OVERVIEW OF THE DOE-2
BUILDING ENERGY ANALYSIS PROGRAM

Version 2.1D

B. Birdsall, W.F. Buhl, K.L. Ellington,
A.E. Erdem and F.C. Winkelmann
Simulation Research Group
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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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. Program 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 the calculations be based upon well-established algorithms,

3) that the program permit the simulation of commonly available heating, ventilating, and air-conditioning (HVAC) equipment,

4) that the costs of running 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. We present here an overview of the DOE-2.1D version of the program. An annotated example of DOE-2 input and output is shown in the Appendix.
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BACKGROUND

In 1976, both the U.S. Energy Research and Development Administration (ERDA) and the California Energy Commission (CEC) 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 (Lawrence Berkeley Laboratory (LBL), Argonne National Laboratory and Los Alamos National Laboratory), and Consultants Computation Bureau, a private company; project leadership was centered at LBL. In 1976, the project produced a program called Cal-ERDA. At that point the joint CEC/ERDA sponsorship came to an end and ERDA was absorbed into the new U.S. Department of Energy (DOE). A slightly improved version of the program, developed with the support of the DOE Office of Buildings and Community Systems, was called DOE-1 and became the first of a series of versions leading to a much more sophisticated program called DOE-2. The latest version of DOE-2, called DOE-2.1D, was released in 1989.

Program Structure

DOE-2 consists of two major sections, as shown in Fig. 1.

1. An input processor called the Building Description Language (BDL) Program that accepts user-provided data for the building.

2. Simulation subprograms called LOADS, SYSTEMS, PLANT, and ECONOMICS that use the input data plus hourly weather information to calculate the hourly energy performance of the building.

In addition, DOE-2 contains

1. Reporting programs that print the results of the calculations.

2. A weather data processor that accepts a tape of hourly weather information for a particular city and puts it in a form the simulation subprograms can use.

3. A library of materials that can be enlarged by the user.

4. A library of response factors for common wall and roof constructions that can be added to by the user.

5. A program for calculating wall and roof response factors.

6. A program for calculating room weighting factors.

Simulation Approach

A building, examined thermodynamically, involves non-linear flows of energy 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.
Figure 1: The DOE-2 Program
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 SYSTEMS calculation of the energy addition and extraction to be supplied at the coils by the HVAC system in order to meet the 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 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 is the PLANT calculation. It 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?

Fourth is the calculation, by ECONOMICS, of the cost of fuel and electricity, taking into account the building’s utility rate schedule.

The continuous time dependence of energy flows 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.
THE DOE-2 SIMULATION SUB-PROGRAMS:
LOADS, SYSTEMS, PLANT and ECONOMICS

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:

- solar heat gain from radiation through windows and skylights,
- heat conduction through walls, roofs, windows, and doors in contact with the outside air,
- infiltration air (unintended ventilation),
- heat conduction through walls and floors in contact with the ground,
- heat conduction through interior walls, floors, ceilings, and partitions,
- heat gain from occupants,
- heat gain from lights,
- 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 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 resolved 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 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 there are several features that greatly extend the usefulness of the program. In the LOADS program these include 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 considers such factors as:

- window size and orientation
- glass transmittance
- inside surface reflectances of the space
- sun-control devices; blinds and overhangs
- luminance distribution of the sky
- 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. The daylight factor calculation takes into account the different paths by which light can reach the workplane (Fig. 2).

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.

An example building whose design involved extensive use of DOE-2 daylighting and thermal analysis is shown in Fig. 3.

Figure 2: Paths by which sunlight can reach a workplane through a transparent, unshaded window.
Figure 3: Interior view of the Great Gallery, Pacific Museum of Flight, Seattle, WA. The daylighting and thermal analysis of this heavily glazed building was done with DOE-2.1C (see V. Bazjanac and F. Winkelmann, "Daylighting Design of the Pacific Museum of Flight: Energy Impacts", in the BIBLIOGRAPHY).
Sunspace Model. DOE-2 allows the user to model the different forms of heat transfer that can occur between a sunspace (or atrium) and adjacent spaces, as shown in Fig. 4:

Figure 4: Forms of heat transfer between a sunspace and an adjacent room (XBL 843-10167).
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.

In the SYSTEMS subprogram, the sunspace model also simulates venting of the sunspace with outside air to prevent overheating and, for residential applications, the use of a sunspace to preheat outside ventilation air.

