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Overview of the DOE-2 Building Energy Analysis Program, Version 2.1D

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OVERVIEW OF THE DOE-2 BUILDING ENERGY ANALYSIS PROGRAM

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OVERVIEW OF THE DOE-2 BUILDING ENERGY ANALYSIS PROGRAM

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Summary

The DOE-2 Building Energy Analysis Program was designed to assist engineers and architects in the performance of design studies of whole-building energy use under actual weather conditions. Its development was guided by several objectives: 1) that the description of the building entered by the user be readily understood by non-computer scientists, 2) that, when available, the calculations be based upon well established algorithms, 3) that it permit the simulation of commonly available heating, ventilating, and air-conditioning (HVAC) equipment, 4) that the computer costs of the program be minimal, and 5) that the predicted energy use of a building be acceptably close to measured values. These objectives have been met. This paper is intended to give an overview of the DOE-2.1C version. In the Appendix is an annotated example of program input and output.

Background

In 1976 both the Energy Research and Development Administration (ERDA) and the Energy Commission of the State of California determined that existing building energy analysis programs were inadequate for the non-academic practitioner and that development of a new public-domain program should be undertaken. A project was established among several National Laboratories (Argonne National Laboratory and Los Alamos National Laboratory) with the project leadership centered at Lawrence Berkeley Laboratory (LBL). This project, sponsored by both the State of California and ERDA, produced a program in 1976 called Cal-ERDA. At that point the joint sponsorship came to an end and ERDA was absorbed into the new Department of Energy. A slightly improved version of the program was called DOE-1 and became the first of a series of versions culminating to date in a much more sophisticated program called DOE-2.1C. Validation studies have been carried out on various versions of the program, including DOE-2.1C (see the Validation section below).

Today, the realization that the basic algorithms of the program have been stretched to their limits has lead to a decision to bring the development of DOE-2 to a close with the DOE-2.1D version. Current development activities are designed to leave the user community with a flexible and fairly complete simulation tool, which will continued to be supported by LBL. With that end in view the authors of the program want to take this opportunity to summarize what has been done.

DOE-2 Program Structure

A building, examined thermodynamically, involves non-linear flows of heat through and among all of its surfaces and enclosed volumes, driven by a variety of heat sources. Mathematically, this corresponds to a set of coupled integral-differential equations with complex boundary and initial conditions. The function of a program like DOE-2 is to simulate the thermodynamic behavior of the building by approximately solving the mathematical equations.

DOE-2 performs its energy use analysis of buildings in four sequential steps.

First is the calculation of heat loss and gain to the building spaces and the heating and cooling loads imposed upon the building HVAC systems. This calculation is carried out for a space temperature fixed in time and is commonly called the LOADS calculation. It answers the question: how much heat addition or extraction is required to maintain the space at a constant temperature as the outside weather conditions and internal activity vary in time and the building mass absorbs and releases heat?

Second is the calculation of the energy addition and extraction actually to be supplied at the coils by the HVAC system in order to meet the possibly varying temperature set-points and humidity criteria subject to the schedules of fans, boilers and chillers, and to outside air requirements. This calculation results in the demand for energy that is made on the primary energy sources of the building. This step, called the SYSTEMS calculation, answers the question: How are the accumulative heat extraction and addition rates modified, when the characteristics of the HVAC system, the time-varying temperature set-points, and the heating, cooling and fan schedules are all taken into account?

Third is the determination of the fuel requirements of primary equipment such as boilers and chillers, and the electric generators, etc., in the attempt to supply the energy demand of the HVAC systems. This PLANT calculation answers the question: how much fuel and electrical input is required by the HVAC system given the efficiency and operating characteristics of the plant equipment and components?

The *fourth* step, ECONOMICS, evaluates the costs of equipment, fuel, electricity, labor and retrofit components. It answers the question: Is the expenditure of funds for energy conserving materials and systems cost effective, when compared with alternative systems?

The continuous time dependence of energy flow phenomena is approximated by making the calculation in hourly time intervals even though phenomena may occur with a time constant that is smaller than one hour. Averaging algorithms have been developed that correct the net energy consumption effect of more rapidly changing events, such as temperature controllers.

LOADS

General Considerations

The LOADS program computes the hourly cooling and heating loads for each space of the building. A *load* is defined as the rate at which energy must be added to or removed from a space to maintain a constant air temperature in the space. A *space* is a user-defined subsection of the building. It can correspond to an actual room, or it may be much larger or smaller, depending upon the level of detail appropriate to the simulation.

The space loads are obtained by a two-step process. First, the heat gains (or losses) are calculated; then the space loads are obtained from the space heat gains, taking into account the storage of heat in the thermal mass of the space. A *space heat gain* is defined as the rate at which energy enters or is generated within a space in a given moment. The space heat gain is divided into radiative and convective components, depending on the manner in which the energy is transported into or generated within the space. The components are:

1. solar heat gain from radiation through windows and skylights,
2. heat conduction through walls, roofs, windows, and doors in contact with the outside air,
3. infiltration air (unintended ventilation),
4. heat conduction through walls and floors in contact with the ground,
5. heat conduction through interior walls, floors, ceilings, and partitions,
6. heat gain from occupants,
7. heat gain from lights,
8. heat gain from equipment.

The calculation of heat conduction through walls involves solving a one dimensional diffusion equation each hour. In DOE-2 the equation is presolved for each wall or roof using triangular temperature pulses as excitation functions. The resulting solutions, called "response factors" are then used in the hourly simulation modulated by the actual indoor and outdoor temperatures. This approach assumes that the wall properties, including inside film coefficients, do not change during the simulation.

The solar gain calculation starts with the direct and diffuse solar radiation components, which are obtained from measured data or computed from a cloud cover model, taking into account the actual position of the sun each hour. The radiation is projected onto glass surfaces, after taking into account the shading (for the direct component) of exterior shading surfaces, and is transmitted, absorbed, and reflected in accordance with the properties of the glass in the window. As with the conduction through walls, the problem is presolved for a finite class of window properties.

Heat flow through interior walls and through surfaces in contact with the soil is treated as steady state, i.e., the capacitive effects of the walls are ignored in the hourly calculation, although they are taken into account in the calculation of the weighting factors (see below). For interior walls that are light and not load bearing, this is a reasonable assumption. Interior walls between a sunspace and an interior space, on the the other hand, can be massive and delayed conduction through such walls can be modeled.

The internal heat gains from people, lights, and equipment are basically fixed by the user's input of peak values multiplied by hourly values in the schedules for these gains.

In general, space heat gains are not equal to space cooling loads. An increase of radiant energy in a space does not immediately cause a rise in the space air temperature. The radiation must first be absorbed by the walls, cause a rise in the wall surface temperature, and then (by convective coupling between the wall and the air) cause an air temperature rise. This is handled in

DOE-2 through weighting factors. The weighting factors are determined from a detailed heat balance which gives the response in time of a zone (with all its mass and walls and fenestration) to a unit pulse of each of the zone heat gains. The user can choose either to use precalculated ASHRAE weighting factors or to have the program calculate custom weighting factors for the space as input.

Special LOADS Features

In DOE-2.1C there are several additional features that greatly extend the usefulness of the program. These include in the LOADS program the ability to take advantage of credit for daylighting, the ability to model sunspaces and the transmission of solar radiation through interior windows, and a mechanism by which users can substitute their algorithms for those used by the program. Each of these features is described below.

- **Daylighting Credit**

The daylighting simulation in DOE-2, coupled with the thermal loads and HVAC analysis, allows users to evaluate the energy- and cost-related consequences of daylighting strategies. The program takes into account the availability of daylight from sun and sky, window management in response to solar gain and glare, and various electric lighting control schemes.

The daylight illuminance calculation in DOE-2.1C considers such factors as:

1. window size and orientation,
2. glass transmittance,
3. inside surface reflectances of the space,
4. sun-control devices such as blinds and overhangs,
5. luminance distribution of the sky,
6. discomfort glare.

For each daylit space, a preprocessor calculates and stores a set of daylight factors for a series of sun positions covering the annual ranges of solar altitude and azimuth at the specified building latitude. These factors relate interior illuminance and glare levels to outdoor daylight levels.

In the hourly daylighting calculation, the illuminance from each window or skylight is found by interpolating stored daylight factors using current-hour sun position and cloud cover, then multiplying by current-hour exterior horizontal illuminance. If the glare-control option has been specified, the program will automatically close window blinds or drapes in order to decrease glare below a pre-defined comfort level. Adding the illuminance contributions from all the windows then gives the total number of footcandles at each reference point.

The program then simulates the lighting control system to determine the artificial lighting electrical energy needed to make up the difference, if any, between the daylighting level and the required illuminance. Finally, the lighting electrical requirements are passed to the thermal calculation which determines hourly heating and cooling requirements for each space.

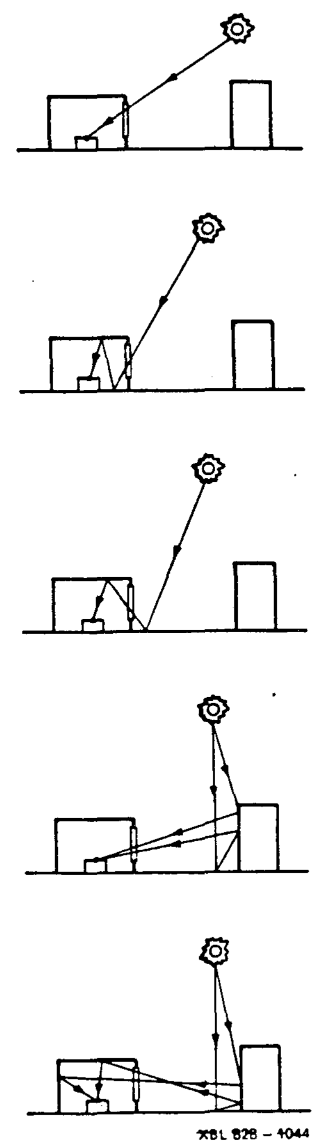

Fig. 1. The various paths by which light originating from the sun can reach a workplane through an unshaded window.

