0 to 0.5 air changes per hour reduced the total site energy consumed by 11.9 percent to 45.2 KBtu/sq-ft-yr gross area.

SHADING COEFFICIENT

Venetian blinds are the existing shading device and the shading coefficient value is 0.57. Two models were studied, one at 0.75, the other at 0.30, modeling a light reflecting screen. It was determined that the 0.30 study saved about 9 percent of the energy, while at the PLANT level, the energy used at the site increased by 1.3 percent. The 0.75 study illustrated the reverse effect, while at the LOADS and the SYSTEMS level there was a respective increase of 5.8 to 7.1 percent; there was a savings of 2.1 percent at the PLANT level. Closer examination of the data seems to illustrate an understanding of the nature of the school building type. The initial assumption was that the school's internal thermal loads operated exactly like office buildings; however, for the hottest part of the year and of each school day the structure was not in use. Therefore, even in the hot, humid climate almost an equal amount of heating and cooling months occur at the school. Increasing the amount of sunlight caused a savings in the total energy consumed because heating this building under these conditions appears to require more energy.

INSULATION

Insulation levels were increased for both walls and roofs. Three inches of insulation were added to the interior of the roof with a savings from LOADS to SYSTEMS of 4.5 to 4.8 percent, while the total energy saved at the PLANT was 3.5 percent. Simulating an addition of one inch of exterior insulation, similar results occurred; however, at the SYSTEMS level, more cooling energy was required, probably due to the blanket effect of holding in the internal loads. The results were a savings of 4.7 percent at the LOADS program, a 4.8 percent savings at the SYSTEMS program, and a total site savings of 4.0 percent.

GLAZING

Two panes of glass were substituted with a decrease in energy LOADS of 6.0 percent, mostly due to reducing the heating load. The SYSTEMS energy was decreased by 9.4 percent; however, an increase in the cooling load occurred, brought on by an increase in the internal gain because of the blanket effect of double-paned glass. The total site energy consumed showed a savings of 9 percent and a 45.1 KBtu/sq-ft-yr gross area.

OVERHANGS

The southwest-facing wall with 60 percent glazing was modeled with a three-inch fin overhang and, because of the nature in which it was modeled, produced minimal results. LOADS were increased by only 2 percent. SYSTEMS energy was reduced by 2.7 percent; however, there was an increased demand for heating energy from 272 MBtu to 280 MBtu. The final totals at the site yielded a 0.2 percent savings. This technique needs to be modeled as an eggcrate-type structure to demonstrate better energy savings.

COMPOSITE

This study involves the variation in four components simultaneously. The change in lighting from 4.0 to 2.7 watts per sq-ft; the addition of two panes of glass; the addition of three inches of roof insulation; and the reduction to 0.5 air changes per hour. The results suggest a dramatic decrease in LOADS of 56 percent and at the SYSTEMS level a savings of 32 percent while at the PLANT level a decrease in 30 percent of the energy required to 33.2 KBtu/sq-ft-yr gross area.

The reduction in the amount of electric lighting seems to be a viable retrofit strategy to pursue. Daylighting studies need to follow this to determine this concept's efficacy. Further studies should deal with the window portion of the envelope to determine the factors that will be most cost effective.

Reducing infiltration into the building envelope and adding two panes of glass appear to serve as big contributions to energy conservation. Installation of the double-glass scheme, however, will be more costly and the long-term payback needs further

McKINLEY MIDDLE MAGNET SCHOOL
MODEL EXISTING SCHOOL CONDITIONS

LOADS: Heating and Cooling
SYSTEM: Heating, Cooling, and Electrical Energy
PLANT: Total Site Energy, KBtu/sqft-yr Gross Area