Functional Input Approach. For advanced users, DOE-2 allows the user to modify the way that DOE-2 does its LOADS calculations without having to recompile the code. This "Functional Input Approach" involves writing FORTRAN-like functions in the LOADS input that compute the program variables desired by the user. The possibilities of this feature are many and include changing the value of the glass shading-coefficient depending on the amount of solar radiation on the windows, 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. A similar feature is available in SYSTEMS.
New LOADS Features in DOE-2.1D

Generalized Library. In the past it has only been possible to create DOE-2 libraries of materials, envelope constructions, and weighting factors. A new general library feature has been designed which will allow users of DOE-2.1D to create custom libraries containing descriptions of any building component or system of components. This will allow definition of libraries containing data which could consist of standard operation schedules for different zone types or of complex component descriptions. Even libraries of entire zone descriptions can be created.

Fenestration. Because heat gain and loss through windows has a large impact on energy performance of most buildings, the DOE-2 window thermal calculations have been improved, including:

- an automatic calculation of the shading of diffuse solar radiation by neighboring buildings and by architectural elements such as overhangs (previously only the shading of direct solar radiation was calculated);

- an improved calculation of infra-red radiation loss from the building envelope to the sky, taking into account atmospheric conditions (atmospheric moisture, cloud coverage) and blocking by architectural obstructions; and

- an improved calculation of the amount of sky diffuse radiation falling on windows and walls.
SYSTEMS

General Considerations
The SYSTEMS program simulates not only the equipment that provides heating, ventilating and/or air conditioning to the thermal zones, but also the interaction of this equipment with the building envelope.

This simulation comprises two major parts:

Since the LOADS program calculates the "load" at constant space temperature, it is necessary to correct these calculations to account for equipment operation.

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 generic system types with many sizing and control options, depending upon the type chosen. The following table lists them with their familiar trade names.

<table>
<thead>
<tr>
<th>Category</th>
<th>Trade Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Supply Duct Types</td>
<td>Variable Temperature</td>
</tr>
<tr>
<td></td>
<td>Packaged DX Variable Temperature</td>
</tr>
<tr>
<td></td>
<td>Packaged Rooftop Desiccant Cooler</td>
</tr>
<tr>
<td></td>
<td>Ceiling Induction</td>
</tr>
<tr>
<td></td>
<td>Reheat</td>
</tr>
<tr>
<td></td>
<td>Variable Air Volume</td>
</tr>
<tr>
<td></td>
<td>Powered Induction Unit</td>
</tr>
<tr>
<td></td>
<td>Packaged DX VAV</td>
</tr>
<tr>
<td></td>
<td>Ceiling Bypass</td>
</tr>
<tr>
<td>Air Mixing Types</td>
<td>Multizone</td>
</tr>
<tr>
<td></td>
<td>Packaged DX Multizone</td>
</tr>
<tr>
<td></td>
<td>Dual Duct</td>
</tr>
<tr>
<td></td>
<td>Two Pipe Fan Coil</td>
</tr>
<tr>
<td></td>
<td>Four Pipe Fan Coil</td>
</tr>
<tr>
<td>Terminal Unit Types</td>
<td>Two Pipe Induction</td>
</tr>
<tr>
<td></td>
<td>Four Pipe Induction</td>
</tr>
<tr>
<td></td>
<td>Packaged Air Conditioner</td>
</tr>
<tr>
<td></td>
<td>Water/Air Heat Pump</td>
</tr>
<tr>
<td>Residential</td>
<td>Furnace and Condensing Unit</td>
</tr>
<tr>
<td>Heating Only</td>
<td>Panel Heating</td>
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<tr>
<td></td>
<td>Central Ventilation</td>
</tr>
<tr>
<td></td>
<td>Unit Heater</td>
</tr>
<tr>
<td></td>
<td>Classroom Unit Ventilator</td>
</tr>
<tr>
<td>Diagnostics</td>
<td>Sums Zone Loads</td>
</tr>
</tbody>
</table>

See Figure 5 on the next page for a drawing of a typical system.
Figure 5: Variable-Air-Volume System

Special SYSTEMS Features
The DOE-2 program allows the user to attach many special features onto the generic system types. 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 Convection 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 to calculate most of these parameters if the user does not provide 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.