- **Sunspace Model**

DOE-2.1C allows the user to model the different forms of heat transfer that can occur between a sunspace (or atrium) and adjacent spaces. As seen in Fig. 2, these include:

1. direct and diffuse solar gain through interior glazing,
2. forced or natural convection through vents or an open doorway,
3. delayed conduction through an interior wall, taking into account the solar radiation absorbed on the sunspace side of the wall,
4. conduction through interior glazing.

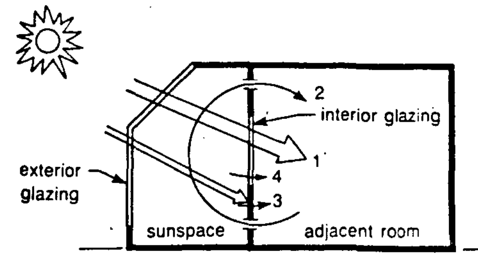

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Fig. 2

The sunspace model also simulates (in SYSTEMS) the venting of the sunspace with outside air to prevent overheating, and, for residential applications, the use of a sunspace to preheat outside ventilation air. The model is intended primarily for residential and small commercial building applications, since DOE-2 calculates only a single, average air temperature in a space. It cannot be expected to give accurate results for multi-story atria unless there is sufficient air mixing to eliminate temperature stratification.

- **Functional Approach**

For advanced users, DOE-2.1C allows the user to modify the way that DOE-2 does its calculations in LOADS without having to recompile the code. This "Functional Approach" involves writing FORTRAN-like functions in the LOADS input that compute the program variables as desired by the user. The possibilities of this feature are many and include changing the value of the glass shading-coefficient depending upon whether the space has a heating or cooling load, making the outside film coefficient dependent upon the wind direction, entering measured values of daylight factors, printing user designed reports, and changing schedules depending upon the thermal state of the building. This feature is limited at present to LOADS only.

SYSTEMS

General Considerations

The SYSTEMS program simulates the equipment that provides heating, ventilating and/or air conditioning (HVAC) to the thermal zones and the interaction of this equipment with the building envelope. This simulation comprises two major parts:

1. Since the LOADS program calculates the "load" at constant space temperature, it is necessary to correct these calculations to account for equipment operation.
2. Once the net sensible exchange between the thermal zones and the equipment is solved, the heat and moisture exchange between equipment, heat exchangers, and the heating and cooling coil loads can be passed to the primary energy conversion equipment or utility.

The dynamics of the interaction between the equipment and the envelope are calculated by the simultaneous solution of the room air-temperature weighting factor equation with the equipment controller relation. The former relates the "load" from LOADS and the heat extraction rate (the sensible coil load) to the zone temperature. The latter relates the heat extraction rate to the controlling zone temperature. Once the supply and thermal zone temperatures are known, the return air temperature can be calculated and the outside air system and other controls can be simulated. Thus the sensible exchange across all coils are calculated.

The moisture content of the air is calculated at three points in the system: the supply air leaving the coil, the return air and the mixed air. These values are calculated assuming that a steady state solution of the moisture balance equations each hour will closely approximate the real world. The return air humidity ratio is used as the input to the controller activating a humidifier in the supply airflow or resetting the cooling coil controller to maintain maximum space humidity set points. The moisture condensation on the cooling coils is simulated by characterizing the coils by a bypass factor and solving the coil leaving air temperature and humidity ratio simultaneously with the system moisture balance.

Once the above sequence is complete, all sensible and latent coil loads are known. These values are then either passed to the PLANT program as heating and cooling water circuit loads or, as in the case of direct-expansion equipment, the energy conversion is simulated in SYSTEMS.

System Types

The DOE-2 program provides the user with 22 generic system types with many sizing and control options, depending upon the type chosen. The following table lists them with their familiar trade names:

Index of System Types

Category	*Trade Name*
Single Supply Duct Types	Variable Temperature
	Packaged DX Variable Temperature
	Ceiling Induction
	Reheat
	Variable Air Volume
	Powered Induction Unit
	Packaged DX VAV
	Ceiling Bypass
Air Mixing Types	Multizone
	Packaged DX Multizone
	Dual Duct
Terminal Unit Types	Two Pipe Fan Coil
	Four Pipe Fan Coil
	Two Pipe Induction
	Four Pipe Induction
	Packaged Air Conditioner
	Water/Air Heat Pump
Residential	Furnace and Condensing Unit
Heating Only	Panel Heating
	Central Ventilation (e.g. schoolhouse)
	Unit Heater
	Classroom Unit Ventilator
Diagnostics	Sums Zone Loads

Special SYSTEMS Features

The DOE-2 program allows the user to attach many special features onto the generic system types listed above. Some of the features only apply to one system type, but most features are compatible with all system types. Special features are as follows:

1. Baseboard or Convector Heaters:
    a) temperature control reset by outdoor air.
    b) temperature control by room temperature.
2. Supply Air Temperature Reset:
    a) controlled by outdoor air master/submaster.
    b) controlled by "warmest" zone.
    c) controlled by "coldest" zone (for dual duct and multi-zone hot decks).
    d) controlled by seasonal adjustments on predefined calendar dates.
3. Return Air Humidity Controller to either:
    a) reduce temperature of coil leaving air (and thus humidity content) to maintain a maximum relative humidity.
    b) add reheat using condenser waste heat or new energy to prevent overcooling of the space.
    c) inject moisture into the supply air stream to maintain a minimum relative humidity.
4. Outdoor Air Economizers controlled by:
    a) mixed air temperature with a dry bulb high-limit temperature override.
    b) mixed air temperature with an enthalpy comparison of return and outside air plus a dry bulb high-limit temperature override.
    c) mixed air temperature with a dry bulb low-limit temperature override.
5. Air/Air Heat Pumps for commercial unitary air-handling units with economizers as well as heat pumps for PTAC units and residential split systems. Supplemental heat using fossil fuels in lieu of electric resistance heaters is also feasible.
6. Air-Handling Unit Fans may be defined either as draw-through or blow-through and the fan motor can be placed in or outside the air stream.
7. Air-Handling Unit Fans for VAV systems can be controlled using:
    a) discharge dampers.
    b) inlet vanes.
    c) speed control.
    d) customized curve fit for special applications.
8. Natural Ventilation for simulation of opening and closing windows in a residence.
9. Forced Ventilation for simulating fabric roof system pressurization fans and/or ventilation for precooling buildings using cool night air.
10. Optimum Fan Start Control to prevent fans from starting earlier than necessary to provide satisfactory space temperatures at time of occupancy.
11. Heat Recovery of Sensible Heat in the return air stream and its exchange to the incoming outside ventilation air.

12. Night Temperature Setback (and setup if required) with provision to maintain setback minimum temperature by:

    a) cycling main fans on.

    b) cycling powered induction unit fans on (with main fans off).

    c) modulating baseboard radiation.

13. Heat Recovery from Supermarket Refrigerated Casework including provisions for defrost control, anti-sweat heaters, etc. This routine is also applicable to ice-rinks or cold storage applications.

System Design

Many equipment design parameters must be known before the hourly simulation can proceed. The user can specify these parameters in the description of the thermal zone or the HVAC system, or make use of a set of default procedures which has been included in the program to calculate most of these parameters, if the user has not provided the information. Before the simulation can start, all air flow rates, equipment capacities, and off-design performance functions must be known. Default curves for part-load operation are available for all the off-design performance functions; however, the user can replace one or more of these curves through a curve fitting command.

PLANT

The PLANT program simulates primary HVAC equipment, i.e., central boilers, chillers, cooling towers, electrical generators, pumps, heat exchangers, and storage tanks. In addition, it also simulates domestic or process water heaters, and residential furnaces. Its purpose is to supply the energy needed by the fans, heating coils, cooling coils, or baseboards (simulated in SYSTEMS), and the electricity needed by the building's lights and office equipment (simulated in LOADS). Building loads can be satisfied by using the user-defined plant equipment or by the use of utilities: electricity, purchased steam, and/or chilled water.

Plant Equipment

As in SYSTEMS, there are a number of generic plant equipment types whose characteristics and part-load performance curves can be defaulted or shaped by the the user:

Category	*Trade Name*
Heating Equipment	Fossil Fuel Steam Boiler
	Fossil Fuel Hot Water Boiler
	Electric Steam Boiler
	Electric Hot Water Boiler
	Residential Furnace
	Domestic Hot Water Heater
	Electric DHW Heater
Electricity Generators	Steam Turbine
	Diesel Generator
	Gas Turbine

Chillers	{	Open Centrifugal Open Reciprocal Hermetic Centrifugal Hermetic Reciprocal One Stage Absorption Two Stage Absorption Double Bundle
Storage Tanks	{	Hot and Cold
Cooling Towers	{	Conventional and Ceramic

Plant Management

The user may establish the management of the plant equipment by setting up schedules and/or load ranges under which specified equipment will operate. In the absence of a user-defined plant management scheme, the equipment is simulated by default in the following order:

1. The hot and cold loop circulation pumps are simulated if they exist. The heating and cooling loads are adjusted for any losses that occur in the circulation loops and for the addition of pump heat.
2. The following equipment is modeled iteratively to minimize source energy consumption (see below for a fuller discussion):
    a. The chillers, cooling tower, and cold storage tanks.
    b. The electrical generators, operating under several tracking options.
    c. Heat recovery equipment and hot storage tanks are simulated to link the user-specified sources of waste heat to the user-specified heat demands.
3. Following the heat recovery, the boilers are operated to satisfy any remaining heating loads.
4. Finally, the program allocates any remaining heating, cooling, and electrical loads to the appropriate utility. If a utility has not been provided for, the remaining load is reported as an overload.

