BUILDING ENERGY SIMULATION IN THE ENGINEER'S OFFICE - A USEFUL TOOL

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ABSTRACT - Building energy simulation programs are used by practicing mechanical engineers to perform feasibility studies, system design, development of operating strategies, and Code required energy budget compliance. The technical and economic reasons for selecting programs for different applications are discussed. Energy analysis, including daylighting, off-peak cooling using DOE-2, and peak load calculations using a microcomputer program on an engineering and computer science

INTRODUCTION

To accurately predict the energy consumption in proposed new buildings or existing buildings requires very difficult and complex calculations. The buildings are subjected to dynamic loads due to weather, and internal loads due to lights, equipment, and people, and the Heating, Ventilating and Air-Conditioning (HVAC) system and equipment attempts to maintain indoor comfort conditions by responding to these loads. Over the past 20 years, computer programs have been developed to predict hourly loads and energy requirements. The most important building energy analysis programs are ESP, developed by the Automated Procedures for Engineering Consultants (APEC) whose members share the development costs; TRACE, by the TRANE Company, a HVAC equipment manufacturer; AXCESS and E-CUBE, by the Edison Electric Institute (EEI) and the American Gas Associations (AGA); TRNSYS, a solar program by the University of Wisconsin; DOE, by the U. S. Department of Energy (DOE), and BLAST by the U.S. Department of Defense (DOD). These programs were designed with different objectives and capabilities, and all are available to engineering firms through major computer service centers and/or memberships.

APPLICATIONS

Building designers use building energy simulation computer programs to perform feasiblity studies, near-optimal designs c the building and its energy systems investigations of the impact of variou operating strategies, and energy budge compliance calculations required to mee state and local building codes

For non-conventional applications, feasibility study will usually be require to evaluate the cost effectiveness of th proposed system before the project i funded for actual design. The energ analysis must be performed using a progra that can simulate a conventional (base system and the proposed alternate system With the appropriate energy charge rate and other economic parameters, the enginee is able to perform comparative life cycl analysis on each system. Solar heating, off-peak cool storage, and cogeneratio applications are good examples wher building energy simulations are require for feasibility studies.

During the schematic design phase, when the architectural drawnings are not well defined, building energy simulations are used to perform parametric analysis of alternate design concepts to arrive at near-optimal enery efficient design. Building designers (depending on the available design fee) will perform numerous simulations to evaluate the impact of building orientation, glass area, type and fenestrations, roof and wall insulation and other variables, on the total building energy consumption. Mechanical engineers will perform simulations to evaluate, modify, and re-evauate alternate HVAC designs to assure efficient design and proper equipment type, size and control systems. During the schematic and design development phases, it is important to culate the energy consumption so that when the building design is completed it will comply with the state and local building energy standards.

When the construction documents are completed, a final energy simulation is performed to meet code compliance, and if requested by the building owner, to predict energy costs. If the simulations are performed on completed buildings to study alternate energy conservation options and operating strategies, detailed field surveys are required to obtain reliable program input data. The calculated energy requirements are then compared to actual utility bills and usually input adjustments and reruns are required to match the real building performance. Once this base case is established, the various energy conservation options can be priced, energy savings calculated, and the life cycle costs of each option determined.

PROGRAM SELECTION

The selection of a building energy program for routine use in an engineering office depends on three major factors. First, the program must meet the technical requirements. This means that the program must simulate that particular building configuration and its energy systems as accurately as possible. The level of detail required and the phases of design work also influence this determination. Second is the cost of using the program, including the amount of labor required in learning and using the program, plus the computer cost to run the program. Finally, the program must meet the client's requirements. Very often, the client may require that a particular program is used. For example, the California Energy Commission (CEC) requests DOE-2 or TRNSYS for a study, and DOD requires BLAST on military projects.

