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ANALYSIS OF ENERGY CONSERVATION OPTIONS FOR U.S.D.O.E. CHILD DEVELOPMENT CENTER

PRELIMINARY DRAFT SUMMARY REPORT

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ABSTRACT

The Child Development Center (CDC) was designed to be a "showpiece" model building. Its construction included energy efficient features, including a photovoltaic system, solar hot water system, energy efficient lighting, and energy efficient heat pumps. The architect's estimate of the energy savings from these measures totaled 31.5 MWh per year, an annual savings of about $1,575 (at $0.05/kWh). The DOE-2 predicted total annual energy use for the CDC with all the ECO's installed is 146,317 kWh or 61,652 Btu/ft^2-yr which is a 12% reduction from the DOE-2 predicted energy use of 166,559 kWh (70,181 Btu/ft^2-yr using 1 kWh=3,413 Btu) if the ECOs had not been installed.

This report presents the results of a study that verifies the energy savings due to the individual ECOs through the use of a calibrated DOE-2 simulation. The results show that roughly 84% of the savings estimated by the GSA architect can be accounted for by the calibrated simulation.

PREFACE

The U.S.D.O.E. Child Development Center was designed and built to serve as an example of an energy efficient daycare center for federal employees and their children. As part of this effort the United States Department of Energy decided to verify the effectiveness of the Energy Conservation Options through the use of an analysis that utulized a calibrated simulation program. This report presents the preliminary findings of this effort.

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DISCLAIMER

EXECUTIVE SUMMARY

The Child Development Center was designed as a "showpiece" demonstration of an energy efficient daycare center for federal employees and their children. Its construction included energy efficient features including a photovoltaic system, solar hot water system, energy efficient lighting, and energy efficient heat pumps. The GSA architect estimate of the energy savings from these measures totaled 31.5 MWh per year (13,270 Btu/ft^2-yr) or 19% of the estimated use without the energy conservation options for an annual savings of $1,575 (at $0.05/kWh).

This report presents the results of a study that verifies the energy savings from the individual ECOs through the use of a calibrated DOE-2 simulation. The results show that roughly 84% of the savings estimated by the GSA architect can be accounted for by the calibrated simulation which indicates a remarkably good overall estimate by the architect, although individual measures varied significantly.

DOE-2 has been extensively used over the years to simulate hourly building energy consumption in design considerations. In order to investigate the effects of ECOs on a building, a calibrated DOE-2 baseline model representing the existing building (including all the ECOs) was compared to simulations without individual ECOs and the difference tabulated.

Table 1 shows the energy conservation options calculated in this study versus savings predicted by the GSA architect. Currently, 34 W energy efficient fluorescent lights are installed which save 40.8% more than predicted. Photovoltaic generation saves 4.6% more than predicted. The energy management system saves 460.1% more than expected. Lighting controls and dimmers were not verified since the dimmers were not installed. Insulation, front entrance airlock, and south window shading save 41.9% less than predicted. The clear-story windows save 120.6% less. Clear-story simulation indicates that the windows actually cause the building to use more energy than would otherwise be necessary since interviews with the USDOE staff revealed that automatic dimmers were not installed and the CDC staff only turned off lights when the children sleep. The improved EER heat pumps save 42.4% less than originally stated. The solar domestic hot water system saves 4.2% less than predicted. Clearly, the solar domestic hot water system and the photovoltaic system came the closest to the savings estimates. Total simulated savings represent 84% of the architectural proposals.

The bar chart in Figure 1 compares the simulated ECO's versus the original architect predictions. Part (a) is the verification of the seven individual energy conservation options while part (b) is a breakdown of key energy using systems with and without ECOs including interior lighting (8.1% less with the ECOs), space heating (17.2% less), HVAC fans (11.7% less), equipment (no change), space cooling (15.8% less), electric DHW (180.0% less including the solar DHW), and photovoltaic (no photovoltaic in w/o ECO case) classified by energy use from largest to smallest.

	U.S.D.O.E. Forrestal Child Development Center					
	Energy Conservation Option	DOE-2 Basemodel "as-built" (kWh)	DOE-2 Predicted w/o ECO (kWh)	DOE-2 Predicted Savings (kWh)	Architectural Proposal (kWh)	Percent Difference (7)
1.	Energy Efficient Lights	151,852	156,539	4,686	3,328	40.8%
2.	Photovoltaic Generation (1)	-7,880	0	7,880	7,530	4.6%
3.	Energy Management System (2)	151,852	157,453	5,601	1,000 (est)	460.1%
4.	Lighting Controls & Dimmers (3)	-	-	-	-	-
5.	Insulation, Airlock, South Shading	151,852	155,340	3,488	6,000	-41.9%
6.	Clear Story Windows	151,852	150,615	-1,237	6,000	-120.6%
7.	Improved Heat Pumps	151,852	153,754	1,902	3,300	-42.4%
8.	Solar Hot Water (4)	2,345	6,565	4,220	4,407 (6,033 is incorrect)	-4.2%
	All ECO's Combined (5)	146,317	166,559	20,242	-	-
	Total		(6)	26,540	31,565	-15.9%

(1) Difference was determined by a curve fit equation comparing photovoltaic generation as a function of global horizontal radiation. Global horizontal radiation was extracted from a Washington, D.C. TMY weather tape. DOE-2 was not used for this verification.

(2) According to U.S.D.O.E. personnel, the HVAC system is manually operated each day. The 1,000 kWh savings by the GSA architect were based on engineering judgement.

(3) According to U.S.D.O.E. personnel, the dimmers were not installed.

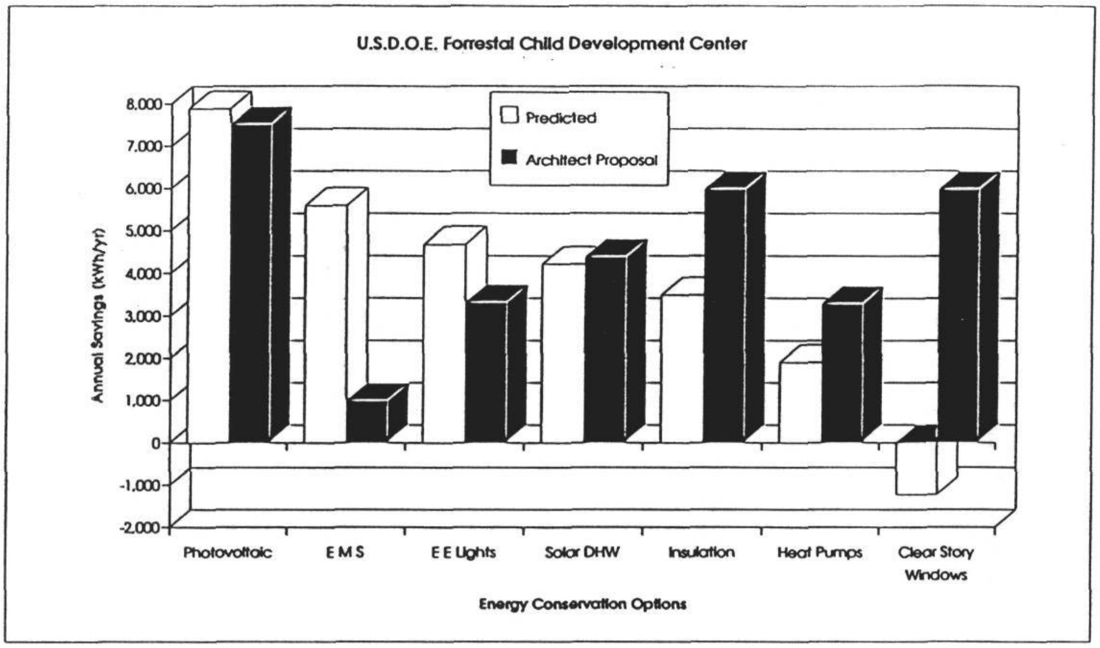
(4) Savings was determined by F-chart. The value of 6,033 as specified in the original estimate is incorrect.

(5) Not part of original ECO list. Calculated by: (Basemodel + photovoltaic + dhw)

(6) Savings total does not include "All ECO's Combined."

(7) The percent difference was calculated as follows: ((DOE-2 savings - architect proposal) / architect proposal) x 100

Table 1 - Comparison of Energy Conservation Options to Savings Predictions



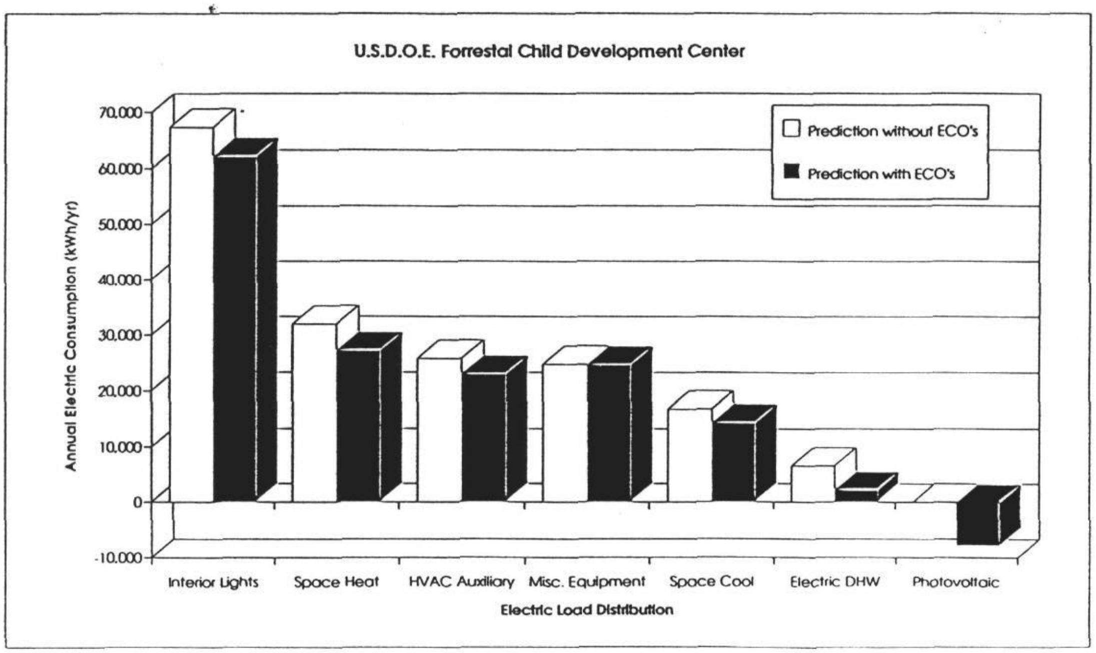


Figure 1 - (a) Annual ECO Savings. (b) Annual Electric Load Distribution.

ANALYSIS OF ENERGY CONSERVATION OPTIONS FOR U.S.D.O.E. FORRESTAL CHILD DEVELOPMENT CENTER

INTRODUCTION

This project intends to verify the effects of various energy conservation options (ECO) at the Child Development Center (CDC) by using a calibrated simulation program. Such simulations allow for energy use comparisons by running one base model simulation of the existing building and comparing it to simulations for each ECO. The difference may then be found by comparing the annual energy use with the ECO from baseline annual energy use without the ECO.

Figure 2 is a model of the building as seen by DOE-2. This figure was generated with a viewing package called drawBDL (Huang 1993) which reads building dimensions directly from the DOE-2 BDL input code. The most beneficial feature of this viewing package is that it provides a means to eliminate inevitable errors in dimensioning of the building. Figure 3 shows the location of the Child Development Center building with respect to neighboring buildings and shows its north-south orientation.

The DOE-2 Simulation Program

DOE-2 is divided into four main sections: LOADS, SYSTEMS, PLANT, and ECONOMICS. The LOADS sub-program calculates the heating/cooling load on a building based on 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 systems on electric consumption, including all HVAC equipment, lights, and appliances. 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 will then simulate interior conditions such as temperature and relative humidity control. After receiving the information from SYSTEMS, the PLANT sub-program then uses its routines to simulate all primary energy-using equipment in the building such as chillers, condensers and hot water heaters. Finally, the ECONOMICS sub-program calculates utility costs and life cycle costs for a prescribed period of time.

Measuring the Energy Use and Environmental Parameters

Figure 4 is an electrical monitoring diagram detailing the original lights and equipment monitoring points for the Forrestal Building and Child Development Center. Figure 5 is a thermal monitoring diagram showing the cooling and heating energy points as well as ambient weather parameters. Pertinent data channels were recorded and inspected with weekly data processing. Figures 6 and 7 are examples of weekly summary plots that show which data were collected. These metering plots provide a means of verifying logger operation so that data loss is kept to a minimum in the event of logger or power failure.

On a weekly basis, the data is added to a contiguous database which allows for an analysis to be made over the entire dataset. Figures 8 and 9 show a summary of the entire seven month dataset of weather data. It includes NWS relative humidity, ambient dry-bulb temperature, peak hourly wind speed, and global horizontal solar radiation. Figure 9 (a) is a plot of the monitored whole-building electricity use for the CDC. Figure 9 (b) shows the electricity produced by the photovoltaic array.

In order to calibrate the DOE-2 simulation to the existing building, several tasks needed to be accomplished. First, an accurate description of the building was created using the DOE-2 Building Description Language (BDL). This included a careful assessment of all architectural features and shading from nearby objects. Second, measured weather data was processed or "packed" into a format that DOE-2 can read. This included dry-bulb temperature, relative humidity, solar radiation, and wind speed. Finally, numerous iterations were then made to match the simulated output to the measured whole-building electricity data.

DOE-2 uses ambient weather conditions from a weather tape. The user may choose either to employ standard weather tapes available from the National Weather Service or to pack a site-specific Typical Reference Year, or TRY, weather tape for a more accurate weather dependent calibration.