Earlier versions of the DOE-2 code assumed simply that, in the case of the electricity generators, only the electrical demands of a facility were important to decisions concerning the operation of a central plant. This reasoning stemmed from the fact that utility and regulatory attitudes toward the on-site generation of power often meant that a decision to generate power on-site was tantamount to leaving the electric grid entirely. The Public Utilities Regulatory Policy Act of 1978 mandated changes in those attitudes by requiring that utilities abandon discriminatory practices and offer fair prices to cogenerators and small power producers. The outcome of this change is that the actual electrical loads of a facility need not be the only consideration in determining the output of primary energy conversion equipment in a central plant.

The concept embodied in DOE-2.1C treats the diesel engine and gas turbine as energy conversion devices with two useful outputs: electricity and recoverable heat. Accordingly, the choice of which output to use in controlling the operation of these machines has been made an explicit option specifiable by the user. That is, the user can specify that the machines generate enough heat to meet thermal loads, irrespective of the amount of electricity produced and vice versa. The default allocation routines also ensure that the thermal and electrical output of the generators, when coupled with absorption and compression chillers, will be balanced when meeting heating and cooling loads.

Special PLANT Features

The DOE-2 program allows the user to address conventional chiller/boiler plants as well as many load management and energy saving techniques associated with energy conversion equipment. Special features are as follows:

1. Cool Weather Water Chilling using:
   a) centrifugal chiller thermo-cycle (also referred to as "free cooling").
   b) strainer cycle.
2. Peak Electric Demand Shaving using:
   a) absorption chillers.
   b) diesel-driven generators.
   c) gas-driven generators.
   d) cold water storage, off-peak.
   e) the operation of the above equipment may be set up for programmed charging at night and programmed release, based either on peak demand or a "time-of-day" period.
3. Electric Load Shifting and "Load Shedding" may be addressed by making parametric studies to determine advantageous system and equipment operating strategies based on either reductions in peak demand or "time-of-day" energy use.
4. Pumping Energy for Hot and Cold Water Circuits may be set up for either variable or constant flow rates.
5. Hot Water Storage of Recovered Heat may be analyzed including programmed release of the stored media. An example might be an all-electric building with the stored heat released during the morning start-up period to reduce electric peaks caused by resistance heaters.

ECONOMICS

The ECONOMICS portion of the program computes the costs of energy for the various fuels or utilities used by the equipment. A wide variety of tariff schedules can be encompassed as well as computations that simulate the sale of electricity to the utility.

Rate Schedules

DOE-2 allows the following energy resources to be used: chilled water, steam, electricity, natural gas, fuel oil, coal, diesel oil, methanol, LPG, and biomass. For each of these resources that is used by a building the user may specify uniform cost rates, escalation rates, fixed monthly charges by season, various block charges by season, whether there are demand charges and how much, time-of-day charges, and, for electricity only, details about ratchet periods and types and conditions of sale to utilities. Not all of these apply to every fuel or resource, of course, and defaults exist for the simplest tariffs. On the other hand, most of the existing tariff structures can be simulated.

Investment Statistics

In addition to the possibility of treating the costs of energy, DOE-2 allows the user to simulate the life cycle costs of a building, from data provided and input by the user, and to compare the costs between two configurations of the building. Assuming one is the base case and the other is a retrofit or an alternative design, investment statistics such as pay back period, savings to investment ratio, etc., are computed over the life cycle of the building.

DOE-2 Input/Output

In order to simulate a building, the user must describe the building, its equipment and operating schedules, and the economics input data to the computer. This is done in DOE-2 through a quasi-English description of the building using specially designed input language called BDL for *B*uilding *D*escription *L*anguage.

As with any language, BDL has a vocabulary and a syntax. The vocabulary in BDL consists of commands, keywords and code-words (all shown in upper case in the example that follows), in addition to user-defined names and numerical values. The syntax is a set of rules that regulate the relative position of the words and punctuation. In BDL this syntax is quite simple and consists, basically, of the sequence:

```
u-name = COMMAND   KEYWORD1 = value1
                   KEYWORD2 = value2
                        .
                        .
                        .
                   KEYWORDn = valuen ..
```

For example, the BDL input for a window might look like:

```
WIND-1 = WINDOW   HEIGHT = 4
                  WIDTH = 3
                  GLASS-TYPE = W-1
                  SETBACK = .5        ..
```

The symbol (..) is the terminator for the command and corresponds to the period in English. Some commands, like RUN-PERIOD or BUILDING-LOCATION, are required commands, while others, like DOOR or ENERGY-STORAGE, are optional and are entered only when the building being modeled has the feature being described or the modeler thinks they are thermodynamically important.

Similarly, the keywords within each command can be required or optional. Thus, even though DOOR is an optional command, once it has been used, the user must supply values for its HEIGHT, WIDTH, and CONSTRUCTION. On the other hand, the optional keywords within a command often have default values; i.e., if the user does not enter the keyword and a value, the program will assume that the keyword should take on a preassigned value. This is the case for the TILT of an EXTERIOR-WALL, which the program assumes is vertical unless told the contrary. These default values can reduce the necessary input for a building considerably when they are appropriate.

Because BDL ignores extra blank spaces in the input, the user can arrange the commands and keywords to provide the most clarity. As can be seen from the example of the BDL sample input in the Appendix, an engineer or architect does not need to be a computer scientist to read the input and understand what has been done. This is important for two reasons. First, interested parties other than the author can read and evaluate the modeling with a minimum of effort. Second, the author can return to the input after several months or a year and quickly grasp what had been done earlier.

In addition to describing the building, the BDL portion of DOE-2 performs several other functions. From the user description of the layers of an exterior wall, BDL computes, and stores for later use by the simulation part of the program, the factors describing the delayed response of the wall to a temperature pulse. It also computes, for each space of the building, the weighting factors that describe the thermal response of the space to various heat gains. Since these calculations consume computer time and thus incur computer costs, a library feature exists that allows the user to store response factors and weighting factors permanently in a computer file.

Finally, BDL performs curve fitting for user input data describing the performance characteristics of equipment in both SYSTEMS and PLANT.

Output Reports

Although no one really wants or can use the detailed results of the literally millions of calculations involved in a year's simulation of the energy performance of a building, everyone seems to want a different set of summary data. Each successive version of DOE-2 has seen an expansion of the output reports, usually in response to the expressed needs of the user community. In DOE-2.1C there are three different types of reports that the user can choose to have printed: preformatted, hourly, and user-generated. For most purposes only a selection of the preformatted reports, the easiest to request, are of use.

- **Preformatted Reports**

There are two kinds of preformatted reports in DOE-2: verification reports and summary reports. Verification reports, available in each of the subprograms, echo the user's input in a different form, allowing a check that the building being simulated has been properly described. These reports are especially helpful in catching input errors and modeling flaws. The summary reports are the results of the simulation presented in various formats to stress different aspects of the building's performance. See the Appendix for some examples of summary and verification reports.

- **Hourly Reports**

Many of the internal program variables in each of LOADS, SYSTEMS, and PLANT are accessible to the user for listing on an hour by hour basis. These variables, such as solar gain through a particular window or the temperature in a particular zone, can be listed according to a schedule defined by the user. In DOE-2.1C it is possible to report these variables by day or month rather than hourly and automatically to get summary statistics such as maximum and minimum values during the period as well as averages and sums.

- **User Designed Reports**

With the ability to change program algorithms through the functional value approach, it is possible for the user to design an individualized report for the LOADS program by writing a FORTRAN program describing the output variables and the format for the report.

Validation

Versions of DOE-2, up to the DOE-2.1C level, have been verified against manual calculations and against field measurements on existing buildings. One such project was sponsored by DOE and conducted by the Los Alamos National Laboratory. Results are presented in the *DOE-2 Verification Project, Phase I, Interim Report*, NTIS order number LA-8295-MS, issued in April 1981. A summary of the final report of Phase I by the LANL group was presented at the 1985 Annual Meeting of the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE). This paper, *User-Effect Validation Tests of the DOE-2 Building Energy Analysis Program*, by S.C. Diamond, C.C. Cappiello, and B.D. Hunn, (HI-85-13 No.3) appears in *ASHRAE Transactions 1985,*, Vol. 91, Part Two.

A second study undertaken here at LBL, *A Comparison of DOE-2.1C Prediction with Thermal Mass Test Cell Measurements*, by B. Birdsall, LBL-18981, compares DOE-2.1C results with test cells constructed in Tesuque Pueblo, NM, and in Gaithersburg, MD.

A third study, *A Comparative Validation Study of the BLAST-3.0, SERIRES-1.0, and DOE-2.1A Using the Canadian Direct Gain Test Building*, by R. Judkoff, Solar Energy Research Institute, January 1985, is available from SERI, order number SERI/TR-253-2652.

And finally, the Tishman Research Corporation has prepared a study of DOE-2.1B in *DOE-2: Comparison With Measured Data, Design and Operational Energy Studies in a New High-Rise Office Building - Vol. 5*, NTIS order number DE84010570/LA.

These studies all show that, with few exceptions, the DOE-2 predictions agree well with ASHRAE calculation methods, manufacturers' data, and measured annual building energy consumption. DOE-2 results also agree well with predictions of other building energy analysis computer programs (BLAST, NBSLD).

Documentation

The following publications comprise the literature that supports the DOE-2 program.

1. The *DOE-2 Users Guide* is an introduction to building energy analysis and to the DOE-2 input language. [NTIS order number: LBL-8689,Rev. 2]
2. The *DOE-2 Reference Manual,* Parts 1 and 2, describes the input language and the program output reports in detail and lists the contents of the weather and materials libraries. [NTIS order number: LBL-8706,Rev. 2]
3. The *DOE-2 Supplement* is a companion volume to the *Reference Manual* and contains instructions for using the new 2.1B and 2.1C features. [NTIS order number: DE85012581]
4. The *DOE-2 BDL Summary* is a concise list of all commands and keywords used in the DOE-2 input language, together with their minimums, maximums, and default values. [NTIS order number: DE85012580]
5. The *DOE-2 Sample Run Book* contains both input and output for 15 sample buildings and system and plant configurations. [NTIS order number: DE85012582]
6. The *DOE-2 Engineers Manual* gives an engineering description and derivation of the algorithms used in the program. [NTIS order number: DE83004575]
7. The *DOE-2 User News* is a quarterly publication containing articles and announcements of interest to users of the program. [NTIS order number: PB81912100]

The first five titles may be purchased as a set [NTIS order number PB85211449]. DOE-2 publications may be ordered from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, Virginia, (703) 487-4650, or FTS 737-4650.

