DOE-2 SIMULATIONS FOR CUERO AND KARNES COUNTY PRISON SITES

DRAFT PROGRESS REPORT

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PREFACE

The Texas Department of Criminal Justice (TDCJ) Karnes County and Cuero prison sites were designed and built to serve as maximum and medium security prisons, respectively. As part of this effort the TDCJ decided to evaluate the energy consumption of these prototype units with the DOE-2 building energy simulation program so that future prison sites may be designed with as many energy efficient features as possible. This report presents a summary of the simulation work accomplished to date, and reviews the work that remains to complete this task of the TDCJ project.

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DOE-2 SIMULATIONS FOR CUERO AND KARNES COUNTY PRISON SITES

INTRODUCTION

The intent of this project was to model each of the large buildings at the Karnes County 2,250 bed and Cuero 1,000 bed prison sites with the DOE-2 building energy simulation program and to deliver a working model to the Texas Department of Criminal Justice (TDCJ) for future use by TDCJ staff. The project was terminated prematurely and the DOE-2 input files for both sites were therefore not completed. This report details the work that remains and points out the steps that must be completed to properly calibrate the models.

SCOPE OF WORK

The DOE-2 Simulation Program

The DOE-2 hourly simulation program is composed of four sub-programs: LOADS, SYSTEMS, PLANT, and ECONOMICS (LBL 1981). Figure 1 (LBL 1980) provides an overview of the DOE-2 program and shows the three general inputs required to run the Building Description Language (BDL) processor, including weather data, a materials library, and the DOE-2 BDL input file. A weather data file is used to drive the simulation program and includes ambient dry bulb temperature, relative humidity, solar radiation, and wind speed. The materials library contains a set of default values for building construction components and is used when certain construction specifications are not provided by the user. The BDL input file describes the features of the building in detail including architectural information, occupant schedules, systems, plant, and economic information. The BDL processor compiles the input file information, verifies proper syntax and forwards it to the four main sub-programs, one at a time. The four sub-programs perform successive energy use calculations and generate standard monthly reports and specific hourly reports when called for. The DOE-2 simulation involves encoding the building into an "input file" to be read by the DOE-2 BDL. The information is fed into the LOADS sub-program based on architectural data such as the building location, building elevation, orientation of each wall, window, door, roof panel, shading surface, and building construction materials and their thermal properties. The heating, ventilating, and air conditioning (HVAC) equipment is then detailed in SYSTEMS for such factors as cooling and heating capacities, system efficiencies, fan sizes, and air volume requirements. Occupancy, lights, equipment, and system schedules are added to the input file on an hourly basis to control equipment and lights. Then, hourly estimates of the exterior lighting loads must be encoded separately from interior lighting systems which are summarized for each internal zone. Exterior lighting should be calculated separately from interior lighting because it has no thermal effect on interior heating or cooling loads. The exterior electricity load is then passed by DOE-2 directly to the PLANT sub-program bypassing the LOADS and SYSTEMS calculations. The reader is referred to the DOE-2.1 reference manuals for further details (LBL 1980; 1981; 1982; 1989; 1994).

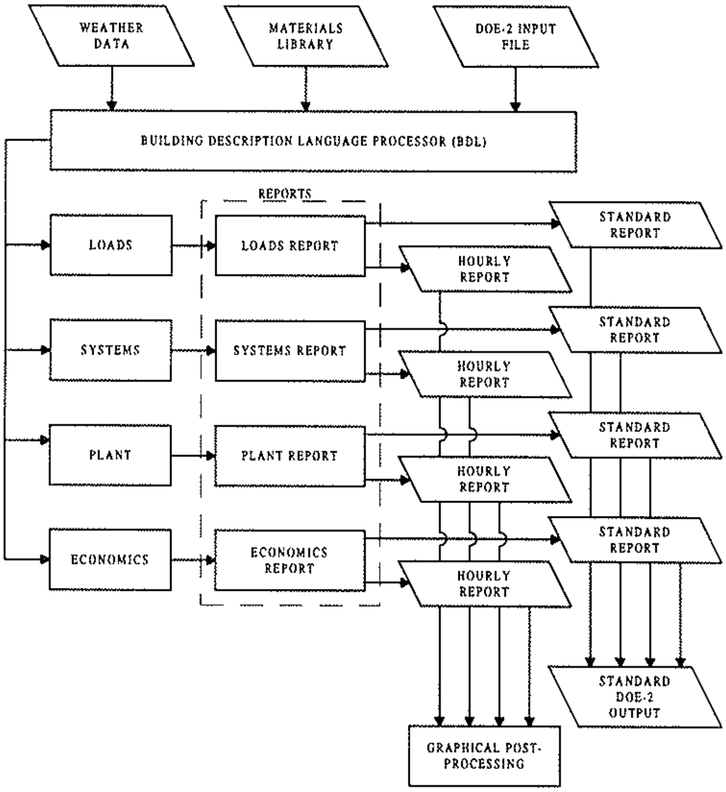


Figure 1: Overview of the DOE-2 Program.

The LOADS sub-program calculates the heating/cooling loads in a building based on information gathered from architectural specifications, interior loads, ambient conditions from a weather tape, and shading surfaces. Once hourly loads are calculated, the information is passed on to the SYSTEMS sub-program which then simulates the influence of internal equipment and HVAC secondary systems on electricity consumption, including all HVAC equipment, lights, and office equipment. It allows the user to specify various system types such as single or dual duct systems, packaged residential systems, and heat pumps; as a result of these factors SYSTEMS simulates interior conditions such as temperature and relative humidity control. After receiving the information from SYSTEMS, the PLANT sub-program then calculates all primary energy-using equipment in the building such as chillers, condensers and domestic hot water systems. Finally, the ECONOMICS sub-program calculates utility costs and life cycle costs for a prescribed period of time. For this project, the ECONOMICS sub-program may be omitted since no long-term economics study is being performed.

LOADS Sub-program

The first sub-program, LOADS, calculates the heating and cooling loads imposed by the building envelope in all zones based on architectural specifications, shading surfaces, interior loads specified in the BDL, and ambient conditions from a weather tape (LBL 1981). Figure 2 (Haberl 1988) provides a flow diagram for the LOADS sub-program including the hierarchy for the architectural, scheduling, equipment, and space condition information required.

The LOADS sub-program begins with the building geographical location and orientation information. As seen in Figure 2, occupancy, lighting, equipment, infiltration, domestic hot water, and other schedules are described for use by the SPACE-CONDITIONS command. The user then specifies building material details such as the layering and construction of the interior walls, exterior walls, roof, and floor. The window shading coefficients, glass types, and number of panes describe the window details. Then, the positioning and assembly of exterior and interior walls, the windows, the roof, and the floor details are then described by one or more SPACE commands to characterize the entire building. The BDL commands at the top and right of Figure 2 such as END, DIAGNOSTIC, and PARAMETER provide essential operations details without which LOADS does not function properly.

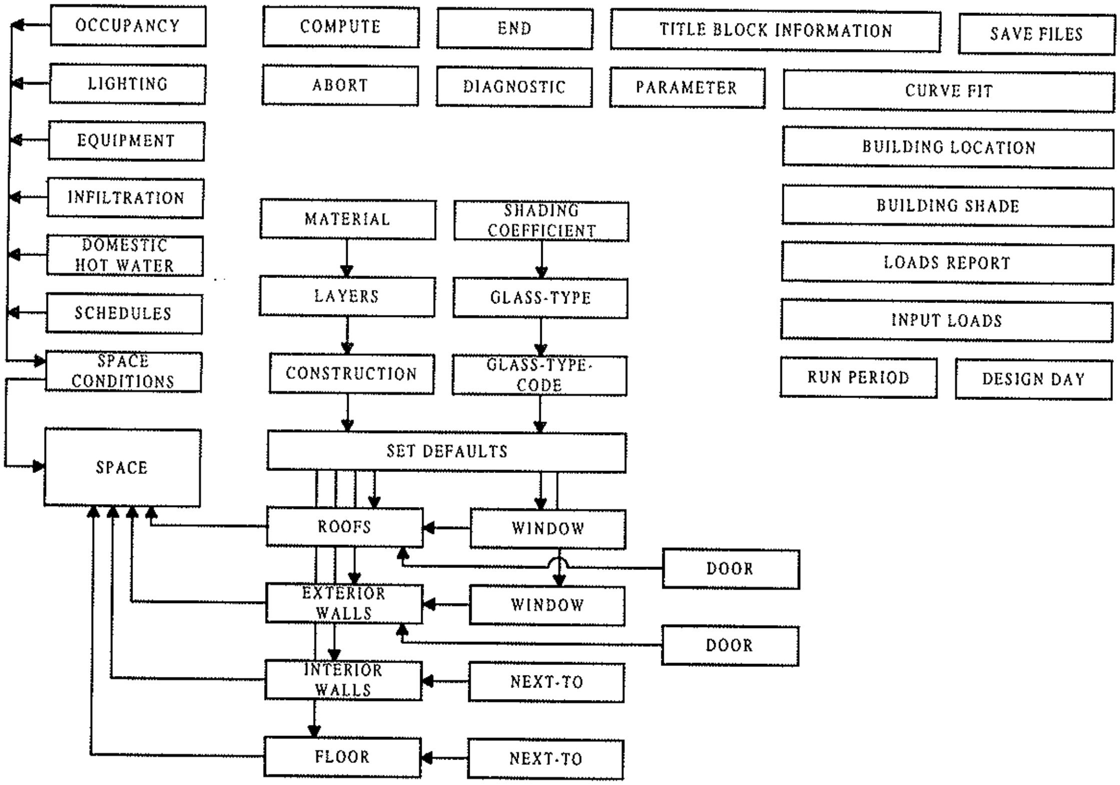


Figure 2: LOADS Sub-program Flow Diagram.

LOADS utilizes the ASHRAE weighting factor method (LBL 1981) which uses z-transform techniques to solve complex dynamic heat transfer through the exterior surfaces. Latent and sensible heat gains or losses through the building envelope, internal energy use including lighting and equipment, and heat gain due to occupants are accounted for in the LOADS sub-program. LOADS performs zone calculations based on a user specified constant space temperature to establish an initial thermal baseline profile and to reduce computation time. Once hourly loads are calculated and reports generated, the information is then passed on to the SYSTEMS sub-program. SYSTEMS estimates the energy required by the secondary HVAC systems to meet the LOADS-calculated envelope loads and ventilation loads after adjusting for thermostatic controls.

SYSTEMS Sub-program

With hourly information passed-on from LOADS, SYSTEMS simulates the secondary HVAC systems such as fans, coils, thermostats, and zones (LBL 1981). This sub-program uses a variety of techniques including additional weighting factors and curve-fits to correct the initial baseline calculations performed earlier at a constant reference space air temperature in the LOADS section. The system curve-fits may either be user specified or DOE-2 default equations. Some difficulty is encountered with both methods since default curves are often not the same as the building HVAC system. If a user specifies a custom system curve-fit equation based on empirical data, uncertainty still remains due to both equipment testing conditions and post-testing calculations.

Figure 3 (Haberl 1988) diagrams the SYSTEMS sub-program hierarchy and shows the inputs needed for describing the secondary HVAC systems. SYSTEMS allows the user to specify various system types such as single-duct or dual-duct systems, packaged residential systems, and/or heat pumps. Unlike the values calculated at a constant temperature in LOADS, SYSTEMS corrects the interior conditions discrepancy for temperature and relative humidity control with weighting factors (LBL 1981).

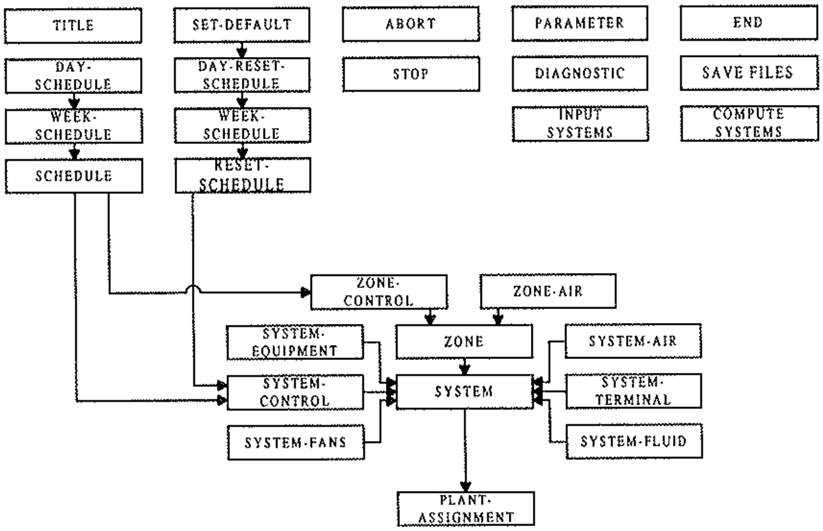


Figure 3: SYSTEMS Sub-program Flow Diagram.

