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THE U.S.D.O.E. FORRESTAL BUILDING LIGHTING RETROFIT: ANALYSIS OF ELECTRICAL AND THERMAL ENERGY SAVINGS

FINAL
SUMMARY REPORT

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ABSTRACT

In September of 1993 a 36,832 fixture lighting retrofit was completed at the United States Department of Energy Forrestal complex in Washington, D.C. This retrofit represents DOE's largest project to date that utilizes a Shared Energy Savings (SES) agreement as authorized under Public Law 99-272[1]. As DOE's first major SES contract, it was important that every aspect of this project serve as the cornerstone of DOE's Federal Relighting Initiative, including the careful measurement of the electricity and thermal energy savings.

The Department of Energy estimated that the lighting retrofit would reduce annual electricity use by 6.146 million kWh (62% of the lighting electricity use), and lower peak electric demand by 1,300 kW. Estimates of the electricity savings were $399,058 per year, or $1,350,386 over a seven year period[2]. Environmental impacts of this project have been estimated in the range of 3,791 to 4,160 tons/yr (3.4 to 3.8 million kg) of carbon dioxide (CO_2) avoidance, 31.7 to 33.2 tons/yr (28.7 to 30.1 thousand kg) of sulfur dioxide (SO_2) avoidance, and 13.6 to 16.0 tons/yr (12.3 to 7.3 thousand kg) of nitrous oxide (NO_2) avoidance[3].

Since this project represents one of DOE's first major SES projects, special effort was given to carefully measuring every aspect of the project in order to create a well documented case study to serve as a model for other federal agencies. One of these efforts, initiated in 1991, included measuring hourly electricity and thermal savings using pre-post, whole-building measurement techniques developed as part of the Texas LoanSTAR program[4]. In September of 1991, whole-building hourly monitoring equipment was installed and used to develop an hourly baseline record of pre-retrofit, whole-building energy use. Monitoring has continued through August of 1995, twenty four months after the September 1993 retrofit completion date.

This report provides an overview of the lighting retrofit and the resultant electricity and thermal savings. It presents results from the whole-building monitoring effort that show that the measured gross electricity savings accounted for $324,705 or 76% of the total monetary savings. The measured energy savings performed within 90% of the estimated savings. Quite surprisingly, the thermal savings which were not included in initial estimates by the USDOE accounted for $102,824 or 24% of the overall savings and increased the total cost savings to $427,529 (107% of expected electricity cost savings of $399,058). The measured reductions in monthly peak hourly electric demand performed within 68% to 91% of estimated demand reductions depending upon the month of the year.

[1] This was also included as a provision in the 1992 National Policy Act.

[2] Savings to the Department of Energy also include a $1,257,409 rebate from the local utility (PEPCO 1993). The estimated electricity savings are from DOE's "Forrestal Relighting Project Profile" brochure.

[3] These estimates are taken from a letter to Mr. Ed Liston of the EUA Cogenex company from Dr. Allan Evans of Princeton Economic Research Inc. (PERI) (PERI 1993). The lower value represent those of PERI, and the higher values represent those published by EUA Cogenex. PERI's estimates are based on pollutant conversions contained in the Electric Power Annual (1990) and assume a savings of 5.2 million kWh per year. PERI's estimates do not include thermal energy savings (i.e., chilled water or steam).

[4] For more information on the Texas LoanSTAR program see Verdict et al. 1990; Claridge et al. 1991, Claridge et al. 1994). The pre-post measurement technique used in this study was intended to comply with Option C of DOE's North American Energy Monitoring and Verification Protocol (NEMVP).

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

PREFACE

In September of 1993 a 36,832 fixture lighting retrofit was completed at the United States Department of Energy (USDOE) Forrestal complex in Washington, D.C. As part of this effort, the USDOE decided to evaluate the resulting electrical and thermal energy impact to verify the original estimated savings projections. This report presents an overview of the lighting retrofit along with the methodology used to prepare the calculations of electricity and thermal savings.

This report was prepared by Jeff Haberl, Ph.D., P.E. and Tarek Bou-Saada. Significant input has been provided by David Claridge, Ph.D., P.E. and T. Agami Reddy, Ph.D., P.E. The bin method analysis used in this report was provided by Sabaratnam Thamilseran of the ESL.

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THE U.S.D.O.E. FORRESTAL BUILDING LIGHTING RETROFIT: ANALYSIS OF ELECTRICAL AND THERMAL ENERGY SAVINGS

INTRODUCTION

The USDOE Forrestal Complex

The James Forrestal building, located at 1000 Independence Avenue, Washington, D.C., is comprised of interconnected north, south and west wings, and a newly built Child Development Center [5] directly south of the cafeteria. The north wing of the Forrestal complex is elevated three stories above Independence Avenue and is comprised mostly of executive offices. As shown in Figure 1a Tenth street passes directly underneath the north building and separates the south and west buildings. The south building is connected to the north building with four aerial walkways and to the west building with corridors underneath Tenth Street. The south building surrounds an interior courtyard and contains office space, several small cafeterias and an employee gym. The west building is comprised mostly of a cafeteria and related services.

Figure 1b is a view of the south and north buildings from the south corner of DOE's cafeteria located in the west building. Figure 2 shows the layout of the DOE Forrestal building with respect to its surroundings. In September of 1991 a USDOE Child Development Center was completed and opened for use by DOE staff. This 8,100 ft^2 (752.5 m^2) facility is located adjacent to the DOE cafeteria on the south side.

The Forrestal building is primarily constructed of precast and cast-in-place concrete. Precast recessed window units, encasing 1/4 inch (0.64 cm) plate glass, are the most prominent feature of the envelope. The main entrance to the complex is located below the north building through automated sliding doors that lead into a glazed vestibule.

The 1,632,000 ft^2 (151,617 m^2) facility contains 315,000 ft^2 (29,264 m^2) of parking and 1,317,000 ft^2 (122,353 m^2) of office space and corridors. A detailed accounting of the building is contained in the JRB reports (1981). In general, the exterior envelope of the building has minimal insulation. A large portion of the building representing 668,000 ft^2 (62,059 m^2) is actually below grade and connects the north, south and west buildings underneath Tenth Street. Roofs throughout the building are high mass composite construction with 2 inch (5.1 cm) rigid insulation.

The Forrestal building receives steam and chilled water from the Central Heating and Refrigeration Plant operated by the General Services Administration (GSA) located a few blocks to the southwest of the Forrestal building at 12th and C Streets. Steam is metered at the Forrestal building with an electronic, insertion-type, axial, turbine steam meter. The chilled water is metered both at GSA's Central plant and at the Forrestal building using permanently-mounted clamp-on ultrasonic meters. Electricity and natural gas are metered separately within the building and are provided by local suppliers. Potable water is also metered on-site [6].

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[5] The Child Development Center, opened in September 1991, receives its electricity from the Forrestal building which represents roughly 134 MWh/yr in 1992. A report on the energy conserving retrofits for the CDC is available from the Energy Systems Laboratory (Haberl and Bou-Saada 1993).

[6] For a more detailed look at previous metered energy analysis efforts see the paper by Haberl and Vajda (1988).

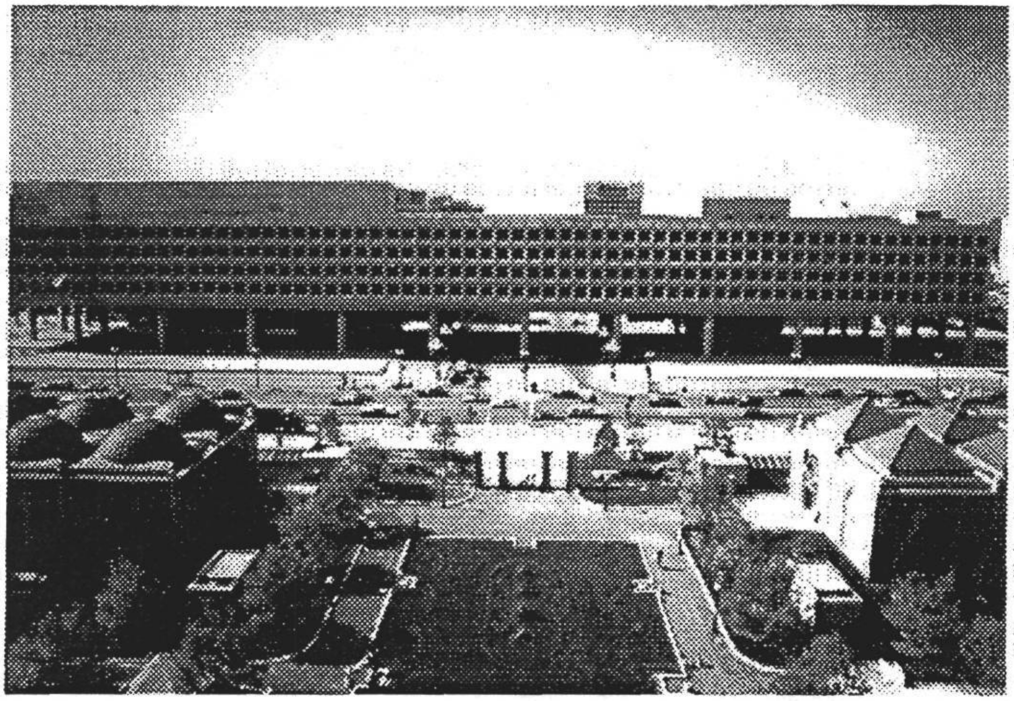


FIGURE 1A,B: THE DOE FORRESTAL COMPLEX. FIGURE 1A SHOWS THE USDOE FORRESTAL COMPLEX AS SEEN FROM THE SMITHSONIAN CASTLE AND FIGURE 1B SHOWS THE SOUTH BUILDING AS SEEN FROM THE FORRESTAL CAFETERIA.

Perimeter heating and cooling is provided by two primary types of systems: four-pipe fan coil units (south and west exposure), and two-pipe fan coil units. Other specialty systems include reheat coils, baseboard units (cafeterias and corridors), north building (fourth floor) hydronic slab heating [7], heating and ventilating unit heaters (garage), and specialty computer room cooling systems. Ventilation and cooling for the building is provided by a low-pressure, constant volume air distribution system serviced by air-handling units located in 22 mechanical rooms throughout the building. Hot water is supplied by four steam-fed, domestic water converters. Three of the converters supply 105 °F (40.6 °C) water for lavatories and one supplies 140 °F (60.0 °C) water for kitchen use.

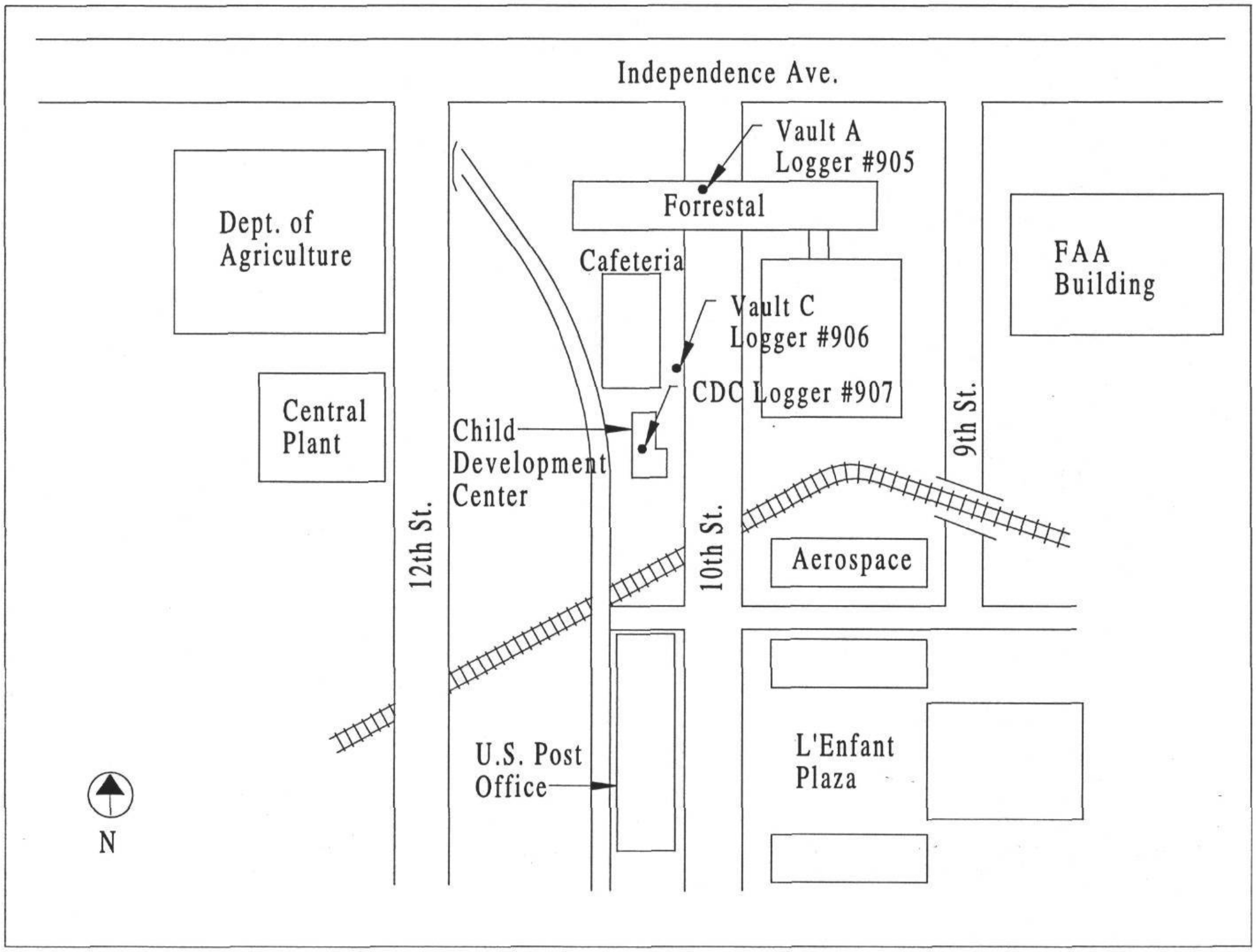


FIGURE 2: LAYOUT OF THE DOE FORRESTAL COMPLEX. THIS FIGURE SHOWS THE LAYOUT OF THE DOE FORRESTAL BUILDING WITH RESPECT TO ITS SURROUNDINGS. THE LOCATION OF LOGGERS IN ELECTRICAL VAULTS A AND C, AND THE CHILD DEVELOPMENT CENTER (CDC) ARE ALSO SHOWN.

[7] This slab heating is required to keep the cold from penetrating up into the fourth floor from the exposed underside below.

Prior to 1992, control of systems at the Forrestal building was provided by effective manual schedules, timeclocks and local pneumatic controllers. In 1993 a state-of-the-art computerized Energy Management and Controls System was installed that now performs the basic functions that the previous manual system performed [8]. Normal business hours for the 4,400 employees are from 6:30 a.m. to 6:30 p.m., Monday through Friday [9].

Energy conservation efforts at the Forrestal building (1986-1995)

In FY 1992/93 the total utility costs for the Forrestal building were $3,054,957, or $2.31 per square foot ($24.97 per square meter) [10]. These costs were broken down as follows, $3,141 for natural gas, $452,298 for steam, $927,473 for chilled water and $1,672,045 for electricity. Figure 3 provides a summary of the utility costs from FY 1987/88 through FY 1994/95. Figures 4a and 4b show the monthly electricity use, and peak electric demand, respectively. Figure 4c shows the steam and Figure 4d shows the chilled water use from utility billing records, respectively [11]. Prior to the lighting retrofit the average

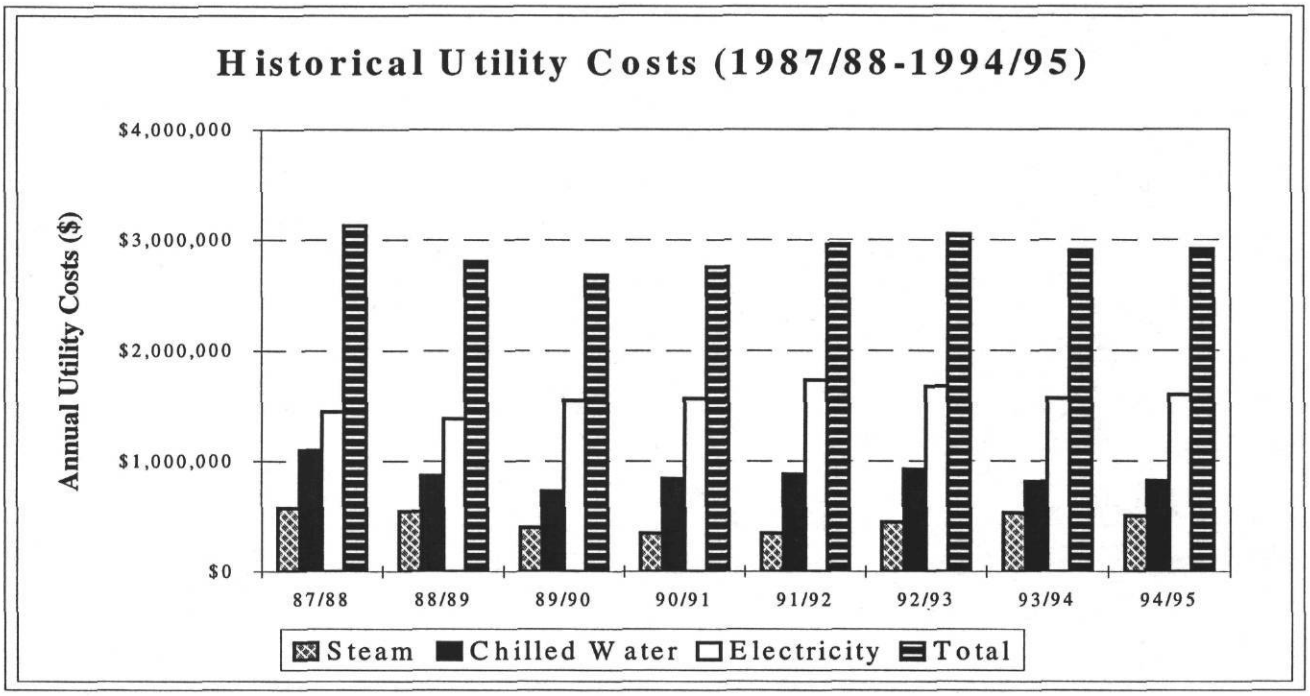


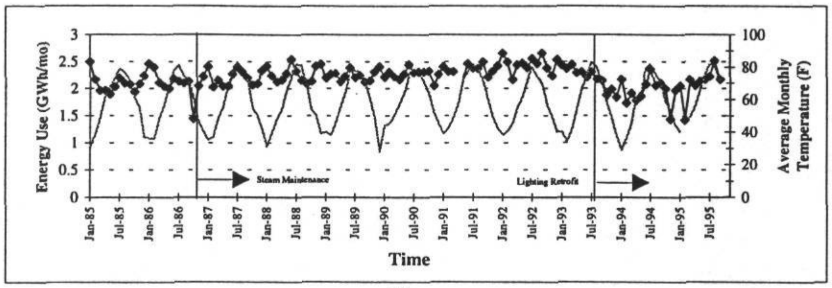
FIGURE 3: HISTORICAL UTILITY COSTS 1987 - 1995. THIS BAR GRAPH SHOWS THE HISTORICAL UTILITY COSTS FROM FY 1987/88 THROUGH FY 1994/95. THE FORRESTAL COMPLEX CONSUMES NATURAL GAS, STEAM, CHILLED WATER, ELECTRICITY, AND POTABLE WATER (NOT SHOWN).

[8] The EMCS was installed in February 1993 and controls the start-stop of the AHUs, pumps, and chilled water supply to the AHUs.

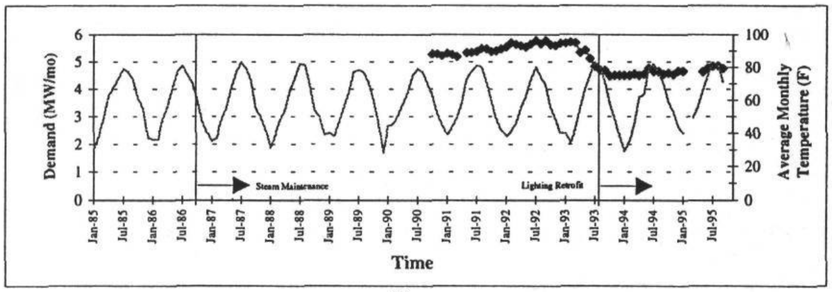
[9] This is determined by the AHU schedule on the newly installed EMCS. Previously reported hours were from 8:30 a.m. to 5:00 p.m. (Haberl and Vajda 1988).

[10] This calculation uses 1,317,000 square feet which includes the underground, enclosed garages.

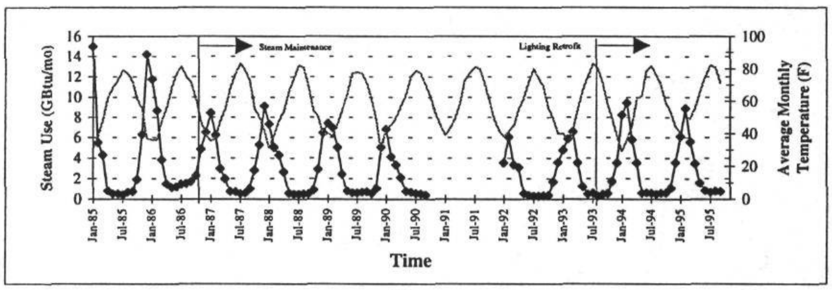
[11] Both figures use information from unadjusted, monthly utility billing data. The monthly data shown in Figure 4 are contained in Appendix C.



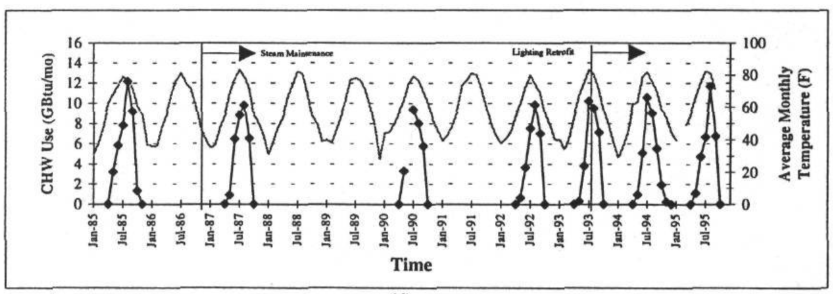
(a)



(b)



(c)



(d)

FIGURES 4A,B,C,D: MONTHLY UTILITY BILLING DATA FOR THE DOE FORRESTAL COMPLEX. THE FIRST TWO GRAPHS SHOW THE MONTHLY ELECTRICITY USE (4A) AND PEAK ELECTRIC DEMAND (4B) FOR THE FORRESTAL BUILDING FROM JANUARY 1985 THROUGH SEPTEMBER OF 1995. FIGURES 4C AND 4D SHOW THE MONTHLY STEAM AND CHILLED WATER USE FROM JANUARY 1985 THROUGH SEPTEMBER OF 1995. AVERAGE MONTHLY TEMPERATURE IS ALSO SHOWN.

monthly electricity use for the Forrestal building increased by roughly 400 MWh/mo over an eight year period from 1985 through 1993. It is believed that this is due to the large numbers of personal computers, printers, and office equipment that were purchased and installed during this period. A similar increase can be seen in the peak monthly electric demand for the building which reached a peak of 5,777.3 kW in July of 1992.