Program Access and Storage Requirements

Source code for DOE-2.1C is available, in the form of magnetic tape, from Lawrence Berkeley Laboratory, Building Energy Simulation Group; from the National Energy Software Center at Argonne National Laboratory; and from NTIS. The program is also accessible through the nation's major commercial computer service networks.

The minimum hardware configuration required for in-house use is 30 megabytes on disk. Instructions for bringing up the program are included on the tape, and sample run inputs are provided for verification purposes. The following machine versions have been developed.

Machine Type	*Operating System*	*Memory Required*
CDC	SCOPE/NOS	64K words
DEC-PDP 10/20	TOPS 10/20	256K words
DEC-VAX series	VMS	1 megabyte
ELXSI 6400	EMBOS	1 megabyte
IBM	CMS/various	1 megabyte/32-bit words

For more information, contact Karen H. Olson, Building Energy Simulation Group, Lawrence Berkeley Laboratory, Building 90, Room 3147, Berkeley, CA 94720, (415) 486-5711.

Acknowledgements

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This paper is derived from the LBL report, ***The DOE-2 Building Energy Analysis Program***, by R.B. Curtis, B. Birdsall, W.F. Buhl, E. Erdem, J. Eto, J.J. Hirsch, K.H. Olson, and F.C. Winkelmann, April 1984, LBL-18046.

APPENDIX

Simple Structure Run

The following example of a DOE-2 run describes a simple structure in Chicago with five zones and a return air plenum complete with an HVAC system and plant equipment, including a time-of-day electric rate structure. The user's input is echoed at the beginning of the program output. Comment lines ***imbedded in the input*** begin with a dollar sign ($). The authors' annotations appear in the margins in italic type.

Of the 63 preformatted summary and verification reports available in DOE-2, 9 have been chosen here to demonstrate the reporting capability of the program.

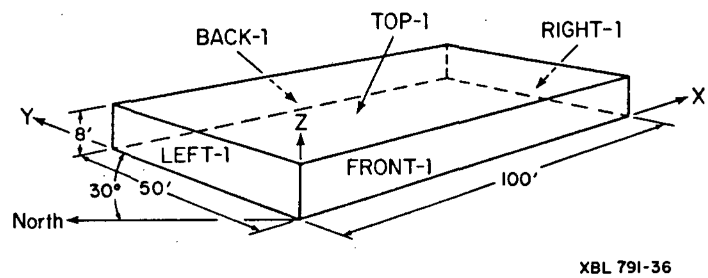

Fig. 1. Isometric view of basic building showing orientation. FRONT-1, RIGHT-1, etc., are u-names (user-defined names) for the front wall, right-hand wall, etc. The building coordinate axes (X, Y, and Z) are shown. The building is oriented 30° from true North.

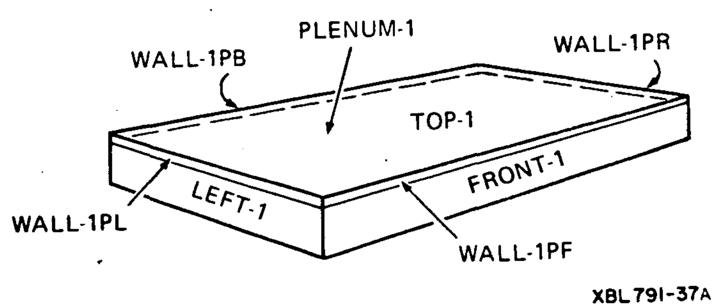

Fig. 2. Basic building with plenum and its walls (u-named WALL-1PF, WALL-1PL, etc.).

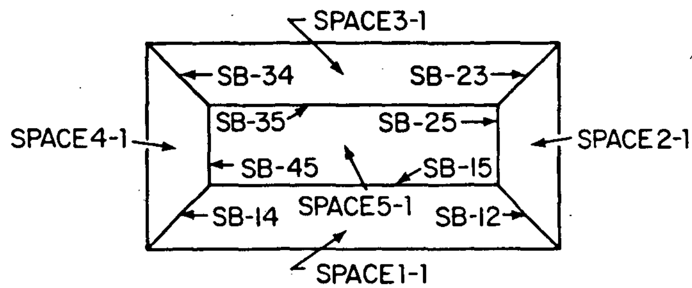

Fig. 3. Plan view showing zoning and u-names of spaces and interior walls.

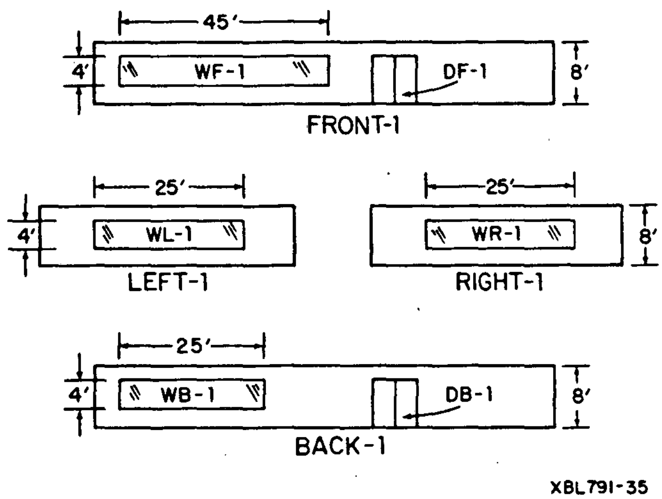

Fig. 4. Elevations showing placement of windows, doors, and their u-names.

DOE-2.1C

B U I L D I N G   E N E R G Y   A N A L Y S I S   P R O G R A M

The first page output is a banner page produced by the program.

DEVELOPED BY

LAWRENCE BERKELEY LABORATORY/UNIVERSITY OF CALIFORNIA

WITH MAJOR SUPPORT FROM

UNITED STATES DEPARTMENT OF ENERGY
ASSISTANT SECRETARY FOR CONSERVATION AND RENEWABLE ENERGY
OFFICE OF BUILDINGS ENERGY RESEARCH AND DEVELOPMENT
BUILDING SYSTEMS DIVISION

LBL RELEASE MAY 1984

```
  *   1 *  INPUT LOADS  ..
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  INPUT-UNITS        = ENGLISH
-DEFAULT -                                                              OUTPUT-UNITS       = ENGLISH
                    L D L   P R O C E S S O R   I N P U T   D A T A

                         Ø3-Jun-85    14:4Ø:48RUN  Ø
```

Input and reports can also be in metric units.

L D L   P R O C E S S O R   I N P U T   D A T A

Ø3-Jun-85   14:4Ø:48LDL RUN 1

```
*   2 *  TITLE            LINE-1 *SIMPLE STRUCTURE RUN, CHICAGO*  ..
*   3 *
*   4 *
*   5 *                   RUN-PERIOD         JAN 1 1974 THRU DEC 31 1974     ..
*   6 *                   ABORT              ERRORS  ..
*   7 *                   DIAGNOSTIC         WARNINGS  ..
*   8 *                   LOADS-REPORT       SUMMARY = (LS-C)
*   9 *                                      VERIFICATION = (LV-D)   ..
*  1Ø *                   BUILDING-LOCATION  LATITUDE=42.Ø  LONGITUDE=88.Ø
*  11 *                                      ALTITUDE=61Ø
*  12 *                                      TIME-ZONE=6  AZIMUTH=3Ø.Ø   ..
*  13 *
*  14 *                        $ CONSTRUCTION AND GLASS-TYPES
*  15 *
*  16 *  WA-1-2          =LAYERS  MATERIAL=(WDØ1,PWØ3,INØ2,GPØ1)  ..
*  17 *  ROO-1           =LAYERS  MATERIAL=(RGØ1,BRØ1,IN46,WDØ1)
*  18 *                           INSIDE-FILM-RES=.76  ..
*  19 *
*  2Ø *  WALL-1          =CONSTRUCTION      LAYERS=WA-1-2  ..
*  21 *  ROOF-1          =CONSTRUCTION      LAYERS=ROO-1  ..
*  22 *  CLNG-1          =CONSTRUCTION      U = Ø.27  ..
*  22 *  SB-U            =CONSTRUCTION      U = 1.5   ..
      *  FLOOR-1         =CONSTRUCTION      U = Ø.Ø5  ..
      *
      *  W-1             =GLASS-TYPE        GLASS-TYPE-CODE = 3  ..
      *  DOORS           =GLASS-TYPE        GLASS-TYPE-CODE = 5  ..
      *
      *                        $ OCCUPANCY SCHEDULE
*  3Ø *
*  31 *  OC-1            =DAY-SCHEDULE      (1,8) (Ø.Ø)
*  32 *                                     (9,11) (1.Ø)
*  33 *                                     (12,14) (Ø.8,Ø.4,Ø.8)
*  34 *                                     (15,18) (1.Ø)
*  35 *                                     (19,21) (Ø.5,Ø.1,Ø.1)
*  36 *                                     (22,24) (Ø.Ø)  ..
*  37 *
*  38 *  OC-2            =DAY-SCHEDULE      (1,24) (Ø.Ø)  ..
*  39 *
*  4Ø *  OC-WEEK         =WEEK-SCHEDULE     (WD) OC-1 (WEH) OC-2  ..
*  41 *
*  42 *  OCCUPY-1        =SCHEDULE          THRU DEC 31 OC-WEEK  ..
*  43 *
*  44 *                         $ LIGHTING SCHEDULE
*  45 *
*  46 *  LT-1            =DAY-SCHEDULE      (1,8) (Ø.Ø5)
*  47 *                                     (9,14) (Ø.9,Ø.95,1.Ø,Ø.95,Ø.8,Ø.9)
*  48 *                                     (15,18) (1.Ø)
*  49 *                                     (19,21) (Ø.6,Ø.2,Ø.2)
*  5Ø *                                     (22,24) (Ø.Ø5)  ..
*  51 *
*  52 *  LT-2            =DAY-SCHEDULE      (1,24) (Ø.Ø5)  ..
*  53 *
*  54 *  LT-WEEK         =WEEK-SCHEDULE     (MON,FRI) LT-1   (WEH) LT-2  ..
*  55 *
*  56 *  LIGHTS-1        =SCHEDULE          THRU DEC 31 LT-WEEK  ..
*  57 *
```

The year of the weather tape used.