At this stage of the DOE-2 program, the system equipment, the system control, the system fans, and zone requirements are modeled based on specific user input information such as air flow rates, thermostat settings, equipment schedules, reset schedules, and heating and cooling capacities. When all sensible heat interaction between each zone and HVAC equipment is calculated heat and moisture calculations are performed between all the equipment, the heat exchangers, and the building.

At the top of Figure 3 the unattached boxes represent SYSTEMS commands that are required for verifying proper operation such as the ABORT function, which is used when an error is encountered. Verification and/or hourly reports are produced and program control is advanced to the PLANT sub-program.

PLANT Sub-program

After receiving the information from SYSTEMS, the PLANT sub-program then uses additional information from the BDL to simulate all primary energy-using equipment in the building such as chillers, boilers, cooling towers, and domestic water heaters (LBL 1981). Figure 4 (Haberl 1988) is a flow chart of the PLANT sub-program information including operation schedules, the number and sizes of chillers, boilers, and cooling towers. The PLANT end-use energy reports provide electrical and thermal energy consumption data. The reports are commonly used to calibrate the model to the actual measured data since these data usually correspond to measurements made at the whole-building boundary.

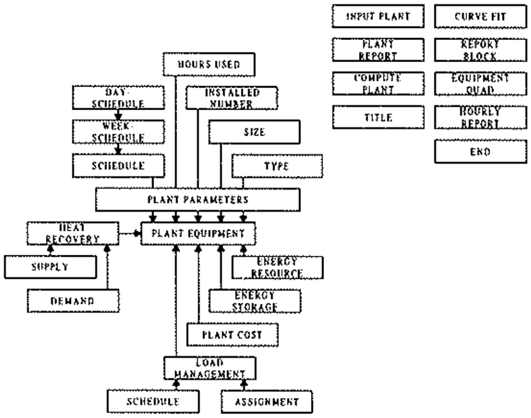


Figure 4: PLANT Sub-program Flow Diagram.

DOE-2 Required Information

In order to calibrate a DOE-2 simulation to the existing building, several tasks must be accomplished. First, accurate descriptions of each building must be created using the DOE-2 BDL. This includes a careful assessment of all architectural features and shading due to nearby objects using a computerized architectural rendering program. Second, weather data must be obtained which is available from the National Weather Service such as a Test Reference Year (TRY 1983) weather tape or a Typical Meteorological Year (TMY 1988) weather tape for a weather station as close to the simulation site as possible. Finally, once all the syntax errors in the input file are resolved, numerous iterations must be made to match the simulated output to the measured whole-building electricity and natural gas data by using the statistical routines and graphical DOE-2 calibration methods developed by Bronson (1992a) and Bou-Saada (1994).

Figure 5, adapted from Bronson (1992a), presents a general overview of the calibration process used for this project. Bronson's weather tape packing routine and columnar data processing tools will both used in this research. The remainder of the calibrations in this project use either standard simulation practice (i.e., adjusting the input file and iteration) or new routines developed for this project.

The grouping at the top of the Figure 5 includes all the required input information to produce a DOE-2 simulation including: DOE-2 reference manuals, as-built drawings, information from site visits, utility billing data, and on-site measured data. A typical input file may be produced using any number of computerized text editors and requires detailed information. Any DOE-2 simulation usually requires a visit to the standard set of DOE-2 reference manuals to observe correct BDL syntax, the DOE-2 format, and mandatory BDL requirements (LBL 1980; 1981; 1982; 1989, 1994). As-built drawings help to correctly dimension the building and calculate lighting and equipment levels. A site visit is generally essential to verify lighting and equipment counts as well as questionable dimensions and any other miscellaneous discrepancies. The site visit should include photographs of the surroundings and the equipment and detailed interviews with occupants, engineers, architects, and building operations personnel. Also included in the site visit should be equipment nameplate inspections, shading measurements, and electric current clamp-on measurements of several key pieces of equipment.

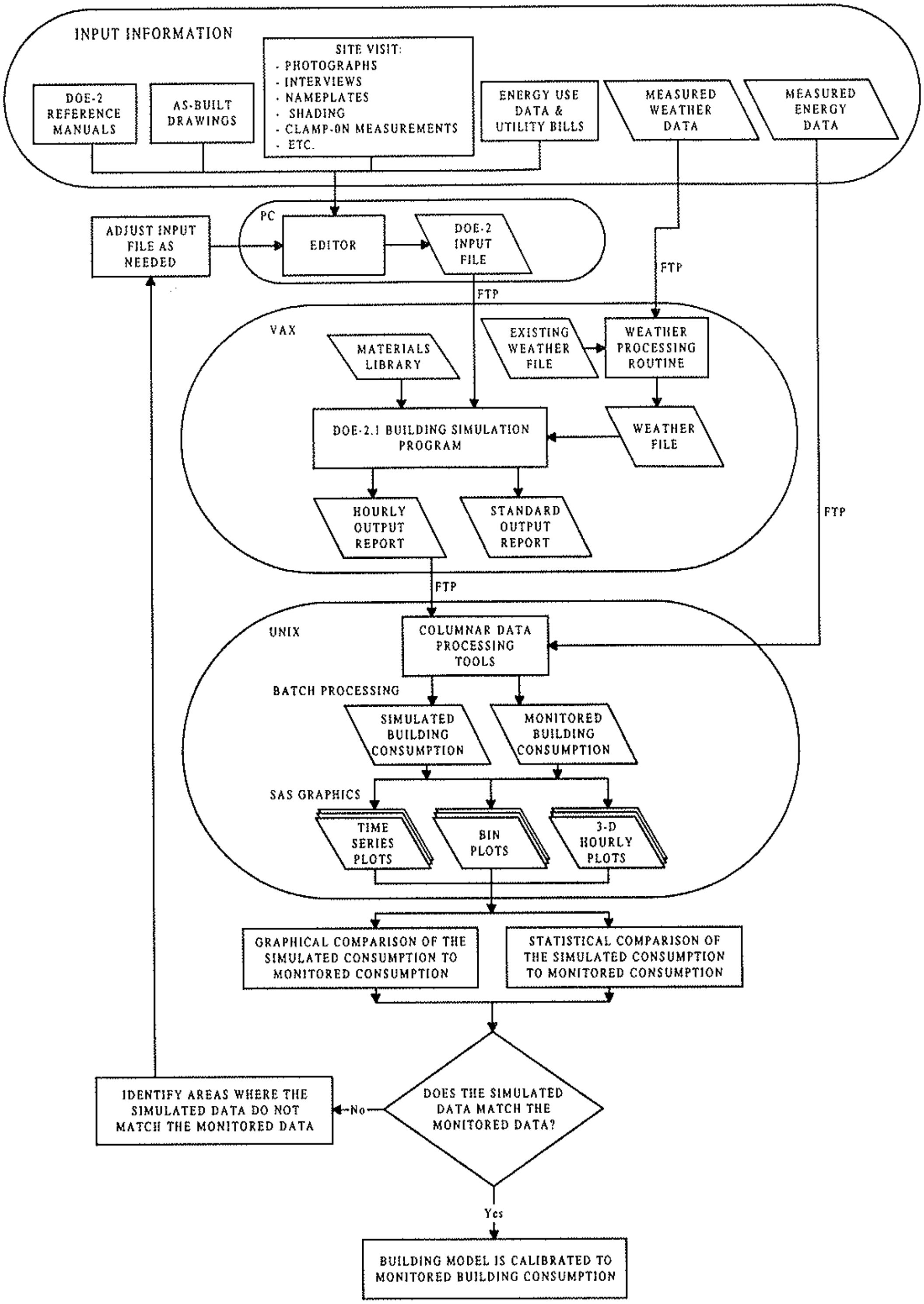


Figure 5: DOE-2 Calibration Procedure.

A major part of the site visit includes the gathering of energy use data and/or monthly utility bills. Either is acceptable, but neither is a strict requirement to compile the input file. An HVAC system air balance report is also helpful when describing the zone air flow rates. On-site weather data measured for the simulation period has also been shown to be helpful by Haberl et al. (1994). In cases where no data are available, standard average weather tapes such as TRY and TMY may be purchased and used. Finally, prior experience with the DOE-2 simulation program plays a crucial factor that can benefit the user in avoiding commonly made mistakes. Many problems with the input file may be avoided simply by having prior knowledge of program expectations as well as a thorough engineering understanding of HVAC systems and buildings in general.

The DOE-2.1E simulation program uses an input file in conjunction with a weather file and materials library to calculate building energy consumption and generate hourly and standard output reports. Figure 6 is an example of DOE-2's hourly report that was used for this project. The standard reports were also used for general input verification. Once the simulation was completed, the hourly output reports were then transferred to a UNIX system, processed into columnar data form (Bronson 1992a), and merged into a single data file. The same procedure can be performed on a personal computer, provided it has at least a 486 processor and a minimum of 16 megabytes of ram.

This second feature is accomplished with the assistance of the calibration tools developed by Bou-Saada (1994). If it is determined that it is not, the areas where the simulated data do not match the measured data must be identified and adjusted in the input file. The DOE-2 program is run once again and the data processed until an acceptable calibration is reached.

```
HR-3 = HOURLY-REPORT                          PAGE  1-  1
----------------------------------------------------------------------
              MMDDHH    PLANT      GLOBAL

                        TOTAL     AMBIENT
                       ELECTRIC   DRYBULB
                        BTU/HR       F

                        ----(10)    ----( 1)
                 4 1 1    31765.      51.0
                 4 1 2    31765.      51.0
                 4 1 3    31765.      51.0
                 4 1 4    31765.      51.0
                 4 1 5    31765.      51.0
                 4 1 6    92583.      52.0
                 4 1 7    88697.      54.0
                 4 1 8    93380.      55.0
                 4 1 9    84425.      58.0
                 4 110    82571.      59.0
                 4 111    76824.      65.0
                 4 112    72541.      63.0
                 4 113    65436.      64.0
                 4 114    60699.      69.0
                 4 115    58331.      68.0
                 4 116    63067.      64.0
                 4 117    65696.      62.0
                 4 118    65696.      60.0
                 4 119    68555.      58.0
                 4 120    31765.      58.0
                 4 121    31765.      55.0
                 4 122    31765.      55.0
                 4 123    31765.      54.0
                 4 124    31765.      53.0
              0 DAILY SUMMARY (APR  1)
                   MN     31765.      51.0
                   MX     93380.      69.0
                   SM   1356150.    1381.0
                   AV     56506.      57.5
```

Figure 6: Example of DOE-2 Hourly Report.

Calibration Tools and Statistical Graphics

In order to improve the calibration procedures outlined by Bronson (1992a) several new computer programs and graphical tools were developed, including modifying routines originally created by Bou-Saada (1994), Bronson (1992a) and Abbas (1993) as well as routines developed specifically for this project. These improved calibration procedures include building architectural rendering, new graphical methods (52-week box-whisker-mean plots, 24-hour daytype box-whisker-mean plots, and binned box-whisker-mean plots), statistical goodness-of-fit calculations, and special routines for the building in question. These methods are discussed in the following sections.

Architectural Rendering

Several software programs have recently become available for purposes of architectural rendering or viewing of building simulation input files. One such program, DrawBDL (Huang 1993), was used to verify the building envelope descriptions used in the DOE-2 input file. The demonstration building shown in Figure 7 shows a view of the case study building using the DrawBDL program. The software also includes such capabilities as rotating the building in a complete circle, looking at a three-dimensional view, a plan view, an elevation view, and a wire frame view. With a BDL visualization tool, each case study building envelope surface and shading surface can be inspected for proper placement, size, and orientation. This type of checking could not easily be done prior to the creation of such architectural rendering tools.