Packing a tape entails collecting hourly outdoor dry-bulb temperature, outdoor relative humidity, wind speed, and global horizontal solar radiation. Routines were used to lay these data onto a TRY tape for the prescribed time for up to one year (Bronson, 1992). For this building a tape was packed for available data from April through October 1993. Hourly dry-bulb temperature, dew point temperature, and peak wind speed data were obtained from the National Weather Service which has a recording station located nearby at National Airport. Dew point temperature was used along with dry-bulb temperature to calculate relative humidity using a psychrometric routine (Sparks et al., 1993). Global solar radiation was measured on-site at an 18° angle titled from the horizontal toward the south, the same tilt angle of the photovoltaic solar panels located on the roof. The data were then converted into global horizontal solar radiation

(0° tilt) using a correlation developed by Erbs, et al (1982). The Erbs correlation was then used again to synthesize direct and diffuse solar radiation from global horizontal radiation and packed onto the TRY tape. All four parameters were combined into one data file and run through a FORTRAN weather packer program. The routine overlaid dry-bulb temperature, relative humidity, and wind speed onto the TRY tape. Missing data was labeled as "-99.0" and the TRY default value is used instead.

Simulation Method

The DOE-2 simulation involved encoding the building into an "input deck" to be read by the DOE-2 BDL and 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 thermal properties. The heating ventilating and air conditioning, or HVAC, equipment was detailed in SYSTEMS, for such factors as cooling and heating capacities, system efficiencies, fan sizes, air volume requirements. Occupancy, lights, equipment, and system schedules were added on an hourly basis to control equipment and lights. Then, hourly estimates of the exterior lighting loads were encoded separately from interior lighting systems which were summarized for each internal zone. Exterior lighting was calculated separately from interior lighting because it was determined to have no effect on interior heat loads. The exterior electric load was then passed directly to the PLANT sub-program bypassing the LOADS and SYSTEMS calculations. Table 2 summarizes the input variables for the CDC. This brief description highlights the major points for the simulation. The reader is referred to the DOE-2.1-D reference manual (1989) for further details. Additional details concerning the simulation will be available in the report by Bou-Saada (1994).

To verify the effectiveness of the energy conservation options, one DOE-2 model was created for each ECO. The first model was run in order to calibrate the simulation to measured whole-building electricity consumption for the seven month period of April - October 1993. This typically is the most difficult and time consuming task in modeling buildings. In this stage, errors in input must be detected, or one will always be unsure of what is being simulated. Once all the parameters are adjusted to what is believed to be as close as possible to actual building conditions, the model was declared "calibrated". Several methods were used to verify the calibration which are detailed in the report by Bou-Saada (1994). A difference of 5% or less between the modeled energy use and actual measured data is considered acceptable. This DOE-2 simulation is within 1.8% of the monthly data when an overall seven month comparison is taken into account. Table 3 is a monthly comparison between actual and simulated values and the percent difference.

Figure 10 (a) shows a three-dimensional plot of the monitored whole-building electric data while Figure 10 (b) shows the DOE-2 simulation. Figure 11 is also a three dimensional plot which shows the monitored data in part (a) and the base model simulation in part (b). Figure 11 (c) shows the measured data subtracted from the DOE-2 base model and Figure 11 (d) shows the DOE-2 base model subtracted from the measured data. The last two plots show positive residuals only.

Figure 12 (a) through (d) show time series plots of hourly measured data and hourly simulated data (April through July), and the hourly difference. Figure 13 (a) through (c) are the August through October comparisons. Part (d) shows a comparison of the entire dataset. The hourly CV-RMSE error over the seven month calibrated period was 29%.

Data Processing and Statistical Graphics

In order to report the calibration differences, several computer programs and graphical tools were used, including routines by Abbas (1993) and routines developed especially for this report (Bou-Saada 1994). First, the building was simulated with DOE-2 on an hourly basis for a seven month period. The resulting whole-building electric reports were extracted from the DOE-2 output reports and processed with SAS, the Statistical Analysis Software. Three-dimensional daily and box-and-whisker plots were found to be helpful plots during the fine tuning process. The box-and-whisker plots display the maximum, minimum, mean, and median points for a given period of data. The upper and lower tips of the whiskers are the 90th and 10th percentiles respectively representing outliers. The upper and lower box ends are the 75th and 25th percentiles, respectively, with the line in between them being the median, or the 50th percentile. The line connecting each box represents the statistical mean, or average. X-Y scatter plots were also used to display the electric consumption. A combined x-y scatter plot/box-and-whisker plot were found to be helpful in characterizing weather-dependent behavior.

In the next two figures (14 and 15), the data are divided into weekday/weekend weather-dependent profiles corresponding to weekly building occupancy patterns. Weekdays were defined to begin on Mondays at 7 a.m. and end on Fridays at 9 p.m. Weekends began on Fridays after 9 p.m. and end on Mondays at 7 a.m. These figures contain four types of data. In the upper left graph the measured electricity use is shown plotted against average ambient temperature. In the upper right graph, the DOE-2 simulated data is shown. Below each scatter plot (parts (a) - monitored and (b) - calibrated) are box-and-whisker bin plots in parts (c) and (d) showing the whole building electric consumption as a function of temperature bins divided into 10° F segments. The measured data box-and-whisker mean in part (c) (the line connecting the boxes) is superimposed onto the calibrated base model box-and-whisker plot in part (d) to indicate the difference between the two means, and hence how well the model is calibrated.

Figure 16 is similar to the Figure 11 three dimensional graph, but breaks down the energy usage using weekly box-and-whisker plots instead of temperature bins with the measured data in Figure 16 (a) and the base model simulation in Figure 16 (b).

BUILDING DESCRIPTION

The 8,100 sq. ft. modular building is divided into 4 conditioned zones: 2 main classroom zones; 1 kitchen, office, and utilities zone; and 1 play area zone. An unconditioned plenum and an unconditioned crawl space are located above and below the 4 zones respectively. The daycare building is oriented on a North-South azimuth (the east walls face due East, the north wall faces due North, etc.) Figures 17 and 18 show the building orientation without shading and with shading surfaces provided by trees and buildings, respectively. A row of trees surrounds the building on the east, south, and west sides. A wall is located on the west and north side. Three photovoltaic solar collector arrays are mounted on the roof which provide moderate shading. Two horizontal window shades, one above each row, shade the south side windows. For shading simulation purposes, flat horizontal planes represent shading devices and vertical walls were used to represent buildings, walls, and trees.

Construction

The building walls are composed of typical prefabricated construction materials consisting of 5/8" interior gypsum board, R-13 batt insulation in the middle, 5/8" exterior gypsum board sheathing, and 1/2" light brown exterior face brick. Limited daylighting is provided by 1" tinted double pane insulating windows with venetian blinds on the ground level. The classroom side of the building has a raised ceiling with the upper north-facing walls containing 1" clear story untinted insulating windows for daylighting purposes. The roof is constructed with a reflective white roofing membrane, 1½" metal decking on steel beams, and R-30 batt insulation. The floor consists of carpeting and padding, 4" mesh reinforced lightweight concrete, and R-15.4 rigid insulation over a 3' crawl space. The crawl space floor contains gravel on top of a polyethylene vapor barrier.

Systems

The heating, ventilating, and air conditioning (HVAC) system includes 4 packaged single zone high efficiency air-cooled heat pumps, one for each zone (3 - 7½ ton units and 1 - 4 ton unit). Each heat pump is equipped with its own air-handler located in an equipment room. Conditioned air is distributed by supply and return ducts located in the plenum. Outside air is blended with conditioned air at each air-handler. Several exhaust fans are located throughout the building to maintain an air balance. A computer-controlled Energy Management System (EMS) controls the heat pumps and air handlers based on pre-programmed operating schedules and zone temperature night setbacks. The heat pumps are supplemented with electric baseboard heaters which are used when the heat pumps reach the maximum heating capacity.

According to the DOE staff, the EMS periodically fails to set back the thermostats. Therefore, a manual night set-back is being implemented during evening/morning lockup inspections. Since this is accomplishing the same thing that the EMS night set-back was designed to do the DOE-2 simulation included the setback.

The kitchen is equipped with 2 refrigerators, 2 freezers, 1 ice maker, a range, and several other typical kitchen appliances. Domestic hot water (DHW) is primarily supplied by a roof mounted solar DHW system which is capable of handling most of the hot water load. An electric DHW heater is available as a backup unit to meet the balance of the hot water load. Both the solar DHW storage tank and the electric DHW heater are located in an equipment room connected to the kitchen. A photovoltaic system is located on the roof which supplements the whole-building electric energy requirements by up to 6 kW at peak periods. The classrooms, kitchen, hallways, and offices are equipped with energy efficient 34 W fluorescent lights activated by motion sensors. Several emergency lights and exit signs are located throughout the building and remain on continuously. Exterior lighting is provided by 4 - pole-mounted 400 W and 12 - wall-mounted 175 W high intensity discharge fixtures controlled by photo sensors.

Occupancy

Typically, the building is occupied on weekdays by approximately 20 staff members and 60 children. A characteristic day begins at 7 a.m. and ends at 6:30 p.m., Monday through Friday. The HVAC system remains on until 9 p.m. to allow for after-hours work and a nightly inspection by maintenance crew. During afternoon hours, most classroom lights are turned-off during the children's nap time and are turned back on late in the afternoon.

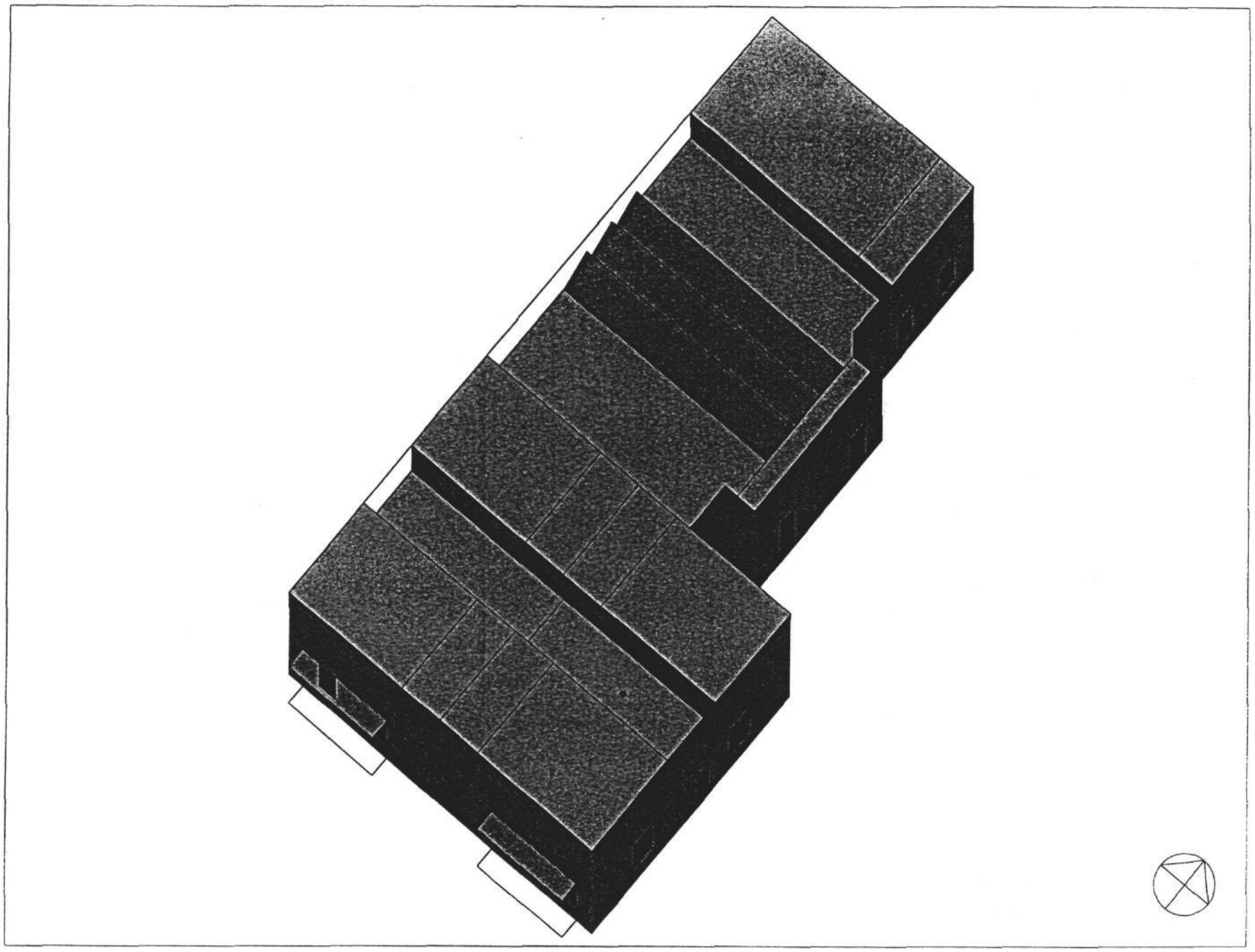


Figure 2 - DOE-2 Child Development Center model.