The building is oriented 30° from true North.

Code-words for building materials — selected from the stored DOE-2 library.

A user-assigned name (u-name) for later reference.

The daily profiles. Hours 1 to 8 at zero occupancy.

Hours 15 to 18 at full occupancy.

Line numbers are provided by program, not input by user.

```
                      $ OFFICE EQUIPMENT SCHEDULE

EQ-1              =DAY-SCHEDULE        (1,8) (Ø.Ø2)
                                       (9,14) (Ø.4,Ø.9,Ø.9,Ø.9,Ø.9,Ø.9)
                                       (15,2Ø) (Ø.8,Ø.7,Ø.5,Ø.5,Ø.3,Ø.3)
                                       (21,24) (Ø.Ø2)  ..

EQ-2              =DAY-SCHEDULE        (1,24) (Ø.2)  ..

EQ-WEEK           =WEEK-SCHEDULE       (MON,FRI) EQ-1   (WEH) EQ-2  ..

EQUIP-1           =SCHEDULE            THRU DEC 31 EQ-WEEK  ..
```

The building-up, thru u-names, of a yearly profile, which is then referenced in the space definition.

```
                      $ INFILTRATION SCHEDULE

INFIL-SCH         =SCHEDULE            THRU MAR 31 (ALL) (1,24) (1)
                                       THRU OCT 31 (ALL) (1,24) (Ø)
                                       THRU DEC 31 (ALL) (1,24) (1)  ..
```

Infiltration is "on" during the winter months.

```
                          $ SET DEFAULT VALUES

                   SET-DEFAULT FOR SPACE  FLOOR-WEIGHT=7Ø  ..
                   SET-DEFAULT FOR EXTERIOR-WALL  CONSTRUCTION=WALL-1  ..
                   SET-DEFAULT FOR WINDOW  HEIGHT=4.Ø  GLASS-TYPE=W-1  ..
```

Same as "SET MASTER DATA" used in other programs.

```
                          $ GENERAL SPACE DEFINITION

OFFICE            =SPACE-CONDITIONS    PEOPLE-SCHEDULE      =OCCUPY-1
                                       NUMBER-OF-PEOPLE     =5Ø
                                       PEOPLE-HEAT-GAIN     =4ØØ
                                       LIGHTING-SCHEDULE    =LIGHTS-1
                                       LIGHTING-TYPE        =REC-FLUOR-RV
                                       LIGHT-TO-SPACE       =.8Ø
                                       LIGHTING-W/SQFT      =3
                                       EQUIP-SCHEDULE       =EQUIP-1
                                       EQUIPMENT-W/SQFT     =1
                                       INF-METHOD           =AIR-CHANGE
                                       AIR-CHANGES/HR       =Ø.25
                                       INF-SCHEDULE         =INFIL-SCH  ..
```

Maximum values which are multiplied by occupancy profiles.

```
                          $ SPECIFIC SPACE DETAILS

PLENUM-1          =SPACE               ZONE-TYPE=PLENUM  AREA=5ØØØ
                                       VOLUME=1ØØØØ  FLOOR-WEIGHT=5  ..

     WALL-1PF     =EXTERIOR-WALL       HEIGHT = 2  WIDTH = 1ØØ
                                       AZIMUTH = 18Ø  ..

     WALL-1PR     =EXTERIOR-WALL       HEIGHT = 2  WIDTH = 5Ø
                                       AZIMUTH = 9Ø  ..

     WALL-1PB     =EXTERIOR-WALL       HEIGHT = 2  WIDTH = 1ØØ
                                       AZIMUTH = Ø  ..

     WALL-1PL     =EXTERIOR-WALL       HEIGHT = 2  WIDTH = 5Ø
                                       AZIMUTH = 27Ø  ..

     TOP-1        =ROOF                HEIGHT=5Ø  WIDTH=1ØØ
                                       X=Ø   Y=Ø   Z=1Ø  AZIMUTH = 18Ø
                                       TILT=Ø  GND-REFLECTANCE=Ø
                                       CONSTRUCTION = ROOF-1  ..
```

The first space definition, using the u-names of the plenum walls and roof, as shown in Fig. 2.

```
SPACE1-1          =SPACE               SPACE-CONDITIONS = OFFICE
```

This assigns the general conditions — energy use and profiles — to this space.

```
                                          AREA = 1Ø56  VOLUME = 8448
                                          NUMBER-OF-PEOPLE = 11   ..
   FRONT-1        =EXTERIOR-WALL          HEIGHT = 8            WIDTH = 1ØØ
                                          X=Ø   Y=Ø   Z=Ø  AZIMUTH = 18Ø   ..
     WF-1         =WINDOW                 WIDTH = 45   ..
     DF-1         =WINDOW                 WIDTH = 8  HEIGHT = 8
                                          GLASS-TYPE=DOORS
                                          OVERHANG-A 1  OVERHANG-B .5
                                          OVERHANG-W 1Ø OVERHANG-D 4  ..
```

Refer to Fig. 4. The door (DF-1) is made of glass and has an overhang.

```
   C1-1           =INTERIOR-WALL          AREA = 1Ø56  NEXT-TO  PLENUM-1
                                          CONSTRUCTION = CLNG-1    ..

   F1-1           =UNDERGROUND-FLOOR      AREA = 1Ø56  CONSTRUCTION = FLOOR-1 ..

   SB12           =INTERIOR-WALL          AREA=135.76  NEXT-TO SPACE2-1
                                          CONSTRUCTION = SB-U    ..

   SB14           =INTERIOR-WALL          LIKE SB12  NEXT-TO SPACE4-1   ..
   SB15           =INTERIOR-WALL          AREA 6Ø8              NEXT-TO  SPACE5-1
                                          CONSTRUCTION = SB-U    ..

SPACE2-1          =SPACE                  SPACE-CONDITIONS = OFFICE
                                          AREA = 456  VOLUME = 3648
                                          NUMBER-OF-PEOPLE = 5    ..

   RIGHT-1        =EXTERIOR-WALL          HEIGHT = 8  WIDTH = 5Ø
                                          X=1ØØ  Y=Ø   Z=Ø  AZIMUTH = 9Ø  ..

     WR-1         =WINDOW                 WIDTH = 25   ..
   C2-1           =INTERIOR-WALL          AREA = 456  NEXT-TO PLENUM-1
                                          CONSTRUCTION = CLNG-1    ..
```

This is the input for the ceiling of SPACE2-1, which is shared by the plenum (as are the ceilings of the other 4 spaces).

```
   F2-1           =UNDERGROUND-FLOOR      AREA = 456  CONSTRUCTION = CLNG-1 ..

   SB23           =INTERIOR-WALL          AREA = 135.76  NEXT-TO SPACE3-1
                                          CONSTRUCTION = SB-U    ..

   SB25           =INTERIOR-WALL          AREA = 2Ø8  NEXT-TO SPACE5-1
                                          CONSTRUCTION = SB-U    ..

SPACE3-1          =SPACE                  SPACE-CONDITIONS = OFFICE
                                          AREA  = 1Ø56  VOLUME = 8448
                                          NUMBER-OF-PEOPLE = 11    ..

   BACK-1         =EXTERIOR-WALL          HEIGHT = 8  WIDTH = 1ØØ
                                          X=1ØØ  Y=5Ø  Z=Ø  AZIMUTH = Ø    ..

     WB-1         =WINDOW                 WIDTH = 45   ..
     DB-1         =WINDOW                 WIDTH = 7  HEIGHT = 7
                                          GLASS-TYPE=DOORS    ..

   C3-1           =INTERIOR-WALL          AREA = 1Ø56  NEXT-TO PLENUM-1
                                          CONSTRUCTION = CLNG-1    ..

   F3-1           =UNDERGROUND-FLOOR      AREA = 1Ø56
                                          CONSTRUCTION = FLOOR-1    ..

   SB34           =INTERIOR-WALL          AREA = 135.8  NEXT-TO SPACE4-1
                                          CONSTRUCTION = SB-U    ..

   SB35           =INTERIOR-WALL          AREA = 6Ø8  NEXT-TO SPACE5-1
                                          CONSTRUCTION = SB-U    ..
```

Notice the hierarchy of input. First is the space, then the exterior walls, then the windows, if any, within each wall.

```
SPACE4-1        =SPACE                  SPACE-CONDITIONS = OFFICE
                                        AREA = 456  VOLUME = 3648
                                        NUMBER-OF-PEOPLE = 5   ..

    LEFT-1      =EXTERIOR-WALL          HEIGHT = 8  WIDTH = 50
                                        X=0   Y=50  Z=0   AZIMUTH = 270  ..

      WL-1      =WINDOW                 WIDTH = 25   ..

    C4-1        =INTERIOR-WALL          AREA = 456  NEXT-TO PLENUM-1
                                        CONSTRUCTION = CLNG-1   ..

    F4-1        =UNDERGROUND-FLOOR      AREA = 456
                                        CONSTRUCTION = FLOOR-1   ..

    SB45        =INTERIOR-WALL          AREA = 208  NEXT-TO SPACE5-1
                                        CONSTRUCTION = SB-U   ..

SPACE5-1        =SPACE                  SPACE-CONDITIONS = OFFICE
                                        AREA = 1976  VOLUME = 15808
                                        NUMBER-OF-PEOPLE = 20   ..

    C5-1        =INTERIOR-WALL          AREA = 1976  NEXT-TO PLENUM-1
                                        CONSTRUCTION = CLNG-1   ..

    F5-1        =UNDERGROUND-FLOOR      AREA = 1976  CONSTRUCTION = FLOOR-1 ..

END  ..
COMPUTE  LOADS   ..
INPUT SYSTEMS   ..
          S D L   P R O C E S S O R   I N P U T   D A T A

                03-Jun-85   14:40:48LDL RUN  1
```