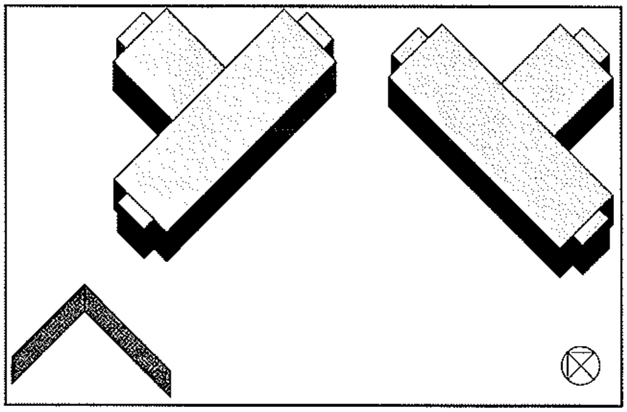


Figure 7: Example of DOE-2 Building Using DrawBDL. The Planes Away from the Buildings Represent Shading from Another Building.

Collect and Prepare Hourly Measured Data

Before DOE-2 is used to simulate an existing building, the user must consider how the model is to be validated. Various options are available varying in usefulness from monthly utility billing data, to short-term end-use hourly data from on-site monitoring, or even long-term end-use hourly data. The user may choose either to employ standard weather tapes available from the National Climatic Data Center (NCDC) or to pack a site-specific weather tape such as a Test Reference Year (TRY) weather tape for a more accurate weather dependent calibration (Haberl et al. 1994).

The TRY weather tape is one of several weather tapes that DOE-2 can use. It was developed in cooperation with ASHRAE, the National Bureau of Standards (NBS), and the National Oceanic and Atmospheric Administration (NOAA) (NREL 1992). The primary purpose was to provide engineers with a long-term dataset containing climatological data for building design utilization. The tapes were compiled from data recorded at sixty weather stations across the United States. Data from the years 1948 through 1975 were analyzed omitting years with high or low mean extremes yielding one year per site. Packing a TRY weather tape requires relative humidity, dry bulb temperature, global horizontal and beam solar radiation, and wind speed.

Another weather tape that DOE-2 can use is the Typical Meteorological Year (TMY) weather tape for 1954 through 1972. TMY data was recorded from 249 weather stations based on the NCDC SOLMET database. A TMY tape includes total horizontal radiation, mean dry bulb and dew point temperature, and the maximum and mean wind speed. A third format, the Weather Year for Energy Calculations (WYEC) tape, developed by Crow (1970), can either be used as bin data from 51 stations (Degelman 1991) or time-series data and includes interpolated solar data measured at sixteen stations from the National Weather Service (NWS) TD 1440 tapes (NREL 1992). WYEC data is in TRY format and is composed of monthly long-term mean data. WYEC2 tapes were recently developed which include improvements to the original 51 datasets as well as the addition of 26 new sites (Augustyn & Co. 1994). Since a TRY tape has been proven to be compatible with the routines already developed by Bronson (1992a), it was decided that it was to be used for this simulation rather than the TMY, WYEC, or WYEC2 tapes.

Packing Site-specific Weather Data

As the previous section illustrated, several weather tapes are commercially available to simulate a building with DOE-2. It has been shown in the past that packing a site-specific weather tape can give far more accurate weather dependent simulations than standard tapes (Haberl et al. 1994). Since TRY weather tapes are compiled using mean weather data averaged over a long-term basis, the simulation accuracy will vary with deviation from the weather mean conditions. If, for instance, a sudden cold front passed over the building's location, use of a standard weather tape would result in significant differences between the simulated output and the measured energy data when considering weather dependent loads. Therefore to avoid DOE-2's modeling errors by using normalized long-term weather data, it is best to measure site-specific weather data as close to the case study building as possible which requires the use of a packed weather tape.

Packing a weather tape involves merging measured hourly outdoor dry bulb temperature, outdoor relative humidity, wind speed, and global horizontal and beam solar radiation into one data file. For this project, a weather tape would be packed using a combination of measured on-site weather data and NWS data. Hourly dry bulb temperature, dew point temperature, global solar radiation, and peak wind speed data is measured onsite. Prior to processing, dew point temperature is converted into relative humidity using a psychometric routine by Sparks et al. (1993). All four parameters are then combined into one data file and processed with Bronson's (1992b) LS2TRY routine that synthesized beam and diffuse solar data before passing the data to Lawrence Berkeley Laboratory's (LBL) FORTRAN weather packing program (LBL 1982). LBL's packing routine overlays dry bulb temperature, relative humidity, and wind speed directly onto an existing TRY weather tape. The solar data requires further processing before it is over-laid on top of the weather tape.

Prior to processing, the measured solar radiation data are passed through a routine (Bronson 1992b) that synthesizes horizontal beam radiation and diffuse radiation which are then over-laid onto the TRY tape. In addition, the weather packer calculates dew point temperature and wet bulb temperature from dry bulb temperature and relative humidity and lays them onto the tape. Any missing data is labeled as "-99.0" by the routine. When missing weather data occurs, the weather packer compensates for the missing record(s) by linear interpolation so that no abrupt changes result on the weather tape (Bronson 1992b).

The version of DOE-2 used for the initial part of this project was on the Texas A&M University VAX computer. The information below on packing a weather file must be modified for use on a PC with the PC version of DOE-2. This was not completed for this project due to time constraints and project termination.

A methodology to pack site monitored weather data into an existing TRY (Test Reference Year) weather file has been developed using a FORTRAN program called LS2TRY.FOR (LoanSTAR weather data into Test Reference Year weather file) and the DOE-2 weather packer developed by Lawrence Berkeley Laboratory. Site monitored weather data in the format shown in Table 1 is processed into a binary file by the DOE-2 program. The methodology is outlined in Figure 8 and detailed in Bronson (1992b).

Table 1: Site Monitored Weather File Format.

Field #	Description	Format
1	Station Number	XXXXX
2	Month	MM
3	Day-of-the-Month	MM
4	Year	YY
5	Julian Date	YYDDD
6	Decimal Date	XXXX.XXXX
7	Hour-of-the-Day	HHMM
8	Relative Humidity	[%]
9	Dry Bulb Temperature	[F]
10	Total Horizontal Insolation	[W/m^2]
11	Wind Speed	[mph]

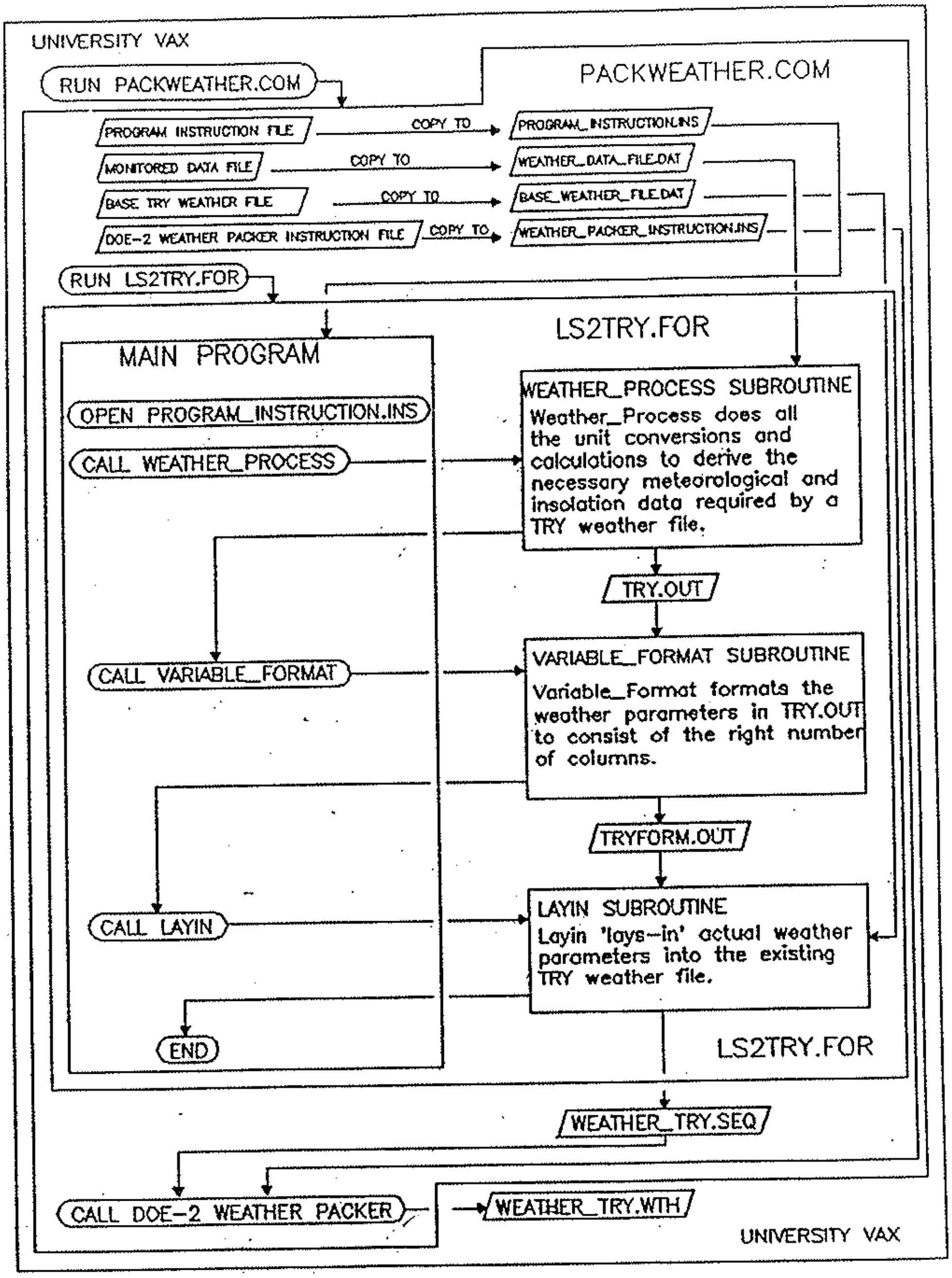
A command procedure (PACKWEATHER.COM) was written to perform the necessary steps to pack the site monitored weather data. The command procedure does the file management, then executes LS2TRY.FOR, and finally calls the DOE-2 weather packer. The DOE-2 weather packer resides on the University VAX, therefore it's used to pack the site monitored weather data. The command line to pack monitored weather data is:

```
@PACKWEATHER <Monitored Data> <Base TRY> <LS2TRY Instructions> <Packer Instructions>
```

where,

<Monitored Data> is the site monitored weather data file.

<Base TRY>	is the base TRY weather file. The base TRY weather file is in ASCII format and contains one-whole year of data.
<LS2TRY Instructions>	is the program instructions file for LS2TRY.FOR. The instruction file gives the methodology the flexibility to process weather data from different sites.
<Packer Instructions>	is the DOE-2 weather packer instruction file.



Weather_Process does all the unit conversions and calculations to derive the necessary meteorological and insolation data required by a TRY weather file.

Variable_Format formats the weather parameters in TRY.OUT to consist of the right number of columns.

Layin 'lays-in' actual weather parameters into the existing TRY weather file.

Figure 8: Methodology to Incorporate Site Monitored Weather Data.

To pack site monitored weather data, these four files and PACKWEATHER.COM must be in the same directory. To compile a successful run, the Monitored Data file needs to have several Attributes. The Monitored Data file **<Monitored Data>**, needs to be in columnar format with a 1-24 hour time stamp. The monitored data file can be as small as one hourly record, but no larger than one year (365 days). The data needs to be in sequence from the earliest time stamp to the latest; based upon Month, Day-of-the-Month, and Hour-of-the-Day fields. The year which the data comes from is not significant to the order which it appears in the data file. The procedure requires the data records to be marked with whole hours, (i.e., zero minutes). This is the format of the TRY weather files and the Hour-of-the-Day field needs to be in the format of HHMM. There should be no records with identical time stamps, and all non-existing monitored weather data should be marked as '-99.0'. The monitored data file should be robustly processed using data processing routines that check for missing hourly records, duplicate records, and hourly records out of sequence.