New SYSTEMS Features in DOE-2.1D

Functional Input Approach. The "Functional Input Approach" available in LOADS can also be used in SYSTEMS. This permits modeling of control strategies that are not simulated in the basic DOE-2 calculation. It also allows very advanced users to describe new system types.

Desiccant Cooling. Several companies are developing desiccant cooling systems in which a hygroscopic material such as lithium chloride is used to remove moisture from the supply air stream. The desiccant is "regenerated" for further use by drying it with hot air from a gas-fired heater. Gas-fired desiccant systems of this type have the potential for being a replacement for, or a supplement to, conventional electric-driven cooling systems. A model for a packaged rooftop desiccant cooling system has been added to DOE-2.1D.
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. Figure 6 shows the primary equipment components and energy flows that can be simulated by PLANT.

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 user:

<table>
<thead>
<tr>
<th>Category</th>
<th>Trade Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating Equipment</td>
<td>Fossil Fuel Steam Boiler</td>
</tr>
<tr>
<td></td>
<td>Fossil Fuel Hot Water Boiler</td>
</tr>
<tr>
<td></td>
<td>Electric Steam Boiler</td>
</tr>
<tr>
<td></td>
<td>Electric Hot Water Boiler</td>
</tr>
<tr>
<td></td>
<td>Residential Furnace</td>
</tr>
<tr>
<td></td>
<td>Domestic Hot Water Heater</td>
</tr>
<tr>
<td></td>
<td>Electric DHW Heater</td>
</tr>
<tr>
<td>Electricity Generators</td>
<td>Steam Turbine</td>
</tr>
<tr>
<td></td>
<td>Diesel Generator</td>
</tr>
<tr>
<td></td>
<td>Gas Turbine</td>
</tr>
<tr>
<td>Chillers</td>
<td>Open Centrifugal</td>
</tr>
<tr>
<td></td>
<td>Open Reciprocal</td>
</tr>
<tr>
<td></td>
<td>Hermetic Centrifugal</td>
</tr>
<tr>
<td></td>
<td>Hermetic Reciprocal</td>
</tr>
<tr>
<td></td>
<td>One Stage Absorption</td>
</tr>
<tr>
<td></td>
<td>Two Stage Absorption</td>
</tr>
<tr>
<td></td>
<td>Direct-Fired Absorption Chiller/Heater</td>
</tr>
<tr>
<td></td>
<td>Double Bundle</td>
</tr>
<tr>
<td></td>
<td>Gas-Engine Driven Reciprocating Chiller</td>
</tr>
<tr>
<td>Storage Tanks</td>
<td>Hot and Cold</td>
</tr>
<tr>
<td>Cooling Towers</td>
<td>Conventional and Ceramic</td>
</tr>
</tbody>
</table>
Figure 6: Possible DOE-2 PLANT components and energy flows. An actual plant would only have a subset of the components shown.

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.

Early 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 later versions of DOE-2 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**

DOE-2 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:

**Peak Electric Demand Shaving using:**
- absorption chillers.
- diesel-driven generators.
- gas-driven generators.
- cold water storage, off-peak.

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.
Electric Load Shifting and "Load Shedding" may be addressed by making parametric studies to determine advantageous system and equipment operating strategies based either on reductions in peak demand or time-of-day energy use.

Pumping Energy for Hot and Cold Water Circuits may be set up for either variable or constant flow rates.

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.

New PLANT Features in 2.1D

Gas-Engine Driven Chillers and Direct-Fired Absorption Chiller/Heater. Two new PLANT equipment simulations are available in DOE-2.1D: a direct fired, double effect absorption chiller-heater model, and an engine driven chiller model.

Direct-fired absorption chillers have enjoyed a strong market in Japan due to a national energy policy mandating gas cooling. Despite high first cost and COPs of only 1.0 to 1.1, the equipment has attained considerable popularity.

The engine driven chiller, on the other hand, is "new" to the market. Engine driven chillers were available in the 1960's, but for a variety of reasons the market for these units dried up in the 70's. The Gas Research Institute, in collaboration with some equipment manufacturers, is attempting to reintroduce this equipment to the market. These units offer good COPs, excellent part load performance, and the capability to overspeed to meet peak loads above the rated capacity. Hot water can be recovered from the engine exhaust and coolant to provide space heating or to run an absorption chiller for extra cooling and greater overall efficiency.