S D L   P R O C E S S O R   I N P U T   D A T A

Ø3-Jun-85   14:4Ø:48SDL RUN 1

```
                       SYSTEMS-REPORT  SUMMARY=(SS-A)  ..

                       $ SYSTEMS SCHEDULES

FAN-1        =DAY-SCHEDULE       (1,6)(Ø)(7,8)(-999)(9,18)(1)(19,24)(Ø)  ..
FAN-2        =DAY-SCHEDULE       (1,24) (Ø)   ..
FAN-SCHED    =SCHEDULE           THRU DEC 31 (WD) FAN-1 (WEH) FAN-2  ..

HEAT-1       =DAY-SCHEDULE     (1,8) (55)   (9,18) (7Ø)  (19,24) (55)  ..
HEAT-2       =DAY-SCHEDULE     (1,24) (55)   ..
HEAT-WEEK    =WEEK-SCHEDULE    (MON,FRI)  HEAT-1   (WEH)  HEAT-2   ..
HEAT-SCHED   =SCHEDULE         THRU DEC 31   HEAT-WEEK   ..
COOLOFF      =SCHEDULE         THRU DEC 31 (ALL) (1,24) (6Ø)   ..
HEATOFF      =SCHEDULE         THRU DEC 31 (ALL) (1,24) (6Ø)   ..

COOL-1       =DAY-SCHEDULE     (1,8) (99)  (9,18) (78)  (19,24) (99)   ..
COOL-2       =DAY-SCHEDULE     (1,24) (99)   ..
COOL-WEEK    =WEEK-SCHEDULE    (MON,FRI)  COOL-1   (WEH)  COOL-2   ..
COOL-SCHED   =SCHEDULE         THRU DEC 31   COOL-WEEK   ..

R1           =DAY-RESET-SCH  SUPPLY-HI=6Ø  SUPPLY-LO=52
                             OUTSIDE-LO=3Ø  OUTSIDE-HI=75  ..
SAT-RESET    =RESET-SCHEDULE  THRU DEC 31 (ALL) R1  ..

                      $ SYSTEM DESCRIPTION

ZAIR          =ZONE-AIR      OA-CFM/PER=7   ..

 CONTROL      =ZONE-CONTROL  DESIGN-HEAT-T=7Ø  DESIGN-COOL-T=78
                             HEAT-TEMP-SCH= HEAT-SCHED
                             COOL-TEMP-SCH= COOL-SCHED
                             THERMOSTAT-TYPE=REVERSE-ACTION  ..

SPACE1-1      =ZONE          ZONE-AIR=ZAIR  SIZING-OPTION=ADJUST-LOADS
                             ZONE-CONTROL=CONTROL ASSIGNED-CFM=191Ø   ..
SPACE2-1      =ZONE          LIKE SPACE1-1   ASSIGNED-CFM=86Ø         ..
SPACE3-1      =ZONE          LIKE SPACE1-1   A-CFM=136Ø       ..
SPACE4-1      =ZONE          LIKE SPACE1-1   A-CFM=86Ø        ..
SPACE5-1      =ZONE          LIKE SPACE1-1   A-CFM=163Ø       ..

PLENUM-1      =ZONE          ZONE-TYPE=PLENUM  S-O=ADJUST-LOADS
                             DESIGN-HEAT-T 5Ø  DESIGN-COOL-T 95   ..

S-CONT        =SYSTEM-CONTROL  COOLING-SCHEDULE= COOLOFF
                               HEATING-SCHEDULE= HEATOFF
                               HEAT-SET-T=65
                               COOL-CONTROL=RESET
                               COOL-RESET-SCH=SAT-RESET
                               MIN-SUPPLY-T=6Ø ..

S-FAN         =SYSTEM-FANS     FAN-SCHEDULE=FAN-SCHED  FAN-CONTROL=SPEED
                               SUPPLY-STATIC=5.5  SUPPLY-EFF=.55
                               NIGHT-CYCLE-CTRL=CYCLE-ON-ANY  ..
```

The fan profile has an optimum start period (-999) from 7 to 8 AM.

The heating setpoint of the thermostat is 70 °F during the day and 55 °F at night.

Cooling is available year-around whenever the outside temperature goes above 60 °F.

The cooling setpoint is 78 °F.

The minimum ventilation per person.

The same u-names of spaces as input in the LOADS portion of the program.

Another schedule being referenced.

```
S-TERM        =SYSTEM-TERMINAL REHEAT-DELTA-T=58
                               MIN-CFM-RATIO=Ø.3   ..

SYST-1        =SYSTEM          SYSTEM-TYPE=VAVS   SUPPLY-CFM=5732
                               SYSTEM-CONTROL= S-CONT
                               SYSTEM-FANS= S-FAN
                               SYSTEM-TERMINAL= S-TERM
                               ECONO-LIMIT-T=65
                               RETURN-AIR-PATH=PLENUM-ZONES
                               PLENUM-NAMES=(PLENUM-1)
                               ZONE-NAMES=(SPACE5-1,SPACE1-1,SPACE2-1
                                          SPACE3-1,SPACE4-1,PLENUM-1)   ..

END   ..
COMPUTE SYSTEMS   ..

INPUT PLANT   ..
          P D L   P R O C E S S O R   I N P U T   D A T A

                Ø3-Jun-85   14:4Ø:48SDL RUN  1
```

The system type selected is a variable-air volume.

The assignment of the spaces (zones) to the VAVS system.

P D L   P R O C E S S O R   I N P U T   D A T A

Ø3-Jun-85   14:4Ø:48PDL RUN 1

```

               PLANT-REPORT  SUMMARY=(PS-D,BEPS) ..

                 $ EQUIPMENT DESCRIPTION

                 $ HOT-WATER BOILER

SBOIL1      =PLANT-EQUIPMENT  TYPE=HW-BOILER  SIZE=.4
                              HOURS-USED=5ØØØØ   ..

              PLANT-PARAMETERS  BOILER-FUEL=NATURAL-GAS
                                HERM-REC-COND-TYPE=AIR  ..

                 $ AIR-COOLED RECIPROCATING CHILLER

CHIL1       =PLANT-EQUIPMENT  TYPE=HERM-REC-CHLR
                              SIZE=.18            $ 15 TONS
                              HOURS-USED=5ØØØØ  ..

            ENERGY-RESOURCE  RESOURCE=ELECTRICITY  ..
            ENERGY-RESOURCE  RESOURCE=NATURAL-GAS  ..

END  ..
COMPUTE PLANT   ..
INPUT ECONOMICS  ..
```

400,000 Btu/hr peak output capacity.

The code-word for a hermetic-reciprocating chiller, whose condenser normally defaults to water-cooled. The PLANT-PARAMETER above changes it to air.

E D L   P R O C E S S O R   I N P U T   D A T A

Ø3-Jun-85   14:4Ø:48PDL RUN 1

E D L   P R O C E S S O R   I N P U T   D A T A

03-Jun-85   14:40:48EDL RUN 1

```
                  ECONOMICS-REPORT  SUMMARY (ES-D,ES-E)  ..

                  ENERGY-COST  RESOURCE=NATURAL-GAS
                               UNIT=100000  UNIFORM-COST=.6
                               ESCALATION=8  ..

                  ENERGY-COST  RESOURCE=ELECTRICITY
                               ASSIGN-SCHEDULE=TIMEOFDAY
                               ESCALATION=7  ..

NIGHT             =CHARGE-ASSIGNMENT  RESOURCE=ELECTRICITY
                                      TYPE=ENERGY  UNIFORM-CHARGE=.05 ..

SHD-P             =C-A  R=ELECTRICITY  TYPE=ENERGY  U-C=.06  ..

PEAK              =C-A  R=ELECTRICITY  TYPE=ENERGY  U-C=.07  ..

WD-RATE           =DAY-CHARGE-SCH  (1,8) (NIGHT) (9,12) (SHD-P)
                                   (13,17) (PEAK)  (18,22) (SHD-P)
                                   (23,24) (NIGHT)  ..

SAT-RATE          =D-C-SCH  (1,8) (NIGHT) (9,17) (SHD-P)
                            (18,24) (NIGHT)  ..

WEH-RATE          =D-C-SCH  (1,24) (NIGHT)  ..

TIMEOFDAY         =SCH THRU DEC 31 (WD) WD-RATE
                       (SAT) SAT-RATE  (SUN,HOL) WEH-RATE  ..

END  ..
COMPUTE ECONOMICS  ..
STOP  ..
```

A simple uniform cost of 60¢ per therm for gas.

A simple time-of-day rate for electricity during the weekdays:

- *5¢ /kwh at night (11 PM to 8 AM)*
- *6¢ /kwh shoulder (9 to 12 noon)*
- *7¢ /kwh peak (1 to 5 PM)*

There are no demand charges.

Abbreviations are allowed for most commands and keywords.