Engineering offices that primarily produce conventional building construction documents and do not specialize in energy studies will usually select a simple, well documented easy to use program such as TRACE for their day-to-day applications. They are mostly concerned with rapid peak ad calcualtions, supply air requirements, .d equipment selections to meet the fast tempo of integrating the HVAC systems into the building architecture. Usually, their main objective in using an energy simulation program is to show the local building department that their design will meet the state and local energy standards. In California where computer programs are certifed by CEC, TRACE is usually used for energy budget compliance when the building designers wish to trade-off options; e.g. less lights for more windows. In our office, where we produce construction documents and also perform sophisticated studies, we require a building energy program that is the latest state-of-the-art, and is capable of simulating almost any type of building envelopes and energy systems. The methodology used by the program has to be well documented in the open literature and available to the public. Only DOE and BLAST meet these requirements. Since our firm has been a consultant to Lawrence Berkeley Laboratory (LBL) in the development of the CAL/ERDA, the original version of the DOE program, and testing of different versions of the program, it has become the choice for routine use in our office. The other advantage of using the DOE program over BLAST is that the program is CEC certified and is constantly updated by LBL. Other programs such as BLAST, F-chart, TRNSYS, and TRACE are also used in our office depending on the particular application.

Because the DOE program was developed for use by researchers, manufacturers, system designers and other users in the building industry, it is extremely flexible and a lot of features are built into the program. To fully describe these features, the program documentation consists of a set of five volumes; each one is approximately 3-1/2 inches thick. These include two volumes of user manuals, one volume of run examples, one volume of user guides, and one volume for the engineering manual. For the non-reseacher, this massive documentation plus unknown computer costs usually discourages the use of the DOE program regardless of its technical accuracy. The program uses the building design language (BDL) which consists of commands and keywords. All of the input information is described by the keywords. As a result, approximately 70% of the inputs are the keywords and the other 30% are the actual values. For the infrequent user, considerable effort is required to generate the input file because all of the commands and keywords have to be input. A routine user, however, can overcome this problem by revising the values of an old input file so that the keywords do not have to be reinput. The amount of labor in revising the old input is no more difficult than preparing the input for a fixed formated program like TRACE, ESP, AXCESS and others.

BUILDING ENERGY SIMULATIONS

In our office it is routine to use the DOE program for analyzing building energy requirements. The input files for the program are first prepared using our in-house micro computer, and to minimize labor, an old input file from another project is used as the starting point. The value for different keywords are then replaced by the appropriate values for the project. For example, in the past three years DOE-2.1A was used to perform over 700 parametric runs for CEC in updating the California Non-Residential Energy Standards. The studies included alternate wall constructions, wall and roof insulations, lighting levels, glass areas, shading coefficients, exterior shadings such as overhangs and side fins, daylighting controls, HVAC systems and controls, minimum ventilation requirements, and central plant equipment performance. In performing the parametrics, very often only minor input changes were required from one run to another. Once the input files were prepared and stored in the micro computer, the input files were than transmitted by telephone to the Boeing Computer Service Center in Seattle for processing in batch mode, and routing to their high speed printer in Los Angeles.

From time to time other computer programs are used for special studies because DOE was not suitable for that particular project. For example, when we were simulating the California State Capitol Building with walls up to six feet thick, BLAST was used instead of DOE because the older version of the DOE program at that time used the ASHRAE weighting factors. We knew that DOE could not correctly simulate the dynamic heat transfer through the massive walls.

Currently our firm is designing the mechanical systems for the new Engineering/Computer Science Laboratory Building at California State university in Long Beach, California. The new 77,000 sq.ft., 6-story building will complete the engineering complex shown in Figure 1. The existing Engineering 1, built in 1968, is a 5-story building with a 1-story west wing, and Engineering 2, built in 1961, is a 3-story building. The two existing buildings were provided with double duct HVAC systems with hot water coils and chilled water coils for future cooling. A feasibility study was performed to evaluate the cost effectiveness of utilizing daylighting and off-peak cooling in the new Enginering/ Computer Science Building, and also to evaluate the impact of enlarging the central plant to provide cooling for Engineering 1 and 2.