In Figure 4c dramatic reductions in steam energy use can be seen beginning in 1986 when the Forrestal's maintenance staff began an aggressive steam trap and steam converter maintenance program and initiated the shutoff of steam during the weekends when heating was not required [12]. This reduction in steam use resulted in an annual savings of over $250,000 per year and, due to the diligence of the Forrestal staff, has persisted for eight years since it was first initiated during the winter of 1986/87 which amounts to a total savings in excess of $2,250,000.

The photograph in Figure 5 has been provided to illustrate some of the "people" issues that can be critical to the success or failure of an energy conservation program. This is a photograph of the Forrestal building's steering-wheel-sized main steam valve that had to be manually turned off by the staff as it appeared in 1986. At first there were objections to this practice because of the difficulty of crawling through the 36 x 36 inch (91.4 x 91.4 cm) hatch into a dark, hot (often 140+ °F (60 °C)) steam tunnel. The final solution involved replacing the hatch with a standard door and installing a light switch [13].

Steam energy use continued to decline until the 1994 heating season when it increased by 27% over the previous year to make up for the decreased heat coming from the newly installed lights. The monthly chilled water consumption for the Forrestal building also increased during this period due mostly to weather conditions. The increased cooling load from the constant addition of personal computers may also have added to the Forrestal building's electrical load [14].

Overview of the 37,000 fixture lighting retrofit

In 1989 a Shared Energy Savings lighting retrofit project was proposed for the Forrestal building that would reduce energy costs at DOE's headquarters building and serve as a demonstration project for the planned Federal Relighting Initiative. As part of the demonstration effort DOE initiated several parallel efforts to document the electricity and thermal savings from the lighting retrofit, including portable before-after, end-use measurements of the lighting loads, a lighting test demonstration room, and long-term whole-building electricity and thermal measurements.

In 1990 DOE established end-use electricity estimates for the Forrestal building using portable RMS electrical data loggers and whole-building data from the local utility's 15-minute electricity demand data (Mazzucchi 1992) [15]. According to Mazzucchi, lighting electricity represented 33% of the whole-building electricity consumption. The 24-hour end-use lighting profiles of the 277-volt fluorescent

[12] Steam is routinely shutoff on Friday nights about 8:00 p.m. and is turned on Sunday night about 12:00 midnight. This manual procedure is followed for all weekends when the ambient temperature is above about 30F (-1 C). Additional details about the steam shutoff program can be found in Haberl and Vajda (1988).

[13] The original hatch (now replaced) is shown directly behind the valve. The turn-on/off of the steam valve was further complicated by the fact that no access light was available and often times the dark steam tunnel contained very large vermin that were crawling under foot.

[14] Prior to 1987 the chilled water use for the Forrestal building was a negotiated amount that represented 40% of the chilled water that was produced by GSA's Central Plant. The remaining 60% was delivered to the Agriculture building which is located one block to the west of the Forrestal building. In 1987 GSA installed meters in the chilled water lines leaving the central plant and began billing according to the measured thermal energy. However, in 1987, the first year that the numbers were reported to DOE using the metered data, the thermal values that were reported were three times the monthly consumption shown, which is an impossible amount. Therefore a 1/3 adjustment factor has been applied to allow for the graphical presentation shown in Figure 4b.

[15] These data loggers are the commercialized version of the data loggers that DOE developed for the ELCAP project through Battelle/PNL. They are also the loggers used in the Texas LoanSTAR program. The manufacturer's name is mentioned in the acknowledgments.

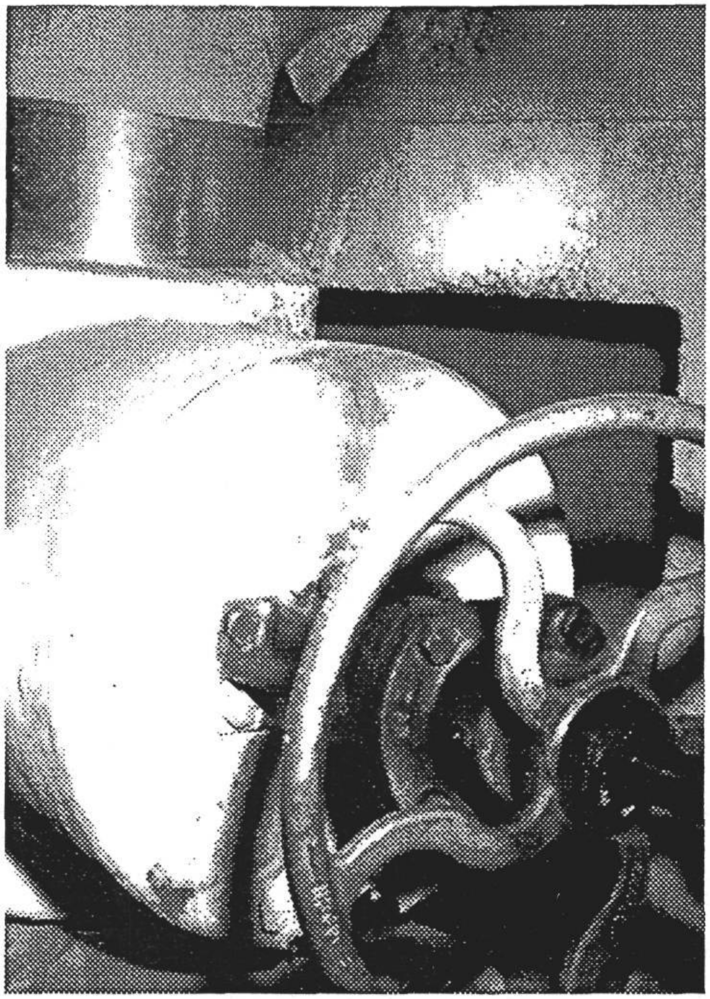


FIGURE 5: MAIN STEAM VALVE FOR THE DOE FORRESTAL COMPLEX. THIS 1986 PHOTOGRAPH OF THE MAIN STEAM VALVE SHOWS MAIN SHUTOFF VALVE AND THE HATCH DOOR THAT WAS PREVIOUSLY USED AS ACCESS TO THE STEAM TUNNEL.

lighting loads were then used by the DOE to establish engineering estimates of the weekday-weekend baseline lighting loads which served as the basis for the RFP [16].

Qualified bidders were then asked to demonstrate their proposed lighting fixtures in a specially equipped room where the same RMS electrical data loggers had been installed to monitor the electricity use and power quality of the lighting fixtures. Lighting quality measurements were also taken to evaluate the different proposals (Halverson et al. 1993a, 1993b, 1994). Finally, in order to supplement the before-after, snap-shot, end-use measurements, baseline whole-building electricity and thermal measurements were initiated in September of 1991 using hourly monitoring equipment [17].

A lighting retrofit contractor was then chosen in November 1992 and the installation of new lighting fixtures began on March 12, 1993. The majority of the lighting fixtures were installed by July 31, 1993.

[16] This represented a significant amount of work because the 131 panels that feed the 277-volt fluorescent lighting are spread throughout the building on various floors inside of electrical risers that feed upward from the five main electrical vaults located below grade. This is further complicated by the fact that there are four 13.2 kV feeders to the five electrical vaults (switchboards) where the electricity is transformed to 460/265V, three phase, four wire service.
[17] This original work was performed as an extension to USDOE grant DE-FG01-90CE21003 to study the use of EMCSs for performance monitoring projects (Claridge et al. 1993).

Final completion of the project occurred on September 30, 1993. Post-retrofit, RMS electrical measurements were then reapplied to the same lighting panels throughout the Forrestal building to establish 24-hour, weekday-weekend post-retrofit lighting profiles [18]. Whole-building electricity and thermal energy use measurements continued through August 1995 [19].

Significance of measuring the savings

Unfortunately, to the dismay of many building owners and energy service companies, cost savings from unadjusted utility bill comparisons do not always match the negotiated dollar savings from a shared energy savings contract. Although the trade journals are usually quick to print the estimated SES success stories, rarely do they follow-up to report the measured savings. Without the extra assurance that careful measurement provides many contracts end up in costly litigation. This might have been the end result for the Forrestal building had the DOE not had the foresight to accurately measure the savings.

To demonstrate this point unadjusted utility costs for the Forrestal complex are shown from August through July for 1992/93 and 1993/94 with the difference plotted against the negotiated savings as shown in Figure 6 [20]. Clearly, had the Forrestal staff only been looking at the monthly cost difference between the two years they would have had cause for alarm because none of the months showed savings that equaled or exceeded the $33,256 which represents 1/12 of the projected $399,058 annual savings. It will be shown that the electricity savings (i.e., kWh) did indeed occur almost as estimated when a more accurate evaluation is conducted that adjusts for several confounding factors.

METHODOLOGY

Measuring the electricity and thermal energy savings with whole-building hourly data

The methodology that has been applied to calculate the gross, whole-building electricity and thermal savings from the lighting retrofit uses a basic before-after analysis of the whole-building electricity and thermal use. This methodology separately calculates weather-dependent and weather-independent energy use by developing empirical baseline models that are consistent with the known loads on a given channel. This report presents the weather-independent electricity savings and the weather-dependent thermal savings from the lighting retrofit.

In the weather-independent procedure a baseline statistical model of the 1992 weather-independent energy use was calculated using 24-hour, weekday-weekend hourly profiles. The hourly electricity savings were then calculated by forecasting the pre-retrofit baseline electricity use into the post-retrofit period and summing the hourly differences between the pre-retrofit and post-retrofit models using a modification to the procedure outlined in Claridge et al. (1992). The general form for this procedure is as follows:

$$E_{save,tot} = \sum_{i=1}^{n} N_i \sum_{j=1}^{m} \left(E_{pre_{i,j}} - E_{post_{i,j}} \right) \quad (1)$$

[18] These measurements were taken during the period of October 23 to November 3, 1993 (Halverson et al. 1994). The data loggers used in PNL's end-use measurements and in the whole-buildings measurements also are the same as indicated in the acknowledgments. A study was also performed to measure the persistence of the lighting retrofit (Chvála et al. 1995).

[19] These are the basis for the current report.

[20] To make this simple comparison the basic utility billing data was used. This includes the following charges: discount charge, fuel adjustment, misc. adjustments, kWh charges, and kW charges. The local utility's "previous balance adjustments" credits were not included in Figure 6.

where:

$E_{pre_{i,j}}$ = the pre-retrofit, bin-model predicted average hourly electricity use during hour (j) of daytype (i) in the post-retrofit period.

$E_{post_{i,j}}$ = the post-retrofit, bin-model predicted average hourly electricity use during hour (j) of daytype (i) in the post-retrofit period.

N_i = the number of days of daytype profile (i) in the post-retrofit period.

i = distinct daytype varying from i = 1 (all seven days per week the same), to i = 365 (every day of the year different).

j = 1 to 24 hours in each day.

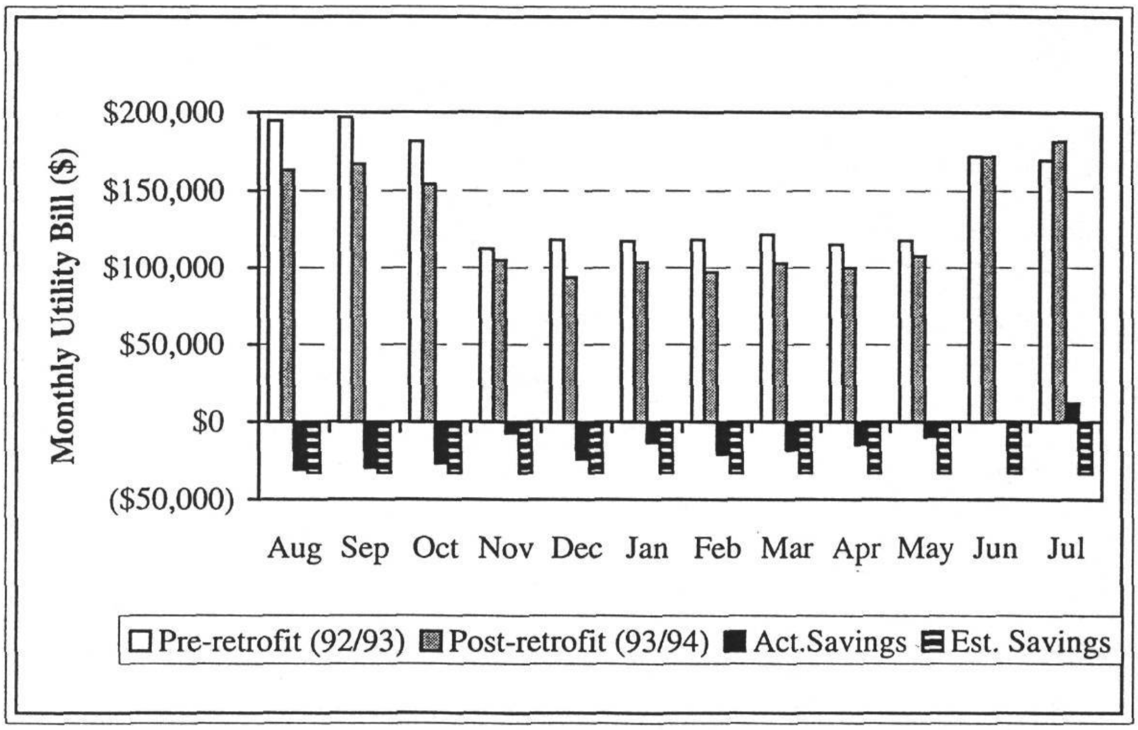


FIGURE 6: COMPARISON OF FY 1992/93, FY 1993/94 UTILITY BILLING DATA AND NEGOTIATED ELECTRICITY SAVINGS FOR THE LIGHTING RETROFIT. THIS PLOT SHOWS THE FY 1992/93 UTILITY BILLING DATA AND THE FY 1993/94 UTILITY BILLING DATA. IN THE LOWER PORTION OF THE GRAPH THE UNADJUSTED UTILITY COSTS FOR THE TWO PERIODS ARE COMPARED AGAINST THE NEGOTIATED ELECTRICITY SAVINGS.

In general, several passes are required through the data set to determine the best number of 24-hour profiles that accurately represent the building's electricity use using an iterative procedure[21] that attempts to select the fewest number of 24-hour profiles that adequately characterize the building's 24-hour profiles. A model is deemed adequate when the model-predicted electricity use matches the actual electricity use to an appropriate goodness-of-fit as determined by the coefficient of variation of the root mean square error (CV-RMSE) and mean bias error (MBE) [22].

The weather-dependent procedure calculated a baseline statistical model of the 1992/1993 pre-retrofit energy use using several techniques, including: a monthly analysis that considered both three parameter and four parameter change-point analysis, and a temperature binned, weekday-weekend analysis. A comparison of the three techniques is provided in the appendix. The total savings for this project includes a weather independent bin model for the electricity savings and a four parameter change-point model for the chilled water savings and the steam increase.

Using a monthly analysis (Kissock 1994), the weather dependent energy savings (or increase in the case of steam) can be calculated by forecasting the baseline thermal use into the post-retrofit temperature period and summing the monthly difference between the pre-retrofit model and post-retrofit measured data. The chilled water savings can be calculated with the following procedure:

$$E_{save,chw} = \sum_{i=1}^{n} (E_{pre,i} - E_{post,i}) \qquad (2)$$

where:

$E_{pre,i}$ = the average monthly pre-retrofit consumption for the month (i) chilled water use as predicted in the post retrofit period.

$E_{post,i}$ = post-retrofit consumption for month (i).

i = 1 to 12 different monthly values either predicted by the four parameter model, or measured during the post-retrofit period.

The steam energy savings can be calculated similarly.

Applying the procedures to the Forrestal building

In the Fall of 1991 long-term monitoring equipment was installed in the Forrestal building to measure the hourly whole-building electricity, chilled water, and steam energy use. Hourly weather data were also recorded during this period from the National Weather Service (NWS) using data from the nearby National Airport weather station [23]. Figures 7a-c show the experiment plan for the initial monitoring installation. Whole-building electricity use was recorded with a single KYZ pulse from a

[21] This procedure uses a modified form of the procedure recommended by Katipamula and Haberl (1991).
[22] The CV-RMSE equations used to evaluate the models are from Thamilseran and Haberl (1995). These equations are also provided in the appendix.
[23] This was accomplished via modem through a commercial account with an authorized NWS weather data distributor located in State College, Pennsylvania.

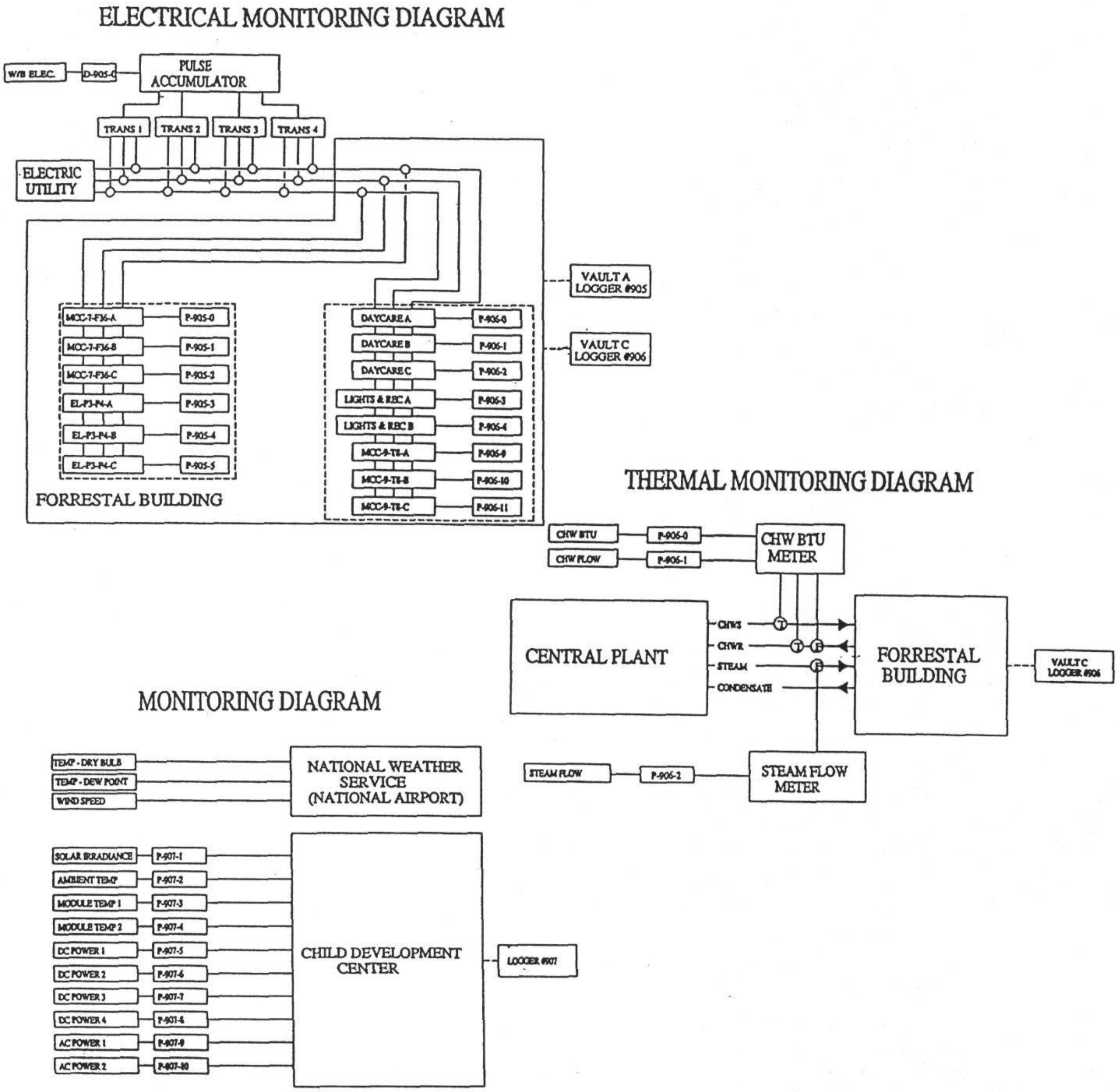


FIGURE 7A,B,C: MONITORING DIAGRAMS FOR THE DOE FORRESTAL COMPLEX. THESE FIGURES SHOW THE ELECTRICAL, THERMAL, AND CDC MONITORING DIAGRAMS.

shared signal from the utility's pulse accumulator that collects the pulses from the four 13.2 kV electricity feeders into the building in the A Vault located underneath the north building[24]. Submetered electricity was also measured for selected motor control centers (MCC), elevator panels, lights and receptacles, and for the USDOE Child Development Center (i.e., labeled as "Daycare") in both the A and C vaults. Additional monitoring was also conducted on the CDC using a separately installed logger in order to determine the effectiveness of the energy conservation measures that had been designed for the building (Haberl and Bou-Saada 1993; Bou-Saada 1994).

Thermal metering consisted of chilled water and steam flow measurements located near the building's C Vault. Chilled water was measured with a permanently installed Btu meter which integrated whole-building flow measurements from an ultrasonic meter with supply and return temperatures. Steam measurements were taken by an insertion-type axial turbine steam meter located in the building's 250 psi (1,724 kPa) steam supply. Meter calibrations were performed by comparing hourly chilled water and electricity measurements against measurements taken by GSA and the local electric utility [25]. Data from three loggers were collected weekly, plotted, and inspected visually for errors using automatic routines developed as part of the LoanSTAR program (Lopez and Haberl 1992).

Electricity data collection

Figure 8 shows the hourly whole-building electricity data collected from the site for the period January 1992 through August 1995 as juxtaposed 3-D time series plots (Abbas 1993). In these plots the day of the year is located left to right along the x-axis and the time of day is located along the y-axis (i.e., time runs into the page). The energy use is the height of the surface above the x-y plane.