The Base TRY weather file, **<Base TRY>** is any TRY weather file in ASCII format containing 365 days of data. The DOE-2 weather packer requires the weather file to contain one full year of data. Actual weather data is laid-into the base weather file to assure the resulting weather file contains a full year of data.

The program instruction file, **<LS2TRY Instructions>**, was created to give the methodology the flexibility to process weather data from different sites. The instruction file consists of two records. The first record, detailed in Table 2, is data instructions for the WEATHER_PROCESS subroutine and the second record, detailed in Table 3, consists of Y's and N's for yes and no to tell the LAYIN subroutine whether or not to replace a weather parameter on the base weather file with actual data. All numeric records except the STATION NUMBER is input as a real variable, the decimal place specified: the STATION NUMBER is input as an integer.

The instruction file for the DOE-2 weather packer, **<Packer Instructions>**, contains the necessary data to pack an ASCII weather file. For more information on creating an instruction file, reference the DOE-2 Reference Manual, Part 2, Appendix VIII.C, pp VIII.37 to VIII.38 (LBL 1982).

Table 2: Description of the Weather Packer Program Instruction File's First Record.

	Columns	First Record Description
1	1 - 6	The standard meridian for the local time zone (i.e., Central Time Zone is 90.0°)
2	7 - 12	The longitude of the weather station in degrees west
3	13 - 18	The latitude of the weather station in degrees west
4	19 - 24	The station's standard atmospheric pressure for the station's altitude [psia]
5	25 - 30	First day of Daylight Savings [Julian date], first Sunday in April
6	31 - 36	Last day of Daylight Savings [Julian date], last Sunday in October
7	37 - 42	5 digit number specifying the STATION NUMBER
8	43 - 48	Dominant wind direction - '999' if missing wind direction data

Table 3: Description of the Weather Packer Program Instruction File's Second Record.

	Columns	Second Record Description
1	1 - 2	Y or N to replace Dry-Bulb Temperature
2	3 - 4	Y or N to replace Wet-Bulb Temperature
3	5 - 6	Y or N to replace Dew Point Temperature
4	7 - 8	Y or N to replace Wind Direction
5	9 - 10	Y or N to replace Wind Speed
6	11 - 12	Y or N to replace Station Pressure
7	13 - 14	Y or N to replace Global Horizontal Radiation
8	15 - 16	Y or N to replace Direct Normal Radiation

Fgure 8 is a flow diagram of the procedure to incorporate site monitored data into a DOE-2 readable binary weather file which is located on the University VAX system. One command procedure, PACKWEATHER.COM, performs the data file management, runs the FORTRAN program LS2TRY.FOR, and calls the DOE-2 weather packer to incorporate site monitored data into a binary weather file.

Hourly Measured Energy Data

As Hinchey (1991) has already shown, the simulation will be more accurate if evaluated with hourly measured data gathered at several monitoring points in the building. This avoids the long-term data averaging encountered with monthly simulation comparisons. Thorough monitoring can be costly when considering the purchase of electronic equipment such as the logger and current transducers as well as installation labor costs. If extensive sub-metering is not feasible even for short-term data collection, it may be necessary to use hourly whole-building energy use data along with special routines to estimate end-use data.

New Calibration Graphing Methods

One improvement over past graphic techniques is shown in Figure 9 which shows an example of a binned plot that is from Bou-Saada (1994). The superimposed and juxtaposed binned box-whisker-mean plots display the maximum, minimum, mean, median, 10th, 25th, 75th, and 90th percentile points for each data bin for a given period of data. These plots are an improvement over the scatter plots previously used by Bronson (1992a) because they eliminate data overlap and allow for more accurate characterization of the dense cloud of hourly points (scatter plots are, however, useful in showing multiple operation modes). The important feature to note about this plot, and box-whisker-mean plots in general, is that the data are statistically binned by temperature. This feature allows for the bin-by-bin goodness-of-fit to be statistically calculated and compared. By using the box-whisker-mean plot combined with a scatter plot, one can visualize the data as a whole while simultaneously being able to see the effects of the outliers (Tukey 1977; Cleveland 1985; Abbas 1993).

In Figure 9 the entire simulation period data are plotted using a technique developed by Abbas (1993) and would be modified for use in this project that includes a combination of juxtapositioning, temperature-based box-whisker-mean binning, and superpositioning. In the upper left graph the hourly measured whole-building electricity use is shown plotted against hourly ambient temperature. In the upper right graph, the corresponding DOE-2 simulated data for the same period are shown. Below each scatter plot (parts (a) - measured and (c) - simulated) are binned box-whisker-mean plots in parts (b - measured) and (d - simulated). These plots show the whole-building electricity consumption as a function of outdoor temperature bins divided into 10° F segments. One final feature of these plots is that the mean of each measured data bin is superimposed with a dashed line onto the box-whisker-mean plot in part (d) which represents data from the calibrated DOE-2 simulation. The difference between mean lines in each bin provides a measure of how well the model is calibrated with respect to temperature. Likewise, the inter-quartile range (i.e., the distance between the 25th and 75th percentiles) represents the hourly variation in a given bin.

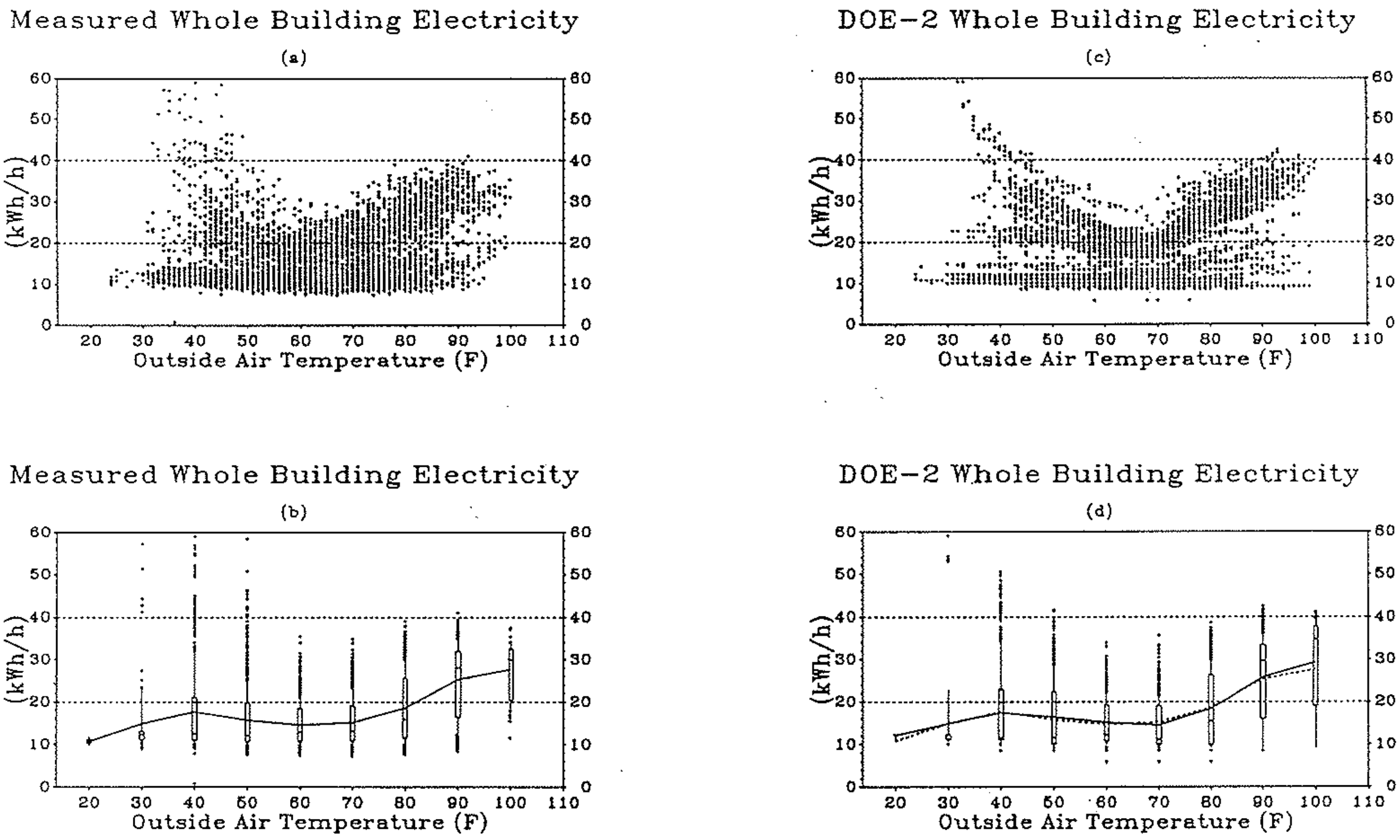


Figure 9: Binned Box-whisker-mean Plot

A new statistical plot has been developed by Bou-Saada (1994) that bins the data into 24-hour weather dependent profiles is shown in Figure 10. The daytypes are divided into temperatures below 45° F, temperatures between 45° F and 75° F, and temperatures above 75° F. The original concept for this plot can be traced to the weather daytype analysis developed by Hadley (1993). The measured data are presented in parts (a), (c), and (e) and the simulated DOE-2 data are shown in parts (b), (d), and (f). These plots confirmed that the building's 24-hour electricity profiles are strongly influenced by the ambient temperature. The plots also provide a more efficient method of viewing the data based on heating only, no heating or cooling, and cooling only modes.

One of the problems with presenting individual data points in an x-y plot (i.e., hour-of-the-day versus kWh/h, is that it is difficult to judge the density of the data at a given point on the graph because the individual data points overlap). One technique that can improve a graph which suffers from this problem is to jitter the individual data points by introducing a random noise into the variables used for the x or y axis (Cleveland 1985).

The graph plots the data in a 24-hour box-whisker-mean format. This additional calibration procedure allows a DOE-2 user to view and analyze the weather dependent data on an hour-by-hour basis and adjust the hourly schedules in the input file accordingly. The solid line in parts (b), (d), and (f) is the simulated mean. The dashed line is the measured mean line from parts (a), (c), and (e) that is superimposed onto the simulated data so that hour-by-hour comparisons may be made.

Calibration Calculation Methods

In a previous work, Bronson (1992a) summed monthly simulation results and verified the calibration via a percent difference. Torres-Nunci (1989) and Hinchey (1991) only declared the model "calibrated" and submitted graphs to demonstrate the goodness-of-fit. Numerical differences only in the form of ± monthly differences were provided. Therefore, in the interest of furthering the calibration procedures, several statistical calculations have been added including a monthly mean difference, and hourly mean bias error (MBE) for each month, an hourly root mean squared error (RMSE) reported monthly, and an hourly coefficient of variation-root mean squared error (CV(RMSE)) (Kreider and Haberl 1994a; 1994b). These indices have proven useful in evaluating hourly models of building hourly use. The values are tabulated for the total