Ice-Storage Simulation. Off-peak production and storage of ice is attracting considerable interest as a way of reducing high daytime electricity costs. The PLANT program in DOE-2.1D contains a new, component-based ice-storage model called CBS/ICE, developed for ASHRAE by the University of Texas Center for Energy Studies. With CBS/ICE, users can configure a large variety of static (ice-on-coil) systems by linking together system components (evaporator, ice-tank, compressor, condenser, expansion value, controller, etc.). Because CBS/ICE is very computer intensive (it does an iterative solution each hour), it can generally only be used to simulate a few typical days of operation per year.
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 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

Building Description Language
In order to simulate a building, the user must provide data on the building, its equipment and operating schedules, and the utility rate schedule. This is done in DOE-2 through a quasi-English description of the building using a specially designed input language called Building Description Language (BDL).

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:

\[
\begin{align*}
\text{u-name} & = \text{COMMAND} \\
\text{KEYWORD1} & = \text{value1} \\
\text{KEYWORD2} & = \text{value2} \\
\vdots \\
\text{KEYWORDn} & = \text{valuen} ..
\end{align*}
\]

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

\[
\begin{align*}
\text{WIND-1} & = \text{WINDOW} \\
\text{HEIGHT} & = 4 \\
\text{WIDTH} & = 3 \\
\text{GLASS-TYPE} & = \text{W-1} \\
\text{SETBACK} & = .5 ..
\end{align*}
\]

The symbol ".." is the command terminator. Some commands, like RUN-PERIOD or BUILDING-LOCATION, are required, while others, like DOOR or ENERGY-STOREAGE, 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. So, 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. Default values can considerably reduce the necessary input.
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 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 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 to user input data that describes the performance characteristics of SYSTEMS and PLANT equipment.
DOE-2 OUTPUT

Although no one needs all of the 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. Successive versions of DOE-2 have seen an expansion in the number of the output reports, usually in response to the expressed needs of the user community. In DOE-2 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. 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. It is also possible to report these variables by day or month, rather than hourly, 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 input approach, it is possible for the user to design an individualized report for the LOADS and SYSTEMS programs by writing a FORTRAN-like input function 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. The main verification project was sponsored by DOE and conducted at Los Alamos National Laboratory. Results are presented in DOE-2 Verification Project, Phase I, Interim Report, and DOE-2 Verification Project, Phase I, Final Report (see BIBLIOGRAPHY). Also, see User-Effect Validation Tests of the DOE-2 Building Energy Analysis Program, ASHRAE Transactions 1985, Vol. 91, Part II. Two representative results from this study are shown in Figs. 7 and 8.

Figure 7: Comparison of DOE-2.0A predictions to monthly utility data for gas consumption, electrical energy consumption, and total energy consumption for a restaurant near Chicago, IL. Numbers at the bottom of a-c are the months of the year (1977).
Figure 8: Comparison of DOE-2.1A predictions to metered hourly electrical energy consumption for a house in Columbus, OH. The house is heated (and cooled) by an electric heat pump.

A second study undertaken by LBL, *A Comparison of DOE-2.1C Prediction with Thermal Mass Test Cell Measurements*, 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*, was conducted by the Solar Energy Research Institute.

Finally, the Tishman Research Corporation described 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*; the report is available from NTIS.

These studies all show that, with few exceptions, the DOE-2 predictions agree well with ASHRAE calculation methods, manufacturers' data, and measured building energy consumption.
DOCUMENTATION

The following user documentation is available for DOE-2. It can be ordered from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161; phone: (703)487-4650. Call NTIS to check prices before placing your order.

<table>
<thead>
<tr>
<th>Document</th>
<th>NTIS Order Number</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>DOE-2 Users Guide</td>
<td>LBL-8689, Rev.2.</td>
<td>[2.1A] introduction to building energy analysis and the DOE-2 input language.</td>
</tr>
<tr>
<td>DOE-2 Reference Manual</td>
<td>LBL-8706, Rev.2</td>
<td>[2.1A] detailed description of the input language and output reports; lists contents of the weather and materials libraries.</td>
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<tr>
<td>DOE-2 BDL Summary</td>
<td>DE-890-17726</td>
<td>[2.1D Update] a concise list of all commands and keywords used in the DOE-2 input language, along with minimums, maximums, and default values.</td>
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<tr>
<td>DOE-2 Sample Run Book</td>
<td>DE-890-17727</td>
<td>[2.1D Update] contains both input and output for 15 sample buildings and system and plant configurations.</td>
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<tr>
<td>2.1D Update Package</td>
<td>PB-901-43074</td>
<td>Updates documentation to the 2.1D version.</td>
</tr>
<tr>
<td>Complete set of 2.1D Documentation</td>
<td>PB-852-11449</td>
<td>All documents listed above, including the Update Package PB-901-43074</td>
</tr>
<tr>
<td>Engineers Manual</td>
<td>DE-830-04575</td>
<td>Gives an engineering description and derivation of the calculations used in the program. [Not included with PB-852-11449]</td>
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</table>