To take advantage of co-funding of the feasibility study and the hardware rebate program offered by the Southern California Edison Company (SCE) for daylighting and off-peak cooling evaluations, the analysis was required to be performed on the DOE-2.1B building energy analysis computer program. This was specified by SCE because DOE-2.1B is the only program that is able to properly simulate daylighting controls.

The daylighting analysis on the new building included options to increase window heights on all levels, the addition of transome windows in the 5th and 6th floor faculty offices, continuous dimming controls, and the addition of the two and three step control systems illustrated in Figure 2. Typical 12 ft. by 10 ft. offices on each facade orientation were used in the initial simulations for screening purposes to reduce the number of parametric runs required for the whole building. All of the windows were to be provided with venetian blinds to control solar heat gain and glare in the occupied space. DOE-2.1B is capable of simulating the closing of the blinds whenever the solar heat gain or glare factor exceeded the maximum allowable design input values. By requesting special reports, the DOE program provided hourly electric demand and consumption for the whole year. Special post-processor programs, developed for use on our micro computer, were then used with the SCE time-of-use rates to obtain the utility costs for the various options. Preliminary design layouts and installation costs were developed for each option and combined with fuel esculations and other costs to obtain life cycle costs. The analysis indicated that it would not be cost effective to increase the glass area in the offices.

Based on these initial findings, only the continuous dimming and step controls were applied to the whole building to evaluate the most cost effective daylighting control system. In simulating the daylighting in the laboratories, a 15 ft. zone next to the window was defined as the daylighting zone. The lighting levels in all of the daylighting zones were set at the required level at the reference point located on the room centerline 10 ft. in from the window. The venetian blinds were controlled similarly to the offices except that the glare indexes were different, depending on the space usage. Using the same economic criteria used in the offices, the results showed that continous diming control had the lowest present value over the 10 year life of the equipment system. The installation system's cost was estimated to be $24,330. With a $6,640 hardware rebate from SCE, the net system's cost was calculated to be $17,690 for the