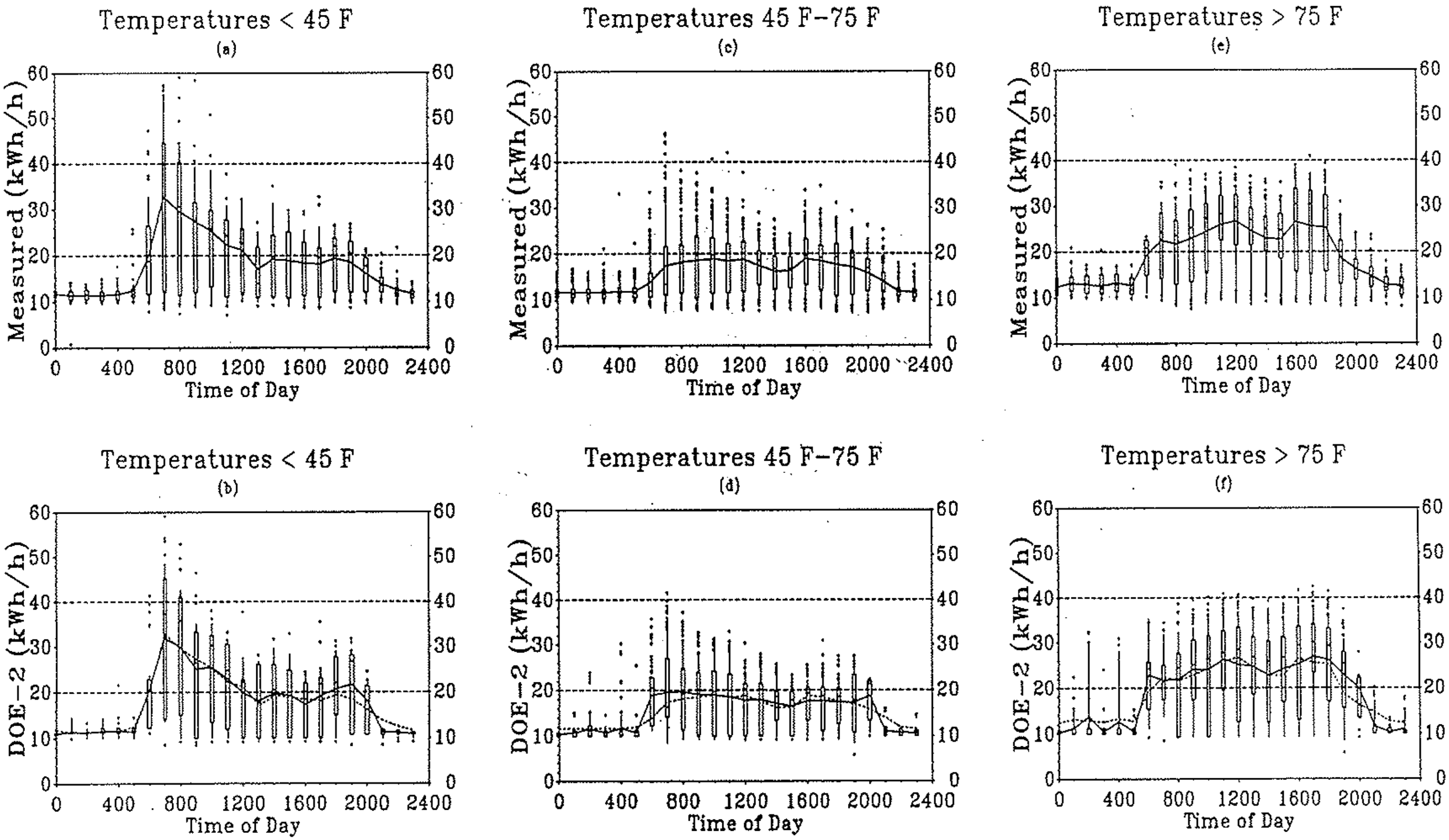


Figure 9: Binned Box-whisker-mean Plot

data as well as for each month. The statistical indices used to evaluate the models are defined below.

The percent difference is a simple calculation whereby a difference for each monthly measured and simulated energy consumption total is taken and divided by the measured monthly total consumption:

$$\text{percent difference} = \left(\frac{\sum_{i=1}^{n} y_{\text{pred},i} - \sum_{i=1}^{n} y_{\text{data},i}}{\sum_{i=1}^{n} y_{\text{data},i}} \right) \times 100$$

where:

$y_{\text{pred},i}$ is the predicted monthly value for the building energy use,

$y_{\text{data},i}$ is the measured monthly value for the building energy use, and

n is the number of months used in the simulation.

This index is the typical value reported for most DOE-2 predictions (Diamond and Hunn 1981; Kaplan et al. 1990; Bronson 1992a; McLain et al. 1993).

The mean bias error[1], MBE (%) (Kreider and Haberl 1994a; 1994b), is a method with which to determine a non-dimensional bias measure (sum of errors), between the simulated data and the measured data for each individual hour. The total difference, or sum of errors, between the predicted data and the simulated data is divided by the total number of hours considered in the calculation, thus rendering a mean bias. The p value, or number of regression parameters, was arbitrarily set to be zero. The result was then divided by the measured data mean to provide a non-dimensional value reported as a percentage. This calculation may be performed on any number of data points; however, it is convenient to show results as a function of monthly or total

$$\text{MBE} = \frac{\dfrac{\sum_{i=1}^{n} \left(y_{\text{pred},i} - y_{\text{data},i} \right)}{n-p}}{\bar{y}_{\text{data},i}} \times 100 \text{ simulation periods.}$$

where:

$\bar{y}_{\text{data},i}$ is the independent variable mean value of the data set corresponding to a

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[1] Srinivas Katipamula, Ph.D. 1994. Personal Communication, Richland, WA: Battelle Pacific Northwest Laboratory.

particular set of the dependent variables,

n is the number of data points in the data set, and

p is the total number of regression parameters in the model (which was assigned as 0 for the DOE-2 models).

The results of this calculation show that the MBE is in actuality the same as the percent difference calculation previously shown. However, the true definition pertains to the bias, or error, of the mean difference value between the simulated data and the measured data.

The root mean squared error, RMSE (kWh/h), is found on an hourly basis by the following equation (SAS 1990):

$$\mathrm{RMSE} = \sqrt{\mathrm{MSE}}$$

where:

the mean square error,

$$\mathrm{MSE} = \frac{\mathrm{SSE}}{\mathrm{n-p}}, \text{ p=0 and}$$

the sum of squares error,

$$\mathrm{SSE} = \sum_{i=1}^{n}\left(y_{\mathrm{pred,i}} - y_{\mathrm{data,i}}\right)^2$$

yielding the equation:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(y_{\mathrm{pred,i}} - y_{\mathrm{data,i}})^2}{\mathrm{n-p}}}$$

The root mean squared error is typically referred to as a measure of variability, or how much spread exists in the data. For every hour, the error, or difference in paired data points is calculated and squared. The sum of squares errors (SSE) are then added for each month and for the total periods and divided by their respective number of points yielding the MSE; whether for each month or the total period. A square root of the result is then reported as the root mean squared error.

The coefficient of variation-root mean squared error, CV(RMSE) (%) (Draper and Smith 1981) is essentially the root mean squared error divided by the measured mean:

$$\mathrm{CV(RMSE)} = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(y_{\mathrm{pred},i} - y_{\mathrm{data},i}\right)^2}{n-p}}}{\bar{y}_{\mathrm{data},i}} \times 100$$

where:

$$\bar{y}_{\mathrm{data},i} = \sum_{i=1}^{n} \frac{y_i}{n}$$

It is often convenient to report a non-dimensional result. CV(RMSE) allows one to determine how well a model fits the data; the lower the CV(RMSE), the better the calibration (the model in this case is the DOE-2 predicted data). Therefore, a CV(RMSE) is calculated for hourly data and presented on both a monthly summary and total data period.

The purpose of calculating the CV(RMSE) and comparing the results with the standard percent difference calculation is to demonstrate that a percent difference report may be misleading. Since the percent difference calculations are usually shown for total monthly simulations or even total simulation data periods, the reader is never certain if the model is a true representation of the actual building or if the ± errors have canceled out. If one examines the hour-by-hour data results, it would be evident that each pair of points would in all likelihood be dissimilar and in some cases be significantly different, despite using measured weather data to drive the simulation model. Reporting monthly data therefore does not take into account the canceling out of individual differences observed when the simulation over-predicts during one hour and under-predicts during the next hour by approximately the same amount.

Karnes County 2250 bed and Cuero 1000 bed prison sites

Several preliminary input files for the Karnes County 2,250 bed and Cuero 1,000 bed prison buildings were created for the DOE-2 simulation. Two initial files were specifically designed for use with the DrawBDL (Huang 1993) architectural rendering software and are named "karnes.inp" and "cuero.inp". They are shown in Figures 11 and 12, respectively, to show the layout of the entire site. For the next part of the project, these two input files were divided into separate buildings and the systems and plant sections of the DOE-2 input files were created for the individual buildings. The information for the systems and plant sections of the input files was taken from the architectural and engineering drawings of each building as well as personal interviews with TDCJ staff members. Each building was simulated as the input files were modified to catch and identify any errors quickly. The number of zones per input file was kept as small as possible to minimize the amount of calculations required by DOE-2.

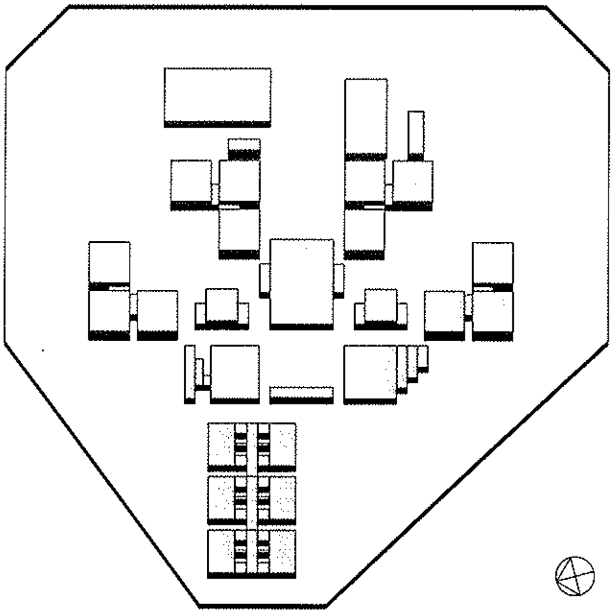

Figure 11: Karnes County 2250 bed site as shown by DrawBDL.

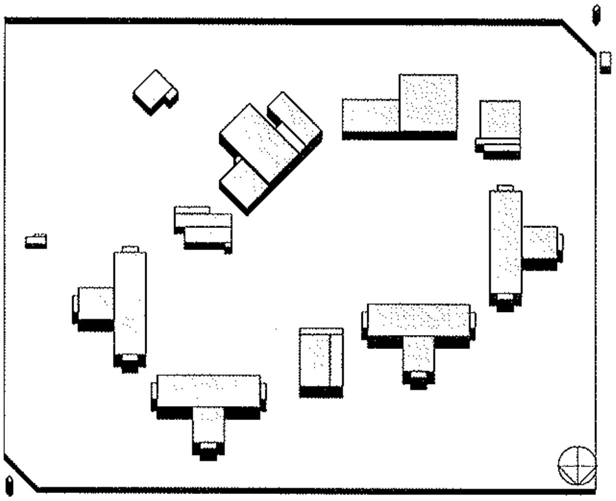

Figure 12: Cuero 1000 bed site as shown by DrawBDL.

After the SYSTEMS and PLANT portions of the input files for the individual buildings at the Cuero site were completed, the files were pieced together so that the buildings that are monitored together on the same logger channel can be simulated together. Test runs for all the input files were run using TRY weather data from the DOE-2 distribution package for locations that are as close as possible to the actual sites.

Current Status of the BDL Input Files

The Cuero input files are nearly complete for calibration and simulation once weather data and actual measured data for the site are available. In addition, every command in the input files must be verified including schedules (people, equipment, lights) and equipment schedules and kW. For the Karnes site, the input files must first be combined to represent the actual logger configurations once the site is equipped with the necessary instrumentation. Furthermore, the Karnes input files must be examined carefully to complete the input files. The progress on the Karnes site did not reach the progress level of the Cuero site due to time constraints. Once the input files are combined, the combined files can be calibrated and simulated. The procedure is similar to that followed for the Cuero site.

Other Details About the Input Files

The nomenclature used for the modeled buildings is consistent with the building names on the architectural site plans (i.e., each architectural command is preceded by the prefix of the building name). Exterior walls are named by building name, wall location, wall number, and wall elevation. At the Cuero site for example, wall A-FT-1A is building A (A), front wall (FT), wall 1 (1), on the first floor (A) (B is either the second floor or the plenum depending upon the building). The orientation of front, back, right, and left walls are consistent with the architectural site plans - front being the walls at the bottom of the page closest to the viewer, the back walls being at the top of the page, etc. (front is not necessarily the true front of the building). Exterior walls are either labeled E-W or EXTERIOR-WALL. The windows (W) are named A-W-1A with A being the building name, W or WIN being a window, 1 being the window number, and A being the first level. On some input files, the level name is omitted. The doors are named similarly with the W being replaced by a D. Roofs and floors are labeled similar to exterior walls, for example, A-RF-1A for roof and A-FL-1A for floor. A detailed diagram showing the naming convention used for building B at the Cuero site is included in the Appendix. For the Karnes input files, the same nomenclature was followed, however, the buildings are designated numerically instead of by alphabetical letters.