The DOE-2 User News is also part of the documentation; it is a quarterly newsletter containing bug fixes, updates to user manuals and articles of interest to program users. The newsletter is distributed free of charge; to be put on the distribution list, to obtain back issues, or to submit an article, please write, FAX, or e-mail:

Kathy Ellington  
Simulation Research Group  
Bldg. 90, Room 3147  
Lawrence Berkeley Laboratory  
Berkeley, CA 94720  

FAX: (415) 486-5172  
e-mail: kathy@gundog@lbl.gov
BIBLIOGRAPHY

Validation Studies
Validation studies 1, 2, and 3 are available through the National Technical Information Service; write or call for price and availability. NTIS, 5285 Port Royal Road, Springfield, VA 22161; phone: (703)487-4650.

1. NTIS Order No. LA-8295-MS

2. NTIS Order No. LA-10649-MS

3. NTIS Order No. DE-84010570/LA

From ASHRAE, 1791 Tullie Circle N.E., Atlanta, GA 30329:


From the Solar Energy Research Institute, 1617 Cole Boulevard, Golden, CO 80401:

5. SERI No. TR-253-2852, A Comparative Validation Study of the BLAST-3.0, SERIRES-1.0, and DOE-2.1A Using the Canadian Direct Gain Test Building, 1985.

From Lawrence Berkeley Laboratory:


Of related interest are the following publications, available from the Simulation Research Group at Lawrence Berkeley Laboratory:


PROGRAM ACCESS AND STORAGE REQUIREMENTS

The source code for mainframe computer versions of DOE-2.1D is available on magnetic tape from Lawrence Berkeley Laboratory, from the National Energy Software Center at Argonne National Laboratory, and from NTIS. A version for IBM-PC/XT/AT and compatible microcomputers is also available from vendors in the private sector. 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.

<table>
<thead>
<tr>
<th>Machine Type</th>
<th>Operating System</th>
<th>Memory Required</th>
<th>Disk Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC—VAX</td>
<td>VMS</td>
<td>1 MB</td>
<td>30 MB</td>
</tr>
<tr>
<td>SUN</td>
<td>UNIX</td>
<td>1 MB</td>
<td>30 MB</td>
</tr>
<tr>
<td>IBM-PC/XT/AT and compatibles</td>
<td>MS-DOS</td>
<td>640 KB</td>
<td>20 MB</td>
</tr>
</tbody>
</table>

The calculation time on 80386-based PC's with a math coprocessor is about 1 minute/zone for a full year simulation.

Again, contact the Simulation Research Group at Lawrence Berkeley Laboratory for help information on how to obtain the DOE-2 software and documentation.
APPENDIX

Simple Structure Run

The following example of a DOE-2 run describes a simple structure in Chicago with five zones, a return air plenum complete with an HVAC system and plant equipment, and 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 (\$). Comments on the sample run are indicated by italic type.

Nine preformatted summary and verification reports have been chosen to demonstrate the reporting capability of DOE-2.

![Diagram 1](image1)

**Figure 1A:** 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.

![Diagram 2](image2)

**Figure 2A:** Basic building with plenum and its walls (u-named WALL-1PF, WALL-1PL, etc.).
Figure 3A: Plan view showing zoning and u-names of spaces and interior walls.

Figure 4A: Elevations showing placement of windows, doors, and their u-names.
TITLE LINE-1 *SIMPLE STRUCTURE RUN, CHICAGO *
LINE-2 *EXAMPLE FOR DOE2.1D OVERVIEW* ...