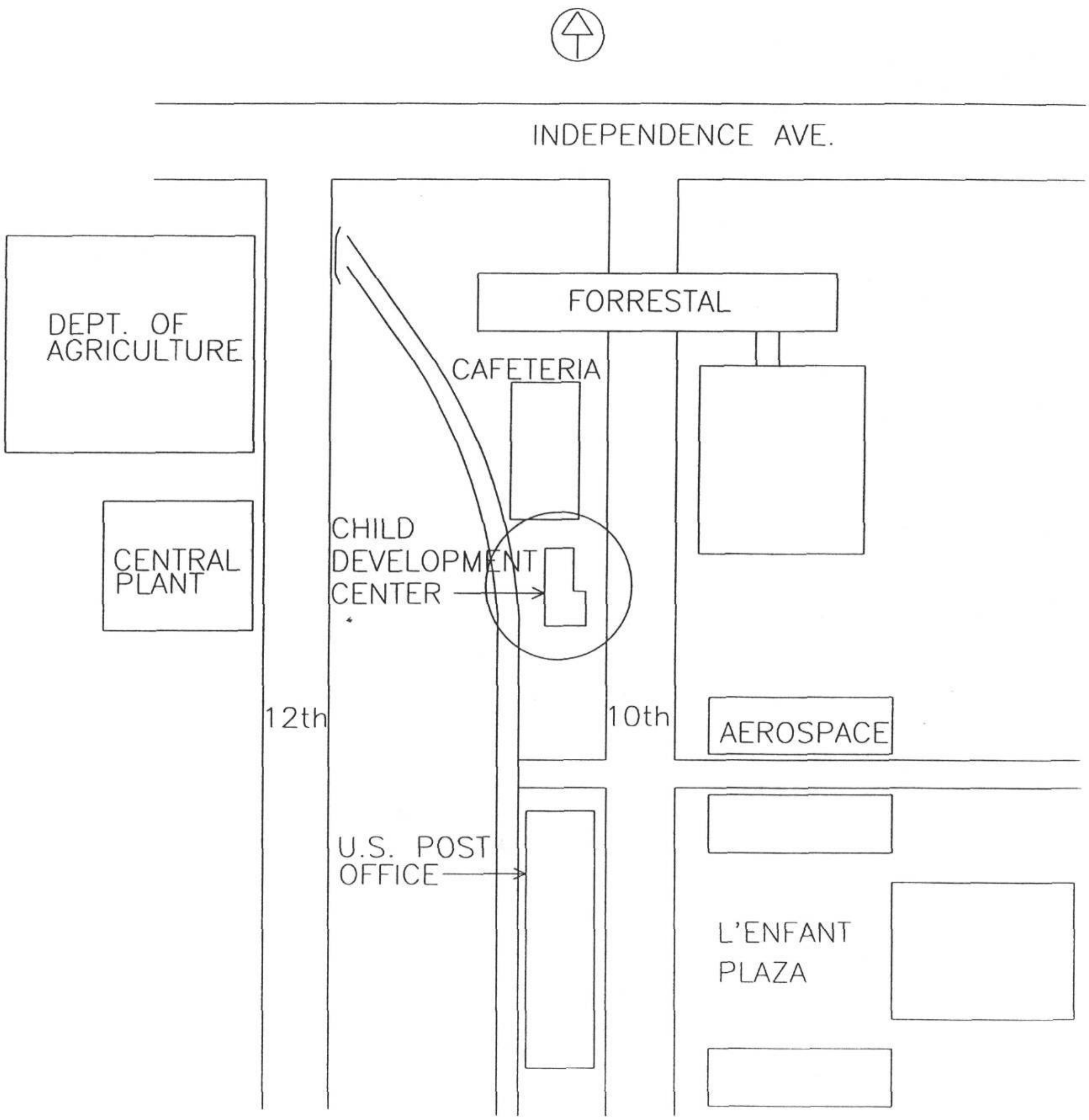


Figure 3 - Map of CDC and Surrounding Buildings.

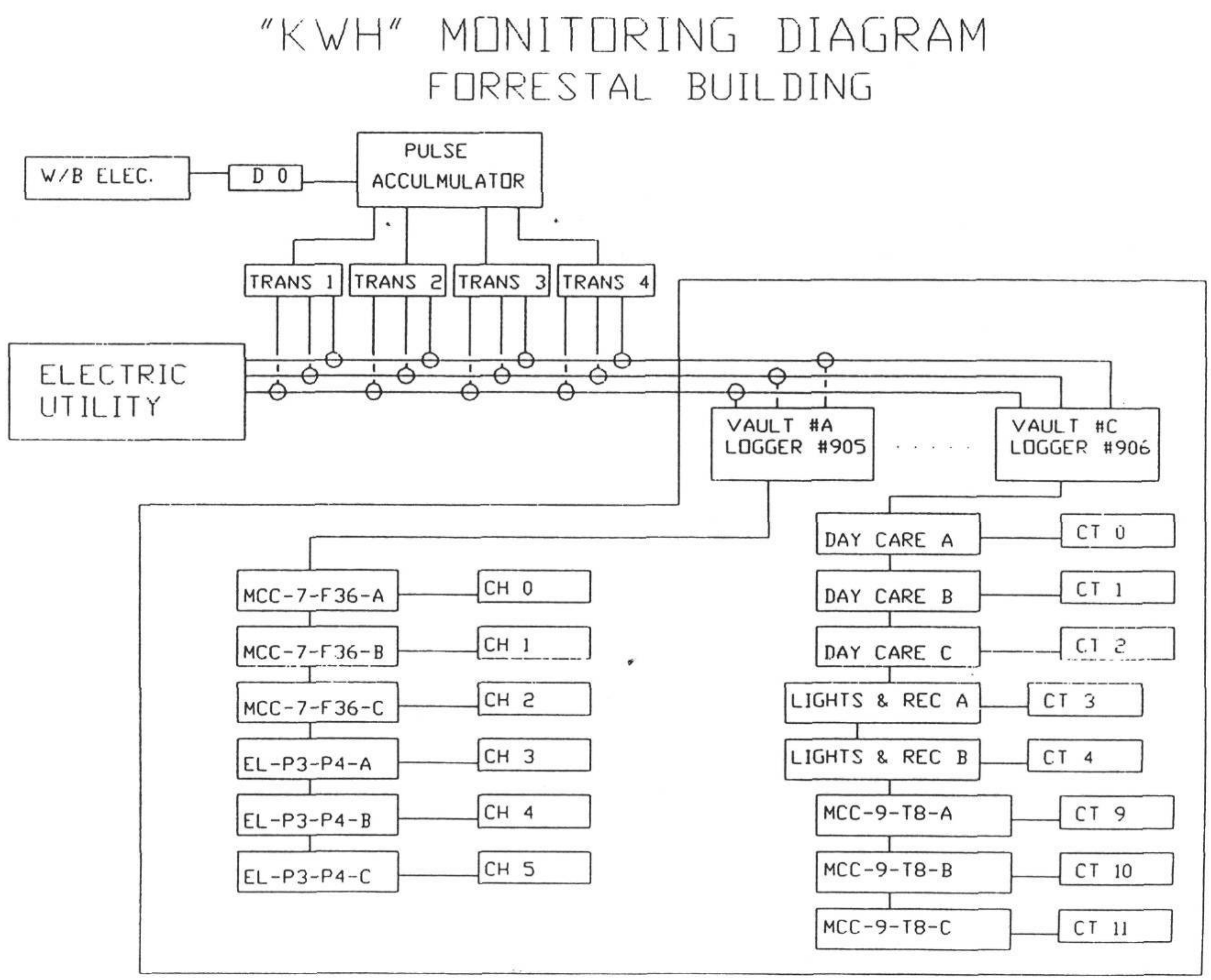


Figure 4 - Electrical Monitoring Diagram.

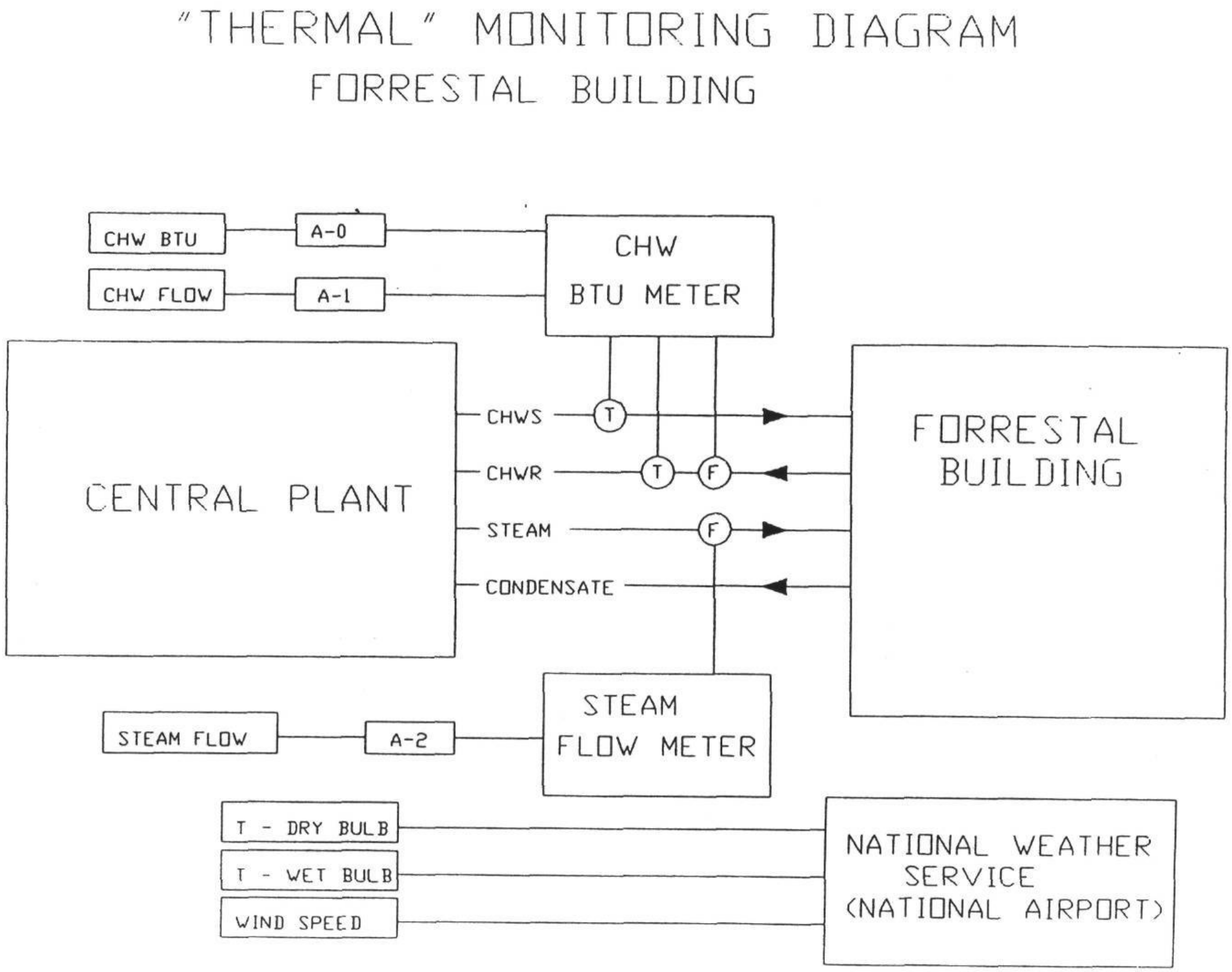


Figure 5 - Thermal Monitoring Diagram.

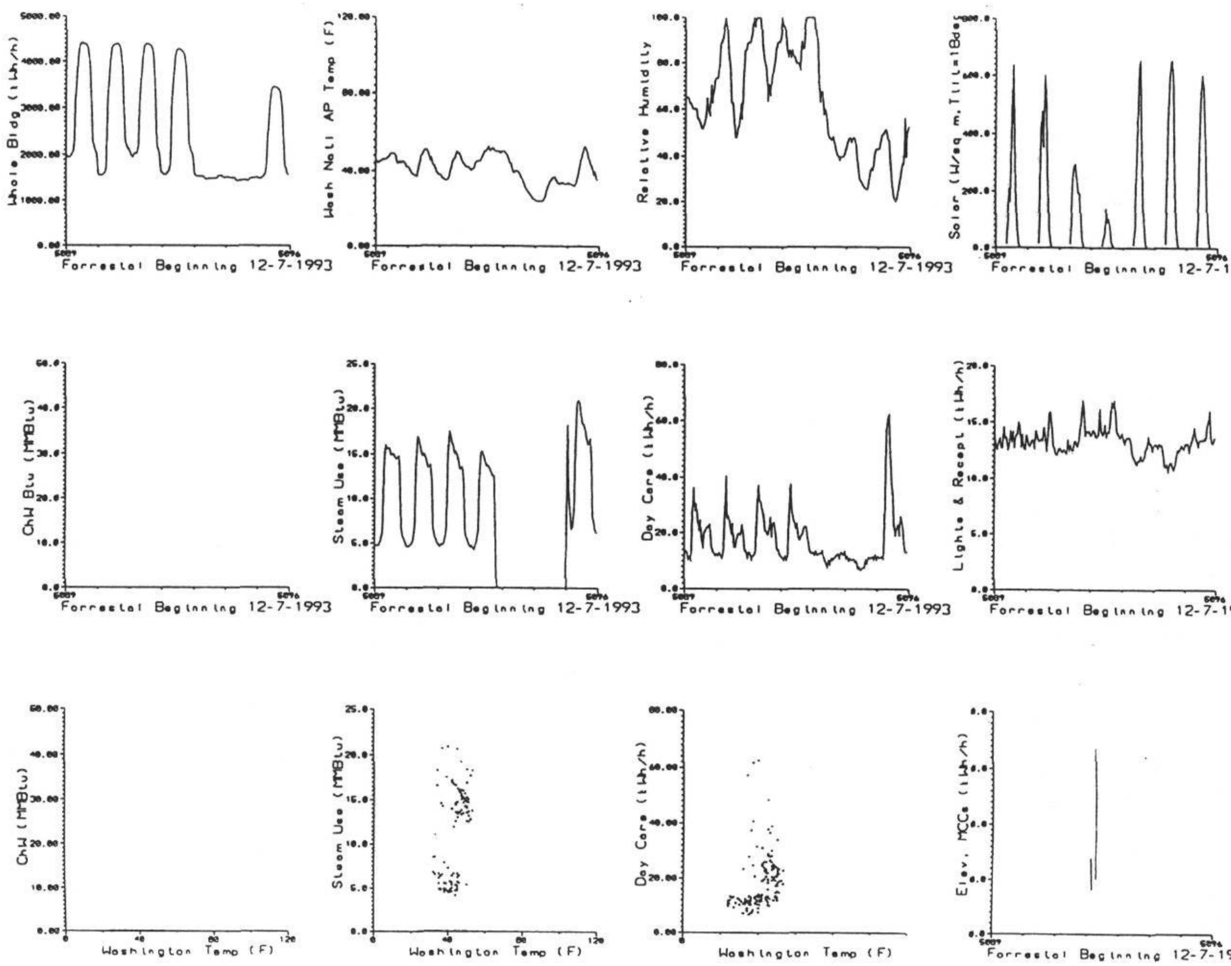


Figure 6 - Forrestal Weekly Summary Plot.