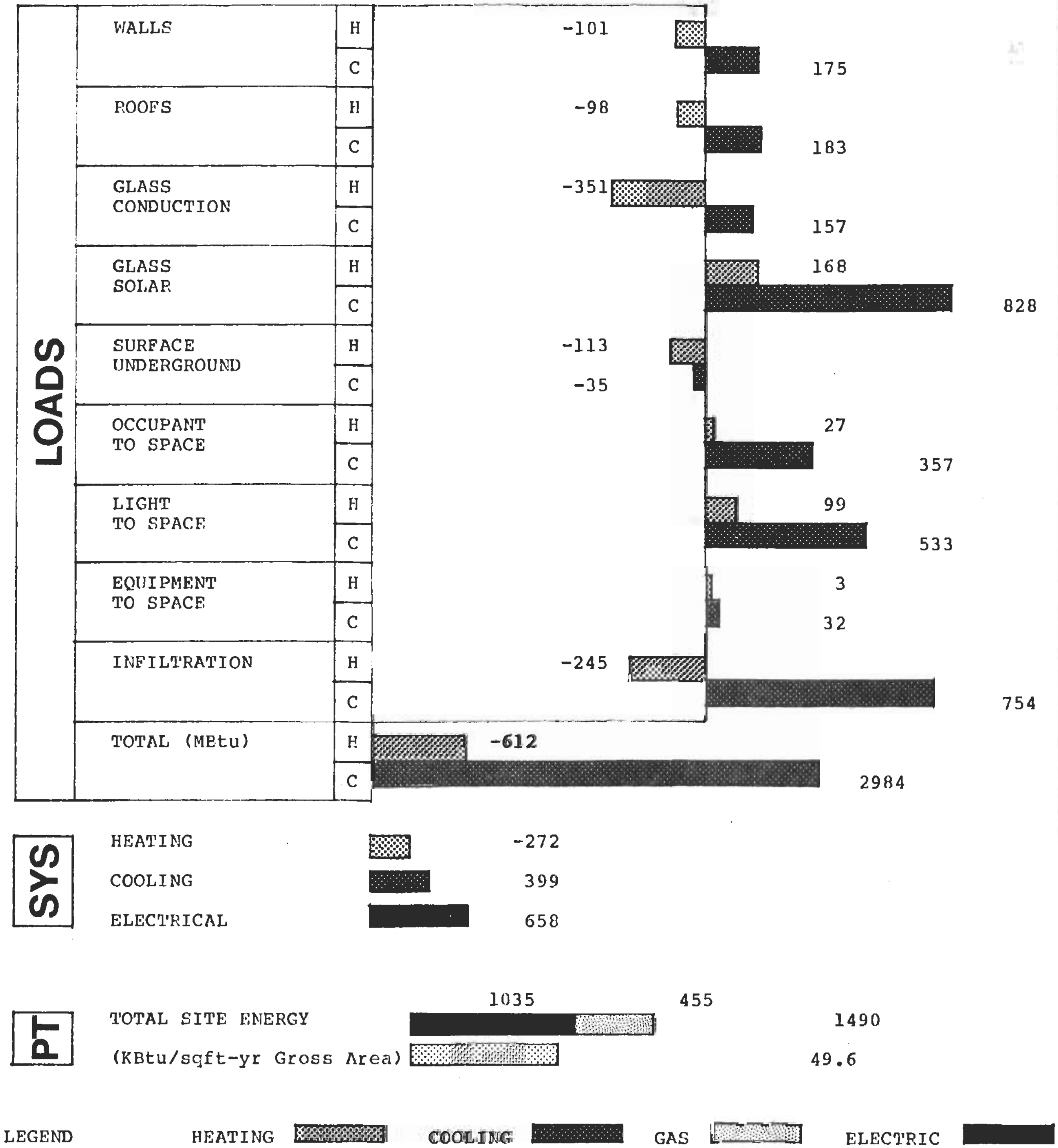


Fig. 3. Base study condition.