Once the individual DOE-2 input files have been successfully debugged and the simulations provide hourly data, the data must be extracted from the DOE-2 output file format. The data must be processed for plotting since most graphical software packages require the data to be in columnar ASCII form. This is accomplished with special routines developed by Bronson (1992a) and modified for this project. Once the buildings are simulated, the data from each individual file must be extracted and merged into a single columnar file with a time and date stamp using the AWK language. This allows one to view data from each building individually, to group buildings, or the entire site at once with the Statistical Analysis Software (SAS 1989). Side-by-side statistical plots can then be produced that compare the measured data to the DOE-2 output for model calibration (Bou-Saada 1994). The statistical plots are most effective and beneficial when comparing simulated hourly data to measured hourly data.

The files required to perform the process of converting the hourly DOE-2 output data to ASCII columnar form for the Cuero site are included in the PROCESS directory on the floppy disk included with this report and commented copies of the files are included in the Appendix. To properly perform the processing, place the DOE-2 simulation files in the PROCESS directory and run the batch file. For the Cuero site, type `cuero`. The batch file, once properly installed and configured for a particular personal computer will perform all the necessary operations to extract and combine the data into one columnar ASCII file. The output files will be named `cuero_el.dat` and `cuero_ng.dat` for electrical and natural gas use respectively. These files can then be compared to actual measured data using plotting software for model calibration. The batch file routines must be modified to support the Karnes site as they have not been developed to date.

Remaining Work and Recommendations

Completion Summary:

1. Software and hardware required for simulation:
    - DOE-2E simulation program for personal computers with a complete set of user manuals and supplements. A list is included in the reference section of this report.
    - DrawBDL architectural rendering software for Windows.

- Microsoft Windows 3.1.
- SAS for personal computers.
- TMY or TRY Weather tapes (note, to date only TRY weather tapes can be packed with measured weather data).
- FORTRAN 77.
- gawk.exe
- 486-33 or 66 MHz personal computer with at least 16 Megabytes of RAM.

2. Energy Systems Laboratory software required for simulation:
   - packweather.com weather packing routine
   - ls2try.for. This program must be recompiled to operate on a personal computer. Currently, it only operates on the university VAX system.
   - Weather packer instruction files specific to the site being analyzed.
   - 023to124.awk routine for weather packer pre-processing.
   - ESL's box-whisker-mean plots for calibration.
   - ESL's hourly data extraction routines provided with this report.
3. Load the DOE-2E program onto a personal computer using the instructions provided with the program.
4. Load the DrawBDL program onto a personal computer using the instructions provided with the program.
5. Load the SAS program onto a personal computer using the instructions provided with the program.
6. Update each DOE-2 input file provided with the Energy Systems Lab Final Report for both sites per architectural specifications and site equipment and operating conditions called for in the LOADS, SYSTEMS, and PLANT portion of DOE-2. Some input files remain unfinished and others require updating pending scheduling information.
7. Update the SPACE-CONDITIONS section of all input files with accurate information including people counts, lighting information, equipment loads, infiltration and air changes per hour.
8. Obtain information pertaining to each individual building at both sites. This includes:
   - Occupancy schedules
   - Equipment schedules
   - Lighting schedules
   - HVAC schedules
9. Obtain measured utility data for calibration. This includes electricity and natural gas.
10. It is necessary to combine the input files for the buildings at the 2,250 bed site per logger site. This is to be performed similarly to the 1,000 bed site.

11. Develop the output processing routines for the Karnes site.
12. Run DOE-2 for each input file to obtain hourly reports for the PLANT sub-program. It is recommended that at least six months of weather data be used which includes the heating, cooling, and intermediate seasonal conditions at a minimum.
13. Extract the hourly data from the PLANT sub-routine of each input file and combine the electricity and natural gas data using the ESL routines developed during this project.
14. Calibrate the input files using SAS graphics per Bou-Saada (1994). This procedure is tedious and requires numerous DOE-2 runs as well as engineering judgment obtained from comparing the SAS graphs and thus tuning the proper DOE-2 input file variables until an acceptable error tolerance is reached between measured and simulated hourly values.
15. The calibrated input file can then be used as a baseline for future DOE-2 runs when TDCJ energy efficient modifications are being considered.
16. Develop end-use load profiles for each site.

The upgraded version, MICRO DOE-2E for the personal computer, was used for all simulation testing.

FILES ON DISKETTE

The files are included on the diskette are listed below:

tdcj.txt - text copy of this report

in the Karnes directory

Karnes 2250 Bed Site
karnes.inp - input file to be used with DrawBDL
1.inp - input file for Building 1
2.inp - input file for Building 2
3.inp - input file for Building 3
4.inp - input file for Building 4
5.inp - input file for Building 5
6.inp - input file for Building 6
7.inp - input file for Building 7
8.inp - input file for Building 8
9.inp - input file for Building 9
10.inp - input file for Building 10
11.inp - input file for Building 11
12.inp - input file for Building 12

in the Cuero directory

Cuero 1000 Bed Site
cuero.inp - input file to be used with DrawBDL
bc.inp - input file for Buildings B & C
d.inp - input file for Building D
ef.inp - input file for Buildings E & F
h.inp - input file for Building H
j12.inp - input file for Buildings J1 & J2
j3.inp - input file for Building J3
j4.inp - input file for Building J4

in the process directory

cuero.bat - main bat file, calls other bat files
bc.bat - processing for the bc simulation
d.bat - processing for the d simulation
ef.bat - processing for the ef simulation
h.bat - processing for the h simulation
j12.bat - processing for the j12 simulation
j3.bat - processing for the j3 simulation
j4.bat - processing for the j4 simulation
dbtemp.bat - processing for dry bulb temp.
cols.com - paste columns together side by side
gawk.exe - run the .awk scripts
min_conv.awk - convert data
out_proc.awk - process DOE-2 output
rawextr.awk - extract raw columns from output

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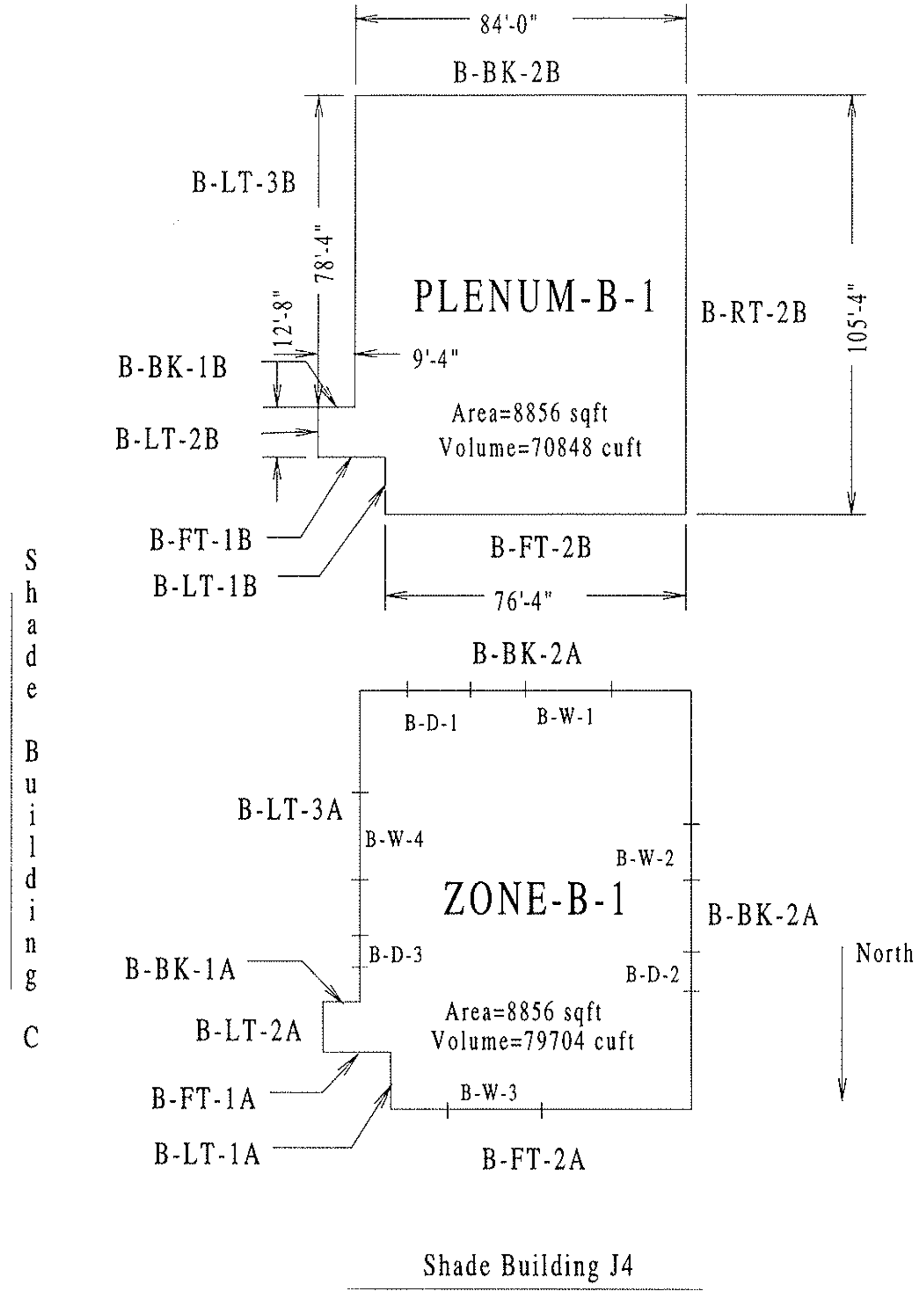
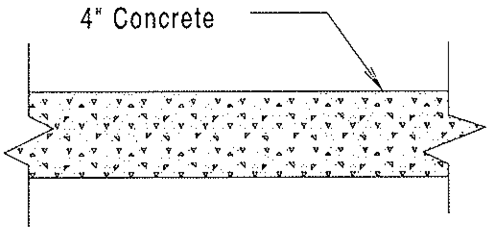
APPENDIX

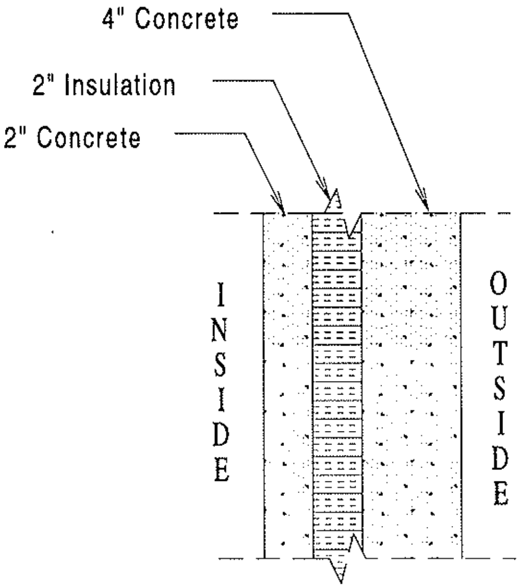
BUILDING B PLAN
(Administration Building)