SIMPLE STRUCTURE RUN, CHICAGO DOE-2.1C 03-Jun-85 14:40:48LDL RUN 1

REPORT- LV-D DETAILS OF EXTERIOR SURFACES IN THE PROJECT WEATHER FILE- TRY CHICAGO

NUMBER OF EXTERIOR SURFACES 9 RECTANGULAR 9 OTHER 0

SURFACE	SPACE	----GLASS---- U-VALUE (BTU/HR - SQFT)	----GLASS---- AREA (SQFT)	----WALL---- U-VALUE (BTU/HR - SQFT)	----WALL---- AREA (SQFT)	- WALL+GLASS - U-VALUE (BTU/HR - SQFT)	- WALL+GLASS - AREA (SQFT)	AZIMUTH
WALL-1PB	PLENUM-1	.00	.00	.07	200.00	.07	200.00	NORTH-EAST
BACK-1	SPACE3-1	1.02	229.00	.07	571.00	.34	800.00	NORTH-EAST
RIGHT-1	SPACE2-1	1.02	100.00	.07	300.00	.31	400.00	SOUTH-EAST
WALL-1PR	PLENUM-1	.00	.00	.07	100.00	.07	100.00	SOUTH-EAST
WALL-1PF	PLENUM-1	.00	.00	.07	200.00	.07	200.00	SOUTH-WEST
FRONT-1	SPACE1-1	1.02	244.00	.07	556.00	.36	800.00	SOUTH-WEST
WALL-1PL	PLENUM-1	.00	.00	.07	100.00	.07	100.00	NORTH-WEST
LEFT-1	SPACE4-1	1.02	100.00	.07	300.00	.31	400.00	NORTH-WEST
TOP-1	PLENUM-1	.00	.00	.05	5000.00	.05	5000.00	ROOF
F1-1	SPACE1-1	.00	.00	.05	1056.00	.05	1056.00	UNDERGRND
F2-1	SPACE2-1	.00	.00	.27	456.00	.27	456.00	UNDERGRND
F3-1	SPACE3-1	.00	.00	.05	1056.00	.05	1056.00	UNDERGRND
F4-1	SPACE4-1	.00	.00	.05	456.00	.05	456.00	UNDERGRND
F5-1	SPACE5-1	.00	.00	.05	1976.00	.05	1976.00	UNDERGRND

An echo of your input.

REPORT- LV-D DETAILS OF EXTERIOR SURFACES IN THE PROJECT WEATHER FILE- TRY CHICAGO

(CONTINUED)

	AVERAGE U-VALUE/GLASS (BTU/HR - SQFT)	AVERAGE U-VALUE/WALLS (BTU/HR - SQFT)	AVERAGE U-VALUE WALLS+GLASS (BTU/HR - SQFT)	GLASS AREA (SQFT)	OPAQUE AREA (SQFT)	GLASS+OPAQUE AREA (SQFT)
NORTH-EAST	1.02	.07	.29	229.00	771.00	1000.00
SOUTH-EAST	1.02	.07	.26	100.00	400.00	500.00
SOUTH-WEST	1.02	.07	.30	244.00	756.00	1000.00
NORTH-WEST	1.02	.07	.26	100.00	400.00	500.00
ROOF	.00	.05	.05	.00	5000.00	5000.00
ALL WALLS	1.02	.07	.28	673.00	2327.00	3000.00
WALLS+ROOFS	1.02	.05	.14	673.00	7327.00	8000.00
UNDERGRND	.00	.07	.07	.00	5000.00	5000.00
BUILDING	1.02	.06	.11	673.00	12327.00	13000.00

A handy report to check wall and glass U-factors (and overall U-factors) plus the areas of wall, roof, and floor surfaces resulting from your inputs.

*** BUILDING ***

FLOOR AREA	5000	SQFT	465	SQMT
VOLUME	50000	CUFT	1416	CUMT

	COOLING LOAD		HEATING LOAD	
TIME	JUL 9 4PM		FEB 4 6AM	
DRY-BULB TEMP	94F	34C	7F	-14C
WET-BULB TEMP	74F	23C	6F	-14C

	COOLING SENSIBLE (KBTU/H)	COOLING SENSIBLE (KW)	LATENT (KBTU/H)	LATENT (KW)	HEATING SENSIBLE (KBTU/H)	HEATING SENSIBLE (KW)
WALLS	3.776	1.106	.000	.000	-6.947	-2.035
ROOFS	.000	.000	.000	.000	.000	.000
GLASS CONDUCTION	16.779	4.914	.000	.000	-45.383	-13.292
GLASS SOLAR	31.986	9.368	.000	.000	1.293	.379
DOOR	.000	.000	.000	.000	.000	.000
INTERNAL SURFACES	.000	.000	.000	.000	.000	.000
UNDERGROUND SURFACES	-2.102	-.616	.000	.000	-11.561	-3.386
OCCUPANTS TO SPACE	13.326	3.903	4.824	1.413	.001	.000
LIGHT TO SPACE	34.938	10.233	.000	.000	2.052	.601
EQUIPMENT TO SPACE	11.185	3.276	.000	.000	.830	.243
PROCESS TO SPACE	.000	.000	.000	.000	.000	.000
INFILTRATION	.000	.000	.000	.000	-15.446	-4.524
TOTAL	109.888	32.183	4.824	1.413	-75.161	-22.013

TOTAL LOAD	114.712 KBTU/H	33.596 KW	-75.161 KBTU/H	-22.013 KW
TOTAL LOAD / AREA	22.94BTU/H.SQFT	72.325 W /SQMT	15.032BTU/H.SQFT	47.389 W /SQMT

The building peak sensible load.

NOTE 1)THE ABOVE LOADS EXCLUDE OUTSIDE VENTILATION AIR LOADS
2)TIMES GIVEN IN STANDARD TIME FOR THE LOCATION IN CONSIDERATION

SIMPLE STRUCTURE RUN, CHICAGO DOE-2.1C Ø3-Jun-85 14:4Ø:48SDL RUN 1

REPORT- SV-A SYSTEM DESIGN PARAMETERS SYST-1 WEATHER FILE- TRY CHICAGO

SYSTEM NAME	ALTITUDE MULTIPLIER
SYST-1	1.Ø2Ø

SUPPLY FAN (CFM)	ELEC (KW)	DELTA-T (F)	RETURN FAN (CFM)	ELEC (KW)	DELTA-T (F)	OUTSIDE AIR RATIO	COOLING CAPACITY (KBTU/HR)	SENSIBLE (SHR)	HEATING CAPACITY (KBTU/HR)	COOLING EIR (BTU/BTU)	HEATING EIR (BTU/BTU)
5847.	6.728	3.6	Ø.	.ØØØ	.Ø	.Ø66	168.953	.8Ø6	.ØØØ	.ØØ	.ØØ

Air-handling unit cooling coil capacity.

ZONE NAME	SUPPLY FLOW	EXHAUST FLOW	FAN (KW)	MINIMUM FLOW RATIO	OUTSIDE AIR FLOW	COOLING CAPACITY (KBTU/HR)	SENSIBLE (SHR)	EXTRACTION RATE (KBTU/HR)	HEATING CAPACITY (KBTU/HR)	ADDITION RATE (KBTU/HR)	MULTIPLIER
SPACE5-1	1663.	Ø.	.ØØØ	.3ØØ	143.	.ØØ	.ØØ	32.32	-1Ø4.15	-86.19	1.Ø
SPACE1-1	1948.	Ø.	.ØØØ	.3ØØ	82.	.ØØ	.ØØ	37.87	-122.Ø4	-1ØØ.99	1.Ø
SPACE2-1	877.	Ø.	.ØØØ	.3ØØ	41.	.ØØ	.ØØ	17.Ø5	-54.95	-45.47	1.Ø
SPACE3-1	1387.	Ø.	.ØØØ	.3ØØ	82.	.ØØ	.ØØ	26.97	-86.89	-71.91	1.Ø
SPACE4-1	877.	Ø.	.ØØØ	.3ØØ	41.	.ØØ	.ØØ	17.Ø5	-54.95	-45.47	1.Ø
PLENUM-1	Ø.	Ø.	.ØØØ	.ØØØ	Ø.	.ØØ	.ØØ	.ØØ	.ØØ	.ØØ	1.Ø

The system design air flow.

The zone space design air flow.

Heating capacity of zone reheat coils.

SIMPLE STRUCTURE RUN, CHICAGO DOE-2.1C 03-Jun-85 14:40:48SDL RUN 1

REPORT- SS-A SYSTEM MONTHLY LOADS SUMMARY FOR SYST-1 WEATHER FILE- TRY CHICAGO

	COOLING						HEATING						ELEC	
MONTH	COOLING ENERGY (MBTU)	TIME OF MAX DY	TIME OF MAX HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM COOLING LOAD (KBTU/HR)	HEATING ENERGY (MBTU)	TIME OF MAX DY	TIME OF MAX HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM HEATING LOAD (KBTU/HR)	ELEC-TRICAL ENERGY (KWH)	MAXIMUM ELEC LOAD (KW)
JAN	.00000					.000	-20.891	7	8	-1.F	-1.F	-371.974	5248.	20.654
FEB	.00000					.000	-17.440	4	8	7.F	6.F	-413.972	4583.	20.505
MAR	.00000					.000	-10.350	25	8	14.F	12.F	-354.036	5004.	20.452
APR	2.30121	29	16	68.F	63.F	88.448	-1.823	1	8	43.F	39.F	-231.966	5138.	21.922
MAY	7.14593	21	14	85.F	75.F	128.210	-.037	9	9	43.F	39.F	-14.185	5371.	23.705
JUN	18.59156	20	16	90.F	77.F	163.063	.000					.000	5364.	25.460
JUL	31.99693	15	8	72.F	70.F	191.713	.000					.000	6395.	27.524
AUG	28.71213	26	17	94.F	76.F	165.279	.000					.000	6170.	26.751
SEP	12.71057	11	15	87.F	72.F	148.399	-.015	23	9	39.F	36.F	-12.982	5202.	25.632
OCT	4.34771	31	15	76.F	65.F	84.222	-.602	21	8	30.F	29.F	-170.773	5217.	21.794
NOV	.65957	1	16	72.F	59.F	87.352	-7.688	18	8	34.F	34.F	-273.298	4607.	22.295
DEC	.00000					.000	-16.701	26	8	15.F	15.F	-395.525	5053.	20.472
TOTAL	106.466						-75.547						63357.	
MAX						191.713						-413.972		27.524

Total cooling coil load passed to the chiller.

Maximum cooling load seen as a start-up condition.