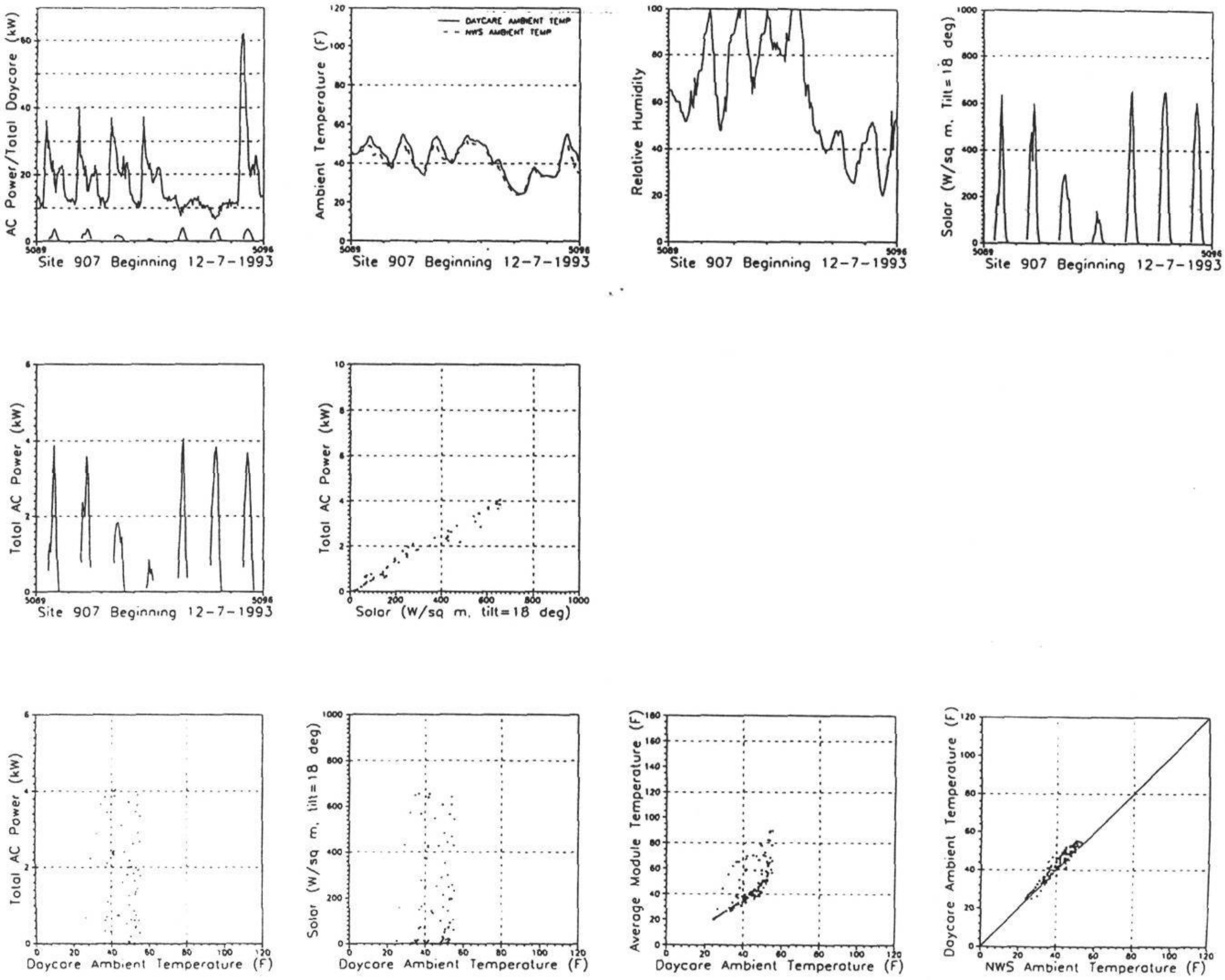


Figure 7 - CDC Weekly Summary Plot.

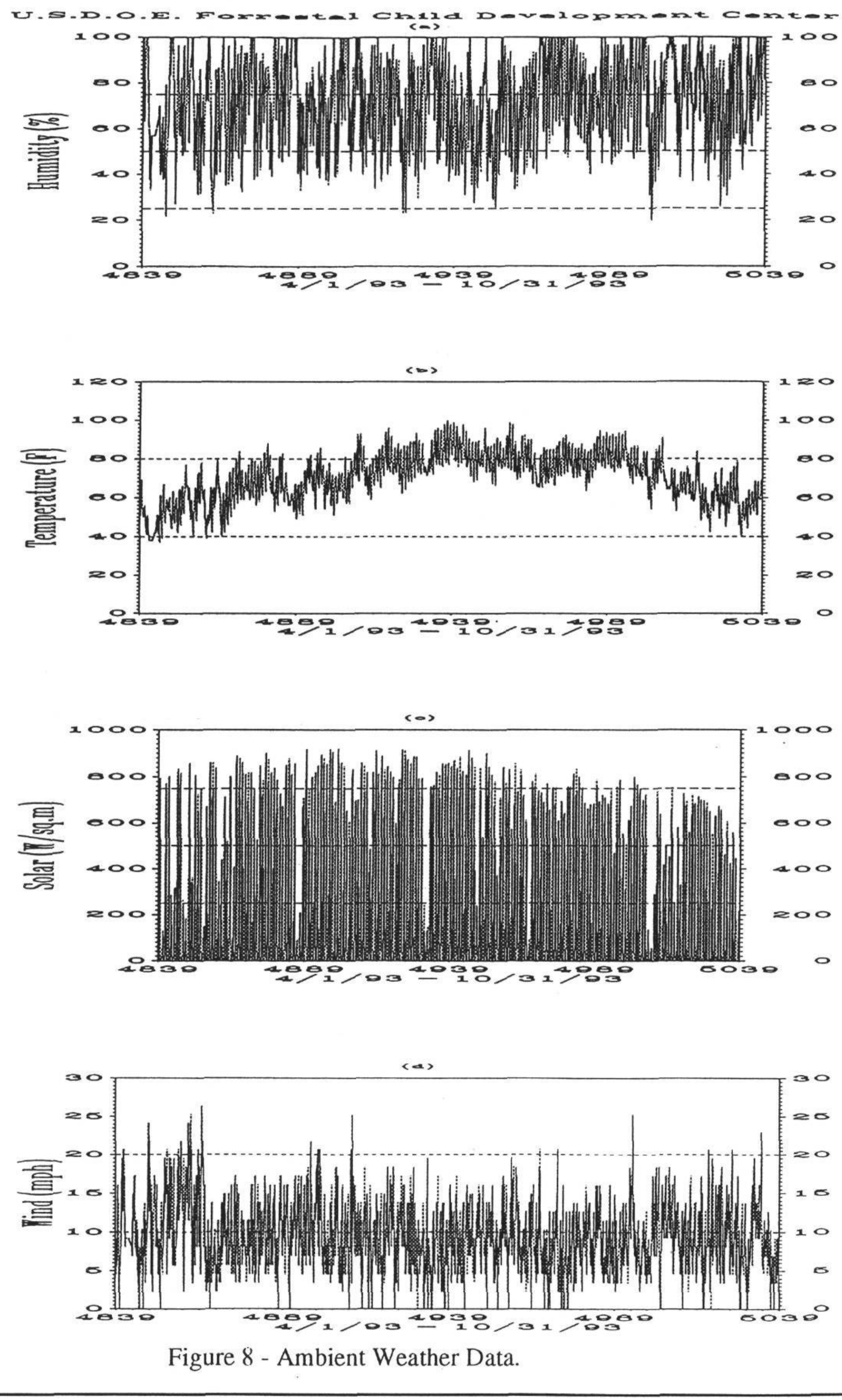


Figure 8 - Ambient Weather Data.

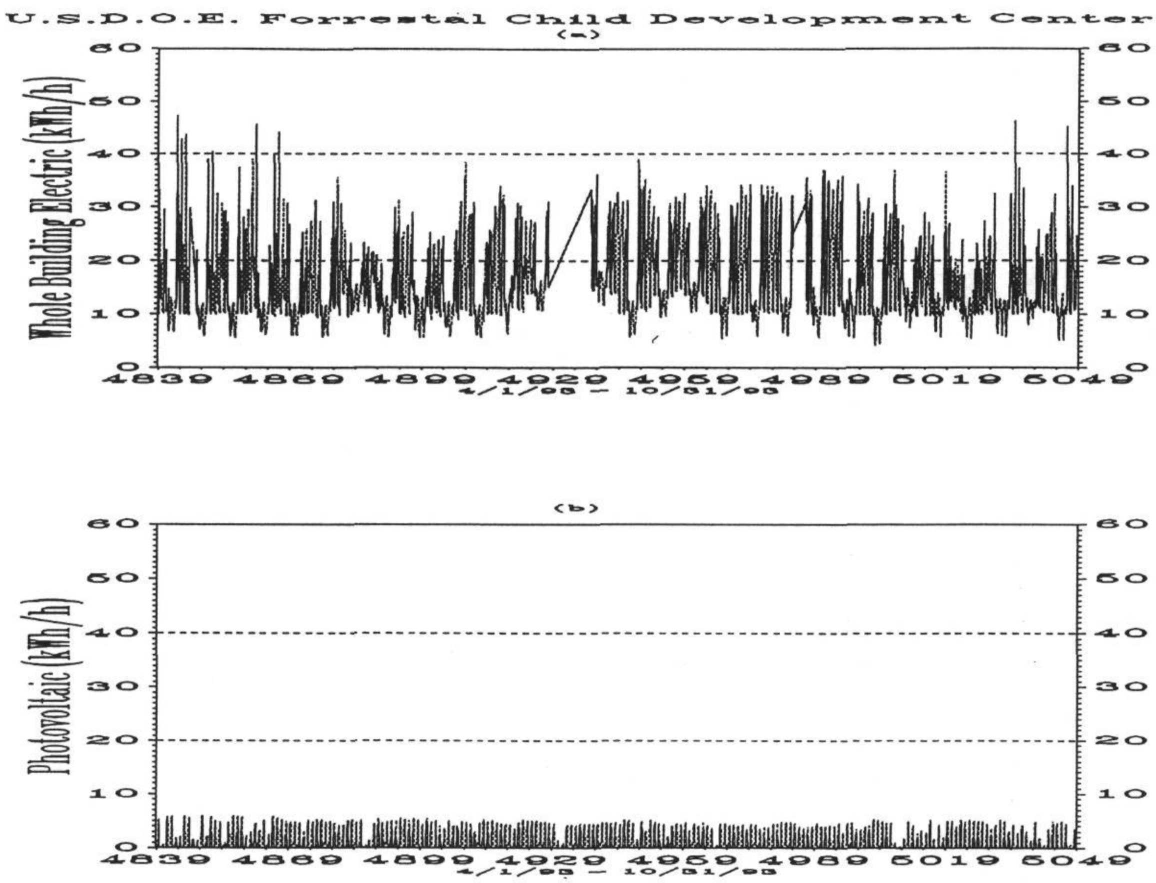


Figure 9 - (a) Whole Building Electric. (b) Photovoltaic.