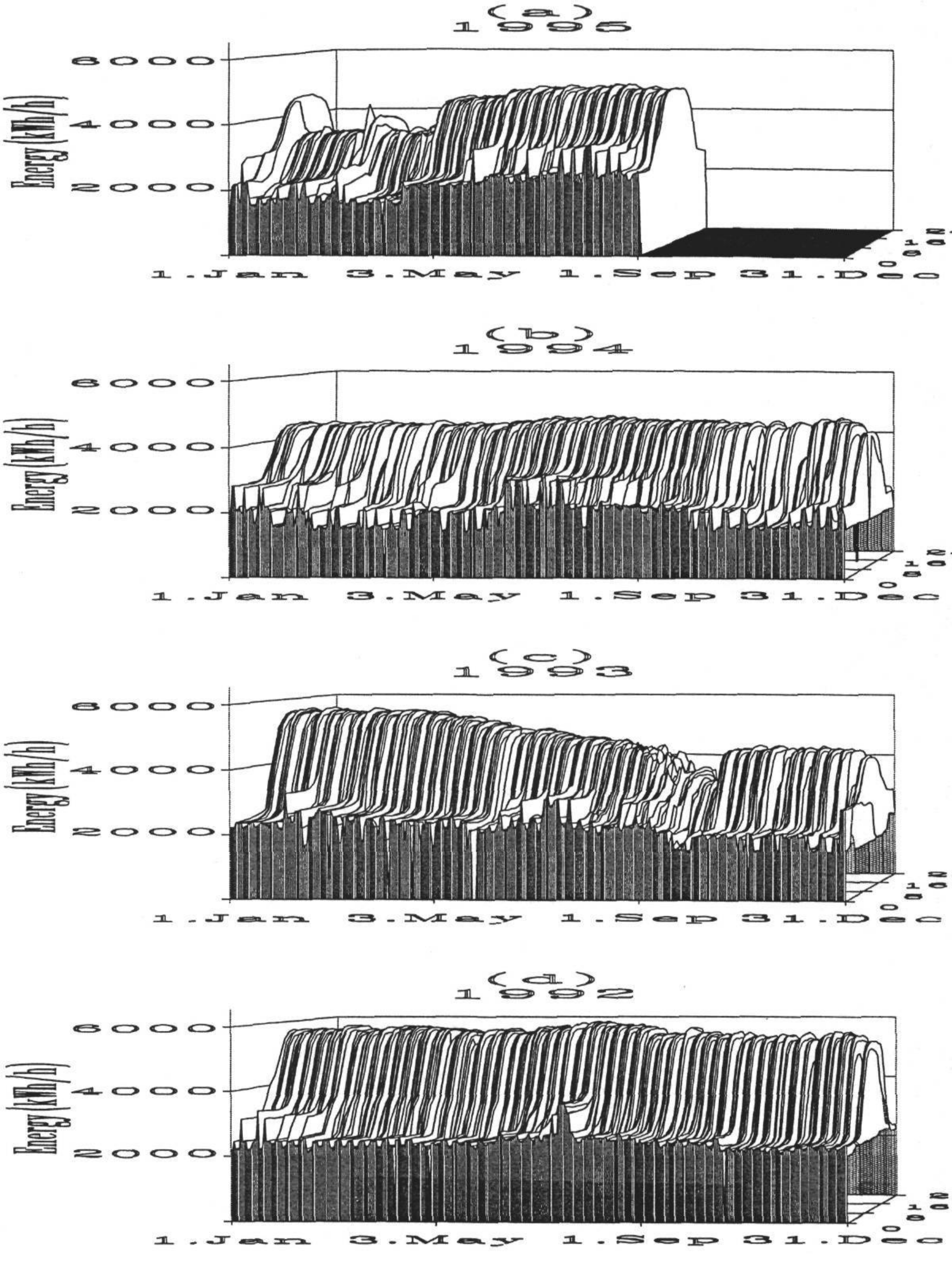
Clearly, several features can be can be seen in the data. First, prior to the 1993 retrofit the whole-building electricity profiles were very uniform with the exception of only a few days during the year when air-handling units were run longer than normal. These periods occurred during severe winter and summer conditions when it was necessary to run the main air-handlers longer to help maintain comfort conditions in the building. Prior to the retrofit, this was necessary during extreme summer conditions because the building's cooling system was running at its rated capacity which required that the air-handling systems to operate 24 hours-per-day to maintain conditions. During extreme winter conditions the air-handling units were run continuously to avoid freeze damage to the cooling coils in the air-handling units.

Beginning in March 1993 and continuing through August 1993 the reduction in whole-building electricity use attributed to the retrofit can be clearly seen. However, beginning in September of 1993 the whole-building electricity data became erratic fluctuating randomly by about 1,000 kW and then continuously dropping-out for no apparent reason. After some investigation it was determined that one of the local utility's mechanical KYZ pulse initiators on the four 13.2 kV feeders had failed.

Unfortunately, shortly after the pulse initiator was fixed it failed again and continued to fail periodically throughout the remainder of the post-retrofit monitoring period. This finally stopped in April, 1995 when the meter was replaced with a new electronic meter. This problem was further

[24] Unfortunately, this 20-year-old mechanical pulse accumulator failed repeatedly after the retrofit was installed thereby necessitating the need for a post-retrofit model to normalize for the lost data. Therefore, the utility billing data shown in Figure 3 represent data that have been adjusted by the electric utility company.

[25] In all cases it was assumed that GSA's readings and the local utility readings were accurate. Steam meter calibrations were performed periodically by the GSA.



FIGURES 8A,B,C,D: WHOLE-BUILDING ELECTRICITY USE FOR THE DOE FORRESTAL COMPLEX. THESE GRAPHS SHOW THE MEASURED, WHOLE-BUILDING ELECTRICITY USE FOR THE FORRESTAL COMPLEX FROM JANUARY 1992 THROUGH AUGUST 1995 DISPLAYED AS AN HOURLY 3-D TIME SERIES PLOT.

compounded by maintenance power outages[26] that were initiated in 1993 and continued through 1994. Both of these problems contributed to abnormal usage profiles that necessitated the use of an empirical pre-retrofit and post-retrofit models to measure the lighting retrofit savings.

Thermal energy data collection

In addition to measuring hourly electricity consumption at the Forrestal building, hourly steam and chilled water data were measured and recorded in the building's C Vault. A significant amount of steam data were recorded for the pre- and post-retrofit periods to complete a successful analysis. Unfortunately, only limited amounts of chilled water data were available due to a hardware failure in the chilled water metering equipment. Figure 9 is a three-dimensional plot of the chilled water data collected at the Forrestal building during the pre- and post-retrofit period. A complete set of post-retrofit chilled water data were not available due to the malfunctioning chilled water meter leaving only a partial dataset for analysis. The chilled water Btu meter was not repaired in time to include the data in this report. As a result, monthly utility bills were used for the analysis of the steam and chilled water energy use. A comparison of the monthly and hourly analysis of the steam use is included in the appendix. The pre-retrofit dataset is shown in Figure 9a and the post-retrofit dataset is shown in Figure 9b.

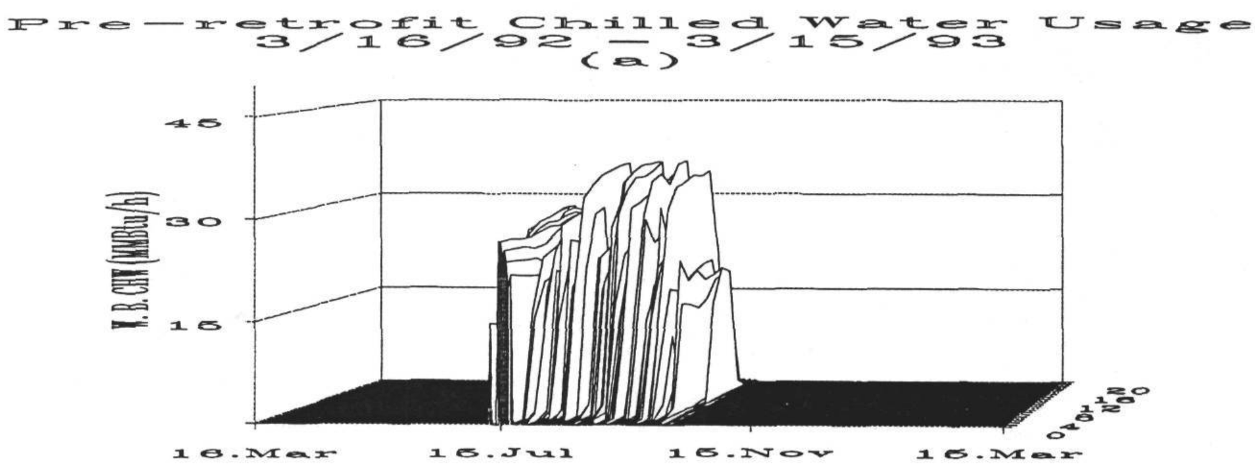
Figure 10 shows two 52-week box-whisker-mean graphs, the pre-retrofit data in Figure 10a and the post-retrofit data in Figure 10b. The superimposed and juxtaposed 52-week box-whisker-mean plots display the maximum, minimum, mean, median, 10th, 25th, 75th, and 90th percentile points for each data bin for a given period of data. These plots eliminate data overlap and allow for a statistical characterization of the dense cloud of hourly points.

Steam data re-scaling

A significant portion of the steam data required re-scaling due to the manner in which the signal was shared with the GSA. The steam valve located in the building's C Vault was originally monitored by a chart recorder. Since the chart recorder received a steam usage signal from the steam flowmeter's output, it was split to send a signal to the hourly monitoring equipment (i.e., the datalogger). According to DOE personnel, an adjustment screw on the chart recorder provided maintenance personnel with a means to easily rescale the steam meter output at will for visual purposes in the event the recorder pen moved off the scale. Unfortunately, any adjustment made to the chart recorder adversely affected the input to the datalogger. During the 1992 to 1994 monitoring period this adjustment was made numerous times at infrequent intervals to the steam meter. This required rescaling of the hourly data.

In order to correct the scaling problems, it became necessary to rescale the measured data. Fortunately, the GSA personnel read and recorded monthly readings from the same meter. This facilitated rescaling of the hourly data to match the GSA data. For each billing month, the hourly data were summed and plotted against the utility bills as seen in Figure 11a. A scaling factor was then calculated for each month. Each month's scaling factor was, in turn, applied to the hourly data for that particular billing period to correct the data. A direct comparison may be seen in Figure 11b between the re-scaled measured data are shown matching the monthly utility bill.

[26] These maintenance outages include an aluminum riser replacement program, maintenance of the computer room UPS, and maintenance of the electrical vault switch gear.



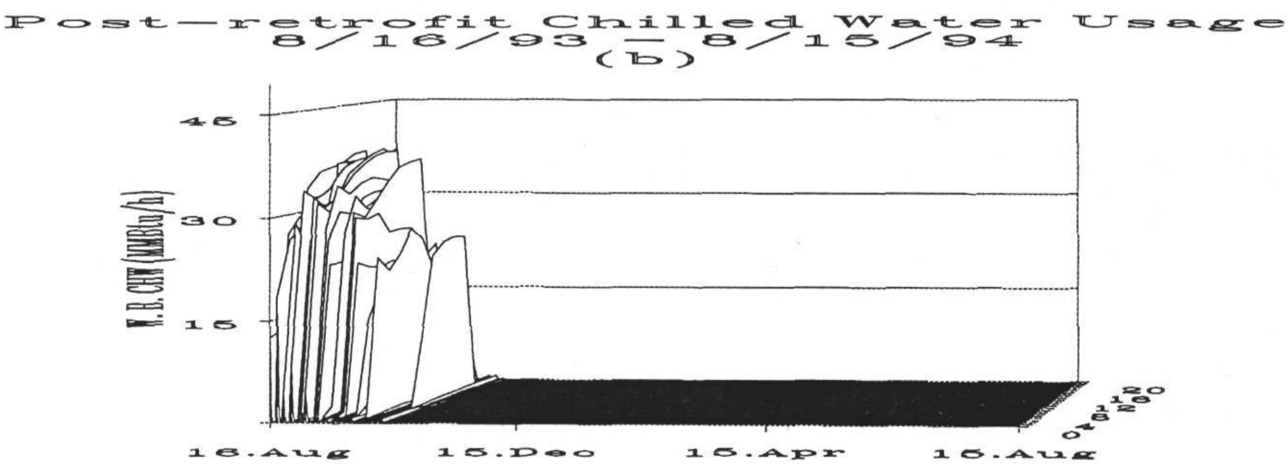
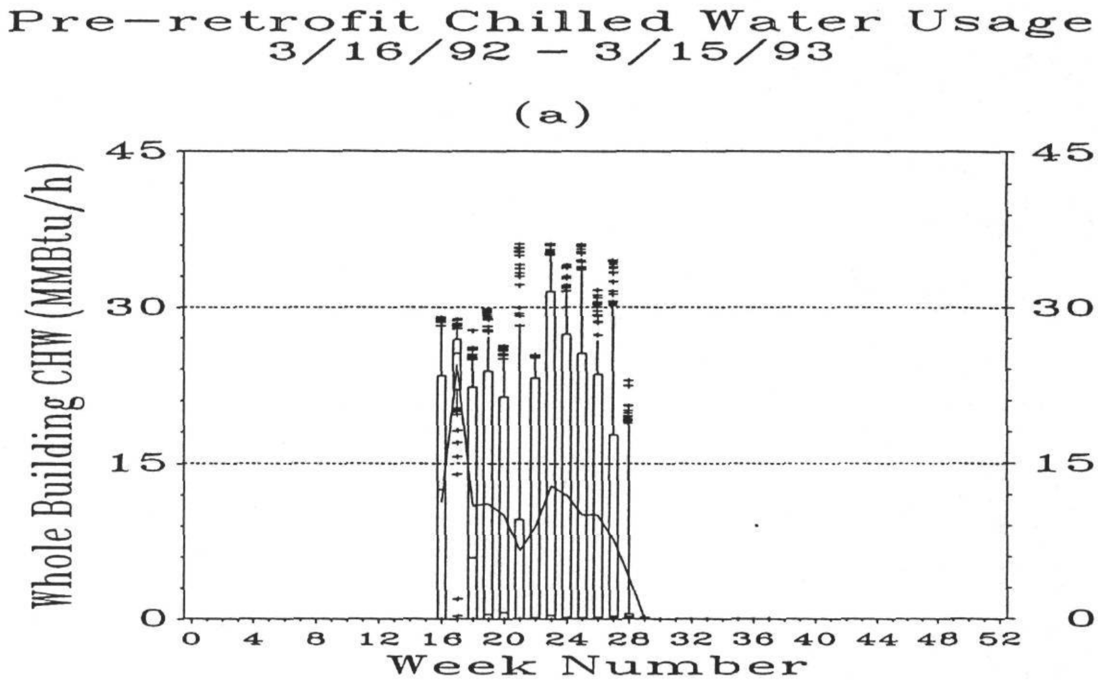


FIGURE 9A,B: WHOLE-BUILDING CHILLED WATER THREE DIMENSIONAL PLOT. THE UPPER PLOT SHOWS THE PRE-RETROFIT HOURLY DATA DATASET IN FIGURE 9A FROM MARCH 16, 1992 THROUGH MARCH 15, 1993 WITH THE Y-AXIS SHOWING THE HOUR OF THE DAY AND THE X-AXIS SHOWING THE DAY OF THE YEAR. THE Z-AXIS SHOWS THE CHILLED WATER CONSUMPTION. THE LOWER PLOT (FIGURE 9B) SHOWS THE LIMITED POST-RETROFIT DATA FROM AUGUST 16, 1993 THROUGH AUGUST 15, 1994.



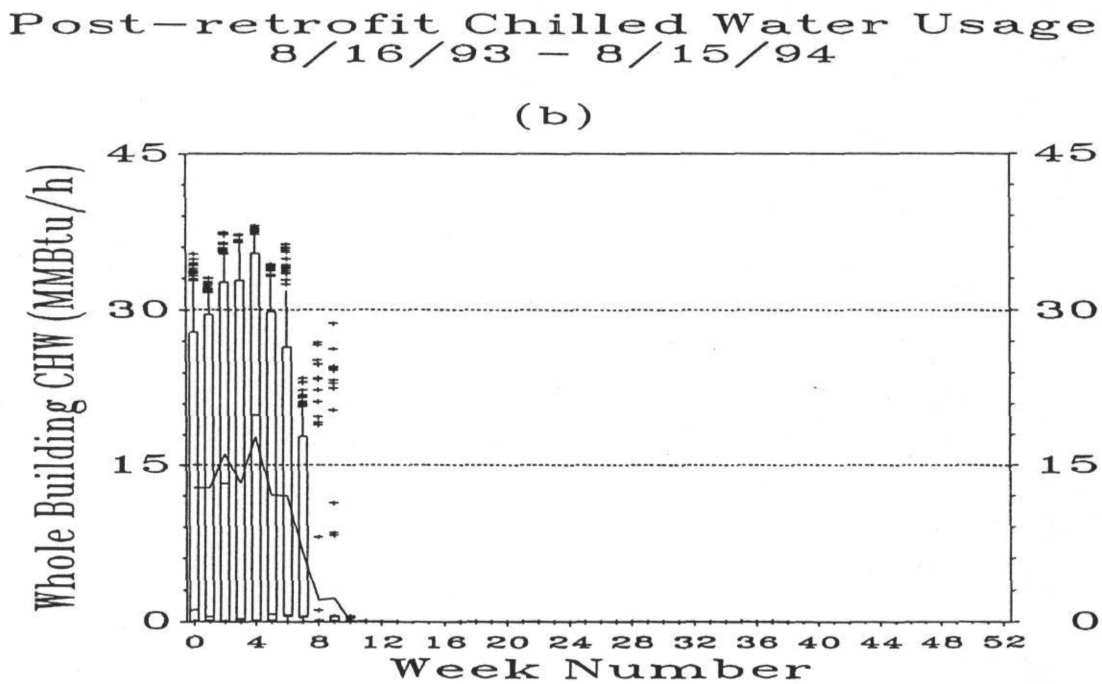
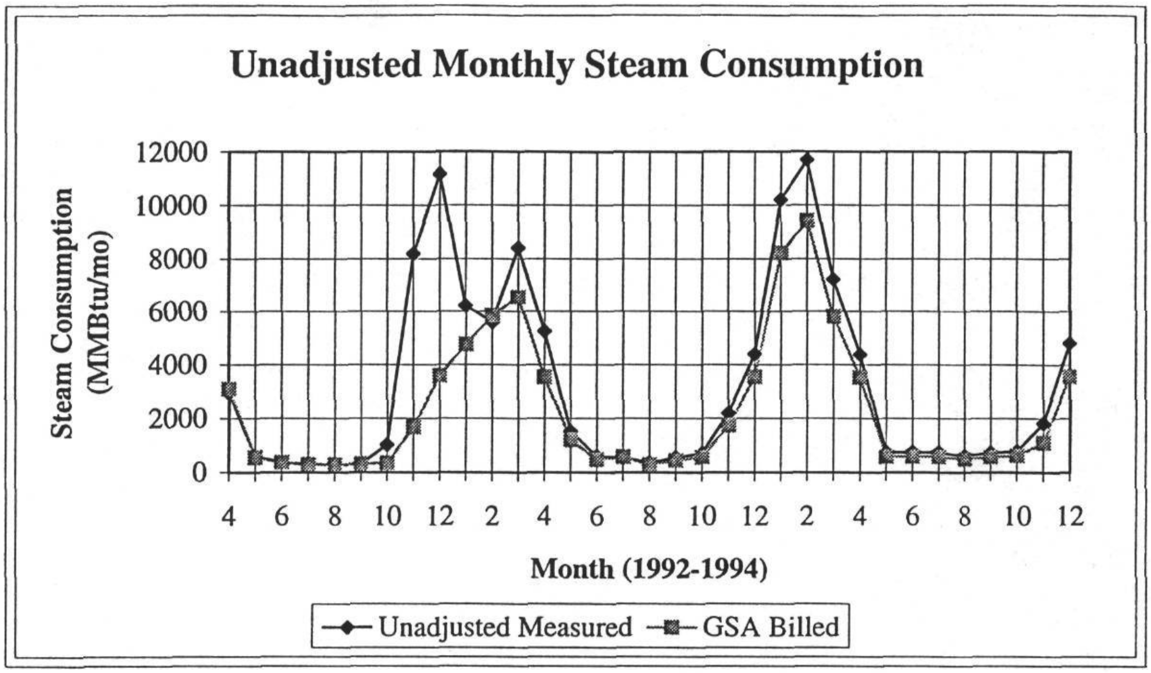


FIGURE 10A,B: 52-WEEK CHILLED WATER BOX-WHISKER-MEAN PLOT. THE UPPER FIGURE SHOWS THE WHOLE-BUILDING CHILLED WATER PRE-RETROFIT DATA (FIGURE 10A) AND THE LOWER FIGURE SHOWS THE POST RETROFIT DATA (FIGURE 10B).