ABORT ERRORS ::
DIAGNOSTIC WARNINGS ::
RUN-PERIOD VERIFICATION = (LV-D) ...
LOADS-REPORT SUMMARY = (LS-C) ::
BUILDING-LOCATION LATITUDE = 42.0 LONGITUDE = 88.0
ALTITUDE = 610 TIME-ZONE = 6
AZIMUTH = 10 ::

$ CONSTRUCTION AND GLASS-TYPES

WALL-1 = LAYERS MATERIAL = (MD01,PH03,INQ01,GPO1)
RB-1-1 = LAYERS MATERIAL = (RG01,BR01,IN22,WD01)
WALL-1 = CONSTRUCTION LAYERS = (WA-1-2)
ROOF-1 = CONSTRUCTION LAYERS = (RB-1-1)
CLNG-1 = CONSTRUCTION U-VALUE = 0.27 ::
SB-U = CONSTRUCTION U-VALUE = 1.5 ::
FLOOR-1 = CONSTRUCTION U-VALUE = 0.05 ::
W-1 = GLASS-TYPE SHADING-COEFF = .45 PANES = 2 ::

$ OCCUPANCY SCHEDULE

OCCUPY-1 = SCHEDULE THRU DEC 31
(MON,FRI) {1,8}(0) {9,11}(1)
{12,14} {8,4,8} {15,18}(1)
{19,21} {5,1,1} (22:247)(0)
(SAT,HOL) {1,24}(0) ::

$ LIGHTING SCHEDULE

LIGHTS-1 = SCHEDULE THRU DEC 31
(WD) {1,8}{.05} {9,14}{.9,.95,1,.95,.8,.9}
{15,18}(1) {19,21}{.6,.2,.2}
{22,24}{.05}
(WST) {1,24}{.05} ::

$ OFFICE EQUIPMENT SCHEDULE

EQUIP-1 = SCHEDULE THRU DEC 31
(WD) {1,8}{.2} {9,14}{.8}
{15,20}{.8,.7,.5,.5,.3,.3}
{21,24}{.02}
(WEST) {1,24}{.02} ::

-33, Apr-
Infiltration is "on" during winter months

Same as "SET MASTER DATA" in other programs

Maximum values that are multiplied by occupancy profiles

The infiltration schedule is referenced in the definition of space conditions

The first space definition, using the u-names of the plenum walls and roof, as shown in Figure 2 of the Appendix.
This assigns the general conditions (energy use and profiles) to the space.

Input for an overhang over the South window.

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

This is the input for the ceiling of SPACE2-1, which is shared by the plenum (as are the ceilings of the other four spaces).
SPACE3-1 = SPACE LIKE SPACE1-1

BACK-1 = EXTERIOR-WALL
  HEIGHT = 8
  WIDTH = 100
  AZIMUTH = 0
  CONSTRUCTION = WALL-1

WB-1 = WINDOW
  WIDTH = 45

C3-1 = INTERIOR-WALL
  AREA = 1056
  NEXT-TO = PLENUM-1
  CONSTRUCTION = CLNG-1

F3-1 = UNDERGROUND-FLOOR
  AREA = 1056
  CONSTRUCTION = FLOOR-1

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

SB35 = INTERIOR-WALL
  AREA = 608
  NEXT-TO = SPACE5-1
  CONSTRUCTION = SB-U

SPACE4-1 = SPACE LIKE SPACE2-1

LEFT-1 = EXTERIOR-WALL
  HEIGHT = 8
  WIDTH = 50
  AZIMUTH = 270
  CONSTRUCTION = WALL-1

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 LIKE SPACE4-1
  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
SYST-1 = SYSTEM
  SYSTEM-TYPE = VAVS
  SYSTEM-CONTROL = 'S'-CONT
  FAN-SCHEDULE = FAN-SCHED
  FAN-CONTROL = SPEED
  SUPPLY-STATIC = 5.5
  SUPPLY-EFF = .55
  NIGHT-CYCLE-CTRL = CYCLE-ON-ANY
  REHEAT-DELTA-T = 58
  MIN-CFM-RATIO = .3
  ECONO-LIMIT-T = 65
  RETURN-AIR-PATH = PLENUM-ZONES
  PLENUM-NAMES = (PLENUM:11,...)
  ZONE-NAMES = (SPACES-1,SPACE1-1,
                SPACE2-1,SPACE3-1,
                SPACE4-1,PLENUM-1)

The system type selected is variable-air volume (VAVS)