	Input Deck Summary Page		
Run Name:	Daycare21	**Remarks:**	Calibrated as-built baseline model

LOADS				**Weather File:**	Washngtndctmy.wth	
Exterior Envelopes						
Roof	Refl. membrane, metal deck, insulation: U=0.033, Absorp. = 0.5					
Walls	Face brick, sheathing, insulation, gyp. board: U=0.068, Absorp. = 0.85					
Window and Glass Doors						
SC= 0.71		External Shading Devices:		Shade over South windows; buildings; trees		
People	10/zone (2 children/adult)					
Sensible - (Btu/h-person)	250					
Latent - (Btu/h-person)	200					
Schedule:	7am - 0.1, 8am-7pm - 0.9, 8pm - 0.05, 9pm-6am - 0.0					
Infiltration						
Zone ->	**1**	**2**	**3**	**4**		
air changes per hour	0.6	0.6	0.6	0.6		
Lights (tot W)	3,002	3,383	5,704	1,790		
Recept. & Equip. (tot W)	0	0	4,794	0		
Floor Weight (lbs/ft^2)	30	30	30	30		

SYSTEMS		**TYPE:**	Package Single Zone Air Cooled Heat Pump			
Heating Capacity (Btu/h) :			**Cooling Capacity (Btu/h) :**		**EER (sum)**	**EER (win)**
Zone 1	85,000		Zone 1	90,000	10.6	10.2
Zone 2	85,000		Zone 2	90,000	10.6	10.2
Zone 3	85,000		Zone 3	90,000	10.6	10.2
Zone 4	42,000		Zone 4	46,000	10.0	8.3
CFM						
Zone ->	**1**	**2**	**3**	**4**		
Supply Air	1,801	2,082	2,285	1,330		
Exhaust Air	585	490	591	345		
Outside Air	580	500	700	315		
Thermostat Type:	Two position (controlled by EMS)					
Throttling Range:	4 F	**Setpoint:**	74 F (summer), 72 F (winter)			
Night Setback:	80 F (summer), 55 F (winter)					
			Sizing Option:	Adjust loads		
Humidity Control:	No					

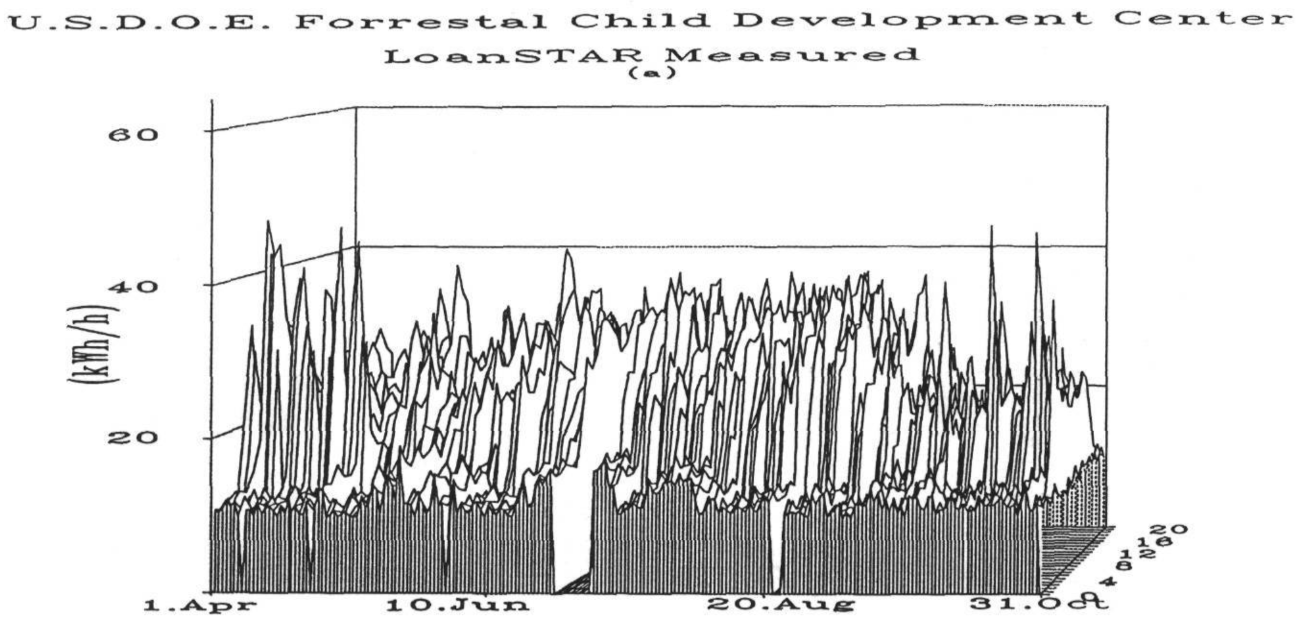
	PLANT
Source:	Electricity

Table 2 - DOE-2 Input Deck Variables.

	Measured	Simulated	Difference	Percent Difference
April	10716.7	10177.9	-538.8	-5.0%
May	10675.0	10256.2	-418.8	-3.9%
June	11731.5	12143.3	411.9	3.5%
July (1)	13200.9	14412.4	1211.5	9.2%
August	13515.4	14034.3	518.9	3.8%
September	11240.9	11721.3	480.4	4.3%
October	10619.7	10462.5	-157.2	-1.5%
Total	81700.1	83207.8	1507.7	1.8%

(1) Data for the period 6/29 - 7/8 was missing and filled in with an estimate based on typical hourly summer usage.

Table 3 - Monthly Measured and Simulated Comparison.



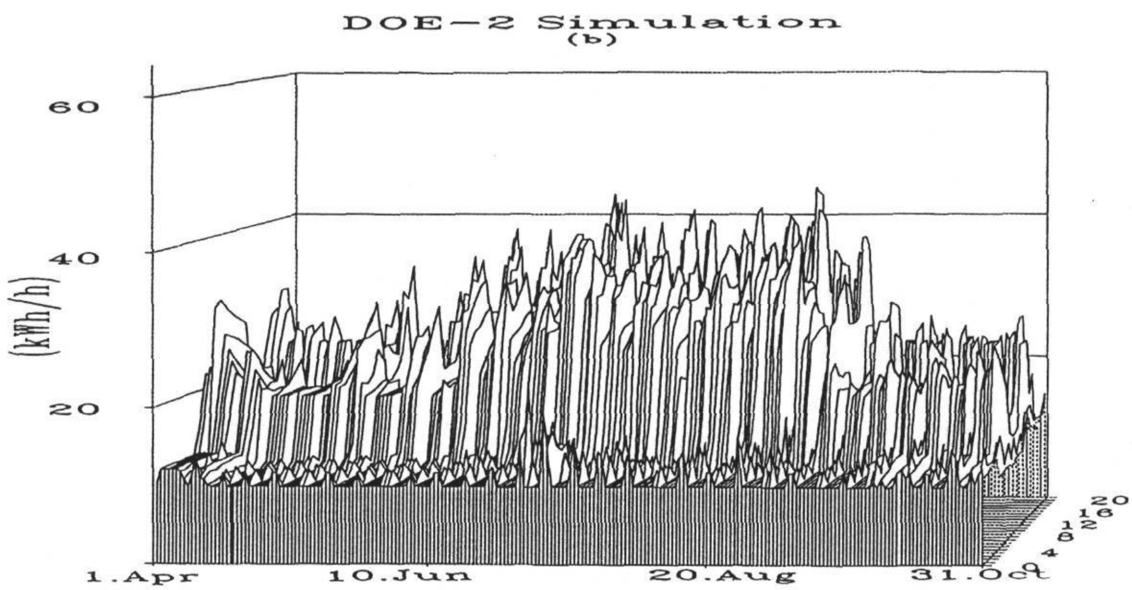


Figure 10 - Three-dimensional Monitored and Simulated Data.

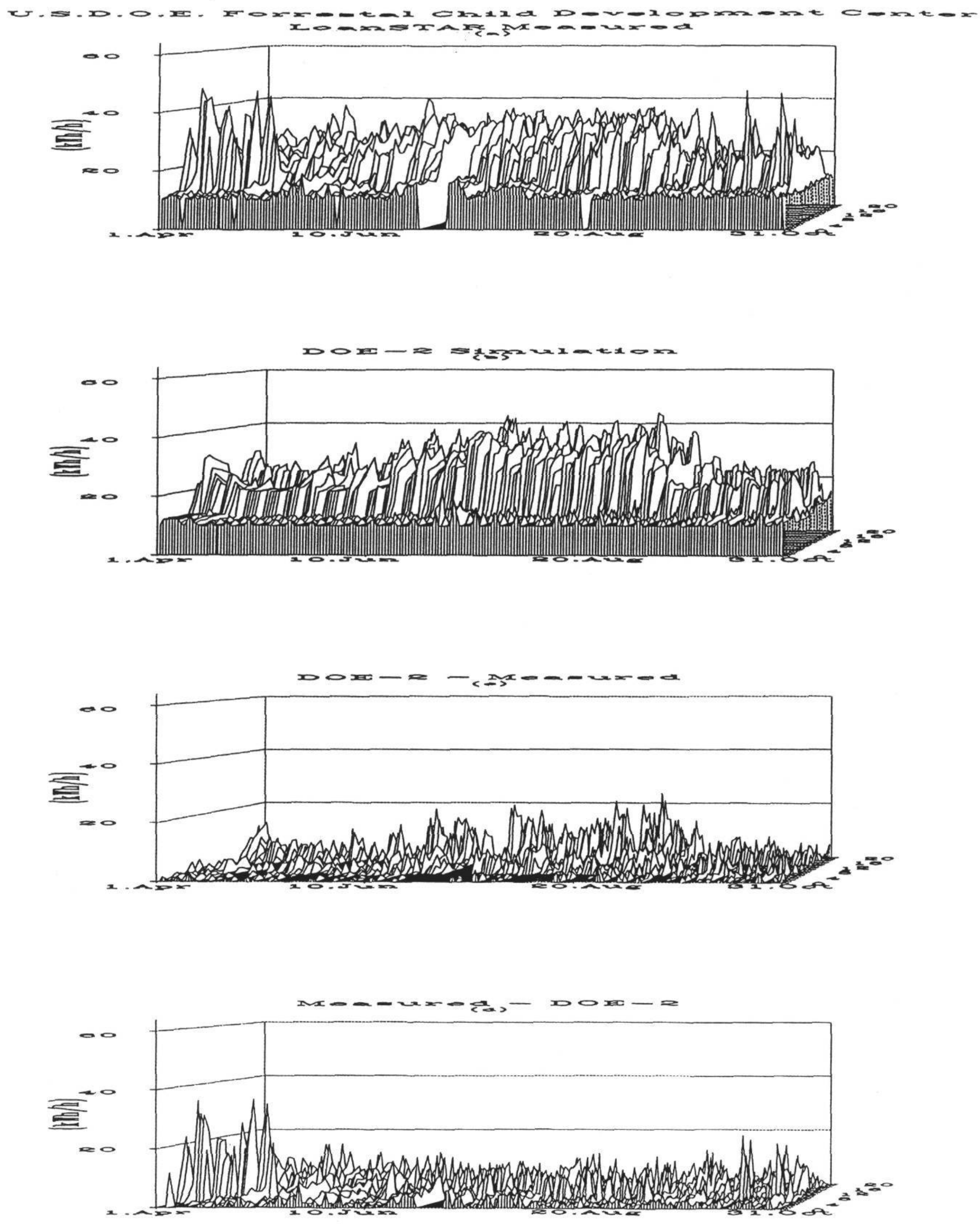


Figure 11 - Three-dimensional Monitored and Simulated Residual Data

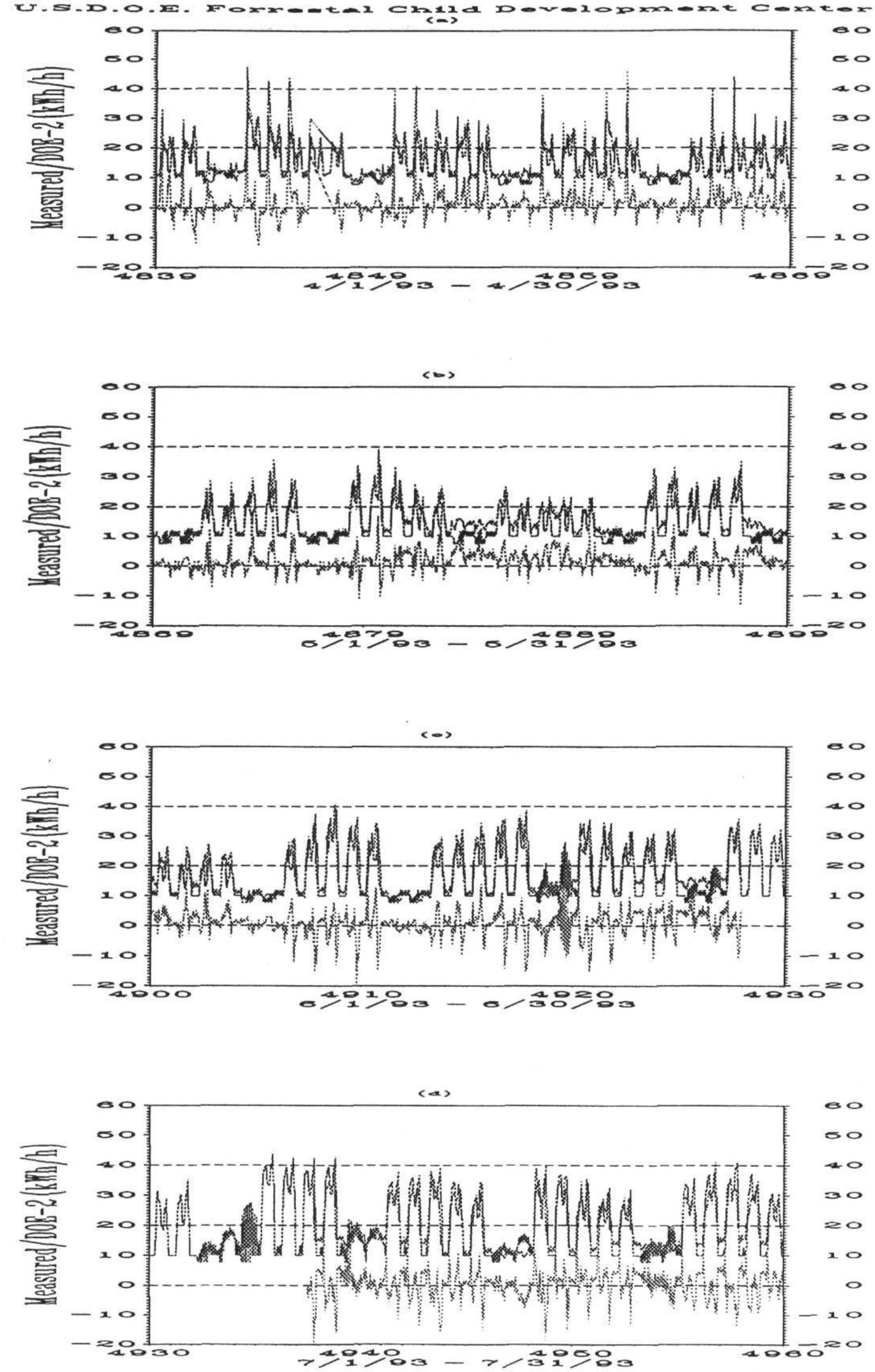


Figure 12 - April - July Monitored and Simulated Comparison.