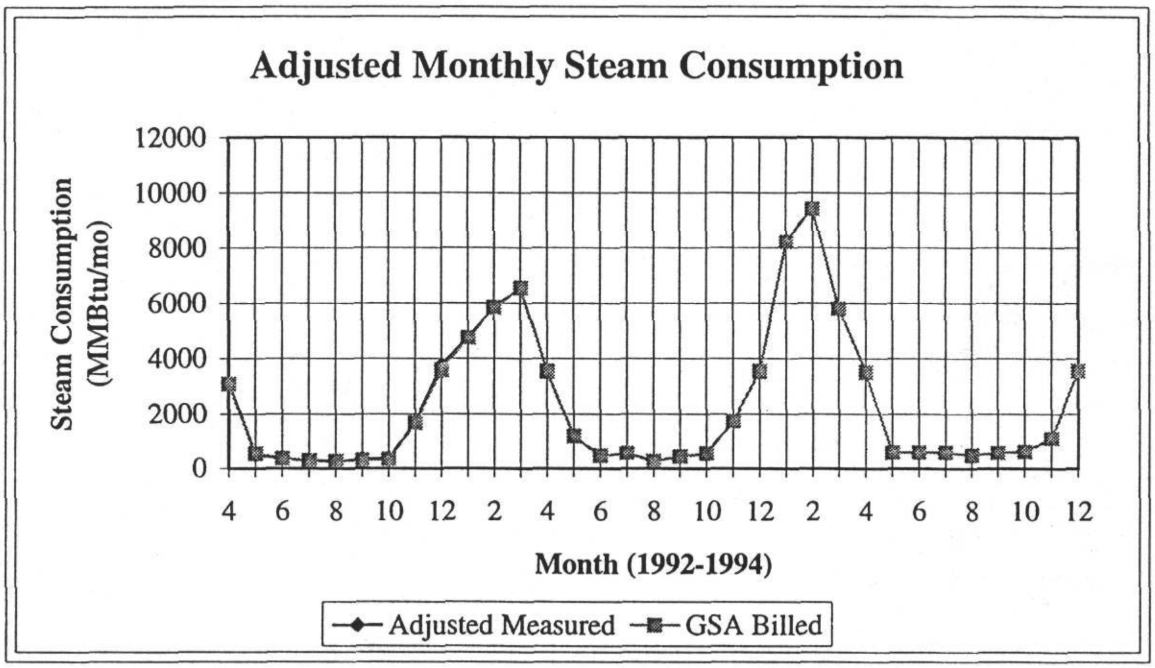
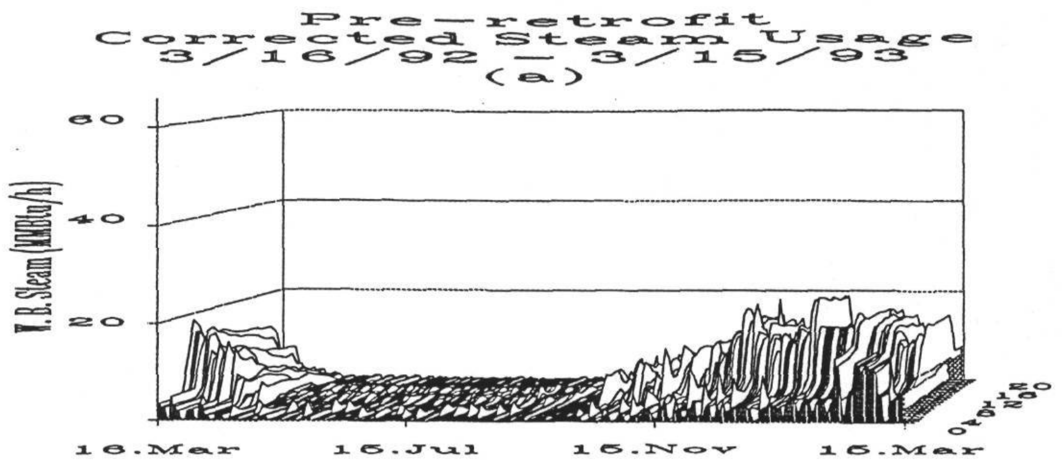


FIGURE 11A,B: WHOLE-BUILDING ELECTRONICALLY MEASURED MONTHLY STEAM COMPARED WITH GSA MONTHLY UTILITY BILLS. THE UPPER PLOT (FIGURE 11A) SHOWS THE COMPARISON BEFORE THE RE-SCALING AND THE LOWER PLOT (FIGURE 11B) SHOWS THE MEASURED DATA COMPARED TO GSA UTILITY BILLS AFTER RE-SCALING.

Since it was difficult to obtain information as to the true billing dates for the steam and chilled water bills, a few initial checks were performed to verify the correct billing period. First, a billing period from the 1st of the month to the end of the month was examined versus the utility bills and graphed. Since this did not appear to have a consistent fit from month to month, an iterative procedure was used to determine the best billing period fit. The steam billing period from the 16th of each month to the 15th of the following month showed the best correlation with the GSA bills and was therefore adopted as the true billing period. Conversations with DOE personnel confirmed this period to be the most likely billing period. Next, it was necessary to label the billing months correctly. For example, a billing period from January 16 to February 15 was flagged as the February bill and considered the billing month.

Figure 12a shows a three-dimensional plot of the corrected hourly whole-building pre-retrofit steam data and Figure 12b shows the corrected post-retrofit data. Figure 12a corresponds with Figure 13a which shows a 52-week box-whisker-mean plot of the corrected pre-retrofit period. Figure 13b shows the post-retrofit period corrected dataset and corresponds with the three-dimensional dataset shown in Figure 12b.

Due to the fact that the hourly steam data required re-scaling, a monthly analysis of the steam data was used in this report. A comparison of an hourly analysis of the steam data to the monthly analysis is presented in the appendix.



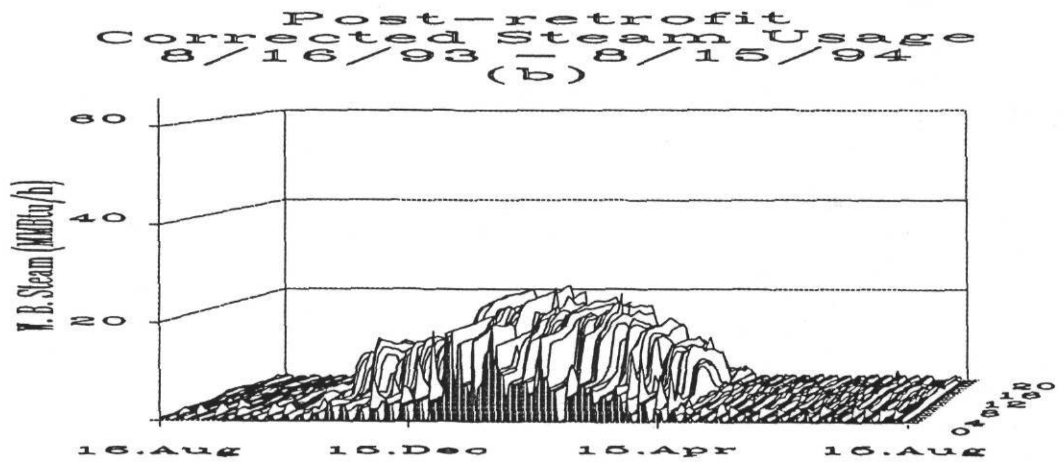
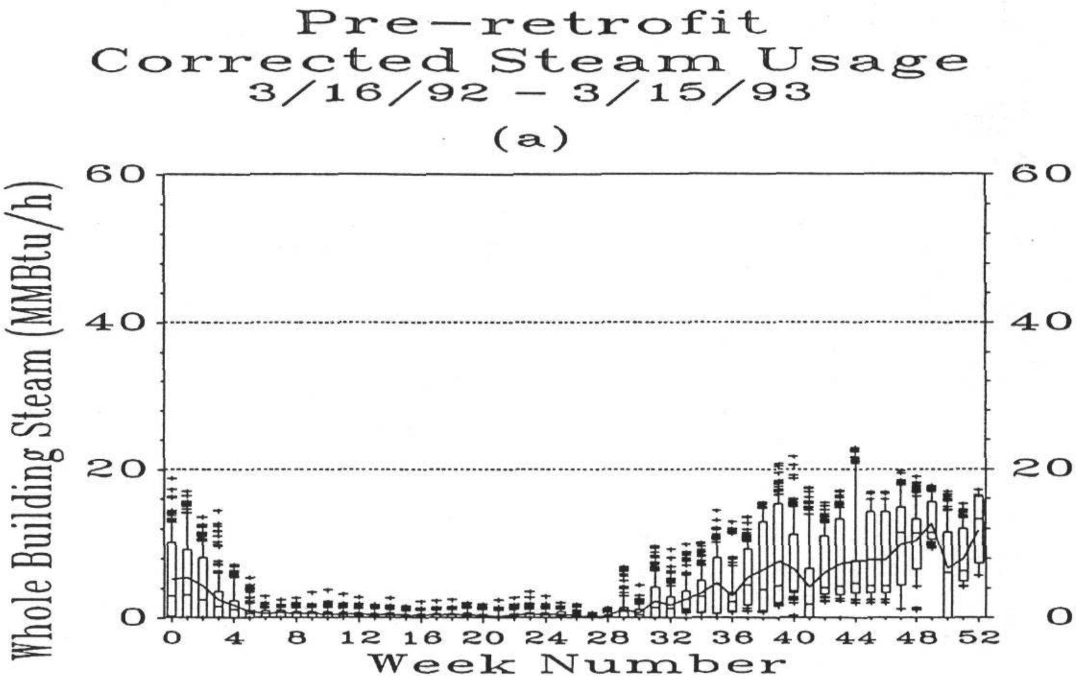


FIGURE 12A,B: THREE-DIMENSIONAL PLOT OF THE CORRECTED ELECTRONICALLY MEASURED STEAM DATA. THE UPPER PLOT (FIGURE 12A) SHOWS THE CORRECTED HOURLY WHOLE-BUILDING PRE-RETROFIT STEAM DATA FOR THE PERIOD 3/16/92 - 3/15/93. THE LOWER PLOT (FIGURE 12B) SHOWS THE CORRECTED POST-RETROFIT DATA FOR THE PERIOD 8/16/93 - 8/15/94.



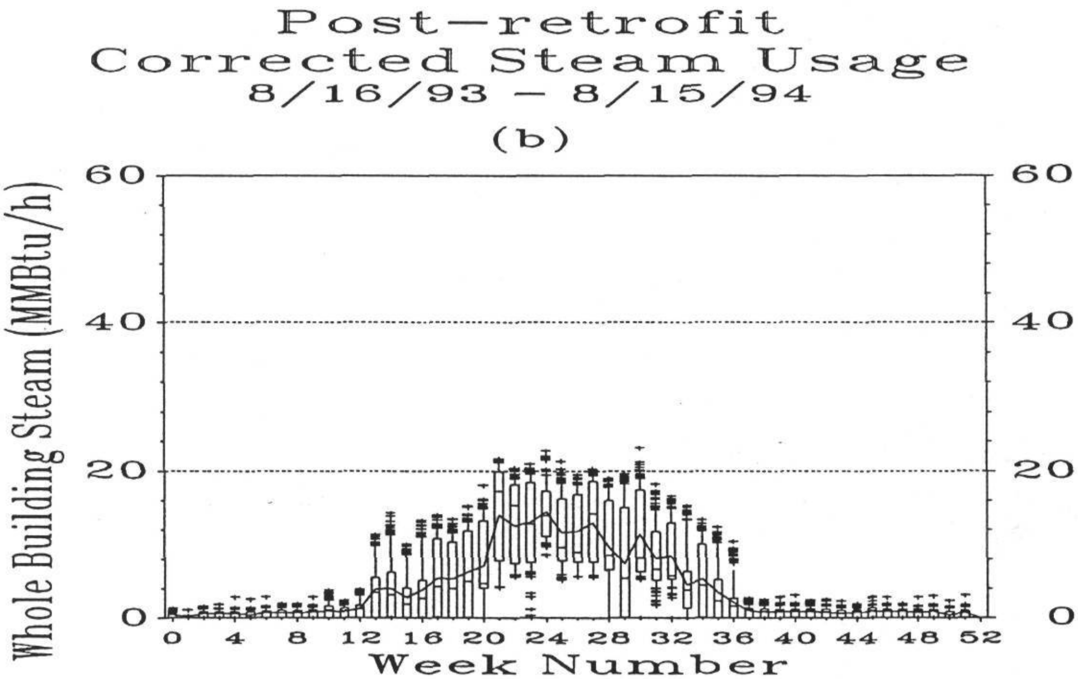


FIGURE 13A,B: 52-WEEK BOX-WHISKER-MEAN PLOT OF THE CORRECTED STEAM DATA. THE UPPER PLOT (FIGURE 13A) SHOWS THE CORRECTED PRE-RETROFIT DATA FOR THE PERIOD 3/16/92 - 3/15/93. THE LOWER PLOT (FIGURE 13B) SHOWS THE POST-RETROFIT DATA FOR THE PERIOD 8/16/93 - 8/15/94.

ELECTRICITY SAVINGS ANALYSIS

General

One of the most prominent features of the 1992 baseline data shown in Figure 8 is the lack of any significant weather dependency. To some extent this was to be expected since the building receives its chilled water from the GSA central plant and therefore does not contain any significant cooling related loads that normally would have been associated with the electricity required to run a large chiller plant[27]. This lack of any weather dependency meant that the whole-building electricity use could be accurately modeled with weather-independent 24-hour daytype profiles.

Development of the 24-hour, pre-post, weekday-weekend electricity profiles

Using the methodology developed by Thamilseran and Haberl (1995) it was determined that three 24-hour daytype profiles would be required to characterize the electricity use for the 1992 baseline period as shown in Figure 14, including: a weekday profile (i.e., the upper plot), a winter weekend profile (middle plot from October 1 through May 31 of the following year), and a summer weekend profile (lower plot from June 1 through September 30). The extremely tight inter-quartile range for each of the 24 bins and CV-RMSE of 6.22% indicated that this was an adequate choice of day-type profiles for the pre-retrofit period as well as the post-retrofit period [28]. Furthermore, an RMSE of 208.75 kWh/h [29] indicated that the model was capable of measuring the estimated 1,300 kW demand savings.

The goodness of fit of the three daytypes to the pre-retrofit data can be seen in Figures 15 and 16. In Figure 15 the whole-building electricity use for 1992 is shown in the upper plot and the 3-daytype predicted electricity use using the daytype profiles is shown in the second plot. In the third and fourth plots positive-only residuals have been plotted to show periods when the simulated electricity use was over-predicting the measured electricity use (simulated-measured -- the middle plot), or under-predicting (measured-simulated -- the lower plot) [30]. Figure 16 shows the goodness of-fit using only 2-daytypes, one weekday profile and one weekend profile. The difference between the 2-daytype and 3-daytype methodology can easily be seen.

Figure 17 shows the post-retrofit measured data, the 3-daytype, post-retrofit model and residual plots for the period August 1993 through July 1994. The presence of the previously mentioned problems in the whole-building post-retrofit period is evident in this plot as well as the drop in the CV-RMSE to 14.67% in Table 1. The major period of bad data from the faulty utility meter occurred in September of 1993 and can be seen in the third plot of Figure 17. The other periods when the meter failed, or power consumption was below normal due to maintenance [31] are evident as positive ridges in the third plot and are scattered throughout the remainder of the monitoring period. The data appearing in the fourth plot represent periods when the measured electricity use was greater than the statistically predicted use.

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[27] It is estimated that this could have increased the peak whole-building electricity use by roughly 4 to 6 MW (4,000 to 6,000 tons of cooling estimated at 200-400 ft^2/ton).

[28] This CV-RMSE compares favorably with CVs reported by Kreider and Haberl (1994a, 1994b) from the application of more sophisticated models such as neural networks.

[29] We use the kWh/h notation to indicate that the data were recorded using an hourly integration period, versus a 15-minute integration period.

[30] The use of these 3-D residual plots has previously been shown to be useful in Haberl and Vajda (1988), Haberl and Komor (1990), and Haberl et al. (1993).

[31] This is referring to the aluminum riser replacement, computer UPS maintenance, and electrical vault switchgear maintenance.

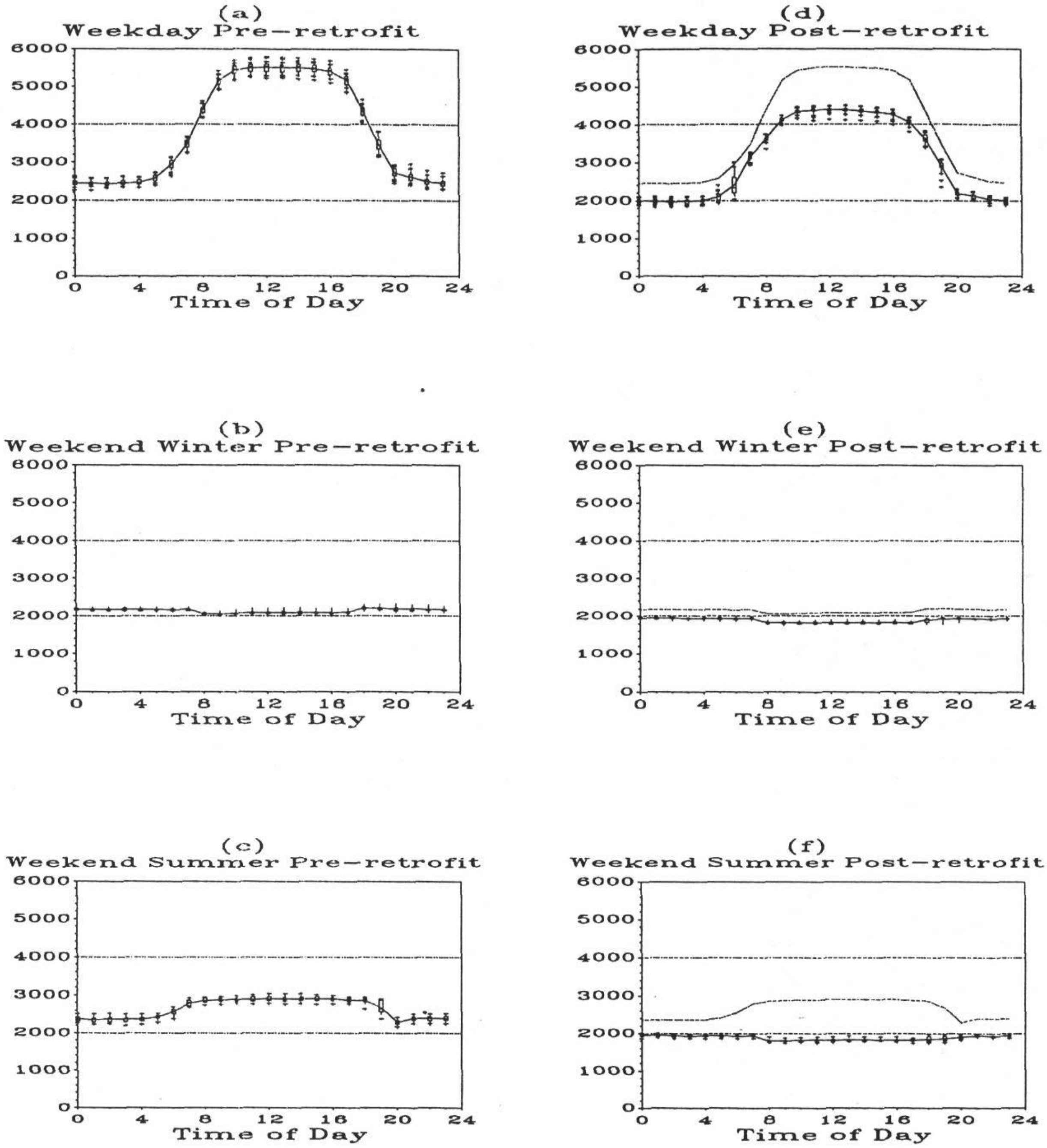


FIGURE 14A,B,C,D,E,F: WHOLE-BUILDING PRE-POST, WEEKDAY-WEEKEND 24-HOUR DAYTYPE PROFILES FOR THE DOE FORRESTAL COMPLEX. THESE FIGURES SHOW THE 24 HOUR STATISTICAL DAYTYPE PROFILES OF THE WHOLE-BUILDING ELECTRICITY USE FOR THREE DAYTYPES (WEEKDAY, WEEKEND-WINTER, WEEKEND-SUMMER) DURING PRE-RETROFIT AND POST-RETROFIT PERIODS.

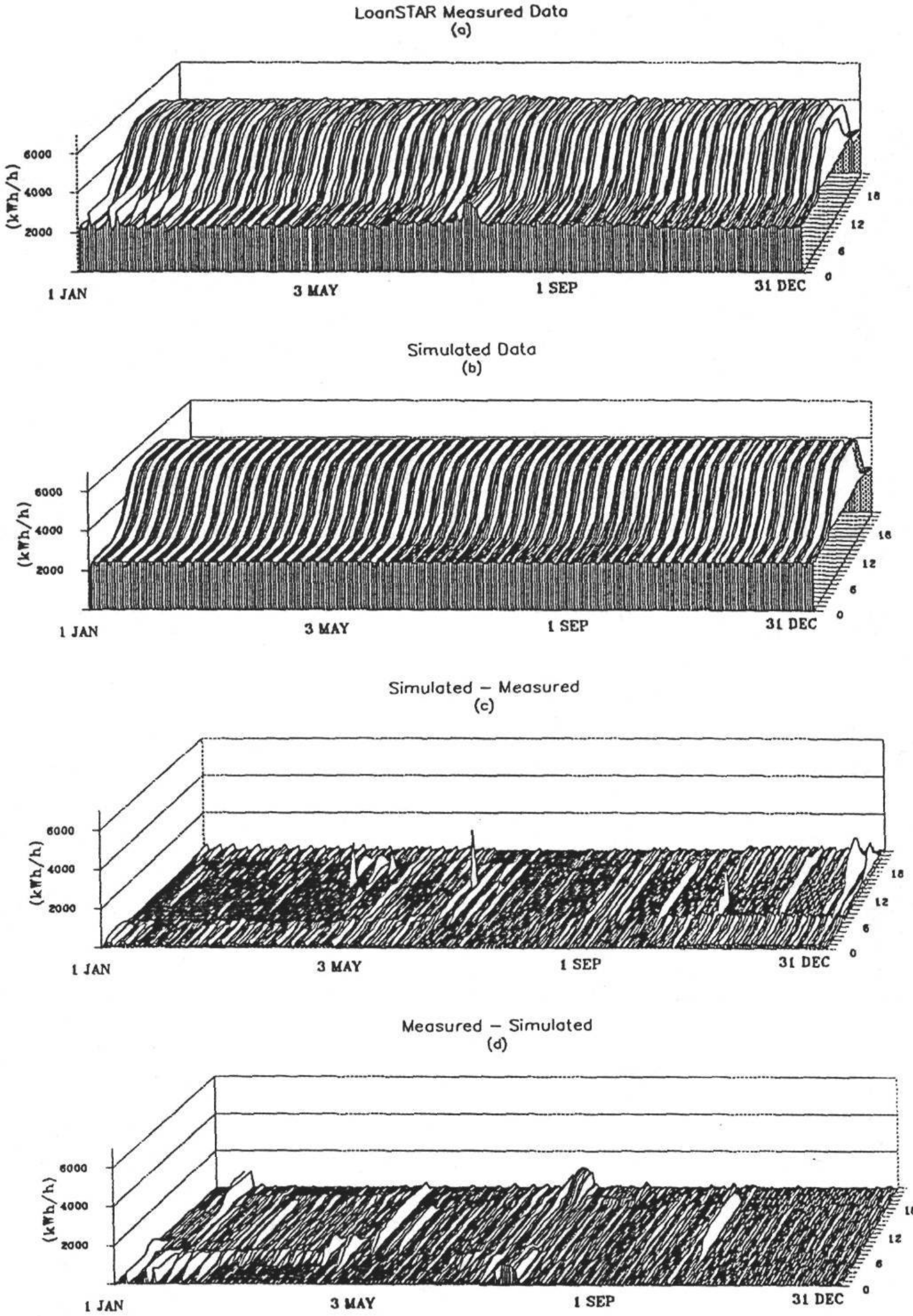


FIGURE 15A,B,C,D: COMPARATIVE WHOLE-BUILDING PRE-RETROFIT ELECTRICITY USE FOR THE DOE FORRESTAL COMPLEX (THREE DAYTYPES) FOR 1992. THESE COMPARATIVE 3-D TIME SERIES PLOTS SHOW THE MEASURED WHOLE-BUILDING PRE-RETROFIT ELECTRICITY USE (UPPER PLOT), ELECTRICITY USE PREDICTED BY THE DAYTYPE (SECOND PLOT), AND RESIDUAL PLOTS THAT SHOW THE HOURLY SIMULATED MINUS MEASURED ELECTRICITY USE (THIRD PLOT), AND MEASURED MINUS SIMULATED ELECTRICITY USE (LOWER PLOT).