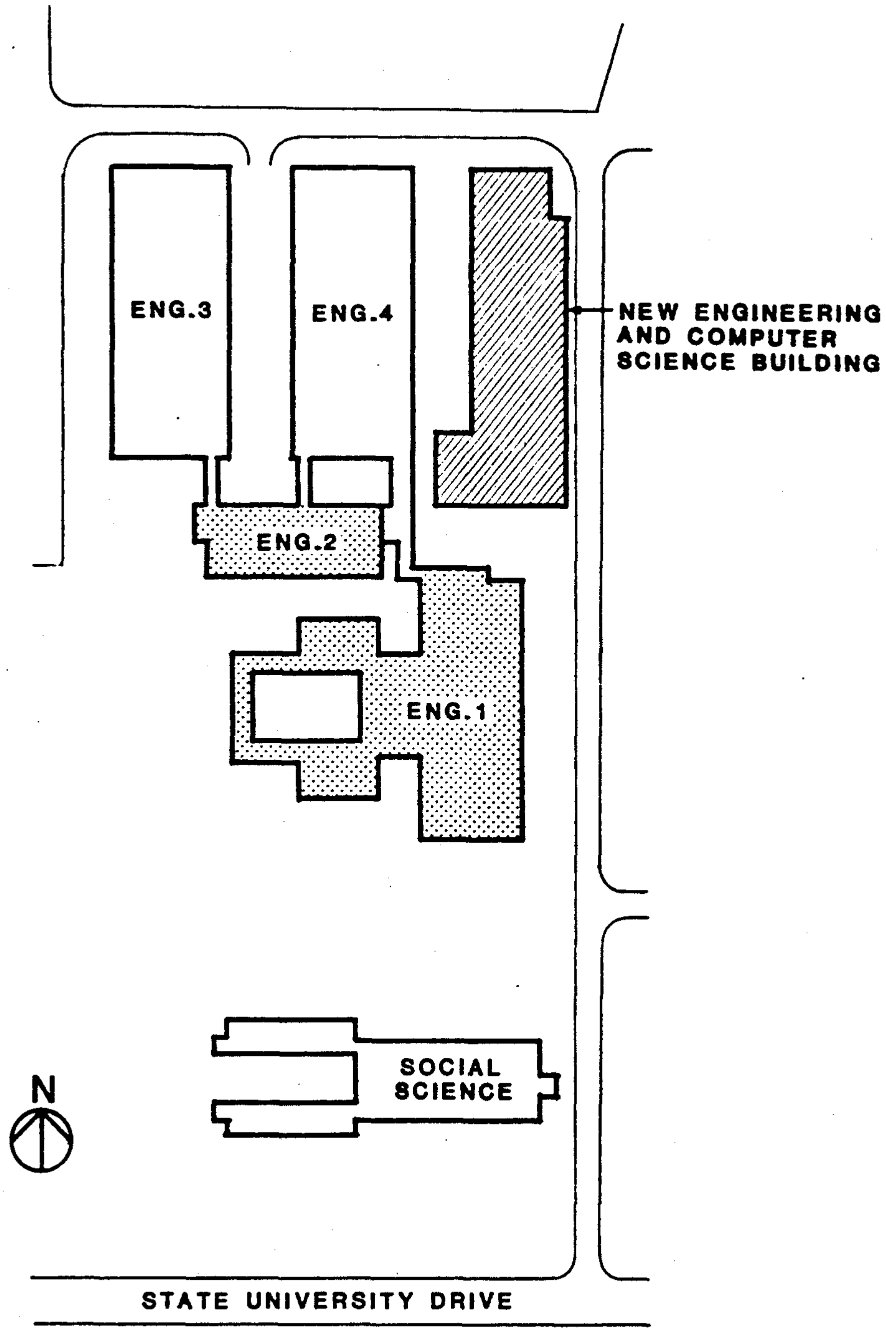
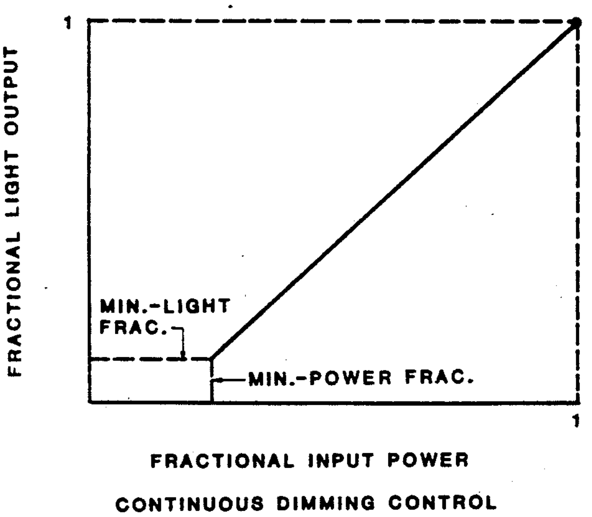