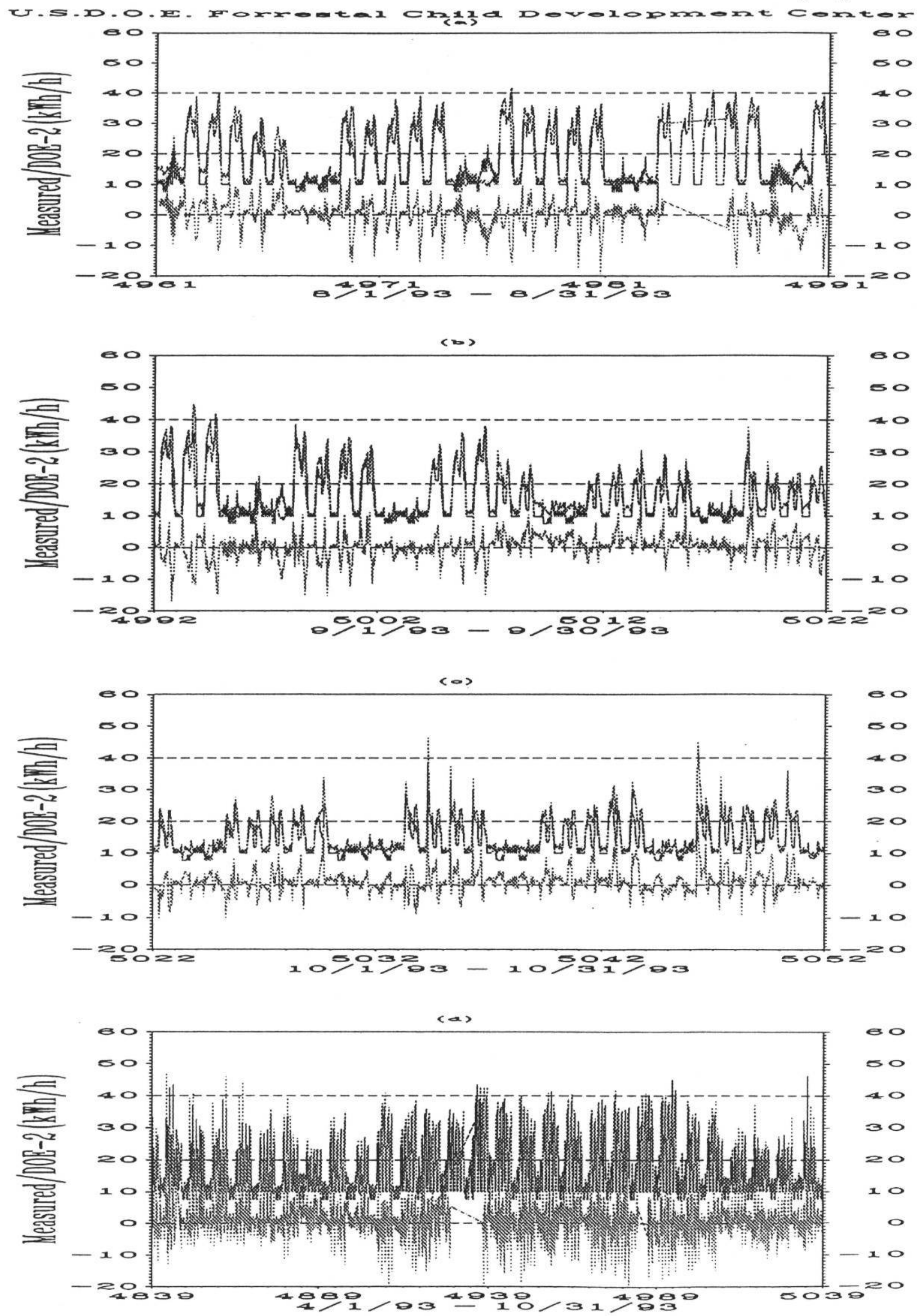


Figure 13 - August - October and Total Monitored and Simulated Comparison.

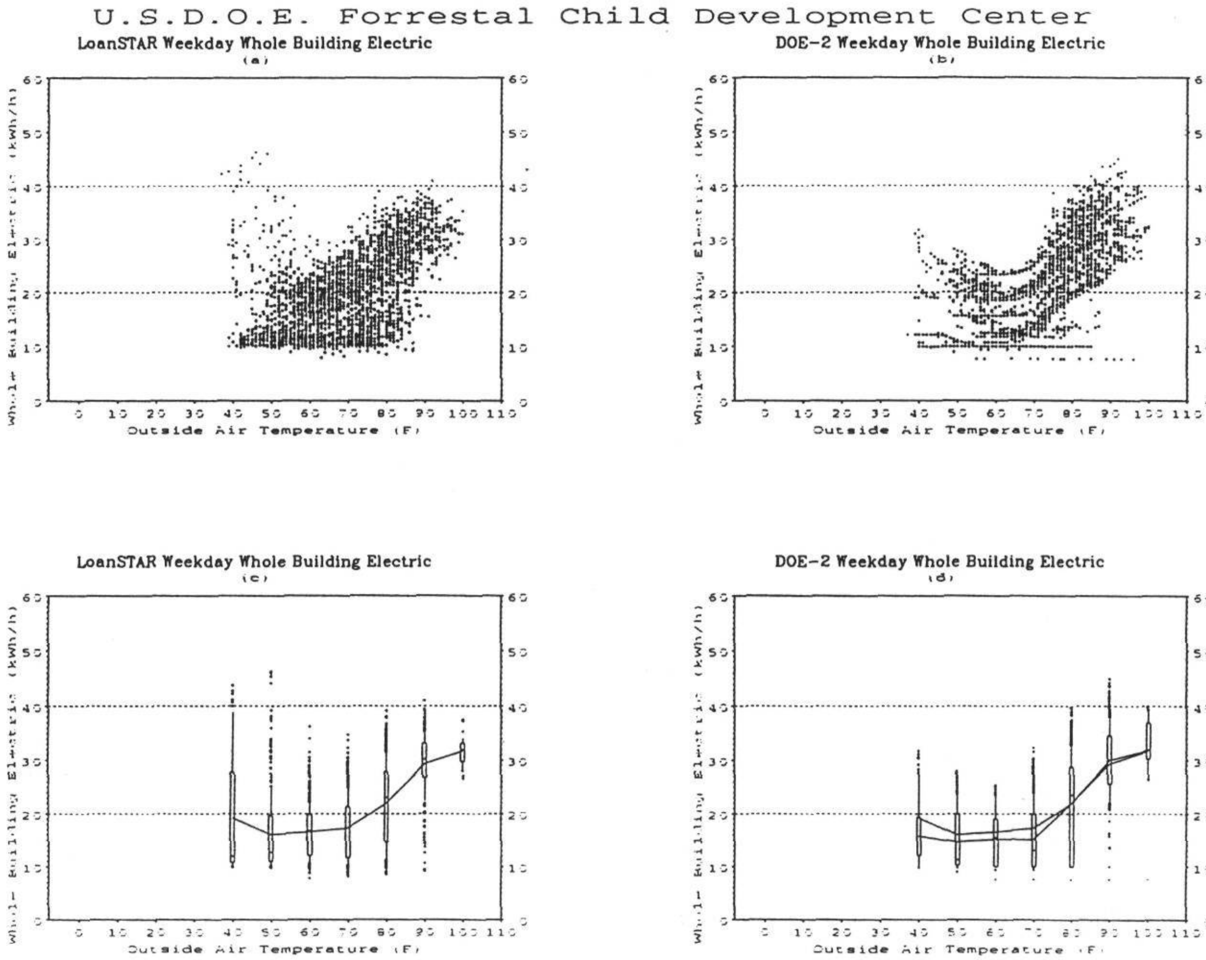


Figure 14 - Weekday Measured and Simulated Scatter Plots and Box-and-Whisker Plots

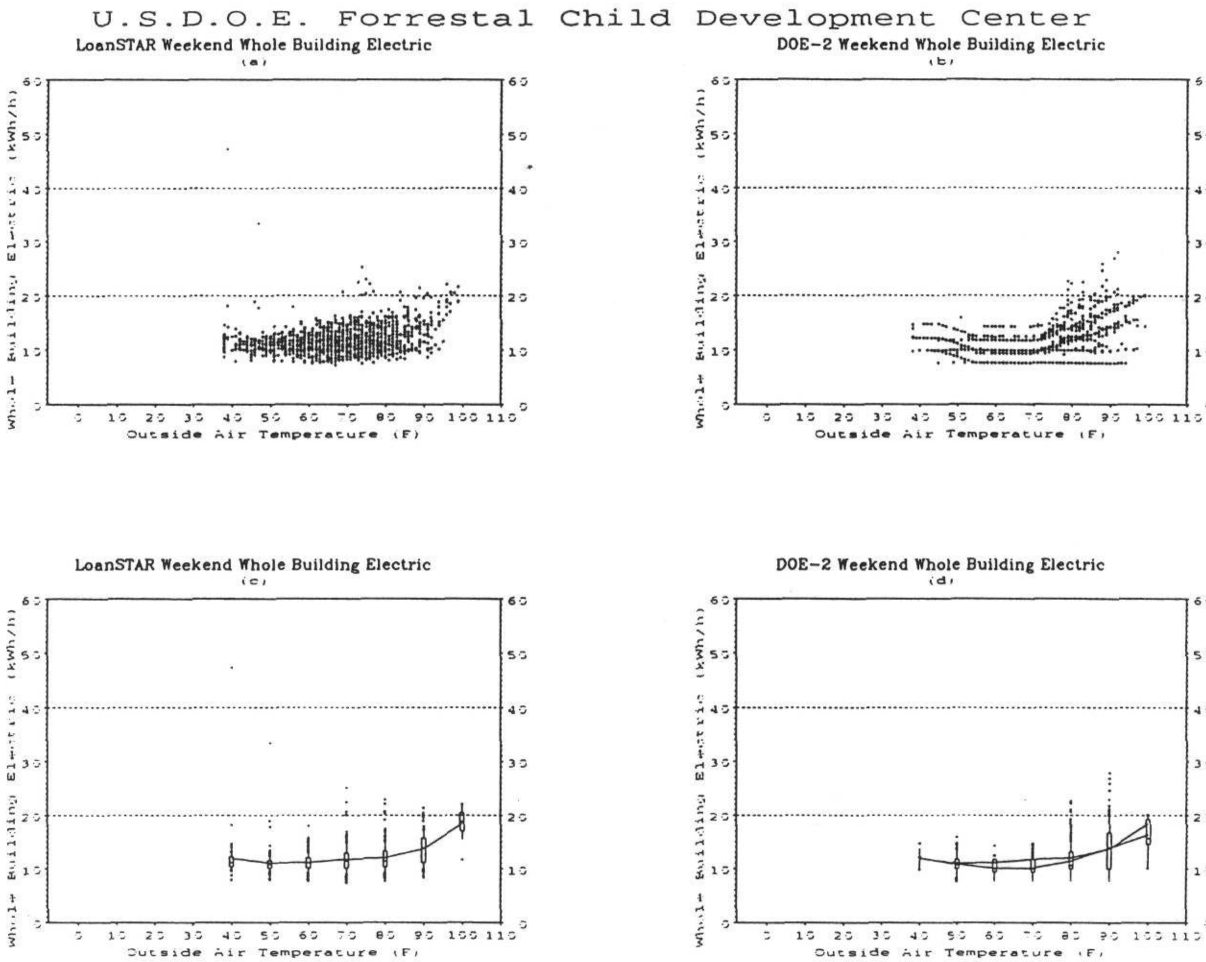


Figure 15 - Weekend Measured and Simulated Scatter Plots and Box-and-Whisker Plots