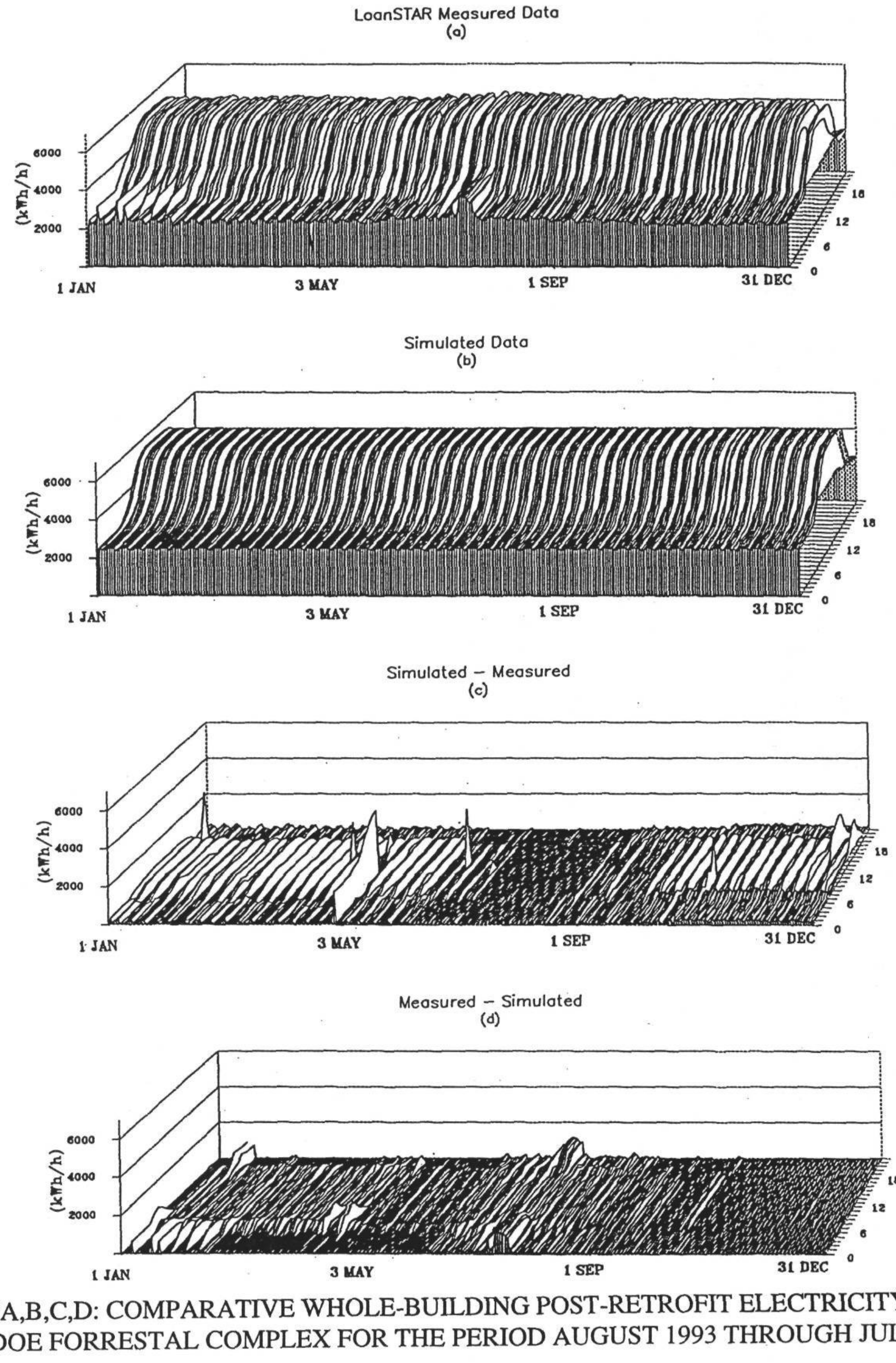


FIGURE 16A,B,C,D: COMPARATIVE WHOLE-BUILDING POST-RETROFIT ELECTRICITY USE FOR THE DOE FORRESTAL COMPLEX FOR THE PERIOD AUGUST 1993 THROUGH JULY 1994.

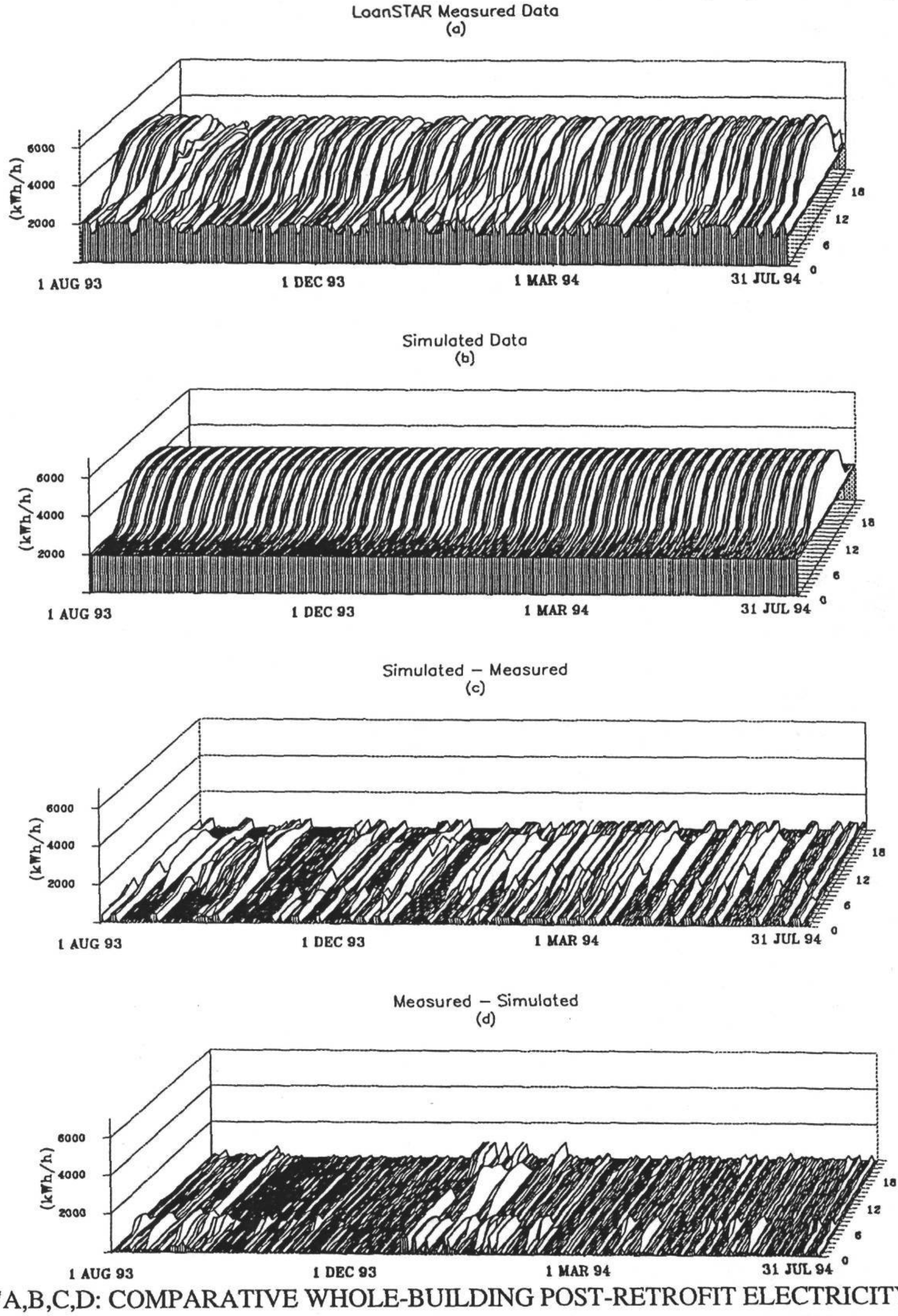


FIGURE 17A,B,C,D: COMPARATIVE WHOLE-BUILDING POST-RETROFIT ELECTRICITY USE FOR THE DOE FORRESTAL COMPLEX FOR THE PERIOD AUGUST 1993 THROUGH JULY 1994. THESE 3-D TIME SERIES PLOTS SHOW THE MEASURED WHOLE-BUILDING POST-RETROFIT ELECTRICITY USE COMPARED TO THE POST-RETROFIT DAYTYPE MODEL.

TABLE 1: EMPIRICAL MODEL PARAMETERS. THIS TABLE COMPARES HOW WELL THE 24-HOUR DAYTYPE MODELS PREDICTED THE BUILDING'S ENERGY USE DURING THE PERIOD SHOWN. IN BOTH THE PRE-RETROFIT AND POST-RETROFIT PERIODS THREE MODELS WERE USED. THEY INCLUDE: WEEKDAY, WINTER WEEKEND, AND SUMMER WEEKEND MODELS.

Period	CV-RMSE	RMSE	MBE
	%	(kWh/h)	%
1/1/92 to 12/31/92	6.22	208.75	-0.61
10/1/93 to 11/30/93	5.66	152.6	-0.17
8/1/93 to 7/31/94	14.67	379.8	3.54

In order to compensate for the bad data in the 1993/94 post-retrofit period a post-retrofit model was developed from representative data from the period immediately after the retrofit of October 1, 1993 to November 30, 1993 [32]. This post-retrofit model consisted of one weekday profile and winter-summer weekend profiles which can be seen in the right hand plots in Figure 14. The CV-RMSE of 5.66% in Table 1 indicates that the post-retrofit model adequately described the post-retrofit data occurring during the October-November 1993 period. The savings from the lighting retrofit were then calculated by comparing annual electricity use predicted by the 1992 pre-retrofit model against the annual electricity use predicted by the 1993 post-retrofit model.

Electricity savings results

Electricity savings are tabulated in Table 2 and compared against the savings calculated by subtracting adjusted utility bills [33]. The savings calculated by simply comparing the utility bills for the 12 month period was 5.532 million kWh. The total savings calculated using the pre-post daytypes for the 12 month period from August 1993 to July 1994 is 5.520 million kWh which is about 10.2% below the estimated savings of 6.146 million kWh. The billed demand savings for 1993/94 compared to similar months in 1992 varied from a low of 959.0 kW to a high of 1,186.6 kW. This compares favorably to the estimated 1,300 kW demand reduction estimate. The comparison of pre-post model's hourly CV-RMSE of 6% to 8% against the annual electricity reduction of 20% indicates that the level of savings is above the statistical noise of the analysis method.

Table 3 is a summary of the monthly total electricity savings resulting from the lighting retrofit and are based on the daytype models which use the number of days included in each month's billing period during the post-retrofit period. Therefore, the months do not show uniform monetary or energy consumption as would be expected when modeled data are coupled with the variable number of weekend days and holidays per month. Each month's energy and demand savings calculated using the weather independent bin analysis are listed along with the monetary savings based on the utility rates that were

[32] Several days of bad data were removed that did not match the average profiles.
[33] The utility billing data for the Forrestal building was adjusted by the local utility to account for the missing data.

charged during the pre-retrofit period. The PEPCO rates shown in Table 4 are calculated using a rate schedule composed of three distinct energy charges and two demand charges [34].

TABLE 2: SAVINGS COMPARISONS. IN THIS TABLE ELECTRIC UTILITY BILLING DATA FOR AUGUST 1993 THROUGH JUNE 1994, AND JANUARY TO DECEMBER 1992 ARE COMPARED AGAINST DAYTYPE MODELED SIMULATED SAVINGS FOR THE SAME CALENDAR MONTHS. THE DEMAND SAVINGS ARE BASED ON A COMPARISON OF THE MONTHLY UTILITY BILLS.

	Aug. 1993 to Jul. 1994		Jan. to Dec. 1992					
		Utility Billed		Utility Billed	Utility Bill Savings	Daytype Model Electricity Savings	Utility Demand Savings	Daytype Model Demand Savings
	Dates	(kWh)	Dates	(kWh)	(kWh)	(kWh)	(kW)	(kW)
Aug	7/24-8/23	2,171,109	7/23-8/21	2,462,147	291,038	540,223	959.0	1052.9
Sep	8/24-9/22	2,150,546	8/22-9/22	2,655,715	505,169	522,009	1,097.3	1052.9
Oct	9/23-10/21	1,872,685	9/23-10/22	2,380,244	507,559	421,826	1,143.4	1052.9
Nov	10/22-11/22	1,983,824	10/23-11/20	2,235,887	252,063	427,802	1,100.2	1052.9
Dec	11/23-12/22	1,838,133	11/21-12/23	2,534,937	696,804	404,412	1,169.8	1052.9
Jan	12/23-1/25	2,165,273	12/23-1/27	2,654,375	489,102	429,778	1,033.9	1052.9
Feb	1/26-2/22	1,731,429	1/28-2/27	2,491,367	759,938	472,599	1,186.6	1052.9
Mar	2/23-3/25	1,913,079	2/28-3/25	2,166,693	253,614	442,892	1,085.8	1052.9
Apr	3/26-4/25	1,780,789	3/26-4/24	2,441,166	660,377	421,464	1,091.5	1052.9
May	4/26-5/24	1,858,445	4/25-5/26	2,469,551	611,106	408,788	996.4	1052.9
Jun	5/25-6/23	2,078,466	5/27-6/24	2,387,796	309,330	486,381	878.4	1052.9
Jul	6/24-7/25	2,356,860	6/25-7/23	2,552,896	196,036	541,385	1,134.7	1052.9
12 Month Total		23,900,638		29,432,754	5,532,136	5,519,559	-	-

According to Table 3, it may be observed that the summer months of June through October produced the highest energy savings while the utility summer rate schedule was in effect. Since a more efficient, lower wattage lighting system produced less internal heat gain throughout the building, the overall load on the cooling system was in-turn reduced. This will be discussed in the section that describes the thermal analysis. Additional savings are realized in the higher production charge which is billed during the summer months. The impact of the avoided cost of demand is easily seen in the demand savings column of Table 3, particularly when the utility company raises rates in coming years. Another aspect of lighting retrofits that should not be ignored is the incurred thermal savings illustrated in the next section.

[34] The energy charges include an off-peak rate, an intermediate rate, and an on-peak rate. The off-peak period covers all weekdays from 12:00 a.m. to 8:00 a.m. and the entire weekend. The intermediate period covers all weekdays from 8:00 a.m. to 12:00 p.m. and 8:00 p.m. to 12:00 a.m. The on-peak period covers all weekdays from 12:00 p.m. to 8:00 p.m. The demand charges consist of a distribution charge and a production charge. The distribution rate is charged as the basic rate for demand and the production rate is charged during the summer rate schedule months effective in June through October. The figures listed in Table 3 do not include local taxes, discounts, or fuel cost adjustment factors which were found to vary dramatically from month to month.

TABLE 3: SUMMARY OF ELECTRICITY AND DEMAND SAVINGS. THE DOLLAR SAVINGS ARE BASED ON THE ACTUAL UTILITY RATES THAT WERE CHARGED DURING THE PRE-RETROFIT PERIOD OF JANUARY TO DECEMBER, 1992. LOCAL TAXES, UTILITY REBATES, AND FUEL ADJUSTMENT FACTORS ARE NOT INCLUDED IN THIS TABLE.

Month	Modeled kWh Savings	Modeled kW Savings	Energy Savings	Demand Savings	Total Savings
Aug	540,223	1,053	$18,202	$17,794	$35,996
Sep	522,009	1,053	$20,326	$17,794	$38,120
Oct	421,826	1,053	$16,598	$17,794	$34,392
Nov	427,802	1,053	$14,228	$6,844	$21,072
Dec	404,413	1,053	$16,411	$6,844	$23,255
Jan	429,778	1,053	$13,957	$6,370	$20,327
Feb	472,599	1,053	$13,945	$6,370	$20,315
Mar	442,892	1,053	$14,678	$6,370	$21,048
Apr	421,464	1,053	$13,661	$6,370	$20,031
May	408,789	1,053	$14,872	$6,370	$21,242
Jun	486,381	1,053	$16,783	$16,583	$33,366
Jul	541,384	1,053	$18,379	$17,163	$35,542
Total	5,519,560	12,635	$192,040	$132,666	$324,706

TABLE 4: UTILITY RATES CHARGED DURING THE PRE-RETROFIT PERIOD ON WHICH THE SAVINGS CALCULATIONS ARE BASED. THE THREE ENERGY PERIODS INCLUDE AN OFF-PEAK PERIOD, AN INTERMEDIATE PERIOD, AND AN ON-PEAK PERIOD. THE TWO DEMAND RATES INCLUDE A DISTRIBUTION RATE CHARGED DURING THE ENTIRE YEAR AND A PRODUCTION RATE CHARGED ONLY DURING THE SUMMER RATE SCHEDULE FROM JUNE THROUGH OCTOBER. LOCAL TAXES, UTILITY REBATES, AND FUEL ADJUSTMENT FACTORS ARE NOT INCLUDED IN THIS TABLE.

Month	$/kWh Off-pk (1)	$/kWh Interm (2)	$/kWh On-pk (3)	$/kW Distribution	$/kW Production
Jan-92	$0.028329	$0.037259	$0.043204	$6.05	$0.00
Feb-92	$0.028330	$0.037260	$0.043204	$6.05	$0.00
Mar-92	$0.028330	$0.037260	$0.043207	$6.05	$0.00
Apr-92	$0.028329	$0.037260	$0.043203	$6.05	$0.00
May-92	$0.028329	$0.037259	$0.043205	$6.05	$0.00
Jun-92	$0.026380	$0.038020	$0.052214	$6.05	$9.70
Jul-92	$0.027361	$0.039433	$0.054151	$6.30	$10.00
Aug-92	$0.028220	$0.040669	$0.055846	$6.50	$10.40
Sep-92	$0.028220	$0.040670	$0.055846	$6.50	$10.40
Oct-92	$0.028220	$0.040669	$0.055847	$6.50	$10.40
Nov-92	$0.030320	$0.039900	$0.046218	$6.50	$0.00
Dec-92	$0.030319	$0.039899	$0.046215	$6.50	$0.00

(1) Off-peak - WD: 12 a.m. - 8 a.m. WE: 24 hours.
(2) Intermediate - WD: 8 a.m. - 12 p.m. WD: 8 p.m. - 12 a.m.
(3) On-peak - WD: 12 p.m. - 8 p.m.

THERMAL SAVINGS ANALYSIS

General

Whenever large-scale lighting retrofits such as the Forrestal building take place, it is important to consider the thermal impacts. Lighting systems, especially aging lamps in large quantities, generate a considerable amount of heat when in use. This can be seen as a benefit during the winter because the heat from the lights reduces the amount of space heat required from the central plant. However, in the summer months, extra space cooling is required to overcome the internal heat load from the lighting as well as the heat load generated by the equipment, occupants, and ambient-related loads. Therefore, consideration should be given to the end result during the winter and summer months alike when retrofitting a building with energy efficient lamps. This section calculates the space cooling savings and the space heating increase from the lighting retrofit. It will be shown that although the building experiences an increase in wintertime heating, the summertime cooling gains more than offset the heating increases.

Modeling the weather dependent thermal consumption

To calculate the thermal savings that resulted from the lighting retrofit, it is necessary to normalize the data for changing weather patterns that occurred from year to year. For the steam and chilled water energy use, it was decided to use a four parameter change-point regression model. A comparison of three parameter, four parameter, and temperature-binned procedures is presented in the appendix.

The four parameter change point chilled water and steam regression models were calculated using monthly utility bills and average monthly temperature data consistent with the utility billing period. First, the GSA utility bill pre-retrofit data were divided by the number of billing days for each month according to the GSA billing period. A statistical energy calculation software tool, EModel (Kissock et al. 1994), was then utilized to calculate monthly models for the cooling and heating periods. The pre-retrofit parameters were then projected into the post-retrofit period using post-retrofit monthly average outdoor dry bulb temperatures. The pre-retrofit model driven by the post-retrofit monthly average dry bulb temperature was then subtracted from the post-retrofit GSA utility consumption for each month to calculate energy savings.

Table 5 shows the model parameters, R^2, and CV-RMSE statistics for the four parameter model used in the steam analysis as shown in Figure 18. Table 6 shows the model parameters, R^2, and CV-RMSE statistics for the four parameter model used in the chilled water analysis and Figure 19 shows the four parameter data in graphical form used in the chilled water analysis.

TABLE 5: STATISTICAL GOODNESS-OF-FIT FOR THE FOUR PARAMETER STEAM MODEL. THIS TABLE PROVIDES STATISTICS FROM THE FOUR PARAMETER MODEL WHICH WERE FIT TO THE PRE-RETROFIT DATA.

Model Type	No. of Points	R squared	CV-RMSE (%)	RMSE	Baseline	Left Slope	Right Slope	Change Point
4P	12	0.99	10.2	7.78	16.40	-10.73	-0.34	53.86

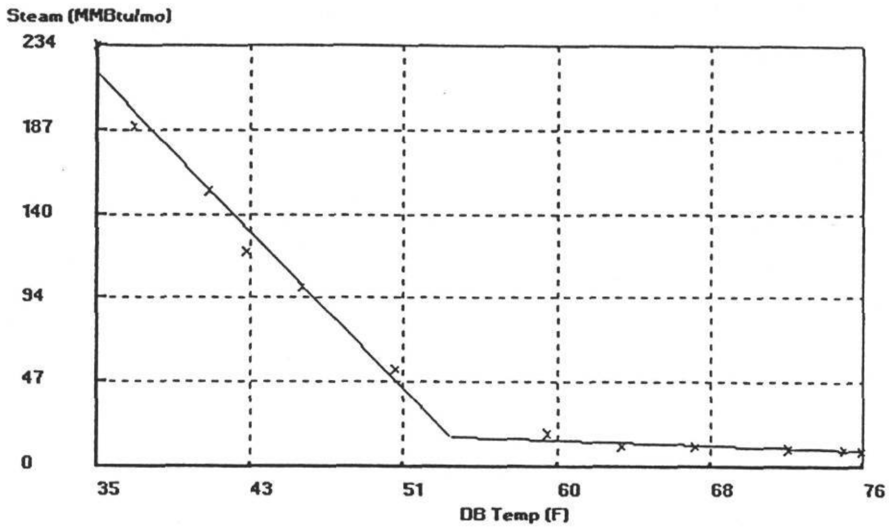


FIGURE 18: FOUR PARAMETER STEAM MODEL. THIS FOUR PARAMETER CHANGE-POINT MODEL FITTED TO THE MONTHLY STEAM DATA.

TABLE 6: STATISTICAL GOODNESS-OF-FIT FOR THE FOUR PARAMETER CHILLED WATER MODEL. THIS TABLE PROVIDES THE STATISTICS FROM THE FOUR PARAMETER MODEL WHICH WERE FIT TO THE PRE-RETROFIT DATA.