FIGURE 1: SITE PLAN



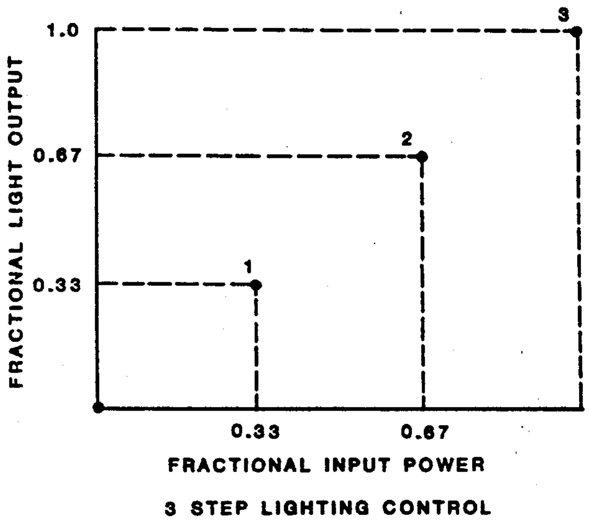


FIGURE 2: DAYLIGHTING CONTROL SCHEMES

daylighting system, therefore, the University would save $81,643 over the 10 year life of the equipment. From the analysis, it was obvious that the building architecture did not lend itself to dramatic savings using daylighting controls.

For the off-peak cool storage system analysis, the new Engineeing building was first simulated on DOE-2.1B to obtain the load on the HVAC systems. The hourly hot water heating and chilled water cooling loads were calculated and saved for central plant parametric analysis. The analysis compared a conventional chilled water plant with electric drive chillers, cooling tower, and pumps with an ice storage system using submerged coil static ice makers, screw compressors, and evaporative condensers under two operating modes. Preliminary designs, layouts and installation costs were developed for each option and combined with fuel escallation and other costs to obtain life cycle costs. The analysis indicated that the ice storage system with two compressors available for 24 hour operation had the lowest present worth over the 20 year life of the equipment. With a $50,200 hardware rebate from SCE, the ice storage system would cost $25,100 less than the conventional system, and over the 20 year life of the equipment the University would save $221,400.

To evaulate the cost effectiveness of enlarging the central cooling plant in the new Engineering building to include a chilled water supply to Engineering 1 and 2, the analysis was repeated and it was determined that the enlarged central plant would cost $29,100 less than the conventional system after the $99,200 SCE rebate, and the University would save $372,500 over the 20 year life of the equipment.

Based on the findings of the study, the University decided to incorporate the daylighting controls and off-peak cooling systems in the final construction documents for the new Engineering building with space, piping stub-outs and electrical provisions for the future cooling of Engineering 1 and 2. The central cooling plant currently under design includes two submerged coil ice makers, two screw compressors, and an evaporative condenser with provisions for the future addition of two more ice makers, one screw compressor and one evaporative condenser, as shown in Figure 3.

We are often asked why DOE is not used to determine peak loads, supply air quantities and equipment capacities in the final design process. One reason is that there are usually architectural design changes between the design development and construction document phases, and it is expensive to rerun DOE. Another is whether the final number of zones match those used in the energy simulations. Generally the heating and cooling loads, determined by the DOE program, can be used to calculate the supply air quantities and peak loads in the equipment if no compromises had to be made in dividing the building into thermal zones to fit within the program limit. In this particular analysis, the desired number of thermal zones exceeded the capacity of the program, and zoning