The assignment of spaces (zones) to the VAVS system

END
COMPUTE SYSTEMS

INPUT PLANT

  PLANT-REPORT. SUMMARY=(BEPS)

$ EQUIPMENT DESCRIPTION

HWG = PLANT-EQUIPMENT
  TYPE = 'H'-BOILER
  SIZE = 40

CHL1 = PLANT-EQUIPMENT
  TYPE = 'HERM-REC-CHR
  SIZE = 18

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

ENERGY-RESOURCE
  RESOURCE = ELECTRICITY

ENERGY-RESOURCE
  RESOURCE = NATURAL-GAS

END
COMPUTE PLANT

The code-word for a hermetic-reciprocating chiller with a condenser that normally defaults to water cooled. The PLANT-PARAMETERS changes it to air

400,000 Btu/hr peak output capacity
INPUT ECONOMICS

ECONOMICS-REPORT SUMMARY = (ES-D, ES-E)

$ GAS ENERGY COSTS

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

$ ELECTRIC ENERGY COSTS

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

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

SHD-P = CHARGE-ASSIGNMENT RESOURCE = ELECTRICITY TYPE = ENERGY
UNIFORM-CHARGE = .06

PEAK = CHARGE-ASSIGNMENT RESOURCE = ELECTRICITY TYPE = ENERGY
UNIFORM-CHARGE = .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 = DAY-CHARGE-SCH [1,8] (NIGHT) [9,17] (SHD-P)
[18,24] (NIGHT)

WEH-RATE = DAY-CHARGE-SCH [1,24] (NIGHT)

TIMEOFDAY = SCHEDULE 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 AM to 12 noon)
7¢/kwh at peak (1 PM to 5 PM)

There are no demand charges
DOE-210
BUILDING ENERGY ANALYSIS 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 AND COMMUNITY SYSTEMS
BUILDING SYSTEMS DIVISION

LEGAL NOTICE

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UNITED STATES GOVERNMENT. NEITHER THE UNITED STATES NOR THE DEPART-
MENT OF ENERGY, NOR ANY OF THEIR EMPLOYEES, NOR ANY OF THEIR CON-
TRACTORS, SUBCONTRACTORS, OR THEIR EMPLOYEES, MAKES ANY WARRANTY,
EXPRESS OR IMPLIED, OR ASSUMES ANY LEGAL LIABILITY OR RESPONSIBILITY
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RATUS, PRODUCT OR PROCESS DISCLOSED, OR REPRESENTS THAT ITS USE WOULD
NOT INFRINGE PRIVATELY OWNED RIGHTS.
## SIMPLE STRUCTURE RUN, CHICAGO

### REPORT- LV-D DETAILS OF EXTERIOR SURFACES IN THE PROJECT

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<th>SURFACE</th>
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<th>GLASS U-VALUE (BTU/HR-SQFT-F)</th>
<th>GLASS AREA (SQFT)</th>
<th>WALL U-VALUE (BTU/HR-SQFT-F)</th>
<th>WALL AREA (SQFT)</th>
<th>WALL+GLASS U-VALUE (BTU/HR-SQFT-F)</th>
<th>WALL+GLASS AREA (SQFT)</th>
<th>AZIMUTH</th>
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<td>0.00</td>
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<td>456.00</td>
<td>0.050</td>
<td>456.00</td>
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</table>

An echo of your input
**SIMPLE STRUCTURE RUN, CHICAGO**

**REPORT - LS-C BUILDING PEAK LOAD COMPONENTS**

**WEATHER FILE - CHICAGO WYEC**

---

### BUILDING ***

<table>
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<tr>
<th>FLOOR AREA</th>
<th>SQUARE FEET</th>
<th>CUBIC FEET</th>
<th>SQUARE METER</th>
<th>CUBIC METER</th>
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#### TIME

**COOLING LOAD**

- AUG 23 4PM
- DRY-BULB TEMP: 94F, 34C
- WET-BULB TEMP: 75F, 24C

**HEATING LOAD**

- FEB 3 5AM
- DRY-BULB TEMP: -3F, -19C
- WET-BULB TEMP: -4F, -28C

---

### SENSIBLE (KBTU/H) (KW) / LATENT (KBTU/H) (KW)

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<tr>
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<th>Latent</th>
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---