EQUIPMENT	SIZE (MBTU/)	NUMBER INSTD	AVAIL	SIZE (MBTU/)	NUMBER INSTD	AVAIL	SIZE (MBTU/)	NUMBER INSTD	AVAIL	SIZE (MBTU/)	NUMBER INSTD	AVAIL	SIZE (MBTU/)	NUMBER INSTD	AVAIL	SIZE (MBTU/)	NUMBER INSTD	AVAIL
HW-BOILER	.400	1	1															
HERM-REC-CHLR	.180	1	1															

REPORT- PS-D PLANT LOADS SATISFIED WEATHER FILE- TRY CHICAGO

HEATING INPUTS	MBTU SUPPLIED	PCT OF TOTAL LOAD
HW-BOILER	79.3	1ØØ.Ø
LOAD SATISFIED	79.3	1ØØ.Ø
TOTAL LOAD ON PLANT	79.3	

COOLING INPUTS	MBTU SUPPLIED	PCT OF TOTAL LOAD
HERM-REC-CHLR	11Ø.8	1ØØ.Ø
LOAD SATISFIED	11Ø.8	1ØØ.Ø
TOTAL LOAD ON PLANT	11Ø.8	

ELECTRICAL INPUTS	MBTU SUPPLIED	PCT OF TOTAL LOAD
ELECTRICITY	262.8	1ØØ.Ø
LOAD SATISFIED	262.8	1ØØ.Ø
TOTAL LOAD ON PLANT	262.8	

SUMMARY OF LOADS MET

TYPE OF LOAD	TOTAL LOAD (MBTU)	LOAD SATISFIED (MBTU)	TOTAL OVERLOAD (MBTU)	PEAK OVERLOAD (MBTU)	HOURS OVERLOADED
HEATING INPUTS	79.3	79.3	.ØØØ	.ØØØ	Ø
COOLING INPUTS	11Ø.8	11Ø.8	.ØØØ	.ØØØ	Ø
ELECTRICAL INPUTS	262.8	262.8	.ØØØ	.ØØØ	Ø

SIMPLE STRUCTURE RUN, CHICAGO   DOE-2.1C 03-Jun-85 14:40:48PDL RUN 1

REPORT- BEPS ESTIMATED BUILDING ENERGY PERFORMANCE   WEATHER FILE- TRY CHICAGO

ENERGY TYPE IN SITE MBTU -	ELECTRICITY	NATURAL-GAS
CATEGORY OF USE		
SPACE HEAT	5.77	123.16
SPACE COOL	36.19	.00
HVAC AUX	26.67	.00
DOM HOT WTR	.00	.00
AUX SOLAR	.00	.00
LIGHTS	149.50	.00
VERT TRANS	.00	.00
MISC EQUIP	44.69	.00
TOTAL	262.82	123.16

TOTAL SITE ENERGY	385.97 MBTU	77.2 KBTU/SQFT-YR GROSS-AREA	77.2 KBTU/SQFT-YR NET-AREA
TOTAL SOURCE ENERGY	912.39 MBTU	182.5 KBTU/SQFT-YR GROSS-AREA	182.5 KBTU/SQFT-YR NET-AREA

PERCENT OF HOURS ANY SYSTEM ZONE OUTSIDE OF THROTTLING RANGE = 2.6
PERCENT OF HOURS ANY PLANT LOAD NOT SATISFIED = .0

NOTE ELECTRICITY AND/OR FUEL USED TO GENERATE ELECTRICITY IS APPORTIONED BASED ON THE YEARLY DEMAND. ALL OTHER ENERGY TYPES ARE APPORTIONED HOURLY.

SIMPLE STRUCTURE RUN, CHICAGO DOE-2.1C 03-Jun-85 14:40:48EDL RUN 1

REPORT- ES-D SUMMARY OF FUEL AND UTILITY USE AND COSTS

MONTH	ELECTRIC UNIT= 3412.97	NTRL-GAS UNIT= 100000.00
JAN		
ENERGY CONSUMPTION (UNIT/MO)	5848.	337.
PEAK DEMAND (UNIT/HR)	24.	5.
TOTAL COST ($)	364.90	202.02
FEB		
ENERGY CONSUMPTION (UNIT/MO)	5082.	280.
PEAK DEMAND (UNIT/HR)	24.	5.
TOTAL COST ($)	316.73	168.27
MAR		
ENERGY CONSUMPTION (UNIT/MO)	5356.	172.
PEAK DEMAND (UNIT/HR)	23.	5.
TOTAL COST ($)	335.28	103.30
APR		
ENERGY CONSUMPTION (UNIT/MO)	5557.	32.
PEAK DEMAND (UNIT/HR)	31.	3.
TOTAL COST ($)	351.72	18.96
MAY		
ENERGY CONSUMPTION (UNIT/MO)	6230.	0.
PEAK DEMAND (UNIT/HR)	36.	0.
TOTAL COST ($)	395.86	.55
JUN		
' CONSUMPTION (UNIT/MO)	7374.	0.
'EMAND (UNIT/HR)	42.	0.
COST ($)	469.50	.00
' CONSUMPTION (UNIT/MO)	9537.	0.
EMAND (UNIT/HR)	44.	0.
TOTAL COST ($)	606.33	.00
AUG		
ENERGY CONSUMPTION (UNIT/MO)	9051.	0.
PEAK DEMAND (UNIT/HR)	43.	0.
TOTAL COST ($)	576.64	.00
SEP		
ENERGY CONSUMPTION (UNIT/MO)	6614.	0.
PEAK DEMAND (UNIT/HR)	41.	0.
TOTAL COST ($)	421.16	.20
OCT		
ENERGY CONSUMPTION (UNIT/MO)	5854.	11.
PEAK DEMAND (UNIT/HR)	32.	3.
TOTAL COST ($)	371.58	6.44
NOV		
ENERGY CONSUMPTION (UNIT/MO)	4952.	128.
PEAK DEMAND (UNIT/HR)	32.	4.
TOTAL COST ($)	310.21	76.98
DEC		
ENERGY CONSUMPTION (UNIT/MO)	5550.	270.
PEAK DEMAND (UNIT/HR)	24.	5.
TOTAL COST ($)	346.38	162.24
TOTAL		
ENERGY CONSUMPTION (UNIT/YR)	77005.	1232.
PEAK DEMAND (UNIT/HR)	44.	5.
TOTAL COST ($)	4866.31	738.95

Btu/therm (100000.00)
Btu/kWh (3412.97)
kWh (5848.)
therms (337.)
kW (24.)

REPORT- ES-E SUMMARY OF ELECTRICITY CHARGES

MONTH	CHARGE-ASSIGNMENT (U-NAME)	LENGTH (HR/MO)	CONSUMPTION BY C-A (KWH)	ENERGY CHARGE ($)	MEASURED DEMAND (KW)	BILLING DEMAND (KW)	DEMAND CHARGE ($)	TOTAL CHARGES ($)
JAN								
	NIGHT	400	823.	41.13	10.	10.	.00	
	SHD-P	234	2800.	167.97	24.	24.	.00	
	PEAK	110	2226.	155.80	22.	22.	.00	
								364.90
FEB								
	NIGHT	370	743.	37.13	11.	11.	.00	
	SHD-P	207	2418.	145.11	24.	24.	.00	
	PEAK	95	1921.	134.49	22.	22.	.00	
								316.73
MAR								
	NIGHT	405	673.	33.66	10.	10.	.00	
	SHD-P	234	2615.	156.90	23.	23.	.00	
	PEAK	105	2067.	144.72	22.	22.	.00	
								335.28
APR								
	NIGHT	376	491.	24.56	7.	7.	.00	
	SHD-P	234	2744.	164.64	30.	30.	.00	
	PEAK	110	2322.	162.53	31.	31.	.00	
								351.72
MAY								
	NIGHT	400	509.	25.47	8.	8.	.00	
	SHD-P	234	3005.	180.30	35.	35.	.00	
	PEAK	110	2715.	190.08	36.	36.	.00	
								395.86
JUN								
	NIGHT	395	597.	29.84	12.	12.	.00	
	SHD-P	225	3476.	208.54	41.	41.	.00	
	PEAK	100	3302.	231.12	42.	42.	.00	
								469.50
JUL								
	NIGHT	400	809.	40.45	24.	24.	.00	
	SHD-P	234	4505.	270.32	43.	43.	.00	
	PEAK	110	4222.	295.56	44.	44.	.00	
								606.33
AUG								
	NIGHT	391	707.	35.35	19.	19.	.00	
	SHD-P	243	4281.	256.86	42.	42.	.00	
	PEAK	110	4063.	284.43	43.	43.	.00	
								576.64
SEP								
	NIGHT	404	570.	28.49	12.	12.	.00	
	SHD-P	216	3041.	182.45	37.	37.	.00	
	PEAK	100	3003.	210.22	41.	41.	.00	
								421.16
OCT								
	NIGHT	400	513.	25.64	5.	5.	.00	
	SHD-P	234	2793.	167.59	30.	30.	.00	
	PEAK	110	2548.	178.36	32.	32.	.00	
								371.58

REPORT- ES-E SUMMARY OF ELECTRICITY CHARGES

CONTINUED

MONTH	CHARGE-ASSIGNMENT (U-NAME)	LENGTH (HR/MO)	CONSUMPTION BY C-A (KWH)	ENERGY CHARGE ($)	MEASURED DEMAND (KW)	BILLING DEMAND (KW)	DEMAND CHARGE ($)	TOTAL CHARGES ($)
NOV								
	NIGHT	409	622.	31.10	8.	8.	.00	
	SHD-P	216	2401.	144.06	30.	30.	.00	
	PEAK	95	1929.	135.05	32.	32.	.00	
								310.21
DEC								
	NIGHT	414	777.	38.86	11.	11.	.00	
	SHD-P	225	2656.	159.38	24.	24.	.00	
	PEAK	105	2116.	148.14	22.	22.	.00	
								346.38
TOTAL			77005.	4866.31			.00	4866.31

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

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