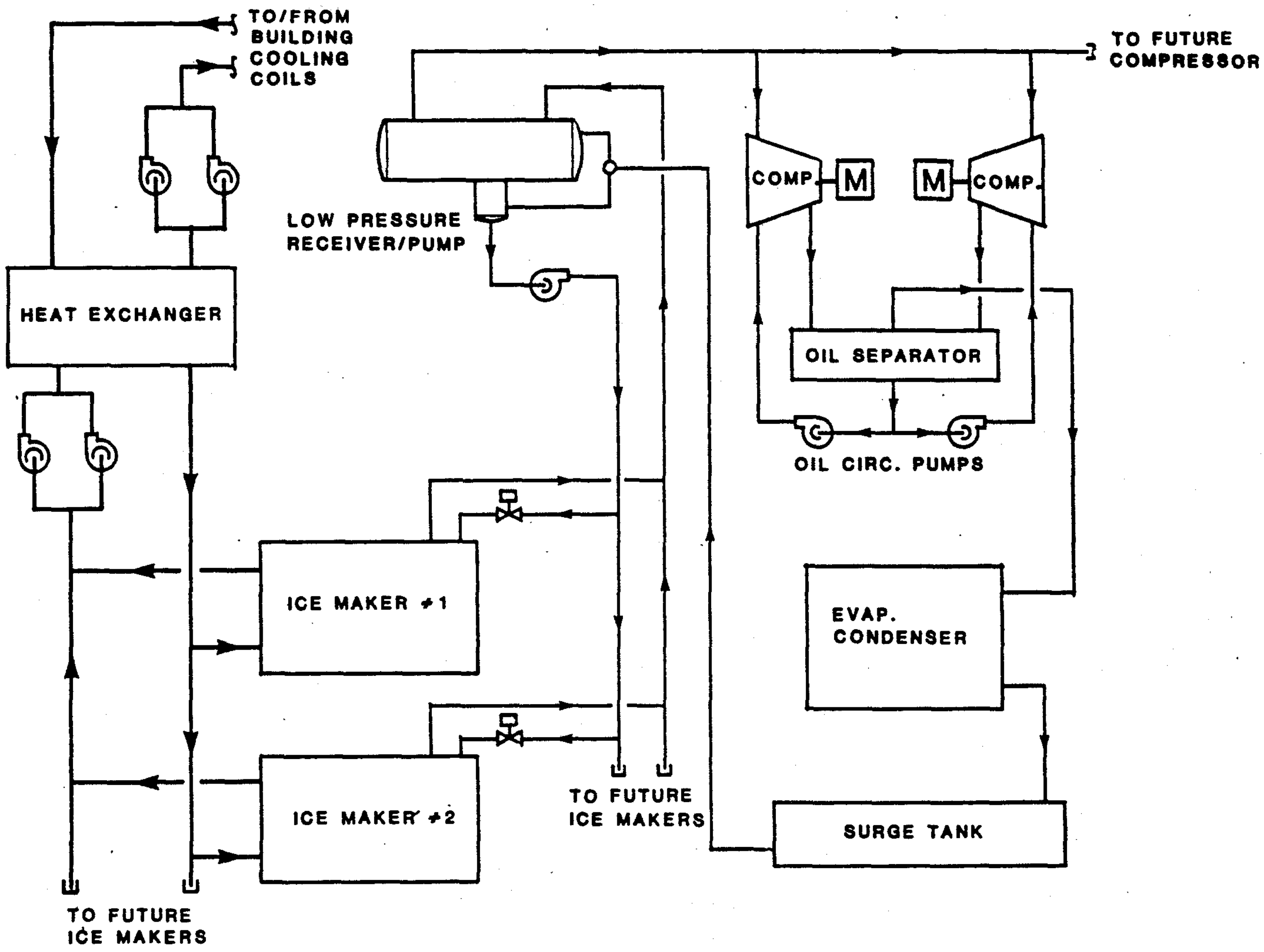


FIGURE 3: ICE STORAGE SYSTEM - SCHEMATIC DIAGRAM

compromises were necessary to complete the feasibility study. For these reasons, staff convenience and reduced engineering costs, the DOE program could not be rerun for the final space and building peak loads. These calculations were performed in our in-house micro computer using CLTD and CLF's from the 1985 ASHRAE Fundamentals handbook. When the final design is completed, the DOE inputs used in the feasibility study will be revised to reflect the final design of the building and the energy budget will be calculated for Code compliance.

The practicing consulting mechanical engineer must operate his office as a business, and must carefully establish which calculation methodologies and procedures are to be used. He must decide how studies are to be made and how he will be reimbursed for his efforts. When does it pay to use simplified energy calculations with compromised accuracies? Why not use ESP and/or TRACE for all energy calculations? When should he go outside his office to obtain DOE or BLAST runs? These questions must be answered by each office based on their knowledge and experience. It is now well established that building energy computer simulations are a very useful tool in an engineering office, and when properly applied, they can lead to significant reductions in building operating costs and help to conserve the energy resources of our country.