**TOTAL LOAD**

- 88,334 KBTU/H: 23,528 KW
- 48,165 KBTU/H: 14,106 KW

**TOTAL LOAD / AREA**

- 16.87BTU/H/SQFT: 58.658 W/SQMT
- 9.633BTU/H/SQFT: 30.368 W/SQMT

---

**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

**REPORT - LV-D DETAILS OF EXTERIOR SURFACES IN THE PROJECT**

<table>
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<tr>
<th></th>
<th>AVERAGE U-VALUE/GLASS (BTU/HR-SQFT-F)</th>
<th>AVERAGE U-VALUE/WALLS (BTU/HR-SQFT-F)</th>
<th>AVERAGE U-VALUE WALLS+GLASS (BTU/HR-SQFT-F)</th>
<th>GLASS AREA (SQFT)</th>
<th>OPAQUE AREA (SQFT)</th>
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This report checks wall and glass U-factors (and overall U-factors) plus the areas of wall, roof, and floor surfaces resulting from the inputs.
### COOLING

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<th>TIME OF MAX COOLING LOAD (DY HR)</th>
<th>DRY-BULB TEMP</th>
<th>WET-BULB TEMP</th>
<th>MAXIMUM COOLING LOAD (KBTU/HR)</th>
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**Total cooling coil load passed to the chiller**

### HEATING

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<th>TIME OF MAX HEATING LOAD (DY HR)</th>
<th>DRY-BULB TEMP</th>
<th>WET-BULB TEMP</th>
<th>MAXIMUM HEATING LOAD (KBTU/HR)</th>
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**Maximum cooling load**

**ELECTRICAL LOAD (KW)**

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**WEATHER FILE: CHICAGO**

**WYEC**
## Simple Structure Run, Chicago

### Report - SV-A System Design Parameters

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<table>
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<th>Supply Flow (CFM)</th>
<th>Exhaust Flow (CFM)</th>
<th>Fan (KW)</th>
<th>Minimum Flow Ratio</th>
<th>Outside Air Capacity (KBTU/HR)</th>
<th>Cooling EIR (BTU/HR)</th>
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<tbody>
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### System Design Air Flow

- **Zone Name**: SPACE1-1
- **Supply Flow**: 1673 CFM
- **Exhaust Flow**: 0 CFM
- **Fan (KW)**: 0.000
- **Minimum Flow Ratio**: 0.388
- **Outside Air Capacity (KBTU/HR)**: 143
- **Cooling EIR (BTU/HR)**: 0.000

### Air Handling Unit Cooling Coil Capacity

- **Zone Name**: SPACE2-1
- **Supply Flow**: 1112 CFM
- **Exhaust Flow**: 0 CFM
- **Fan (KW)**: 0.000
- **Minimum Flow Ratio**: 0.388
- **Outside Air Capacity (KBTU/HR)**: 82
- **Cooling EIR (BTU/HR)**: 0.000

### Heating Capacity of Zone Reheat Coils

- **Zone Name**: SPACE3-1
- **Supply Flow**: 622 CFM
- **Exhaust Flow**: 0 CFM
- **Fan (KW)**: 0.000
- **Minimum Flow Ratio**: 0.388
- **Outside Air Capacity (KBTU/HR)**: 41
- **Cooling EIR (BTU/HR)**: 0.000

<table>
<thead>
<tr>
<th>Heating EIR (BTU/HR)</th>
<th>Heating Capacity Multiplier</th>
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### Weather File - Chicago

- **Syst-1**: SYS1
- **WYEC**: 1.020
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<th>UTILITY TOTAL (MBTU)</th>
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<th>ELECTRICITY DAILY/HOUR</th>
<th>NATURAL-GAS PEAK (KBTU)</th>
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## SUMMARY OF LOADS MET

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**Simple Structure Run, Chicago**

**Report: BEPS Estimated Building Energy Performance**

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**Total Site Energy**: 383.19 MBTU 76.6 KBTU/SQFT-YR Gross-Area

**Total Source Energy**: 879.65 MBTU 175.9 KBTU/SQFT-YR Gross-Area

**Percent of Hours Any System Zone Outside of Throttling Range**: 8.8%

**Percent of Hours Any Plant Load Not Satisfied**: 8.8%

**Note**: Electricity and/or Fuel used to generate electricity is apportioned based on the yearly demand. All other energy types are apportioned hourly.
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