Model Type	No. of Points	R squared	CV-RMSE (%)	RMSE	Baseline	Left Slope	Right Slope	Change Point
4P	12	0.99	18.8	14.63	12.95	0.57	22.03	62.88

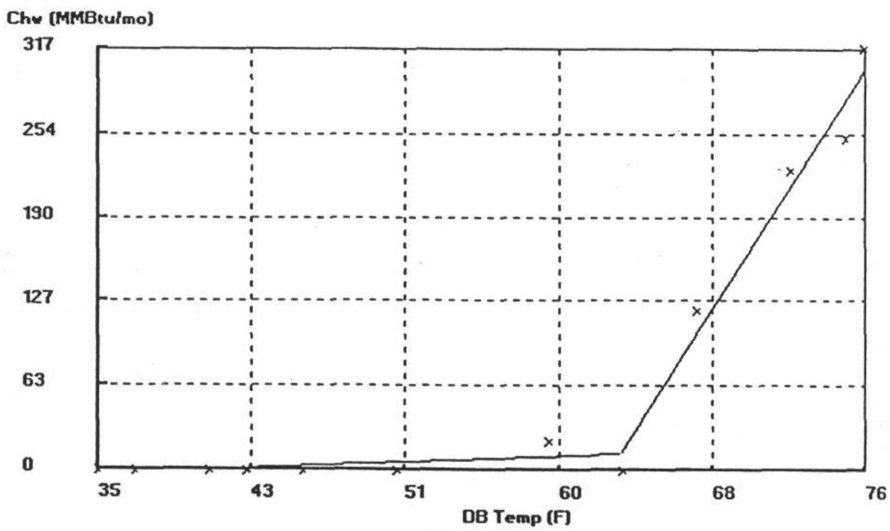


FIGURE 19: FOUR PARAMETER CHILLED WATER MODEL. THIS GRAPH SHOWS THE FOUR PARAMETER MODELED DATA FOR THE WHOLE-BUILDING CHILLED WATER.

Cooling and heating savings results

The steam and chilled water energy savings calculated with the four parameter model are presented in this section. Table 7 and Figure 20 show a comparison of the model used for this analysis to calculate the steam savings due to the lighting retrofit. In Table 7, the monthly and total GSA billed steam consumption for the pre- and post-retrofit periods are shown along with the "GSA Change" or direct utility bill comparison beginning in the fourth column from the left. These are the savings that would be realized when differences in weather from year to year are not taken into account (i.e., by directly comparing the utility bill from one year to the next). The four parameter pre-retrofit model driven by the post-retrofit average monthly temperature was then subtracted from the GSA post-retrofit utility billed consumption to calculate the savings using a four parameter model to weather normalize. The next two columns in Table 7 show the pre-retrofit use forecast into the post-retrofit period as calculated by the four parameter model. The savings (or increase) are shown in the column marked "4-P Change". The savings calculated by the four parameter model provided the basis for the final reported savings due to the retrofit.

TABLE 7: SUMMARY OF THE INCREASE IN STEAM CONSUMPTION DUE TO THE RETROFIT. THIS TABLE SHOWS A MONTHLY SUMMARY OF THE GSA UTILITY BILL SAVINGS COMPARISON AND THE FOUR PARAMETER CHANGE-POINT WEATHER-ADJUSTED SAVINGS.

Mo	GSA Pre-retrofit Utility Bill (MMBtu/mo)	GSA Post-retrofit Utility Bill (MMBtu/mo)	GSA Change (MMBtu/mo)	4-P Pre-retrofit Model (MMBtu/mo)	4-P Change (1) (MMBtu/mo)
Jan	4,756	8,216	3,461	7,777	439
Feb	5,848	9,411	3,563	8,775	636
Mar	6,550	5,797	-753	4,322	1,475
Apr	3,100	3,520	420	1,127	2,394
May	545	585	40	399	186
Jun	361	594	233	329	265
Jul	290	585	295	217	368
Aug	276	483	207	256	227
Sep	310	430	120	246	184
Oct	344	552	208	420	133
Nov	1,671	1,730	59	794	935
Dec	3,589	3,540	-50	3,343	197
Total	27,640	35,444	**7,804**	28,005	**7,438**

(1) This value was calculated by subtracting the pre-retrofit 4-P model consumption from the GSA post-retrofit consumption. Positive values indicate an increase in steam enrgy use.

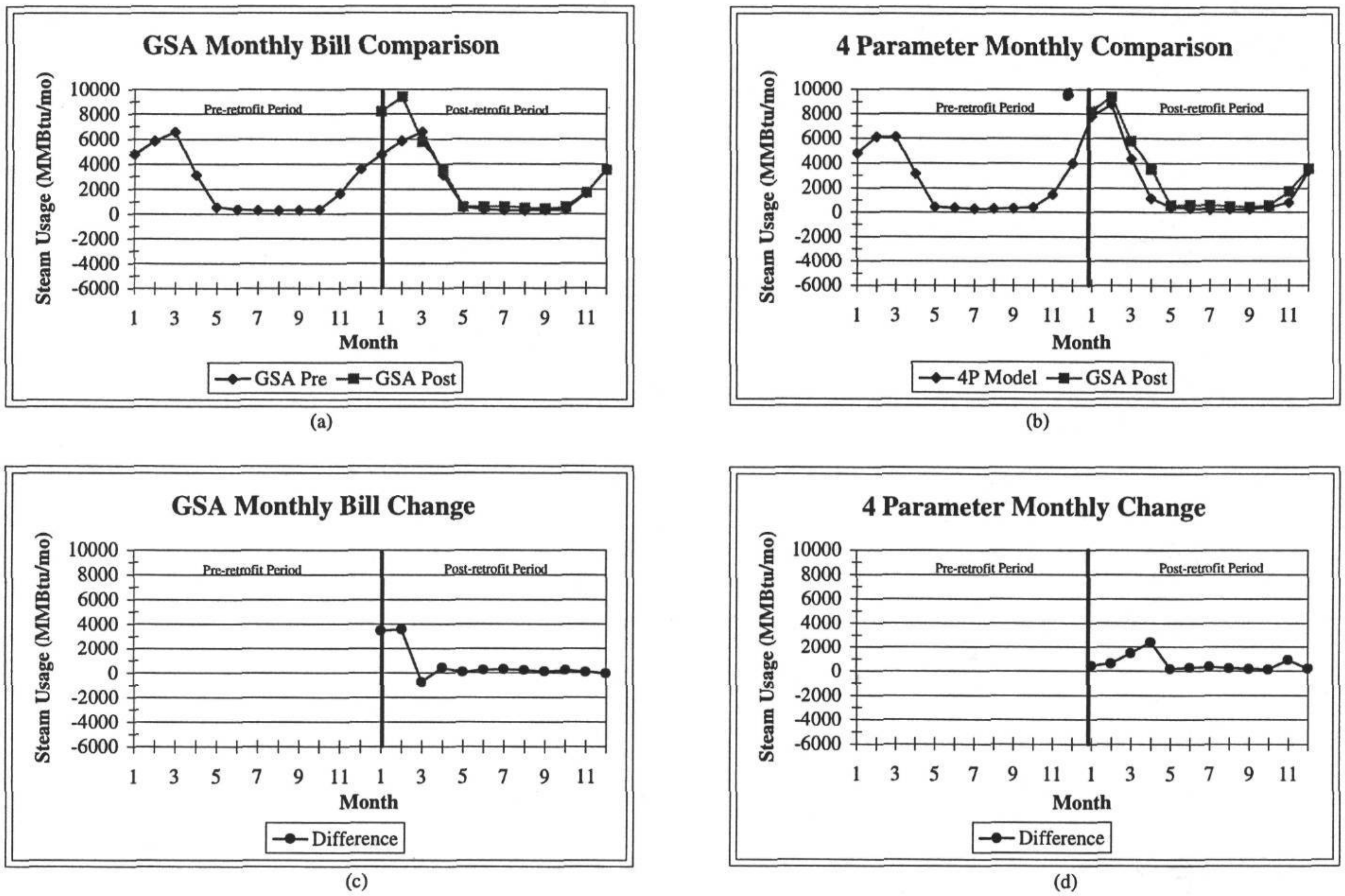


FIGURE 20A,B,C,D: STEAM CONSUMPTION CHANGE DUE TO THE LIGHTING RETROFIT. THESE FIGURES COMPARE THE CHANGE IN THE WHOLE-BUILDING STEAM CONSUMPTION. PART (A) SHOWS THE PRE- AND POST-RETROFIT GSA UTILITY BILL COMPARISON. PART (B) SHOWS THE FOUR PARAMETER WEATHER-ADJUSTED SAVINGS. PARTS (C) AND (D) SHOW THE DIFFERENCE FOR THE BILLED DATA AND THE MODELED DATA RESPECTIVELY.

Figure 20a shows a direct comparison of the steam consumption from the GSA utility bills for the pre- and post-retrofit periods. The pre-retrofit data are projected into the post-retrofit period and denoted by the “GSA Pre” label in the legend. The difference between the GSA Pre and GSA Post is noted on the graph by “Difference”. Figure 20b shows the savings calculated by the four parameter heating model. The “4P Model” in the pre-retrofit period is driven by pre-retrofit monthly average temperature data. It was then projected into the post-retrofit period and driven by post-retrofit average monthly temperature data to represent the pre-retrofit building as it would have performed in the post-retrofit period. The data can be located by the symbols marked “4P Model” in the graph’s legend. The 4P model was then subtracted from the GSA post-retrofit utility consumption to obtain the differences which are also shown on the graph. The positive difference values during the winter are due to a higher amount of steam required to meet the heating load formerly provided by the extra lights in the building prior to the retrofit.

The four parameter model provides a good fit to the baseline data as seen in Figure 18. At temperatures less than 54 °F the data show a linear increase in heating with decreasing temperatures. At temperatures above 54 °F there is a modest decrease in heating energy use as the temperature increases. The calculations for a three parameter model and the bin method model are provided for comparison in Appendix A.

Table 8 and Figure 21 show the whole-building chilled water savings comparisons. In Table 8, the GSA billed consumption for the pre- and post-retrofit periods are shown along with the "GSA Change" or unadjusted utility bill comparison. These are the savings that are realized when differences in weather from year to year are not taken into account (i.e., by directly comparing the utility bill from one year to the next). The final two columns in Table 8 show the usage and savings calculated by the four parameter model. The savings for chilled water use are calculated in a similar fashion to the weather normalized steam differences. The savings calculated by this model provided the basis for the final reported savings due to the retrofit.

TABLE 8: SUMMARY OF THE CHANGE IN CHILLED WATER CONSUMPTION DUE TO THE RETROFIT. THIS TABLE SHOWS A MONTHLY SUMMARY OF THE GSA UTILITY BILL SAVINGS COMPARES TO THE FOUR PARAMETER WEATHER-ADJUSTED SAVINGS.

Mo	GSA Pre-retrofit Utility Bill (MMBtu/mo)	GSA Post-retrofit Utility Bill (MMBtu/mo)	GSA Change (MMBtu/mo)	4-P Pre-retrofit Model (MMBtu/mo)	4-P Change (1) (MMBtu/mo)
Jan	0	0	0	0	0
Feb	0	0	0	0	0
Mar	0	0	0	0	0
Apr	0	0	0	0	0
May	636	970	334	468	502
Jun	3,685	5,099	1,414	5,948	-849
Jul	7,493	10,576	3,083	12,366	-1,790
Aug	9,830	9,051	-779	10,729	-1,678
Sep	6,998	7,094	96	11,412	-4,318
Oct	0	0	0	0	0
Nov	0	0	0	0	0
Dec	0	0	0	0	0
Total	28,642	32,790	**4,148**	40,923	**-8,133**

(1) This value was calculated by subtracting the Pre-retrofit 4-P model consumption from the GSA Post-retrofit consumption.

Figure 21a shows a direct comparison of the GSA billed chilled water use reported in the pre- and post-retrofit period. Figure 21b shows the savings calculated with a four parameter model. Figures 21c and 21d show the difference between the two methods. The graphs shown in this figure were developed similarly to the graphs shown in Figure 20.

In Table 9a, the column labeled "Unadjusted GSA CHW Change" lists the savings obtained by comparing unadjusted GSA utility bills. The final column labeled "Weather Normalized CHW Change" was calculated by projecting the pre-retrofit CHW use into the post-retrofit period and uses the pre-

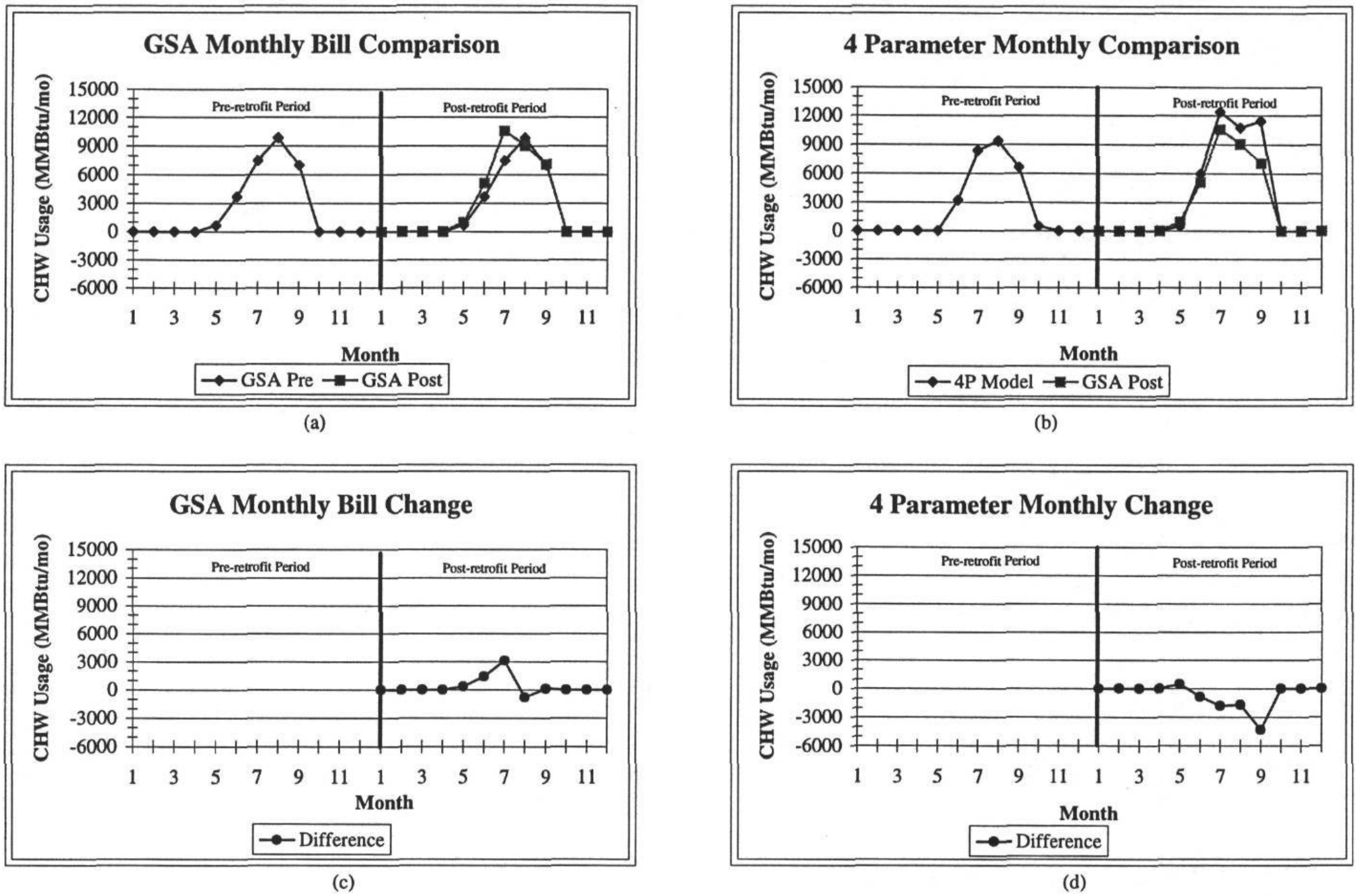


FIGURE 21A,B,C,D: SUMMARY OF DIFFERENCES IN PRE-POST CHILLED WATER USE. THESE FIGURES COMPARE THE WHOLE-BUILDING CHILLED WATER SAVINGS DUE TO THE LIGHTING RETROFIT. PART (A) SHOWS THE UNADJUSTED PRE- AND POST-RETROFIT GSA UTILITY BILL COMPARISONS. PART (B) SHOWS THE WEATHER NORMALIZED SAVINGS USING THE MONTHLY 4P MODEL. PARTS (C) AND (D) SHOW THE DIFFERENCE FOR THE BILLED DATA AND THE MODELED DATA RESPECTIVELY.

retrofit CHW costs. The weather normalized savings in Table 9a for the chilled water are $218,121. In contrast to this, the unadjusted total cost increase of $142,439 is due to a marked increase in the average monthly temperature of the post-retrofit year compared to the pre-retrofit year coupled with a decrease of approximately $10/MMBtu in the average monthly chilled water utility rates.

Table 9b shows an increase in the steam use necessary to make up for the reduced heat from the lights. The major cause for the small difference between the unadjusted steam increased of $120,959 and the weather normalized steam increase of $115,297 lies in the utility rate change. The steam rate charged by GSA was reduced from $15.50/MMBtu during the monthly pre-retrofit period to $14.95/MMBtu during the post-retrofit period. To uphold consistency with the electricity analysis, the pre-retrofit rate was used as a baseline each month in this analysis for both the pre- and post-retrofit periods savings calculations for the weather normalized calculations. The dollar values for the

TABLE 9A,B: SUMMARY OF THE CHILLED WATER AND STEAM SAVINGS DUE TO THE RETROFIT. THIS TABLE SHOWS A MONTHLY SUMMARY OF THE UNADJUSTED GSA MONETARY SAVINGS AND THE WEATHER-NORMALIZED MONETARY SAVINGS.

Pre-retrofit Period Month	Pre-retrofit GSA CHW Utility Bill	Post-retrofit Period Month (1)	Post GSA CHW Utility Bill (2)	Unadjusted GSA CHW Change (2)	Weather Normalized CHW Change (3)
Apr-92	-	Apr-94	-	-	-
May-92	$36,068	May-94	$55,048	$18,980	$28,489
Jun-92	$151,883	Jun-94	$210,134	$58,251	($34,983)
Jul-92	$210,802	Jul-94	$297,509	$86,707	($50,347)
Aug-92	$301,507	Aug-94	$277,591	($23,916)	($51,467)
Sep-92	$177,977	Sep-93	$180,395	$2,418	($109,812)
Oct-92	-	Oct-93	-	-	-
Nov-92	-	Nov-93	-	-	-
Dec-92	-	Dec-93	-	-	-
Jan-93	-	Jan-94	-	-	-
Feb-93	-	Feb-94	-	-	-
Mar-93	-	Mar-94	-	-	-
Total	$878,237		$1,020,676	$142,439	($218,121)

(a)

Pre-retrofit Period Month	Pre-retrofit GSA Steam Utility Bill	Post-retrofit Period Month (1)	Post GSA Steam Utility Bill (2)	Unadjusted GSA Steam Change (2)	Weather Normalized Steam Change (3)
Apr-92	$48,050	Apr-94	$54,566	$6,516	$37,098
May-92	$8,448	May-94	$9,072	$624	$2,888
Jun-92	$5,596	Jun-94	$9,205	$3,609	$4,106
Jul-92	$4,495	Jul-94	$9,072	$4,577	$5,709
Aug-92	$4,278	Aug-94	$7,491	$3,213	$3,523
Sep-92	$4,805	Sep-93	$6,662	$1,857	$2,849
Oct-92	$5,332	Oct-93	$8,562	$3,230	$2,052
Nov-92	$25,896	Nov-93	$26,807	$911	$14,500
Dec-92	$55,633	Dec-93	$54,864	($769)	$3,047
Jan-93	$73,712	Jan-94	$127,354	$53,642	$6,811
Feb-93	$90,650	Feb-94	$145,871	$55,221	$9,858
Mar-93	$101,520	Mar-94	$89,847	($11,673)	$22,856
Total	$428,415		$549,374	$120,959	$115,297

(1) The months shown wrap-around to facilitate direct monthly comparisons from the pre-retrofit period to the post-retrofit period.

(2) The dollar values for the weather normalized changes are calculated based on actual pre-retrofit rates applied to the utility billed consumption of the pre-retrofit period and the post-retrofit period.

(3) A positive value in these columns indicates an increase in energy use when compared to the pre-retrofit period. A negative value indicates a decrease or savings.

(b)

unadjusted GSA changes use the actual $/MMBtu rates for the pre- and post-retrofit periods. This assumption increases the impact of the added steam costs.

Table 10 contains the utility rates charged by GSA for chilled water and steam during the pre-retrofit and post-retrofit periods. These monetary figures provided the basis for calculating costs for both the pre-retrofit and post-retrofit periods and thus, the cost savings.

TABLE 10: GSA THERMAL UTILITY RATES CHARGED DURING THE PRE-RETROFIT PERIOD ON WHICH THE WEATHER NORMALIZED SAVINGS ARE CALCULATED. FOR COMPARISON, THE POST-RETROFIT UTILITY RATES ARE ALSO PROVIDED.

Pre-retrofit Mon-Yr	Pre-retrofit $/MMBtu CHW (1)	Pre-retrofit $/MMBtu Steam	Post-retrofit Mon-Yr (2)	Post-retrofit $/MMBtu CHW (1)	Post-retrofit $/MMBtu Steam
Apr-92	-	$15.50	Apr-94	-	$14.95
May-92	$56.75	$15.50	May-94	$25.93	$14.95
Jun-92	$41.21	$15.50	Jun-94	$25.93	$14.95
Jul-92	$28.13	$15.50	Jul-94	$25.93	$14.95
Aug-92	$30.67	$15.50	Aug-94	$25.93	$14.95
Sep-92	$25.43	$15.50	Sep-93	$26.45	$14.95
Oct-92	-	$15.50	Oct-93	-	$14.95
Nov-92	-	$15.50	Nov-93	-	$14.95
Dec-92	-	$15.50	Dec-93	-	$14.95
Jan-93	-	$15.50	Jan-94	-	$14.95
Feb-93	-	$15.50	Feb-94	-	$14.95
Mar-93	-	$15.50	Mar-94	-	$14.95
Average	$36.44	$15.50	Average	$26.03	$14.95

(1) The '-'s represent months when chilled water is not supplied to the building

(2) The months wrap around to facilitate direct monthly comparisons from the pre-retrofit period to the post-retrofit period. The pre-retrofit period includes utility bills from April 1992 through March 1993. The post-retrofit period includes utility bills from September 1993 through August 1994

SUMMARY AND DISCUSSION

At the present time there is considerable debate concerning how to measure savings from energy conservation retrofits to large buildings. This report has attempted to shed some light on the effectiveness of using whole-building, or gross measurements[35] of electricity and thermal savings from a lighting retrofit. This report has focused on the use of pre-post whole-building measurements that could easily be obtained for any building using the existing revenue meters[36].