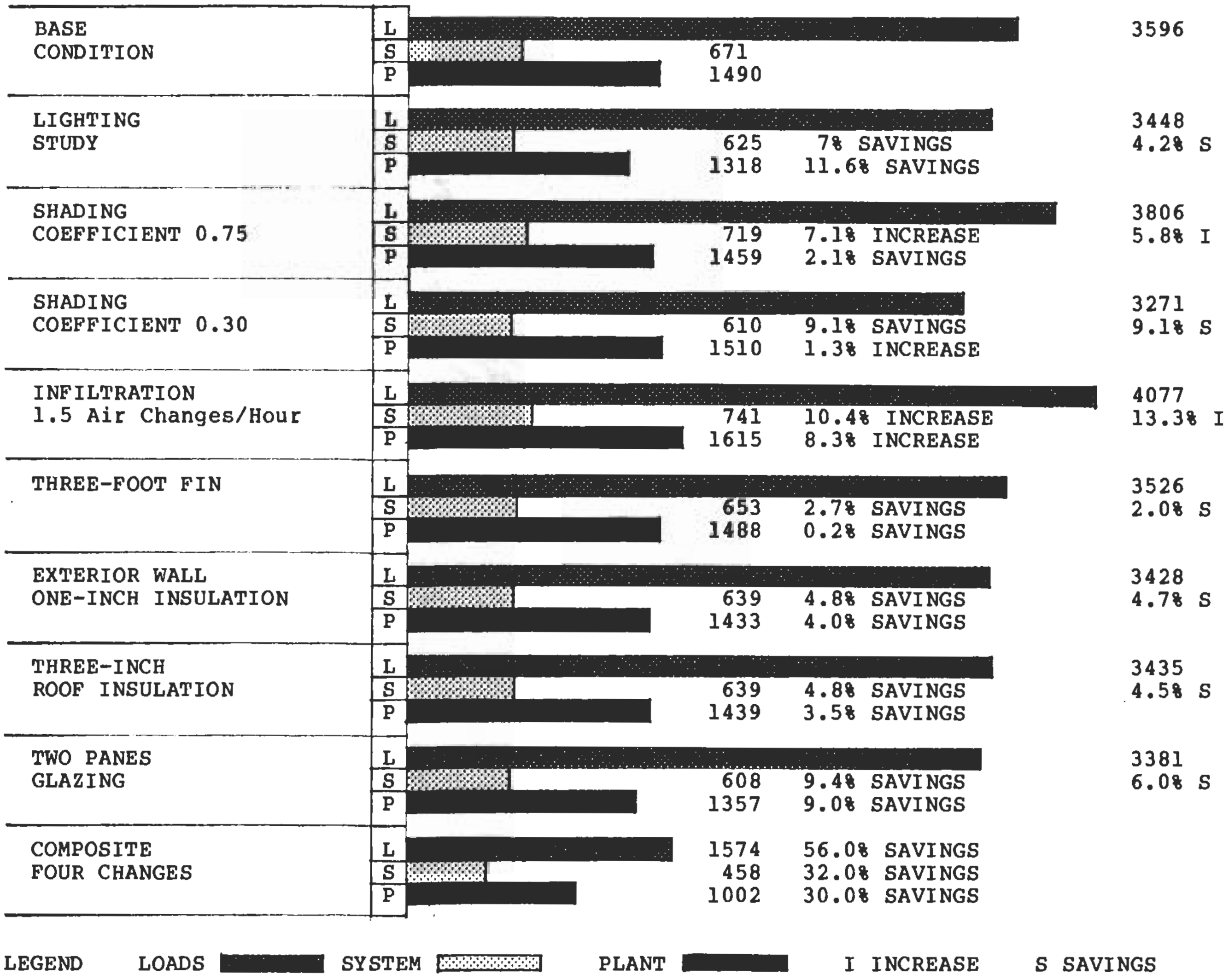


Fig. 4. Proposed strategies.

study. Both insulation strategies and the exteriorshading technique seem to be the least effective on this particular building. Using a couple of the lower-cost strategies proposed could significantly reduce the energy consumption.