ROOF CONSTRUCTION



OUTSIDE WALL CONSTRUCTION



CUERO UNIT BUILDINGS B&C

```
INPUT LOADS ..

TITLE LINE-1 * TEXAS DEPARTMENT OF CRIMINAL
              JUSTICE *
      LINE-2 * 1000 BED SITE - BUILDING B AND
              BUILDING C *
      LINE-3 * CUERO, TEXAS *
      LINE-4 * TEXAS A&M UNIVERSITY * ..

$ HEADING
$ -------

         ABORT          ERRORS ..
         DIAGNOSTIC     CAUTIONS ..
         RUN-PERIOD     JAN 1 1994 THRU JAN 31 1994
..
BUILDING-LOCATION
         LATITUDE=29   LONGITUDE=97
         ALTITUDE=195  GROSS-AREA=31350
         HOLIDAY=NO    DAYLIGHT-SAVINGS=YES
         TIME-ZONE=6   AZIMUTH=180
         GROUND-T= (53,53,53,54,54,55,55,55,54,54,53,53)
         ..

$      LOADS-REPORT
$            VERIFICATION=(LV-C,LV-D,
$                          LV-H,LV-I)
$            SUMMARY=(LS-C) ..

$ INTERIOR EQUIPMENT LOADS SCHEDULE
$ --------------------------------

B-SCH-1        =DAY-SCHEDULE (1,6) (0.8) (7,18) (1.0)
                (19,24) (0.8) ..
B-INT-LDS-1    =SCHEDULE THRU DEC 31 (ALL) B-SCH-1
..
B-INFIL-SCH-1 =SCHEDULE THRU DEC 31 (ALL) (1,24) (1)
..
C-SCH-1        =DAY-SCHEDULE (1,6) (0.8) (7,18) (1.0)
                (19,24) (0.8) ..
C-INT-LDS-1    =SCHEDULE THRU DEC 31 (ALL) C-SCH-1
..

C-INFIL-SCH-1 =SCHEDULE THRU DEC 31 (ALL) (1,24) (1)
..


$ LIGHTS SCHEDULE
$ --------------
B-LT-1     =DAY-SCHEDULE
             (1,8)  (0.05)
             (9,14)  (0.9,0.95,1.0,0.95,0.8,0.9)
             (15,18) (1.0)
             (19,21) (0.6,0.2,0.2)
             (22,24) (0.05) ..

B-LT-WEEK  =WEEK-SCHEDULE   (MON,FRI) B-LT-1
             (WEH) B-LT-1 ..

B-INT-LIGHT-1 =SCHEDULE  THRU DEC 31 B-LT-WEEK ..

C-LT-1     =DAY-SCHEDULE
             (1,8)  (0.05)
             (9,14)  (0.9,0.95,1.0,0.95,0.8,0.9)
             (15,18) (1.0)
             (19,21) (0.6,0.2,0.2)
             (22,24) (0.05) ..

C-LT-WEEK =WEEK-SCHEDULE
             (MON,FRI) C-LT-1 (WEH) C-LT-1 ..

C-INT-LIGHT-1=SCHEDULE  THRU DEC 31 C-LT-WEEK ..

$ BASED ON SUNRISE/SUNSET TIMES $
EXT-LIGHT-1 =SCHEDULE THRU JAN 31 (ALL) (1,7) (1)
         (8,17) (0) (18,24) (1)
         THRU FEB 28 (ALL) (1,7) (1) (8,17) (0) (18,24) (1)
         THRU MAR 31 (ALL) (1,6) (1) (7,18) (0) (19,24) (1)
         THRU APR 30 (ALL) (1,5) (1) (6,19) (0) (20,24) (1)
```

```
          THRU MAY 31 (ALL) (1,5) (1) (6,19) (0) (20,24) (1)
          THRU JUN 30 (ALL) (1,5) (1) (6,19) (0) (20,24) (1)
          THRU JUL 31 (ALL) (1,5) (1) (6,19) (0) (20,24) (1)
          THRU AUG 31 (ALL) (1,5) (1) (6,19) (0) (20,24) (1)
          THRU SEP 30 (ALL) (1,5) (1) (6,19) (0) (20,24) (1)
          THRU OCT 31 (ALL) (1,5) (1) (6,18) (0) (19,24) (1)
          THRU NOV 30 (ALL) (1,7) (1) (8,18) (0) (19,24) (1)
          THRU DEC 31 (ALL) (1,7) (1) (8,17) (0) (18,24) (1) ..

$ OCCUPANCY SCHEDULE BASED ON INTERVIEWS $
B-DAY-1  =DAY-SCHEDULE  (1,9) (1) (10,19) (.85)
           (20,24) (1) ..
B-DAY-2  =DAY-SCHEDULE  (1,24) (1) ..

B-PEOPLE-WEEK  =SCHEDULE  THRU DEC 31 (MON,FRI)
                 B-DAY-1
                 (WEH) B-DAY-2 ..

C-DAY-1     =DAY-SCHEDULE  (1,9) (1) (10,19) (.85)
              (20,24) (1) ..
C-DAY-2     =DAY-SCHEDULE  (1,24) (1) ..

C-PEOPLE-WEEK=SCHEDULE
                THRU DEC 31 (MON,FRI) C-DAY-1
                       (WEH) C-DAY-2 ..

$ WALL MATERIALS
$ --------------
$ 2" FACE BRICK ON 4" BLOCK WITH 2" INSULATION
$ LAYER

WA-1  =LAYERS MATERIAL=(CB21,IN02,CB21)
               THICKNESS=(0.1667,0.1667,0.3333) ..

TIN-OUT =MATERIAL
        THICKNESS=0.02083
        CONDUCTIVITY=26.0
        DENSITY=480.0
        SPECIFIC-HEAT=0.10 ..

WA-2     =LAYERS MATERIAL=(TIN-OUT,IN02,GP02) ..

RF-LAY  =LAYERS MATERIAL=(CB21)
              THICKNESS=(0.3333) ..

$ FLOOR MATERIALS
$ --------------
FL-CONC-1=LAYERS MATERIAL=(CC24) ..

$ GLAZING
$ -------
WINDOW-1=GLASS-TYPE PANES=1 G-T-C=1 ..

$ CONSTRUCTIONS
$ -------------
RF-1=CONS  LAYERS=RF-LAY ..
LAY-4      =LAYERS   MATERIAL=(CC24) ..
CLG-1      =CONS     LAYERS=LAY-4 ..
FLR-1      =CONS     LAYERS=FL-CONC-1 ..
DR-1       =CONS     U=.4 ABS=.78 ROUGHNESS=5 ..
WALL-1     =CONS     LAYERS=WA-1 ..
WALL-TIN =CONS       LAYERS=WA-2 ..
BUILDING-D1=BUILDING-SHADE
               X=399.19  Y=580
               H=20  W=222.5
               AZ=135  TILT=90 ..

BUILDING-D2=BUILDING-SHADE
               X=556.52  Y=738.33
               H=20  W=222.5
               AZ=45  TILT=90 ..

$ BUILDING B ZONE-B-1 SPACE DESCRIPTION
$ ------------------------------------

COND-B-1  =SPACE-CONDITIONS FLOOR-WEIGHT=30
            LIGHTING-SCHEDULE=B-INT-LIGHT-1
            LIGHTING-TYPE=SUS-FLUOR
            LIGHTING-W/SQFT=1.170958
            LIGHT-TO-SPACE=1.0
            TASK-LIGHT-SCH=B-INT-LIGHT-1
            TASK-LIGHTING-KW=.238
            PEOPLE-SCHEDULE=B-PEOPLE-WEEK
            PEOPLE-HG-SENS=250
            PEOPLE-HG-LAT=200
            NUMBER-OF-PEOPLE=10
```

```
          TEMPERATURE=(75)
          EQUIP-SCHEDULE=B-INT-LDS-1
          EQUIPMENT-KW=0.5
          INF-METHOD=AIR-CHANGE
          AIR-CHANGES/HR=.6
          INF-SCHEDULE=B-INFIL-SCH-1 ..

ZONE-B-1  =SPACE A=11081.7  V=176531.6  S-C=COND-B-1
          X=950 Y=700 AZ=0
          ZONE-TYPE=CONDITIONED ..

B-CLG-1A=I-W  H=78.333 W=84 X=9.333 Y=27 Z=8.667
          NEXT-TO=PLENUM-B-1 TILT=0
          AZ=180 CONS=CLG-1 ..

B-CLG-2A=I-W  H=12.667 W=93.333 X=0 Y=14.333 Z=8.667
          NEXT-TO=PLENUM-B-1 TILT=0
          AZ=180 CONS=CLG-1 ..

B-CLG-3A=I-W  H=14.333 W=76.333 X=17 Y=0 Z=8.667
          NEXT-TO=PLENUM-B-1 TILT=0
          AZ=180 CONS=CLG-1 ..

B-BK-1A=E-W   H=8.667 W=9.333 X=9.333 Y=27 S-S=YES
          AZ=0 CONS=WALL-1 ..

B-BK-2A=EXTERIOR-WALL H=8.67 W=84 X=93.3
Y=105.333
          S-S=YES AZ=0 CONS=WALL-1 ..

B-W-1=WI    H=6 W=30 X=22 Y=1.5 G-T=WINDOW-1 ..

B-D-1 =DOOR  H=6.667 W=6 X=55 Y=.833 CONS=DR-1 ..

B-RT-1A=EXTERIOR-WALL H=8.667 W=105.333 X=93.333
          Y=0 S-S=YES AZ=90  CONS=WALL-1 ..

B-W-2 =WI  H=5 W=8 X=50 Y=3.333 G-T=WINDOW-1 ..

B-D-2 =DOOR H=6.667 W=3 X=29.333 Y=.833 CONS=DR-1 ..

B-FT-1A=EXTERIOR-WALL H=8.667 W=17 X=0 Y=14.333
          S-S=YES AZ=180 CONS=WALL-1 ..
```

```
B-FT-2A=EXTERIOR-WALL H=8.667 W=76.333 X=17 Y=0
          S-S=YES AZ=180 CONS=WALL-1 ..

B-W-3    =WI H=6 W=18.333 X=20 Y=1 G-T=WINDOW-1 ..

B-LT-1A=EXTERIOR-WALL H=8.667 W=14.333 X=17
          Y=14.333 S-S=YES AZ=270  CONS=WALL-1 ..

B-LT-2A=EXTERIOR-WALL H=8.667 W=12.667 X=0 Y=27
          S-S=YES AZ=270  CONS=WALL-1 ..

B-LT-3A=EXTERIOR-WALL H=8.667 W=78.333 X=9.333
          Y=105.333 S-S=YES  AZ=270  CONS=WALL-1 ..

B-W-4    =WI   H=6 W=14 X=40 Y=1 G-T=WINDOW-1 ..

B-D-3    =DOOR   H=6.667 W=6 X=56 Y=.833 CONS=DR-1 ..

B-FL-1A = UNDERGROUND-FLOOR H=13.833 W=91.333
         0 Y=107.5 Z=24 AZ=180 TILT=180 CONS=RF-1 ..

B-FL-2A = UNDERGROUND-FLOOR H=107.5 W=27 X=64
          Y=0 Z=24 AZ=180 TILT=180 CONS=RF-1 ..

COND-B-2 = SPACE-CONDITIONS
          ZONE-TYPE=UNCONDITIONED ..

PLENUM-B-1 = SPACE  A=8856.3 V=70850.4 S-C=COND-B-2
          X=950 Y=700 AZ=0 ..

B-RF-1A = ROOF   H=78.333 W=84 X=9.333 Y=27 Z=16.667
          AZ=180 TILT=0 CONS=RF-1 ..

B-RF-2A = ROOF   H=12.667 W=93.333 X=0 Y=14.333
          Z=16.667  AZ=180 TILT=0 CONS=RF-1 ..

B-RF-3A = ROOF    H=14.333 W=76.333 X=17 Y=0 Z=16.667
                  AZ=180 TILT=0 CONS=RF-1 ..

B-FT-1B=EXTERIOR-WALL H=8 W=17 X=0 Y=14.333
                  Z=8.667 S-S=YES
                  AZ=180 CONS=WALL-1 ..
```

```
B-FT-2B=EXTERIOR-WALL H=8 W=76.333 X=17 Y=0
          Z=8.667 S-S=YES
          AZ=180 CONS=WALL-1 ..

B-BK-1B=EXTERIOR-WALL H=8 W=9.333 X=9.333 Y=27
          Z=8.667 S-S=YES
          AZ=0 CONS=WALL-1 ..

B-BK-2B=EXTERIOR-WALL H=8 W=84 X=93.333 Y=105.333
          Z=8.667 S-S=YES
          AZ=0 CONS=WALL-1 ..

B-LT-1B=EXTERIOR-WALL H=8 W=14.333 X=17 Y=14.333
          Z=8.667 S-S=YES
          AZ=270 CONS=WALL-1 ..