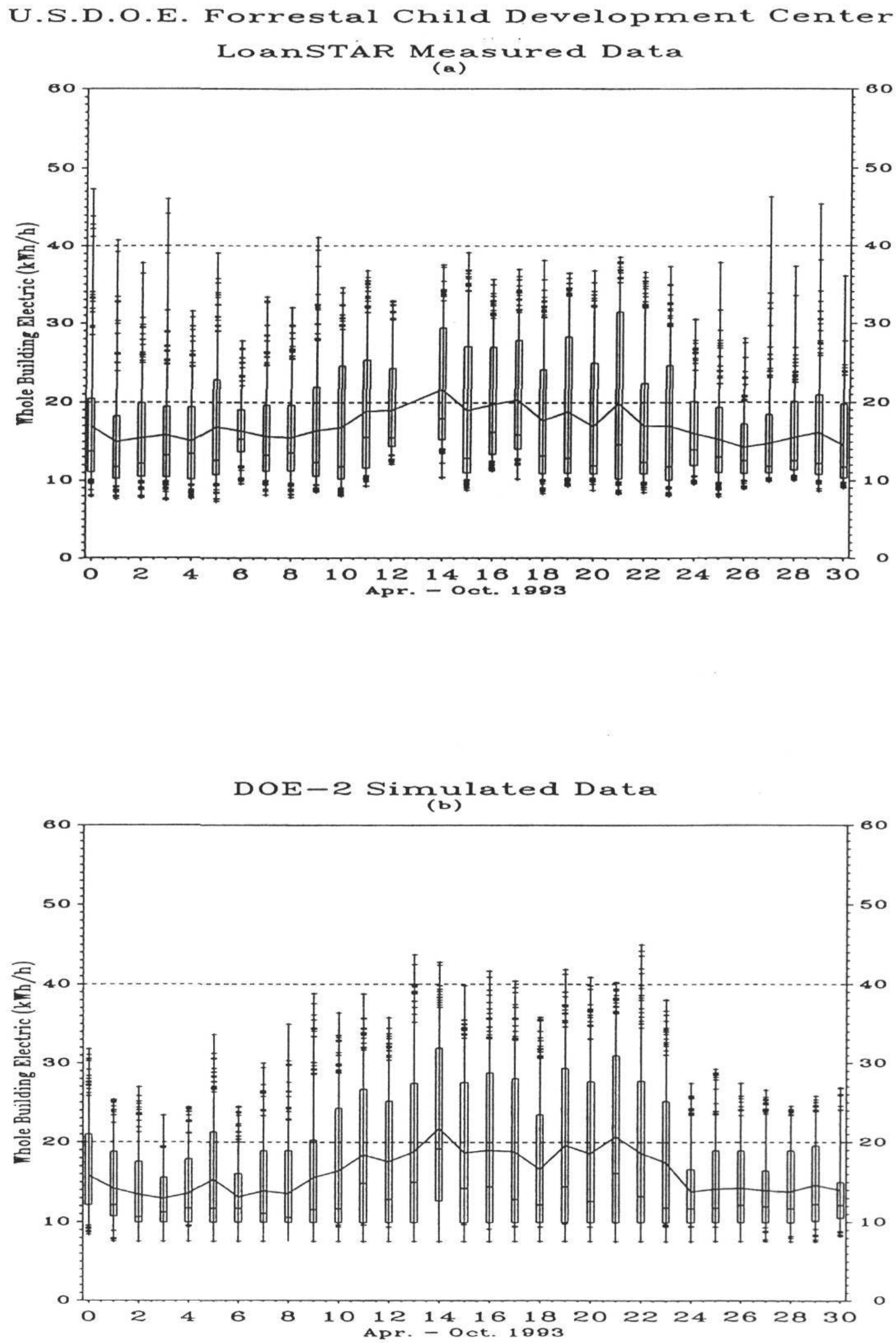


Figure 16 - Weekly Measured and Simulated Box-and-Whisker Plots

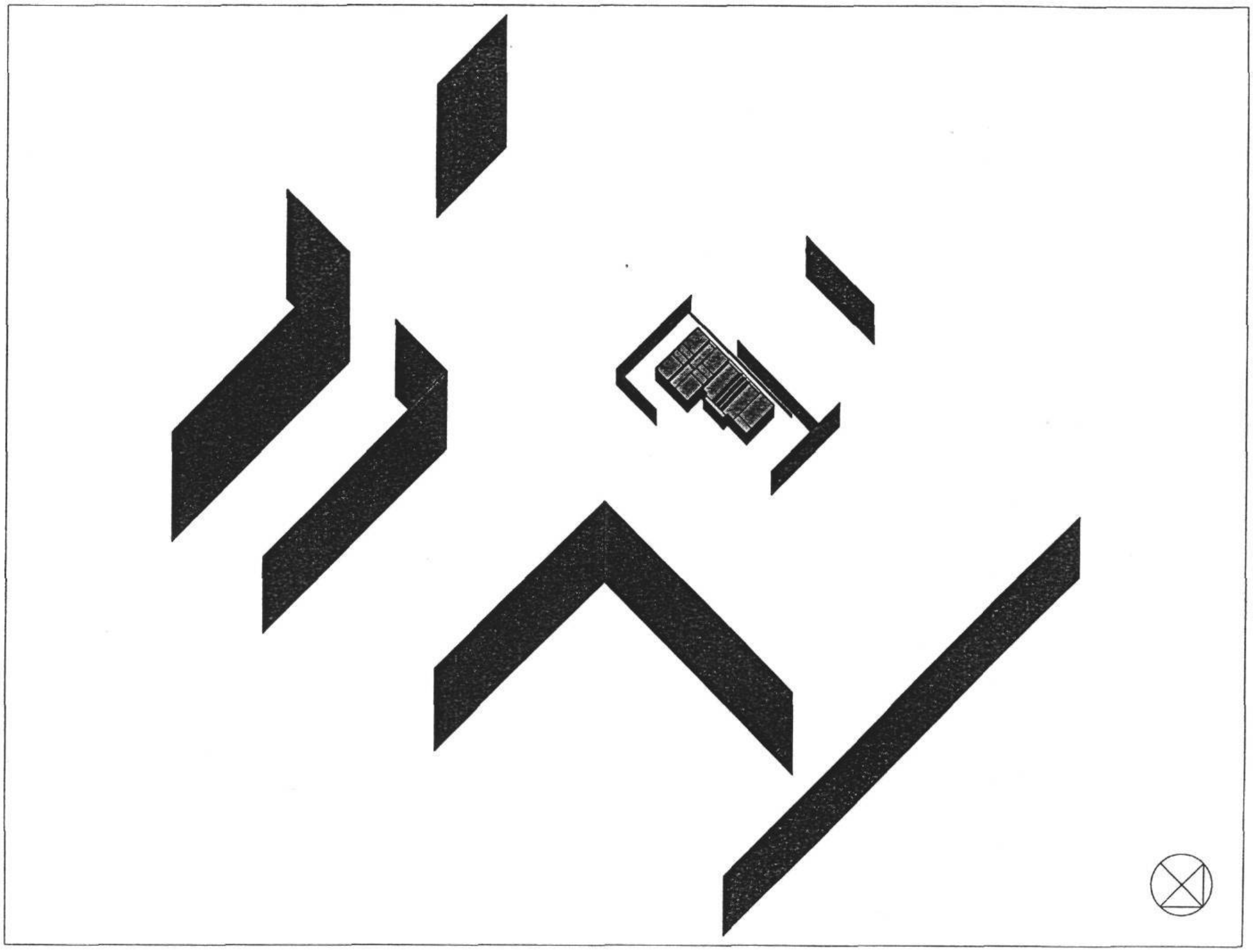


Figure 17 - CDC Building With Shading

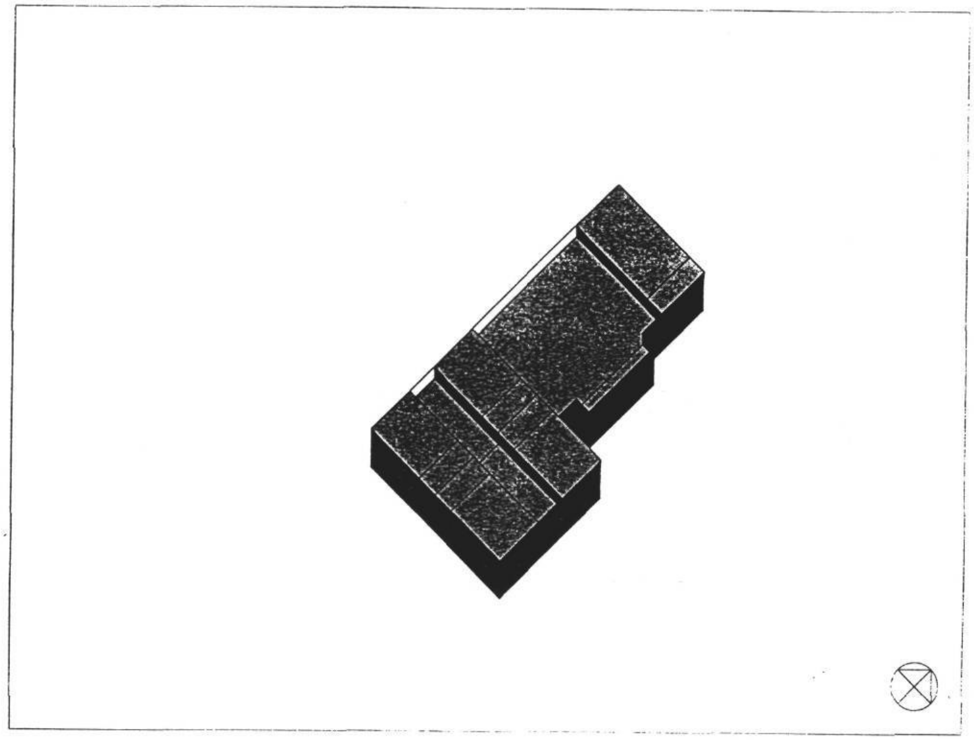


Figure 18 - CDC Building Without Shading

RESULTS

Table 4 is a list of the baseline installed ECO features provided by the GSA architect and standard (w/o ECO) comparisons. A calibrated DOE-2 simulation was used to test each individual ECO over a one year period using the Washington, D.C. TMY (Typical Meteorological Year) weather tape and compared to original architectural savings estimates. A one year base model was run and used as a baseline energy consumption starting point. This model used the same input deck that was calibrated to the 7 months of measured data. In effect, the calibrated model represents the "as-built" building with all the ECOs. The DOE-2 input deck was then modified, one ECO at a time, to determine what the energy use would have been without the ECOs. For each comparison, the ECO parameter in question was changed to the non-ECO value provided by either the architect, or the PEPCo reference value. The annual energy consumption was then measured against the base model and the difference compared to the original estimates. A percent difference was then calculated and tabulated in Table 5 (which is reported from Table 1).

ECO Description

Figure 19 (a) is a bar graph of all the ECO comparisons with architectural savings estimates. Figure 19 (b) shows the electricity end use with and without ECOs, as simulated by DOE-2 (both graphs are reported from Figure 1).

The first energy-efficient feature is the installation of 34 W efficient fluorescent lighting instead of standard 40 W fluorescent lamps. The 34 W lamps are located in each zone for main lighting and used in the base model. The number of fixtures was based on the architectural plans and a total wattage was calculated per zone. For the comparison model, 40 W lamps using metal-core 40 W ballasts were substituted for 34 W lamps and an annual simulation performed. According to DOE-2, the lights are actually saving 40.8% more than the GSA architect predicted.

The next conservation measure evaluated was the installation of a photovoltaic system to supplement whole-building electric usage. This savings verification did not utilize DOE-2. In order to calculate the annual savings from the photovoltaic array, several processing steps were required. First, hourly electricity produced by the photovoltaic array were recorded and compared to the available global horizontal solar radiation data. Then, a quadratic curve fit was calculated as shown in Figure 20. In a separate procedure, 1 year of hourly global horizontal radiation was extracted from the Washington, D.C. TMY weather tape. This radiation data, in turn, was used in conjunction with the curve-fit equation to calculate photovoltaic generation for

1 year which was then summed for comparison to the proposed photovoltaic savings estimates. The existing photovoltaic system, according to this procedure, saves 4.6% more than the architectural estimates. Two interesting features were noted about the photovoltaic system. First, prior to March 1993, half of the photovoltaic system electricity production was not occurring because one of the breakers had tripped on the inverters. Second, shading by nearby trees seems to be decreasing the output above 4 kW. This effect diminishes in the fall when the leaves drop off the trees. Hence, the bimodal pattern in Figure 20.

A computerized Energy Management System was put in place to optimize heat pump operation and air handlers. The base model was run with the parameters such as set-point temperatures, and operations schedules made available from a computer print-out from the EMS system. The DOE-2 standard verification run assumed that the HVAC system is allowed to operate under thermostat control at any time of the year, i.e. 24 hour-per-day operation. DOE-2 predicts that the Energy Management System actually saves 460.1% more that originally stated (only an annual savings estimate was available from the architect; no indication was given as to what conditions the architect assumed).

The original savings calculations for the lighting controls and dimmers were based on the dimmers theoretically reducing light levels by 30 - 40%. This ECO could not be verified since DOE personnel confirmed that dimmers had not been installed. The occupancy sensors, on the other hand, have been installed, but could not realistically be simulated due to unpredictable zone utilization.

The fifth energy conservation option is the installation of additional insulation in the roof and wall, an air-lock at the main entrance, and shading devices at the south-side windows. Roof insulation, as installed, is R-30 batt insulation. This is to be compared to standard R-18 batt insulation. Wall insulation was improved from R-11 batt insulation to R-13 batt insulation. The effect of the main entrance airlock was estimated by simulating for infiltration by setting the base model to 0.6 air changes per hour per zone representing a "tight" building. The savings were simulated by assuming a "loose" building and setting the air leakage to 1.0 air change per hour per zone. The south-side windows are shaded by overhangs which are accounted for in the base model with shading planes. To simulate the savings, the overhangs were omitted from the input deck for the non-ECO option. The savings comparison shows that these combined features save 41.9% less than originally predicted.

Clear-story windows were added to the north-side raised ceiling walls above the classroom areas to provide daylighting. The base model included them as per architectural and manufacturer specifications. They were removed from the model and replaced with equivalent walls to simulate savings. The results revealed that the building actually looses energy as a result of the windows being there to the tune of 120.6% less than the GSA architectural calculations.

The seventh feature is the installation of high efficiency air-cooled heat pumps with a higher EER than standard heat pumps. Manufacturer catalogs were obtained and EER values were detailed in the input deck for the base model. For the standard comparison model, the standard EER reference values provided by PEPCo were used. The difference shows that the installed higher efficiency heat pumps save 42.4% less than originally calculated.

The solar DHW system savings was verified using the F-CHART program instead of DOE-2. By applying the solar DHW system manufacturer specifications, the program estimated annual DHW energy consumption as well as annual solar system contribution. This was then compared to estimated savings calculated by the National Renewable Energy Laboratory (NREL) using F-CHART. The initial GSA savings estimate was inaccurate since an incorrect value was extracted from the NREL F-CHART analysis and published as potential savings (i.e., the original estimate incorrectly used the total DHW requirements in place of the solar system contribution). A verification F-CHART run was compared to the original F-CHART run, however the corrected value was used for comparison and tabulated. The results (when compared to the corrected F-CHART run) were quite good with the solar system actually providing only 4.2% less than originally predicted. The operation of the solar DHW was confirmed by the DOE personnel.

Finally, the base model was compared to a run made with all ECOs removed simultaneously. The total energy consumption revealed that the existing building saves 15.9% less than originally anticipated. This is somewhat skewed, however, by the large underestimation originally made for ECO number 3.