PROJECT STATUS AND DEVELOPMENT

Three basic developments arising from this part of the study are first, a catalog of cost effective energy strategies that can be established as a potential library of energy-saving techniques for school buildings in a hot-humid climate. These strategies obviously apply to certain building contexts; therefore, indiscriminate application must be carefully monitored. Second, the understanding of the dynamic energy behavior produced by the usage of DOE-2 should enable the construction of an energy model that illustrates the interactive forces and their relative relationships with each other. The final development communicates suggestions to the designer based on the case studies and the energy model of the findings of this research to assist them to better understand the effects of design decisions on energy consumption. Each of these developments has many interesting issues, such as the determination of a baseline for energy usage for school buildings in hot-humid climates, or determining whether the walls or the roof form a more critical energy consumer within a given building context. Addressing these and other energy issues should formulate a more conscious awareness of the integrative nature of energy and architecture. Potentially this can lead to more creative design decisions concerning energy usage.

Data collection and the establishment of the complex energy structure are ongoing research activities. Establishing the database for McKinley Middle Magnet School from which to substantiate various retrofit approaches is currently being pursued. Certain assumptions about McKinley have been expressed: the need for shading, ventilation, weatherproofing, insulation, and possibly double glazing. These suggestions must be tested to determine whether they are appropriate cost effective energy-saving approaches.

Additional studies should be conducted using the same building type in various climatic zones to establish the significant effect on retrofit strategies.

ACKNOWLEDGMENTS

The authors note that this work is supported, in part, by LSU Center for Energy Studies under Grant No. 86-02-11. Assistance and contributions were provided by Levy-Kramer and Associates and Dyer & Moody, Inc., Consulting Engineers; East Baton Rouge Parish School Board; CADGIS Laboratory, LSU Department of Geography and Anthropology; and Systems Network Computing Center, LSU.

REFERENCES

1. Lawrence Berkeley Laboratory. 1981. DOE-2 Reference Manual Vol I. Part 1, BDL Summary; Part 2, Users Guide. Lawrence Berkeley Laboratory report LBL-8707 (Version 2.1A).

2. Lawrence Berkeley Laboratory. 1981. DOE-2 Reference Manual Vol II Sample Run Book. Lawrence Berkeley Laboratory report LBL-8706 (Version 2.1A).

3. Lawrence Berkeley Laboratory. 1981. DOE-2 Reference Manual Vol III. Reference Manual, Parts 1 & 2. Lawrence Berkeley Laboratory report LBL-8706 (Version 2.1A).

4. National Energy Software Center. 1985. Abstract 782. Argonne National Laboratory, Argonne, IL.

5. Diamond, S. C., and B. D. Hunn. 1981. "Comparison of DOE-2 Computer Program Simulations to Metered Data for Seven Commercial Buildings." ASHRAE Transactions, Vol. 87, Pt. 1.

6. Kerrisk, J. F., N. M. Schnurr, J. E. Moore, and B. D. Hunn. 1981. "The Custom Weighting Factor Method for Thermal Load Calculations in the DOE-2 Computer Program." ASHRAE Transactions, Vol. 90, Pt. 2.

7. Wagner, B. S. 1984. "Comparisons of Predicted and Measured Energy Use in Occupied Buildings." ASHRAE Transactions, Vol. 90, Pt. 2.

8. Lawrence Berkeley Laboratory. May 1984. DOE-2 Supplement, Version 2.1C. Lawrence Berkeley Laboratory report LBL 8706. Rev 4 suppl.

9. Lawrence Berkeley Laboratory. May 1984. DOE-2 Sample Run Book, Version 2.1C. Lawrence Berkeley Laboratory report LBL 8689. Rev 4.

10. Lawrence Berkeley Laboratory. May 1984. DOE-2 BDL Summary, Version 2.1C. Lawrence Berkeley Laboratory report LBL 8688. Rev 4.

11. CA Systems International, Inc. 1985. PC-DOE User's Manual, Version 2.1B/Mod 1.