Table 11 and Figure 22 compare the individual annual electricity, chilled water, and steam monetary savings resulting from the lighting retrofit. Figure 22a shows the direct pre-post utility bill comparison without weather normalization or utility rate change consideration. Figure 22b shows the change in utility costs based on pre-retrofit utility unit costs and Figure 22c shows the weather normalized change. An unadjusted utility bill using pre-retrofit billing rates yields only a $80,069 savings. In contrast, weather normalized calculations yield a $427,529 savings or 107% of the expected $399,058 audit estimated electricity savings. The data in Tables 11a-c correspond with the data shown in Figures 22a-c.

TABLE 11A,B,C: COMPARISON OF THE ELECTRICITY, CHILLED WATER, AND STEAM MONETARY SAVINGS DUE TO THE LIGHTING RETROFIT.

(a) Utility bills as actually charged

Energy source	Pre-retrofit	Post-retrofit	$ Change	% Change
Electricity	$1,819,147	$1,540,662	($278,485)	-15%
CHW	$878,237	$853,923	($24,314)	-3%
Steam	$428,415	$529,879	$101,464	24%
Total	$3,125,799	$2,924,464	($201,335)	-6%

(b) Utility Bills based only on pre-retrofit billing rates

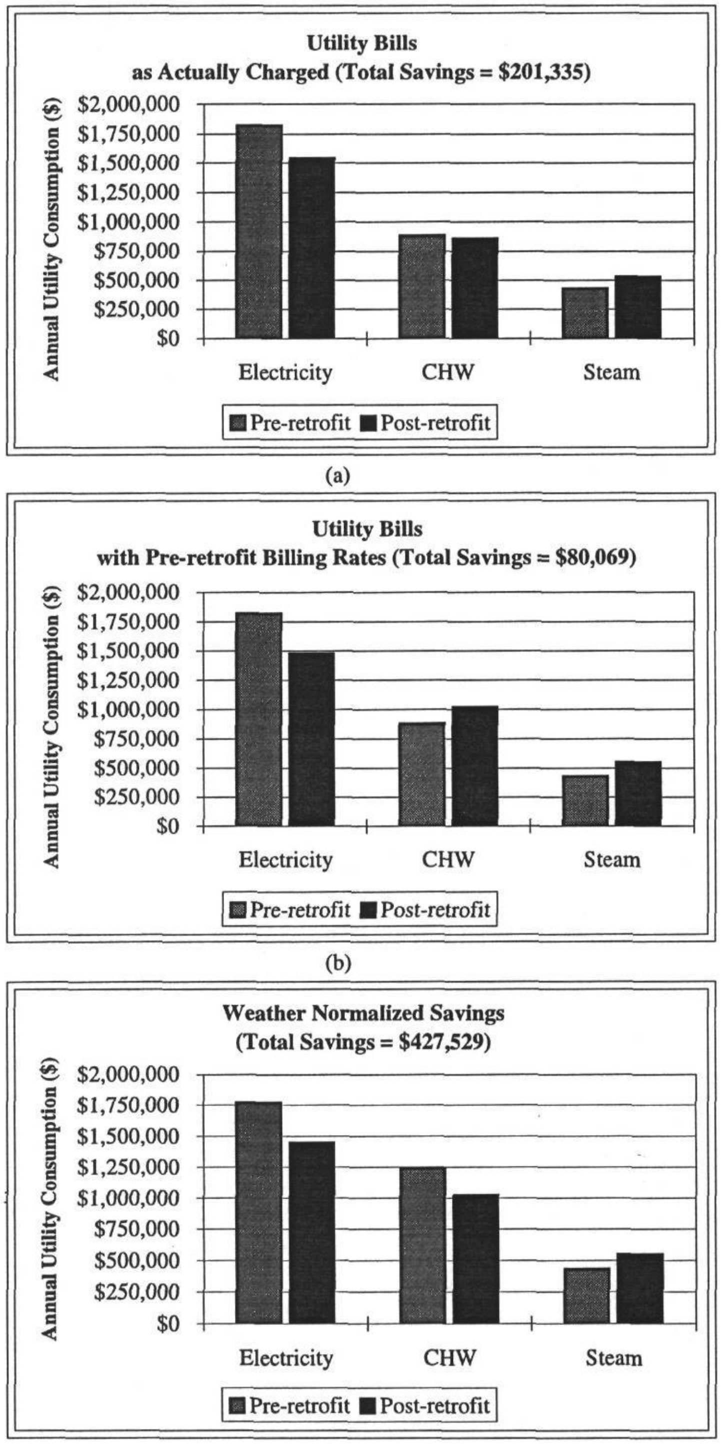
Energy source	Pre-retrofit	Post-retrofit	$ Change	% Change
Electricity	$1,819,147	$1,475,679	($343,468)	-19%
CHW	$878,237	$1,020,676	$142,439	16%
Steam	$428,415	$549,374	$120,959	28%
Total	$3,125,799	$3,045,730	($80,069)	-3%

(c) Weather Normalized Savings (Bin: Electricity, 4P: CHW, 4P: Steam)
Based on pre-retrofit billing rates

Energy source	Pre-retrofit	Post-retrofit	$ Change	% Change
Electricity	$1,771,342	$1,446,637	($324,705)	-18%
CHW	$1,238,797	$1,020,676	($218,121)	-18%
Steam	$434,078	$549,374	$115,297	27%
Total	$3,444,217	$3,016,688	($427,529)	-12%

[35] The term net energy savings measurements would refer to the long term, pre-post measured savings using lighting end-use measurements.

[36] Using the methods developed in the Texas LoanSTAR program it is estimated that whole-building electric and thermal metering can be installed and maintained and an analysis performed for about 5 to 10% of the retrofit costs, or about 3 to 5% of the annual utility bill. Annual reporting costs are about $1,200/year once the analysis has been completed. The level of effort for the analysis depends upon the type of analysis (i.e., monthly, daily, or hourly) and the complexity of the building's energy usage signature.



(c)

FIGURE 22A,B,C: COMPARISON OF THE ELECTRICITY, CHILLED WATER, AND STEAM MONETARY SAVINGS DUE TO THE LIGHTING RETROFIT.

The importance of analyzing the electricity and thermal savings from the lighting retrofit can be seen in the dramatic increase in the total savings from $80,069 (20% of the expected cost savings) for the direct utility bill comparison to $427,529 (107% of the expected $399,058 cost savings) for the weather normalized savings [37].

Clearly, there are several points that warrant further discussion, including:

1. Comparisons of unadjusted utility billing costs may not be sufficient to measure savings from lighting retrofits -- even when the savings amount to 20% of the annual kWh for a facility. In the case of the Forrestal building differences in the utility's month to month unit cost factors and billing adjustments obscured the monetary retrofit savings from the decrease in electricity use.
2. Utility revenue meters can and do fail. Therefore it is recommended that redundant meters be used to either detect the failure of utility meters and/or provide additional measurements of retrofit savings. At the Forrestal building metering problems were experienced with all three whole-building meters (i.e., electricity, steam, and chilled water). Weekly inspection of the hourly metered data proved invaluable in finding and fixing the broken meters quickly.
3. The thermal energy effect from a lighting retrofit can be significant and should be included in all savings measurements where the building is air-conditioned and/or heated. In the case of the Forrestal building the lighting retrofit has lead to a 7,438 MMBtu increase in the annual steam energy use which translates into $115,297 (+27%) per year based on pre-retrofit period utility rates. Chilled water use decreased by approximately 8,133 MMBtu annually for a total savings of $218,121 (-18%). Thermal energy savings are dependent on HVAC system type and utility costs, and therefore require measurement at each site.
4. The electricity energy savings resulting directly from the lighting retrofit accounted for an annual savings of 5.520 million kWh or $324,705 (76%) of the total savings of $427,529.
5. Portable, snap-shot, before-after end-use measurements can provide an accurate measure of the energy use of an individual device or end-use if the uncertainty involved in projecting hourly daytype profiles (or hourly diversity measurements) can be minimized [38]. Therefore it is recommended that these types of measurement methods be supplemented with long-term, before-after, whole-building measurements where feasible.
6. Independent, third party measurement of savings from energy conservation retrofits is highly recommended. Such third parties should be required to use repeatable, consensus-based measurement and analysis techniques such as the DOE's NEMVP (USDOE 1996) using NIST-traceable instrumentation to assure that an accurate, affordable, scientifically-defensible analysis has been performed.
7. The results of this study indicate that there is a need for the creation of federal data centers that could be used to independently and accurately measure shared savings in federal facilities using methods which are compatible with the NEMVP. Such data would provide O&M feedback to building operators.

[37] The actual weather normalized cost savings for the Forrestal complex would probably be higher if the $/unit cost used the post-retrofit periods. If one applies the post retrofit costs to the normalized savings, the resultant monetary savings are ($213,134) for CHW, $111,206 for steam, and ($338,855) for electricity for a total of $440,783, or 110% of the estimated $399,058 savings. The significant increase in the electricity rates, particularly an increase in demand rates, were offset by a decrease in the monthly steam and chilled water rates.

[38] The previously reported electricity savings using portable measurements was 5.7 million kWh per year (Halverson et al. 1994).

CONCLUSION

This report has provided an overview of the lighting retrofit and presented results from the whole-building monitoring effort. Quite surprisingly, the thermal savings which were not included in initial estimates by the USDOE accounted for approximately 24% of the overall savings and increased the total cost savings to $427,529 (107% of expected electricity cost savings). Measured reductions in electricity energy use agreed within 90% of the estimated savings. The monetary savings accounted for $324,705 or 76% of the total savings. Peak hourly electric demand are within an average of 90% ± 10% of pre-retrofit estimated 1,300 kWh demand reductions. The chilled water savings from the reduced cooling load increased the savings by $218,121 or 51% of the total savings. The added cost of steam to make up for the heat from the old inefficient lights decreased savings by $115,297.

Clearly, the lighting retrofit at the USDOE Forrestal building is successful and is saving electricity at or near to the rates that were estimated. Furthermore, the careful study and documentation of the electricity and thermal savings has provided a wealth of information that other federal facilities can use to help secure their own successful energy conservation projects.

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The data loggers used in the Forrestal building are manufactured by the Synergistic Controls Systems, Metairie, Louisiana. Whole-building electricity was measured by sharing the KYZ signal from the building's 20+ year old mechanical totalizer which is fed KYZ pulses from four 2-stator-type, mechanical watt-hour meters manufactured by General Electric. Steam was measured with an axial turbine flow meter, manufactured by the Engineering Measurements Company (EMCO) in Longmont, Colorado. Chilled water was measured with a transit-time thermal energy meter manufactured by Controlotron in Hauppauga, New York. National Weather Service (NWS) weather data was obtained via modem from Accuweather in State College, Pennsylvania.

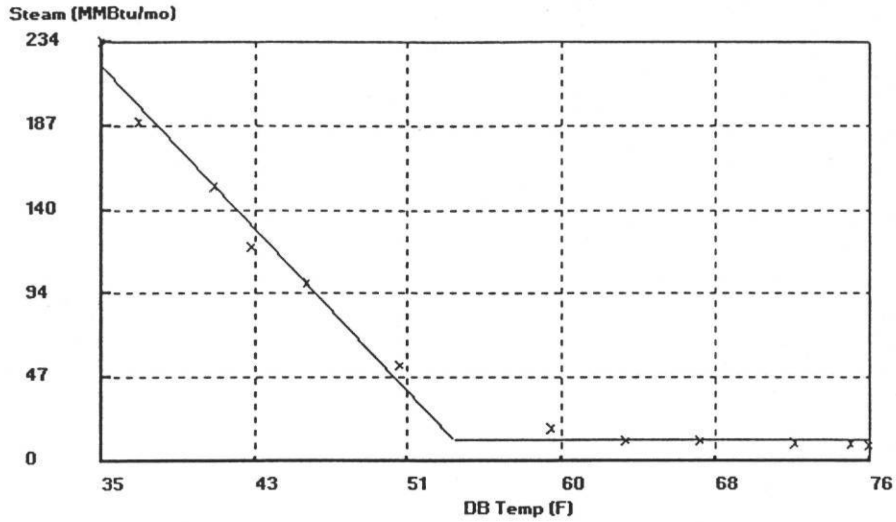
APPENDIX A

This appendix contains a summary of three different models that were evaluated in addition to the four parameter change-point regression model for the thermal analysis, including a three parameter model and an inverse bin model (Thamilseran and Haberl 1995). In the bin method hourly pre-retrofit data was run through the bin routine to calculate a model for weekday occupied, weekday unoccupied, and weekend temperature profiles. The pre-retrofit model was then used with post-retrofit outdoor dry bulb temperature data to simulate the building's pre-retrofit steam use under post-retrofit weather conditions so that direct savings calculations could be made. This procedure was followed to correct for differences in weather patterns between pre and post conditions.

The three and four parameter change point models for chilled water and steam were calculated using monthly utility bills and average monthly temperature data consistent with the utility billing period. First, the GSA utility bill pre-retrofit data were divided by the number of billing days for each month according to the GSA billing period. A statistical energy calculation software tool, EModel (Kissock et al. 1994), was then utilized to calculate monthly models for the cooling and heating periods. The pre-retrofit parameters were then projected into the post-retrofit period using post-retrofit monthly average outdoor dry bulb temperatures. The pre-retrofit model driven by the post-retrofit monthly average dry bulb temperature was then subtracted from the post-retrofit GSA utility bills for each month to calculate energy savings. Table A-1 shows the model parameters, R^2, and CV-RMSE statistics for the three and four parameter data used in the steam analysis as shown in Figure A-1.

TABLE A-1: STATISTICAL GOODNESS-OF-FIT FOR THE THREE AND FOUR PARAMETER STEAM MODELS. THIS TABLE PROVIDES THE STATISTICS FROM THE THREE AND FOUR PARAMETER MODELS WHICH WERE FIT TO THE PRE-RETROFIT DATA.

Model Type	No. of Points	R squared (%)	CV-RMSE (%)	RMSE	Baseline	Left Slope	Right Slope	Change Point
3P	12	0.99	10.10	7.70	12.15	-11.03	0	53.86
4P	12	0.99	10.20	7.78	16.40	-10.73	-0.34	53.86



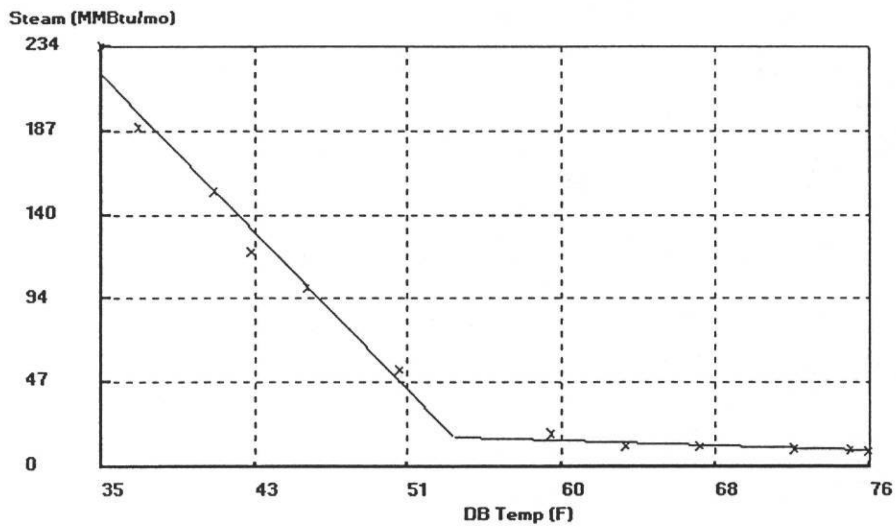


FIGURE A-1: THREE AND FOUR PARAMETER STEAM MODELS. THE UPPER GRAPH SHOWS THE THREE PARAMETER CHANGE-POINT MODEL FITTED TO THE MONTHLY STEAM DATA. THE LOWER GRAPH SHOWS THE FOUR PARAMETER CHANGE-POINT MODEL.

Development of the temperature bin pre-post, weekday-weekend thermal profiles

Figure A-2 shows several plots of the corrected hourly steam energy consumption for the pre- and post-retrofit periods. The top left graph shows a scatter plot of the entire pre-retrofit dataset. Since one year of hourly data on the scatter plot contains data from several modes of operation, it became necessary to separate the data into different modes of building operation. The second plot from the top left shows a temperature-binned plot of the weekday occupied pre-retrofit period in 5° F bins. The third plot from the top left graph of Figure A-2 shows the weekday unoccupied temperature-binned plot and the lower most plots show weekend use. The upper right graph shows a scatter plot of the entire post-retrofit dataset. The second plot from the top right graph shows a temperature-binned analysis of the post-retrofit weekday occupied data and both the pre- and post-retrofit mean lines; the dashed line represents the pre-retrofit mean. The third plot from the top right graph shows the temperature-binned analysis of the weekday unoccupied period with both the pre- and post-retrofit means. The bottom plot includes the weekend data with the left graph showing a pre-retrofit box-whisker-mean plot and the right graph showing a box-whisker-mean plot for the post-retrofit period with the pre-retrofit mean line superimposed onto it.

It would appear from close inspection of Figure A-2 that the building demonstrates a temperature dependence at lower temperatures (i.e., more steam is required as the outdoor temperature falls) during all three daytypes. During weekday-occupied periods, a higher rate of steam is consumed to maintain occupant comfort during the daytime hours. During the unoccupied periods, which include the weekday nights and weekends, steam is still consumed, however, at a lower rate. The maintenance staff operates the heating system during the low outdoor temperatures to maintain freeze protection. In the post-retrofit binned plots, the effect of the lighting retrofit can easily be seen by comparing the mean lines (i.e., the dashed line is the average steam consumption during the pre-retrofit period and the solid line is the average steam consumption during the post-retrofit period). The steam consumption has clearly increased from the pre-retrofit period to the post-retrofit period during temperatures less than the 55° F bin.

Using an inverse bin method, the thermal savings can be calculated by forecasting the baseline thermal use into the post-retrofit temperature period and summing the hourly differences between the pre-retrofit model and post-retrofit measured data using a modification to the procedure outlined in Thamilseran and Haberl (1995). The general form for this procedure is as follows:

$$E_{save,tot} = \sum_{i=1}^{n}\sum_{j=1}^{m} N_{i,j}\left(E_{pre_{i,j}} - E_{post_{i,j}}\right) \qquad \text{(A1)}$$

where:

$E_{pre_{i,j}}$ = the average pre-retrofit consumption for model (i) and temperature bin (j) as predicted in the post retrofit period.

$E_{post_{i,j}}$ = post-retrofit consumption falling within temperature bin (j) for days corresponding to model (i).

N_i = number of hourly data in the bin (j) for the model (i) in the measurement period.

i = 1 to n different models (e.g., i=2 for weekday-weekend models).

j = 5°F temperature bin expressed at the mid-point temperature bin (i.e., 30°, 35°, 40°, etc.)

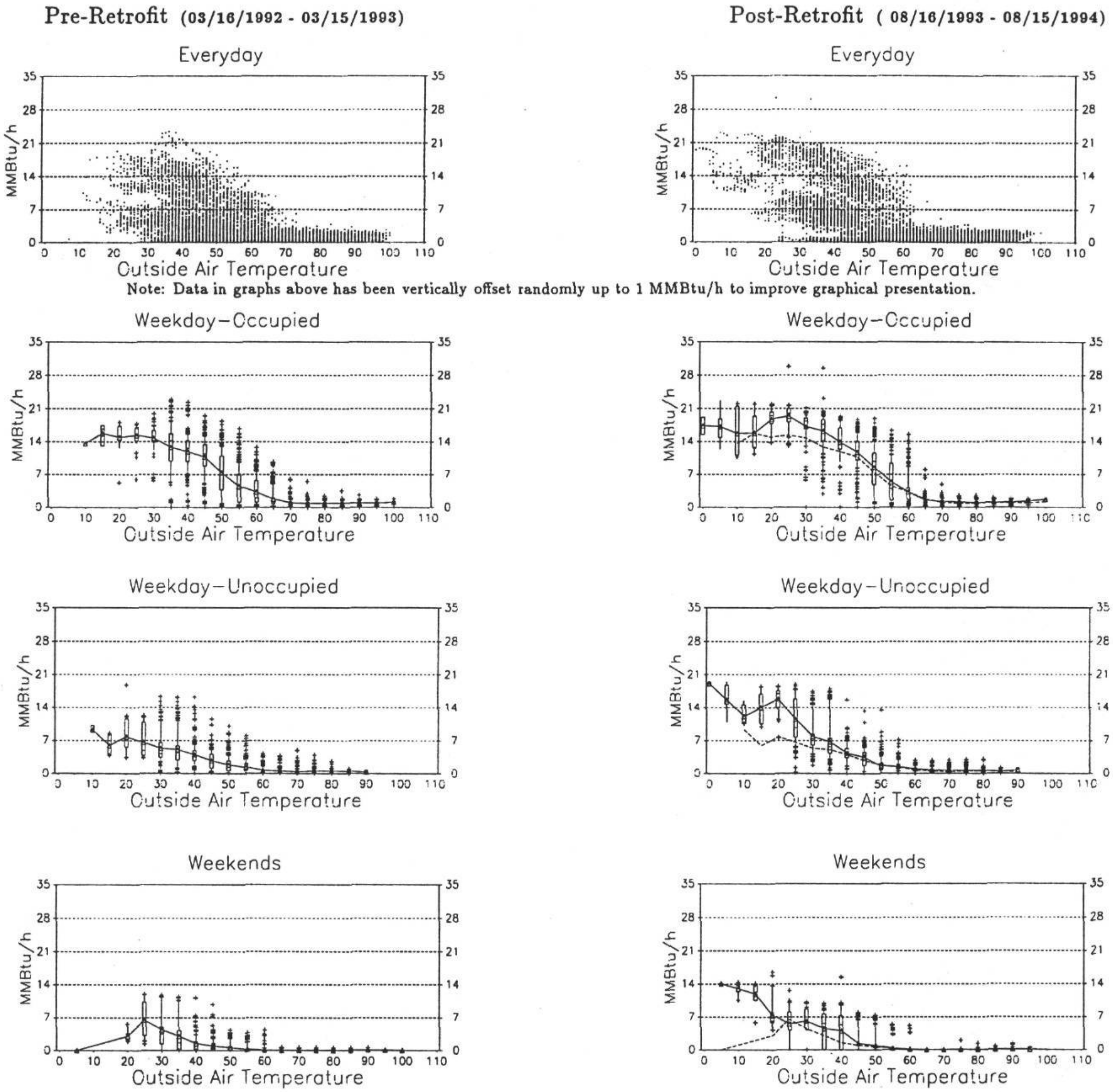


FIGURE A-2: WHOLE-BUILDING BINNED MEASURED STEAM DATA. FIGURE A-2A DIVIDES THE CORRECTED HOURLY DATA INTO PRE- AND POST-RETROFIT WEEKDAY OCCUPIED AND WEEKDAY UNOCCUPIED DATA. FIGURE A-2B SHOWS THE WEEKEND PERIOD.