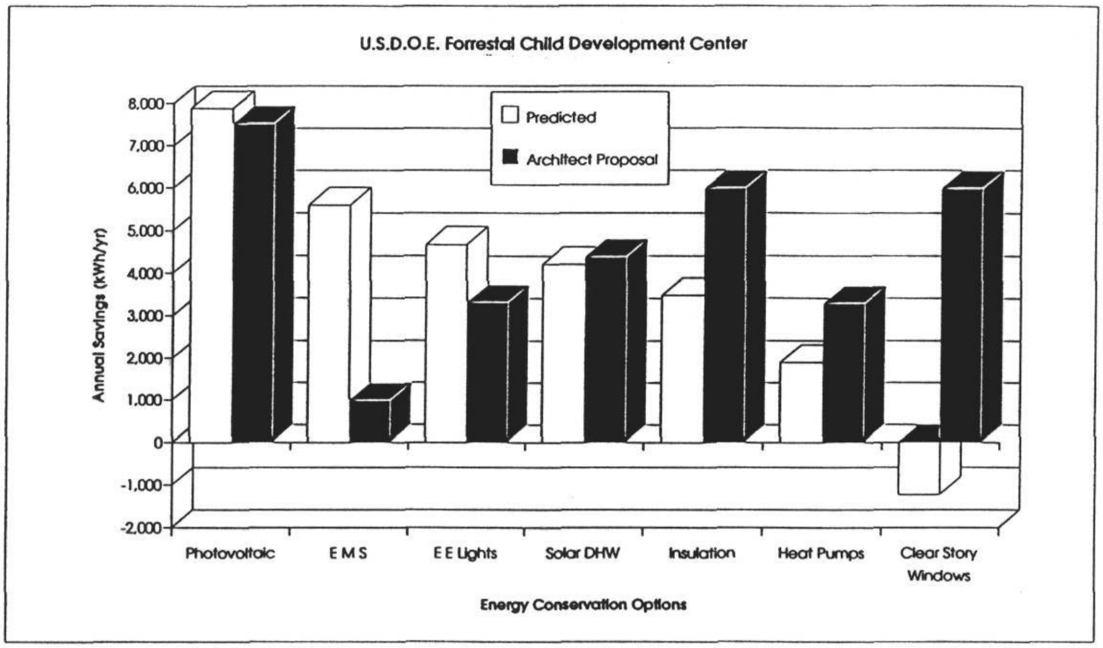
ENERGY CONSERVATION OPTION	BASELINE	STANDARD (W/O ECO)	COMMENTS
Energy Efficient Lighting	Energy efficient 34 W lamps (fluorescent) Architect proposed value	Standard 40 W lamps (fluorescent) Pepco recommended baseline	1 DOE-2 run with either option
Photovoltaic	Use measured data, curve-fit to TMY weather	No photovoltaic	Verification independent of DOE-2
EMS	Schedule Heat Pumps according to on/off period and temperature	T'stat control only (fans on 24 hrs/day)	1 DOE-2 run with either option
Lighting controls	Dimmers (not installed according to Daycare personnel)	No dimmers	No simulation performed
Insulation, airlocks, South Shading	Roof - R-30 Walls - R-13 Tight Bldg - 0.6 ach Shading over South windows	Roof - R-18 Walls - R-11 Loose Bldg - 1.0 ach No shading over South windows	1 DOE-2 run with options combined
Clear story Windows	Add to BDL	Replace with equivalent walls	1 DOE-2 run with either option
Heat Pumps	3 @ 10.6 EER summer 1 @ 8.9 EER summer 3 @ 10.2 EER winter 1 @ 10.0 EER winter	3 @ 8.3 EER summer 1 @ 8.3 EER summer 3 @ 8.3 EER winter 1 @ 8.3 EER winter	Baseline values based on manuf data/ Standard values from Pepco rebate form
Solar DHW System	Solar prediction with F-CHART	No solar; 80 gal/day	F-CHART prediction
All ECO's combined	All above features installed	No ECO's installed	1 DOE-2 run with either option

Table 4 - Baseline And Standard ECO Features

U.S.D.O.E. Forrestal Child Development Center						
	Energy Conservation Option	DOE-2 Basemodel "as-built" (kWh)	DOE-2 Predicted w/o ECO (kWh)	DOE-2 Predicted Savings (kWh)	Architectural Proposal (kWh)	Percent Difference (7)
1.	Energy Efficient Lights	151,852	156,539	4,686	3,328	40.8%
2.	Photovoltaic Generation (1)	-7,880	0	7,880	7,530	4.6%
3.	Energy Management System (2)	151,852	157,453	5,601	1,000 (est)	460.1%
4.	Lighting Controls & Dimmers (3)	-	-	-	-	-
5.	Insulation, Airlock, South Shading	151,852	155,340	3,488	6,000	-41.9%
6.	Clear Story Windows	151,852	150,615	-1,237	6,000	-120.6%
7.	Improved Heat Pumps	151,852	153,754	1,902	3,300	-42.4%
8.	Solar Hot Water (4)	2,345	6,565	4,220	4,407 (6,033 is incorrect)	-4.2%
	All ECO's Combined (5)	146,317	166,559	20,242	-	-
	Total		(6)	26,540	31,565	-15.9%

(1) Difference was determined by a curve fit equation comparing photovoltaic generation as a function of global horizontal radiation. Global horizontal radiation was extracted from a Washington, D.C. TMY weather tape. DOE-2 was not used for this verification.
(2) According to U.S.D.O.E. personnel, the HVAC system is manually operated each day. The 1,000 kWh savings by the GSA architect were based on engineering judgement.
(3) According to U.S.D.O.E. personnel, the dimmers were not installed.
(4) Savings was determined by F-chart. The value of 6,033 as specified in the original estimate is incorrect.
(5) Not part of original ECO list. Calculated by: (Basemodel + photovoltaic + dhw)
(6) Savings total does not include "All ECO's Combined."
(7) The percent difference was calculated as follows: ((DOE-2 savings - architect proposal) / architect proposal) x 100

Table 5 - Comparison Of Energy Conservation Options To Savings Predictions



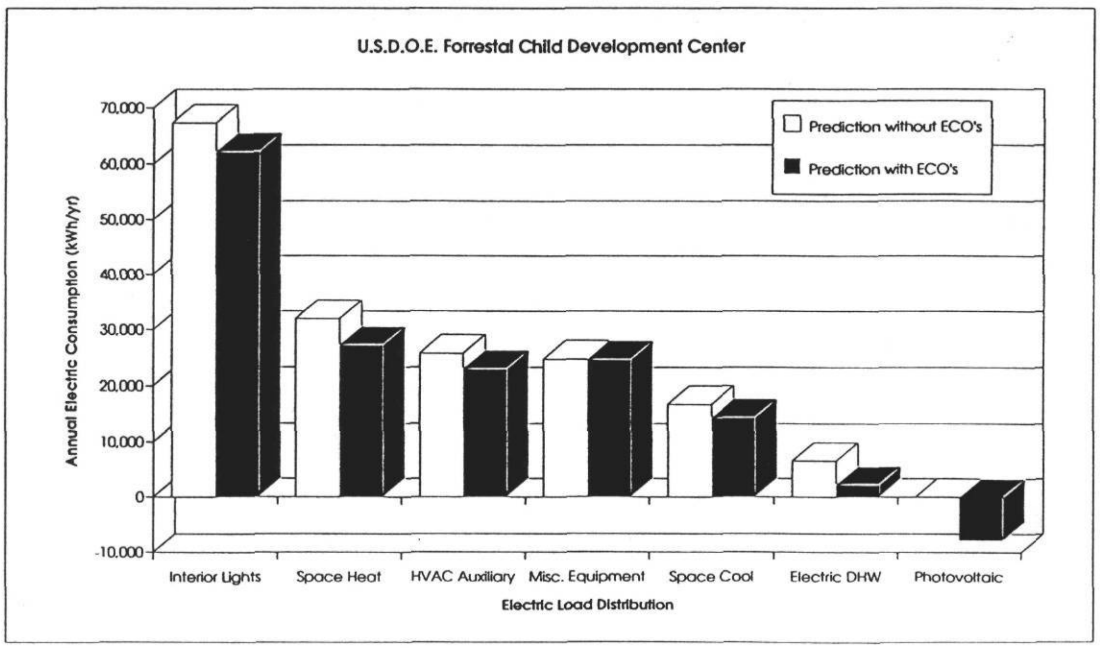


Figure 19 - (a) Annual ECO Savings. (b) Annual Electric Load Distribution.

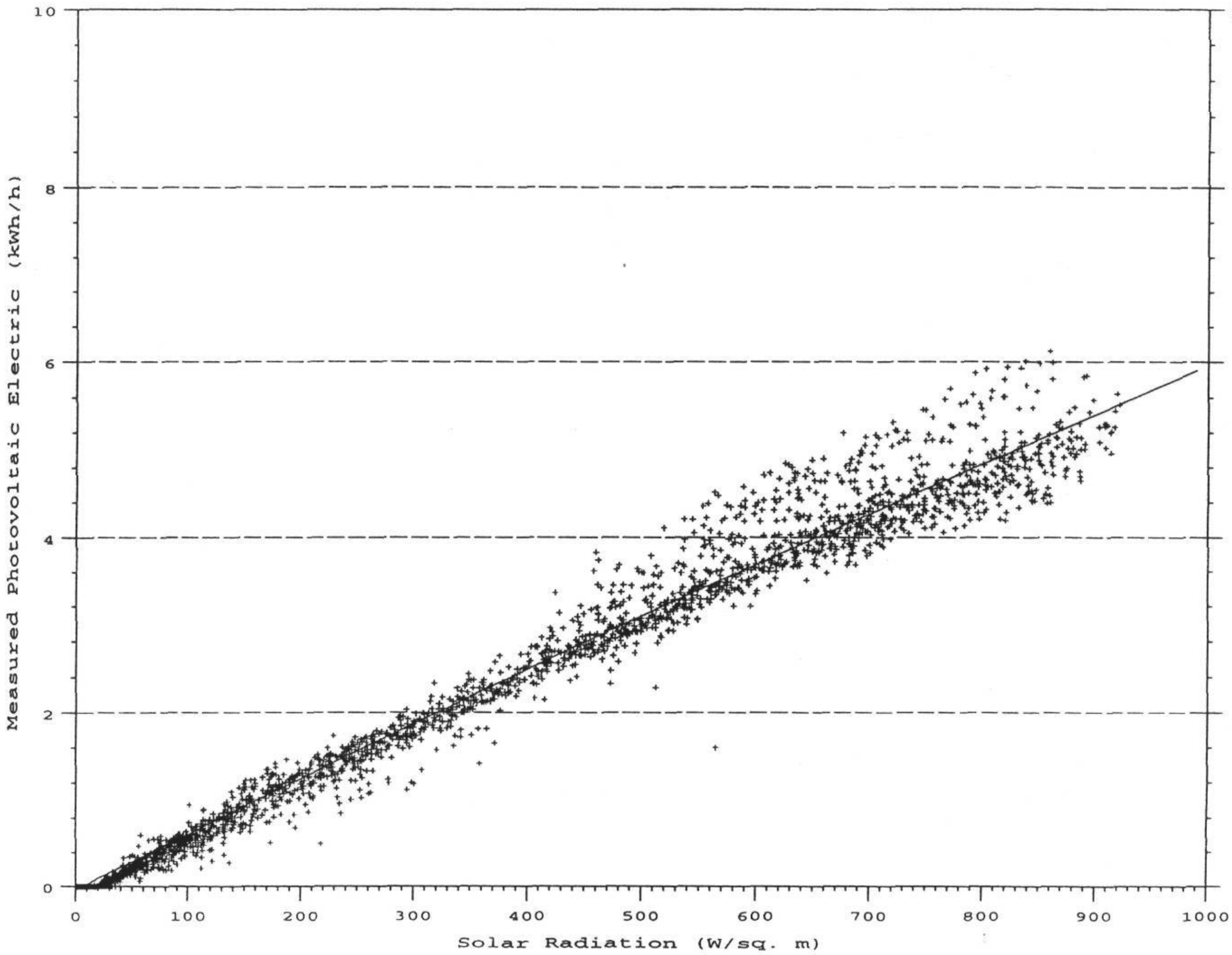


Figure 20 - Photovoltaic Generation As A Function Of Solar Radiation

CONCLUSION

The building was simulated and calibrated to a seven month period which included measured whole-building electric consumption, ambient dry-bulb temperature, dew point temperature, wind speed, and global horizontal solar radiation. After data processing which included merging data from two loggers and the NWS into a single file and converting global solar radiation into global horizontal, diffuse, and direct radiation, a TRY weather tape was packed. Multiple annual DOE-2 models were run, one for a base model and one for each ECO. The difference was calculated and compared to the architect's original energy savings estimates. Several statistical viewing aides are used to show the calibration robustness including time series plots, box-and-whisker plots, three-dimensional plots, and scatter plots as a function of both temperature bins and weekly bins. The photovoltaic system and the solar hot water system show the best results comparing closely with original architect's estimates. The EMS system and clear-story windows were found to have the least accurate design predictions with the EMS system savings being underestimated and the clear-story window savings being overestimated.

RECOMMENDATIONS

1. Maintenance of the ECOs appears to be a major consideration. It is recommended that routine inspections be developed and implemented to confirm the operation of the photovoltaic, solar DHW, and other energy consuming systems.

2. Due to budget constraints, the current effort did not measure infiltration or solar DHW performance. Additional measurements would provide more insight into these measures.

3. Side-by-side comparisons are recommended for the DOE Child Development Center in Germantown.

4. A detailed analysis of the thermal energy savings from the Forrestal lighting retrofit is recommended. As shown in this report total lighting savings (lighting and thermal savings) can be 20-40% more than lighting savings. This 20-40% additional savings has been confirmed by simulations reported in the November 1993 ASHRAE Journal.

ACKNOWLEDGMENTS

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