B-LT-2B=EXTERIOR-WALL H=8 W=12.667 X=0 Y=27
          Z=8.667 S-S=YES
          AZ=270 CONS=WALL-1 ..

B-LT-3B=EXTERIOR-WALL H=8 W=78.333 X=9.333
          Y=105.333 Z=8.667 S-S=YES
          AZ=270 CONS=WALL-1 ..

B-RT-1B=EXTERIOR-WALL H=8 W=105.333 X=93.333 Y=0
          Z=8.667 S-S=YES
          AZ=90 CONS=WALL-1 ..

$ END OF BUILDING B LOADS BEGIN BUILDING C
$ LOADS
$ ZONE-C-1 SPACE DESCRIPTION
$ ---------------------------------------------

COND-C-1   =SPACE-CONDITIONS FLOOR-WEIGHT=30
          LIGHTING-SCHEDULE=C-INT-LIGHT-1
          LIGHTING-TYPE=SUS-FLUOR
          LIGHTING-W/SQFT=1.42091
          LIGHT-TO-SPACE=1.0
          TASK-LIGHT-SCH=C-INT-LIGHT-1
          TASK-LIGHTING-KW=.238
          PEOPLE-SCHEDULE=C-PEOPLE-WEEK
          PEOPLE-HG-SENS=250
          PEOPLE-HG-LAT=200
          NUMBER-OF-PEOPLE=10
          TEMPERATURE=(75)
          EQUIP-SCHEDULE=C-INT-LDS-1
          EQUIPMENT-KW=0.5
          INF-METHOD=AIR-CHANGE
          AIR-CHANGES/HR=.6
          INF-SCHEDULE=C-INFIL-SCH-1 ..

$ C-CLG-SPACE SPACE DESCRIPTION
$ ----------------------------

C-CLG-SPACE=SPACE    FLOOR-WEIGHT=5
          ZONE-TYPE=UNCONDITIONED
          TEMPERATURE=(85)
          AZIMUTH=0
          AREA=14357
          VOLUME=129213
          X=789.667  Y=740  Z=9 ..

C-NWA-CLG=EXTERIOR-WALL  HEIGHT=9
          WIDTH=121.667
          AZIMUTH=180  TILT=90
          X=0  Y=0  Z=0 S-S=YES
          CONSTRUCTION=WALL-TIN ..

C-SWA-CLG=EXTERIOR-WALL  HEIGHT=9
          WIDTH=121.667
          AZIMUTH=0 TILT=90
          X=121.667  Y=118  Z=0 S-S=YES
          CONSTRUCTION=WALL-TIN ..

C-WWA-CLG=EXTERIOR-WALL  HEIGHT=9
          WIDTH=118
          AZIMUTH=90 TILT=90
          X=121.667  Y=0  Z=0 S-S=YES
          CONSTRUCTION=WALL-TIN ..

C-EWA-CLG=EXTERIOR-WALL  HEIGHT=9  WIDTH=118
          AZIMUTH=270  TILT=90
          X=0  Y=118  Z=0 S-S=YES
          CONSTRUCTION=WALL-TIN ..
```

```
C-RF-1A=ROOF  HEIGHT=118  WIDTH=121.667
            X=0  Y=0  Z=9
            AZIMUTH=180  TILT=0
            CONSTRUCTION=RF-1  ..

$ ZONE-C-1 SPACE DESCRIPTION
$ -------------------------

ZONE-C-1   =SPACE    A=14357  V=129213  S-C=COND-C-1
            X=789.667  Y=740  Z=0  AZIMUTH=0  ..

C-FT-1A=EXTERIOR-WALL H=9 W=121.667 X=0 Y=0 S-
        S=YES AZ=180 TILT=90 CONS=WALL-TIN  ..

WIN-1A=WINDOW   HEIGHT=3  WIDTH=3 X=4 Y=4
        GLASS-TYPE=WINDOW-1  ..
WIN-2A=WINDOW   LIKE WIN-1A EXCEPT X=16  ..
WIN-3A=WINDOW   LIKE WIN-1A EXCEPT X=52  ..
WIN-4A=WINDOW   LIKE WIN-1A EXCEPT X=64  ..
WIN-5A=WINDOW   LIKE WIN-1A EXCEPT X=76  ..
WIN-6A=WINDOW   LIKE WIN-1A EXCEPT X=88  ..
WIN-7A=WINDOW   HEIGHT=7  WIDTH=1.5
                X=108  Y=1.5
                GLASS-TYPE=WINDOW-1  ..
WIN-8A=WINDOW    LIKE WIN-7A EXCEPT X=114  ..

DR-1A=DOOR       HEIGHT=7  WIDTH=6  X=43  Y=0
                CONSTRUCTION=DR-1  ..
DR-2A=DOOR       LIKE DR-1A EXCEPT X=94  ..

C-BK-1A=EXTERIOR-WALL H=9 W=121.667 X=121.667
                Y=118 S-S=YES
                AZ=0  TILT=90  CONS=WALL-TIN  ..

WIN-9A=WINDOW    HEIGHT=3  WIDTH=14  X=4  Y=4
                GLASS-TYPE=WINDOW-1  ..

WIN-10A=WINDOW      LIKE WIN-9A EXCEPT X=24  ..
WIN-11A=WINDOW      LIKE WIN-9A EXCEPT X=44  ..
WIN-12A=WINDOW      LIKE WIN-9A EXCEPT X=64  ..
WIN-13A=WINDOW      LIKE WIN-9A EXCEPT X=84  ..

C-RT-1A=EXTERIOR-WALL H=9 W=118 X=121.667 Y=0
        S-S=YES
        AZ=90  TILT=90  CONS=WALL-TIN  ..

WIN-14A=WINDOW      LIKE WIN-1A EXCEPT X=19  ..
WIN-15A=WINDOW      LIKE WIN-1A EXCEPT X=31  ..
WIN-16A=WINDOW      HEIGHT=3  WIDTH=10  X=54
                    GLASS-TYPE=WINDOW-1  ..

C-LT-1A=EXTERIOR-WALL H=9 W=50 X=0 Y=118 S-S=YES
        AZ=270  TILT=90  CONS=WALL-TIN ..

DR-3A=DOOR  HEIGHT=7  WIDTH=6  X=9 Y=0
            CONSTRUCTION=DR-1  ..

C-INW-1A=INTERIOR-WALL H=9 W=68  X=0 Y=68
          AZ=270  TILT=90  CONS=WALL-TIN
          NEXT-TO=ZONE-C-2  ..

C-FL-1A=U-F H=118  W=121.667
          X=0 Y=0 Z=0
          CONSTRUCTION=FLR-1
          AZ=180  TILT=180  ..

$ ZONE-C-2 SPACE DESCRIPTION
$ -------------------------

COND-C-2 =SPACE-CONDITIONS   LIKE COND-C-1
          LIGHTING-W/SQFT=1.42091
          TASK-LIGHTING-KW=.282
          EQUIPMENT-KW=0.75  ..

ZONE-C-2 =SPACE A=1998  V=23967  S-C=COND-C-2
          X=670 Y=740 Z=0  ..

C-FT-2A=EXTERIOR-WALL H=16.5 W=119.667 X=0 Y=0
          AZ=180  CONS=WALL-TIN  ..

DR-1B=DOOR   LIKE DR-1A EXCEPT WIDTH=3  X=36  ..
DR-2B=DOOR   LIKE DR-1B EXCEPT X=82  ..

C-BK-2A=EXTERIOR-WALL H=16.5 W=119.667 X=119.667
        Y=68 S-S=YES AZ=0  CONS=WALL-TIN  ..

DR-3B=DOOR          LIKE DR-2B EXCEPT X=30  ..
```

```
DR-4B=DOOR        LIKE DR-2B EXCEPT X=71 ..
DR-5B=DOOR        LIKE DR-2B EXCEPT X=83 ..

C-LT-2A=EXTERIOR-WALL H=16.5  W=68  X=0  Y=68
        S-S=YES AZ=270  CONS=WALL-TIN ..

C-RT-2A=INTERIOR-WALL H=7.5 W=68 X=119.667
        Y=0  Z=9 AZ=90  CONS=WALL-TIN
        NEXT-TO=C-CLG-SPACE ..

C-RF-2A=ROOF  H=68  W=119.667
          X=0 Y=0 Z=16.5
          CONSTRUCTION=RF-1
          AZ=180  TILT=0 ..

C-FL-2A=U-F  H=68  W=119.667
          X=0 Y=0 Z=0
          CONSTRUCTION=FLR-1
          AZ=180 TILT=180 ..

END ..
COMPUTE LOADS ..

INPUT SYSTEMS ..

CONTROL-B  =ZONE-CONTROL
             DESIGN-HEAT-T=70  DESIGN-COOL-T=76
             THERMOSTAT-TYPE=PROPORTIONAL ..

ZAIR-B-1  =ZONE-AIR
        OUTSIDE-AIR-CFM=1830 ASSIGNED-CFM=10770
..

ZONE-B-1  =ZONE  ZONE-AIR=ZAIR-B-1
          ZONE-CONTROL=CONTROL-B ..

PLENUM-B-1  =ZONE  ZONE-TYPE=UNCONDITIONED ..

S-CONT-B1  =SYSTEM-CONTROL
             MAX-SUPPLY-T=105 MIN-SUPPLY-T=55 ..

S-FAN-B1   =SYSTEM-FANS
             SUPPLY-STATIC=2.61 SUPPLY-KW=0.00121 ..
```

```
S-EQUIP-B1  =SYSTEM-EQUIPMENT
              HEATING-CAPACITY=-194000
               COOLING-CAPACITY=360144 ..

SYST-B1    =SYSTEM   SYSTEM-TYPE=PSZ
             RETURN-AIR-PATH=DUCT
              ZONE-NAMES=(ZONE-B-1,PLENUM-B-1) ..

$ END OF BUILDING B SYSTEM BEGIN BUILDING C
SYSTEM

CONTROL-C  =ZONE-CONTROL  DESIGN-HEAT-T=70
              DESIGN-COOL-T=76
              THERMOSTAT-TYPE=PROPORTIONAL ..

ZAIR-C-1  =ZONE-AIR
          OUTSIDE-AIR-CFM=3150
          ASSIGNED-CFM=13495 ..

ZONE-C-1  =ZONE
           ZONE-AIR=ZAIR-C-1
           ZONE-CONTROL=CONTROL-C ..

ZONE-C-2   =ZONE
            ZONE-AIR=ZAIR-C-1
            ZONE-CONTROL=CONTROL-C ..

C-CLG-SPACE =ZONE
              ZONE-TYPE=UNCONDITIONED ..

S-CONT-C1  =SYSTEM-CONTROL
            MAX-SUPPLY-T=105 MIN-SUPPLY-T=55 ..

S-FAN-C1   =SYSTEM-FANS
            SUPPLY-STATIC=2.67 SUPPLY-KW=0.00097 ..

S-EQUIP-C1  =SYSTEM-EQUIPMENT
              HEATING-CAPACITY=-213700
              COOLING-CAPACITY=499155 ..

SYST-C1 =SYSTEM
    SYSTEM-TYPE=PSZ
```

```
    RETURN-AIR-PATH=DUCT
    ZONE-NAMES=(ZONE-C-1,ZONE-C-2,C-CLG-SPACE) ..

END ..
COMPUTE SYSTEMS ..

INPUT PLANT ..

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

B-EQUIP1   =PLANT-EQUIPMENT  TYPE=FURNACE
            SIZE=0.194 ..

B1-WAT-1   =PLANT-EQUIPMENT  TYPE=DHW-HEATER
            INSTALLED-NUMBER=1
            SIZE=0.206200 ..

B-EQUIP2   =PLANT-EQUIPMENT
            TYPE=HERM-CENT-CHLR
            SIZE=0.360 ..

$ END OF BUILDING B PLANT BEGIN BUILDING C PLANT

C-EQUIP1   =PLANT-EQUIPMENT  TYPE=FURNACE
            SIZE=0.214 ..

C-EQUIP2   =PLANT-EQUIPMENT
            TYPE=HERM-CENT-CHLR
            SIZE=0.499 ..

C1-WAT-1   =PLANT-EQUIPMENT  TYPE=DHW-HEATER
            INSTALLED-NUMBER=1
            SIZE=0.206200 ..

$ HOURLY REPORTS

RP-3        =SCHEDULE THRU JAN 31 (ALL) (1,24) (1) ..

BLOCK-3-1  =REPORT-BLOCK
            VARIABLE-TYPE = GLOBAL
            VARIABLE-LIST = (1) ..

BLOCK-3-2  =REPORT-BLOCK
            VARIABLE-TYPE = PLANT
            VARIABLE-LIST = (10,12) ..

HR-3     =HOURLY-REPORT
          REPORT-SCHEDULE = RP-3
          REPORT-BLOCK = (BLOCK-3-1,BLOCK-3-2) ..

END ..
COMPUTE PLANT ..
STOP ..
```