Table A-2 shows the model parameters, R^2, and CV-RMSE statistics for the three and four parameter model used in the chilled water analysis and Figure A-3 shows the three and four parameter data in graphical form used in the chilled water analysis.

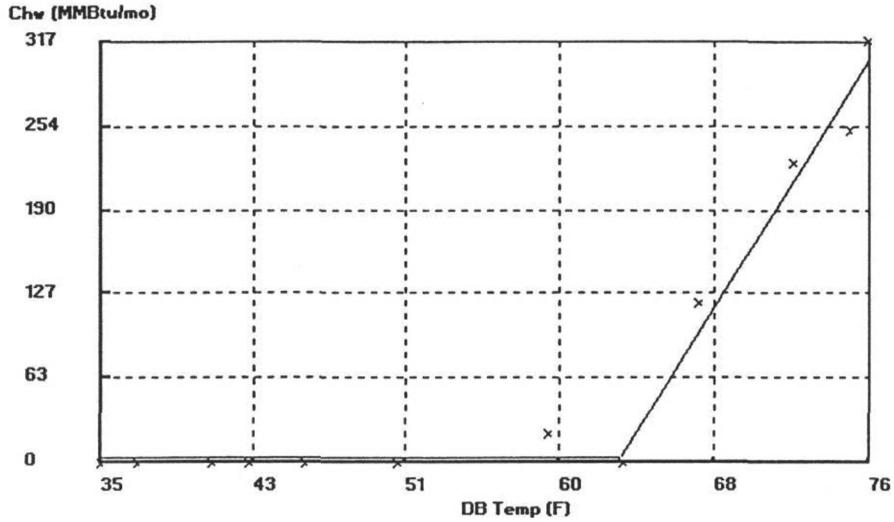
TABLE A-2: STATISTICAL GOODNESS-OF-FIT FOR THE THREE AND FOUR PARAMETER CHILLED WATER MODELS. THIS TABLE PROVIDES THE STATISTICS FROM THE THREE AND FOUR PARAMETER MODELS WHICH WERE FIT TO THE PRE-RETROFIT DATA.

Model Type	No. of Points	R squared (%)	CV-RMSE (%)	RMSE	Baseline	Left Slope	Right Slope	Change Point
3P	12	0.98	19.00	14.80	4.28	0	22.83	62.88
4P	12	0.99	18.80	14.63	12.95	0.57	22.03	62.88

Although the CV-RMSE and the R^2 values for the three and four parameter models are similar, the four parameter model was chosen for the final analysis because it fits the monthly data more accurately by accounting for the single point closest to the change point during the intermediate swing seasons where heating and cooling are both used. The four parameter model provides a slightly better fit of the baseline as seen in Figure A-3 where a small amount of cooling was called for at a temperature lower than the change point temperature during one of the months.

The hourly bin model was not used for chilled water because sufficient amounts of chilled water data in the post-retrofit period were not available. In the interest of keeping the steam and chilled water thermal analysis consistent, therefore it was decided to adopt the four parameter modeling technique and present the results of all the different models in this appendix for comparison purposes.

Table A-3 and Figure A-4 show a comparison of the three parameter, four parameter, and bin analysis models used for this analysis to estimate the steam savings due to the lighting retrofit. In Table A-3, the monthly and total GSA billed steam consumption for the pre- and post-retrofit periods are shown along with the "GSA Change" beginning in the second column from the left. These are the savings that would be realized when differences in weather from year to year are not taken into account (i.e., by directly comparing the utility bill from one year to the next). The three and four parameter pre-retrofit models driven by the post-retrofit average monthly temperature was subtracted from the GSA post-retrofit utility billed amount to calculate the "3-P Change" and the "4-P Change", respectively. These values were found by subtracting the respective forecasts from the pre-retrofit models from the GSA post-retrofit consumption. The final two columns on the right side of the table show the results of the hourly pre-post bin model analysis.



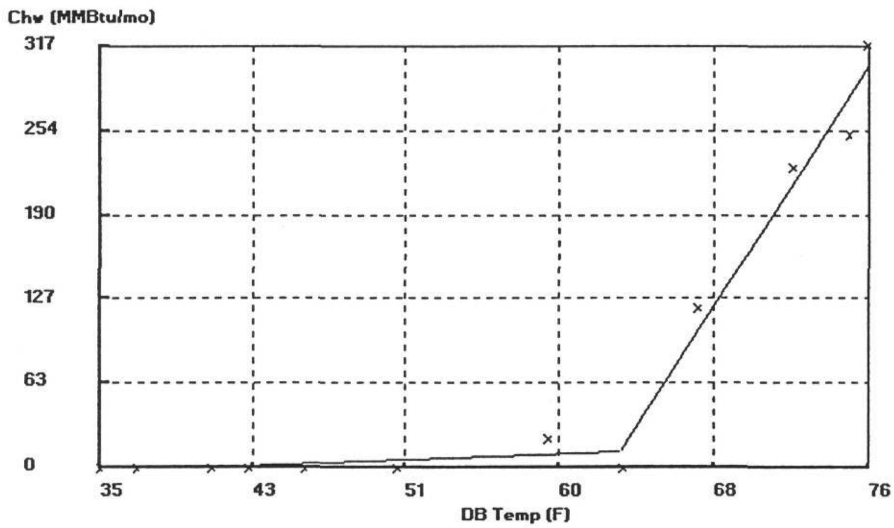


FIGURE A-3: THREE AND FOUR PARAMETER CHILLED WATER MODELS. THE UPPER GRAPH SHOWS THE THREE PARAMETER CHANGE-POINT MODEL AND THE LOWER GRAPH SHOWS THE FOUR PARAMETER MODELED DATA FOR THE WHOLE-BUILDING CHILLED WATER.

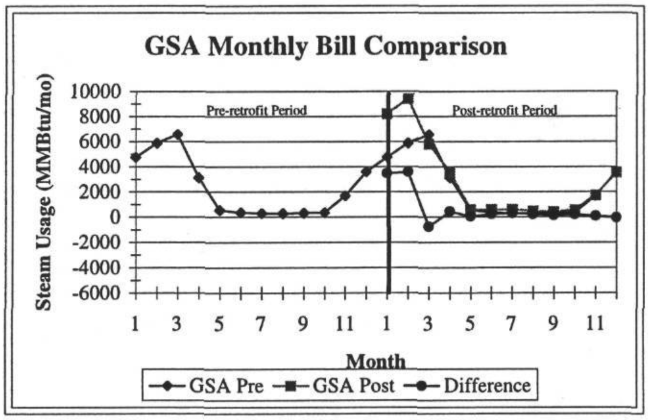
TABLE A-3: SUMMARY OF THE INCREASE IN STEAM CONSUMPTION DUE TO THE RETROFIT. THIS TABLE SHOWS A MONTHLY SUMMARY OF THE GSA UTILITY BILL SAVINGS COMPARISON, THE THREE PARAMETER WEATHER-ADJUSTED SAVINGS, THE FOUR PARAMETER WEATHER-ADJUSTED SAVINGS, AND THE BIN MODEL.

Mo	GSA Pre-retrofit Utility Bill (MMBtu/mo)	GSA Post-retrofit Utility Bill (MMBtu/mo)	GSA Change (MMBtu/mo)	3-P Pre-retrofit Model (MMBtu/mo)	3-P Change (1) (MMBtu/mo)	4-P Pre-retrofit Model (MMBtu/mo)	4-P Change (2) (MMBtu/mo	Bin Pre-retrofit Model (MMBtu/mo)	Bin Change (3) (MMBtu/mo)
Jan	4,756	8,216	3,461	7,849	367	7,777	439	5,609	2,607
Feb	5,848	9,411	3,563	8,875	536	8,775	636	5,144	4,267
Mar	6,550	5,797	-753	4,311	1,486	4,322	1,475	4,002	1,795
Apr	3,100	3,520	420	1,012	2,508	1,127	2,394	2,535	985
May	545	585	40	364	221	399	186	888	-303
Jun	361	594	233	377	217	329	265	788	-194
Jul	290	585	295	364	221	217	368	410	175
Aug	276	483	207	377	107	256	227	335	148
Sep	310	430	120	377	53	246	184	380	50
Oct	344	552	208	364	188	420	133	1,108	-556
Nov	1,671	1,730	59	670	1,059	794	935	2,013	-284
Dec	3,589	3,540	-50	3,295	244	3,343	197	3,447	93
Total	27,640	35,444	**7,804**	28,235	**7,208**	28,005	**7,438**	26,659	**8,785**

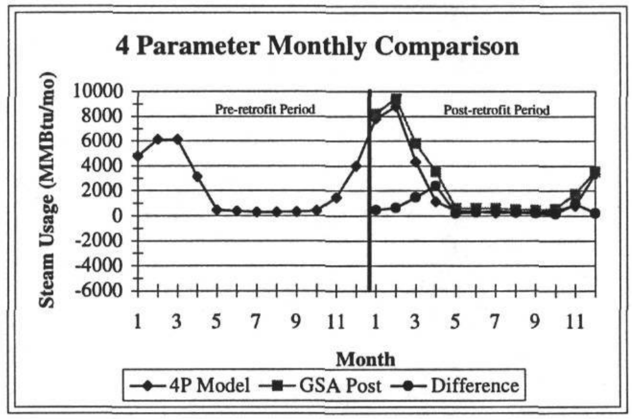
(1) This value was calculated by subtracting the Pre-retrofit 3-P model consumption from the GSA Post-retrofit consumption.
(2) This value was calculated by subtracting the Pre-retrofit 4-P model consumption from the GSA Post-retrofit consumption.
(3) This value was calculated by subtracting the Pre-retrofit bin model consumption from the GSA Post-retrofit consumption.

Figure A-4a shows a direct comparison of the steam consumption from the GSA utility bills for the pre- and post-retrofit periods. The pre-retrofit data were projected into the post-retrofit period and denoted by the "GSA Pre" label in the legend. The difference between the GSA Pre and GSA Post is noted on the graph by labeled "Difference" points. Figure A-4b shows the savings calculated by the four parameter heating model. The data can be located by the symbols marked "4P Model" in the graph's legend. The 4P model was then subtracted from the GSA post-retrofit utility bills to obtain the savings also shown on the graph. The increase in steam use during the winter are due to more steam required to meet the heating load formerly provided by the extra lights in the building prior to the retrofit. Figure A-4c and A-4d show the bin comparison and the three parameter comparisons, respectively.

Table A-4 and Figure A-5 show the whole-building chilled water savings comparisons. In Table A-4, the GSA billed consumption for the pre- and post-retrofit periods are shown along with the "GSA Change". These are the savings that would be realized when differences in weather from year to year are not taken into account (i.e., by directly comparing the utility bill from one year to the next). The three parameter pre-retrofit models driven by the post-retrofit average monthly temperature was subtracted from the GSA post-retrofit utility billed amount to calculate the "3-P Change". The final two columns in Table A-4 show the savings calculated by the four parameter model. The savings calculated by this model and shown in the "4-P Change" column provided the basis for the final reported savings due to the retrofit.



(a)



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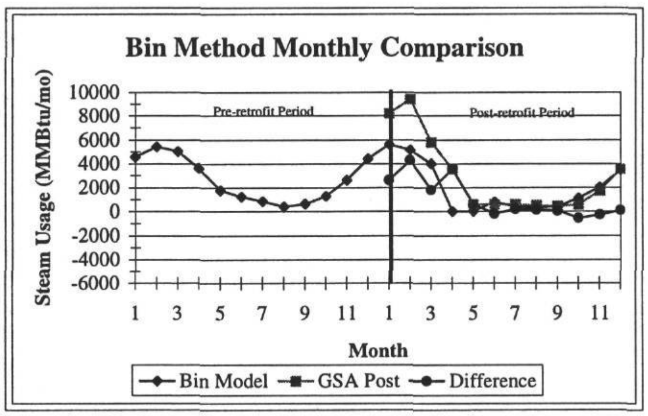
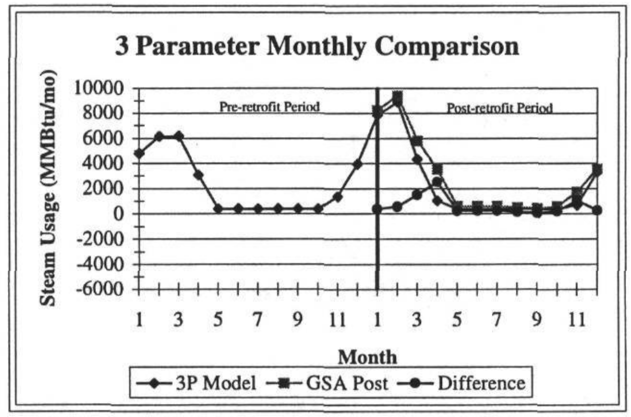


(c)



(d)

FIGURE A-4: STEAM CONSUMPTION CHANGE DUE TO THE LIGHTING RETROFIT. THESE FIGURES COMPARE THE DIFFERENT MODELS USED TO CALCULATE THE CHANGE IN THE WHOLE-BUILDING STEAM CONSUMPTION. FIGURE A-4A SHOWS THE PRE- AND POST-RETROFIT GSA UTILITY BILL COMPARISON. FIGURE A-4B SHOWS THE FOUR PARAMETER WEATHER-ADJUSTED SAVINGS. FIGURE A-4C SHOWS THE RESULTS OF THE TEMPERATURE BIN ANALYSIS. FIGURE A-4D SHOWS THE THREE PARAMETER WEATHER-ADJUSTED RESULTS.

TABLE A-4: SUMMARY OF THE INCREASE IN CHILLED WATER CONSUMPTION DUE TO THE RETROFIT. THIS TABLE SHOWS A MONTHLY SUMMARY OF THE GSA UTILITY BILL SAVINGS COMPARISON, THE THREE PARAMETER WEATHER-ADJUSTED SAVINGS, AND THE FOUR PARAMETER WEATHER-ADJUSTED SAVINGS.

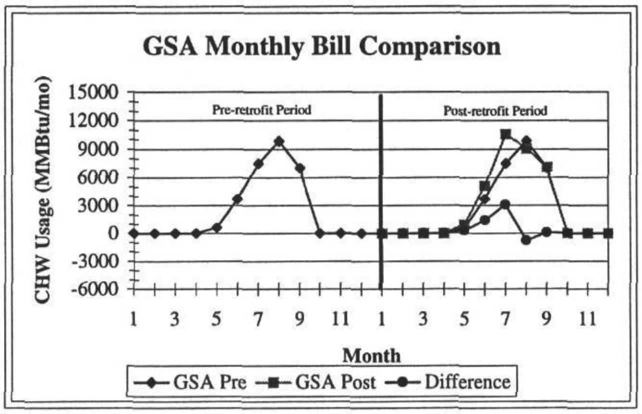
Mo	GSA Pre-retrofit Utility Bill (MMBtu/mo)	GSA Post-retrofit Utility Bill (MMBtu/mo)	GSA Change (MMBtu/mo)	3-P Pre-retrofit Model (MMBtu/mo)	3-P Change (1) (MMBtu/mo)	4-P Pre-retrofit Model (MMBtu/mo)	4-P Change (2) (MMBtu/mo)
Jan	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0
Apr	0	0	0	0	0	0	0
May	636	970	334	82	888	468	502
Jun	3,685	5,099	1,414	5,747	-648	5,948	-849
Jul	7,493	10,576	3,083	12,411	-1,835	12,366	-1,790
Aug	9,830	9,051	-779	10,702	-1,651	10,729	-1,678
Sep	6,998	7,094	96	11,409	-4,316	11,412	-4,318
Oct	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0
Total	28,642	32,790	**4,148**	40,352	**-7,562**	40,923	**-8,133**

(1) This value was calculated by subtracting the Pre-retrofit 3-P model consumption from the GSA Post-retrofit consumption.

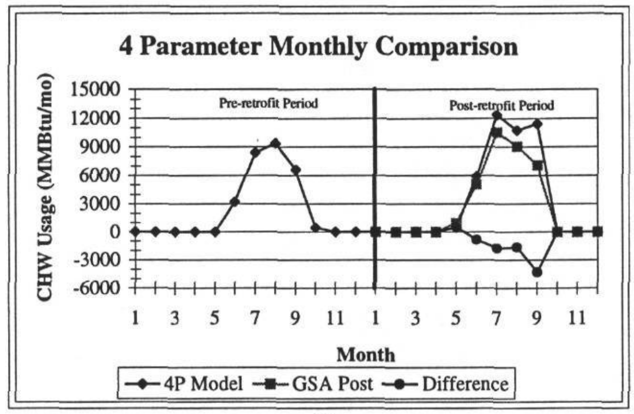
(2) This value was calculated by subtracting the Pre-retrofit 4-P model consumption from the GSA Post-retrofit consumption.

Figure A-5a shows a direct comparison of the GSA billed chilled water use reported in the pre- and post-retrofit period. Figure A-5b shows the savings calculated with a four parameter model. Finally, Figure A-5c shows the three parameter comparisons. The graphs shown in this figure were developed similarly to the graphs shown in Figure A-4.

Table A-5 and Figure A-6 compare the individual electricity, chilled water, and steam monetary savings resulting from the lighting retrofit. Figure A-6a shows the direct pre-post utility bill comparison without weather normalization analysis or utility rate change consideration of the electricity use, the chilled water, and steam use. The monthly costs used to calculate the electricity utility bill do not include local taxes, rebates, or fuel adjustment factors due to their unpredictability from one year to the next. Figure A-6b shows the utility billed cost based on the pre-post energy consumption and calculated with respect to pre-retrofit utility rates (i.e., constant pre-retrofit dollars). This table provides a billed comparison to the electrical and thermal analysis for consistency. Figure A-6c shows the weather normalized savings calculated with the methods described in this paper. This figure compares the savings that result with the use of the 24-hour, weekday-weekend bin method for electricity savings and the four parameter analysis for the chilled water and the steam savings. The data from this graph are used as a basis for the final savings results reported here and in Table A-5. Figure A-6d shows the savings result when using the bin method for electricity savings and the three parameter analysis for the chilled water and steam savings. Figure A-6e shows the savings for the electricity savings using the bin method, the four parameter chilled water analysis, and the bin method for the steam savings analysis. Obviously, the savings vary somewhat with the choice of models and/or cost assumptions. It is therefore recommended that a 24-hour, weekday-weekend bin analysis be used for the electricity savings and four parameter pre-post models for measuring the differences in steam and chilled water use. Constant, pre-retrofit billing rates were chosen to obtain the closest match to the estimated savings.



(a)



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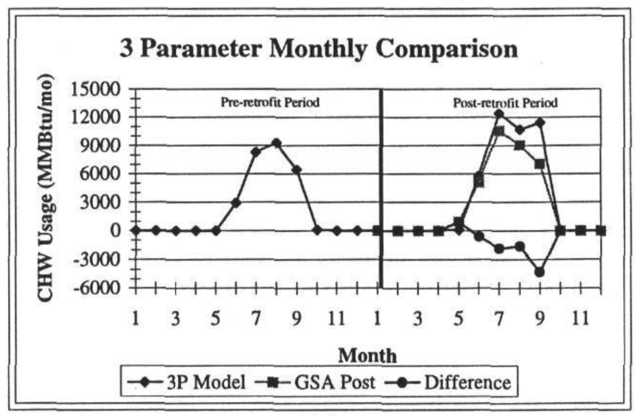
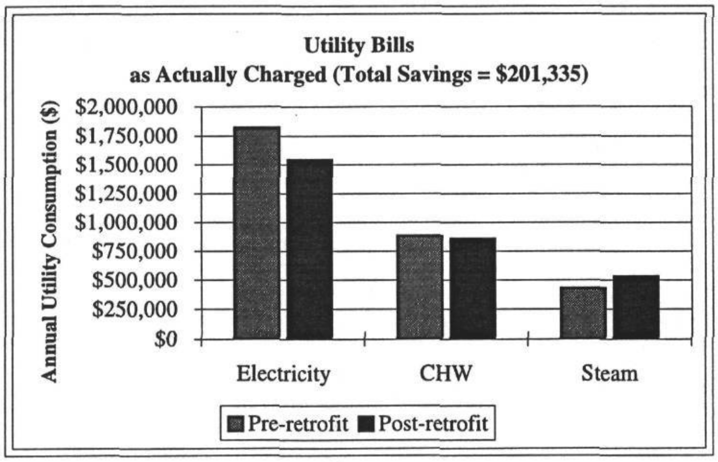


(c)

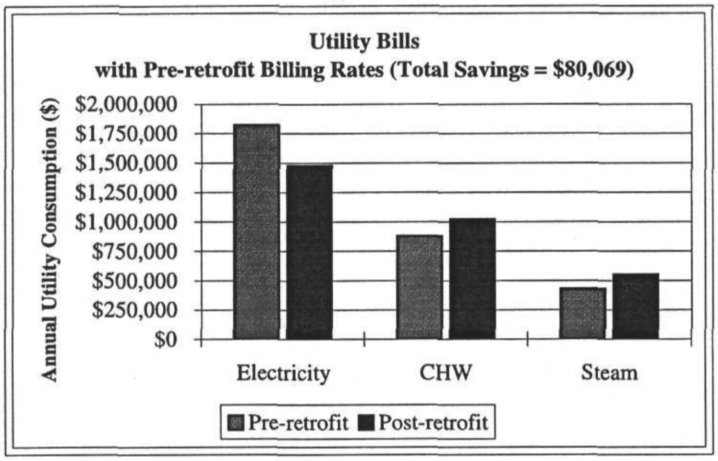
FIGURE A-5: CHILLED WATER SAVINGS SUMMARY. THESE FIGURES COMPARE THE DIFFERENT MODELS USED TO CALCULATE THE WHOLE-BUILDING CHILLED WATER SAVINGS DUE TO THE LIGHTING RETROFIT. FIGURE A-5A SHOWS THE PRE- AND POST-RETROFIT GSA UTILITY BILL COMPARISON. FIGURE A-5B SHOWS THE FOUR PARAMETER WEATHER-ADJUSTED SAVINGS. FIGURE A-5C SHOWS THE THREE PARAMETER WEATHER-ADJUSTED SAVINGS.

TABLE A-5: COMPARISON OF THE ELECTRICITY, CHILLED WATER, AND STEAM MONETARY SAVINGS DUE TO THE LIGHTING RETROFIT.

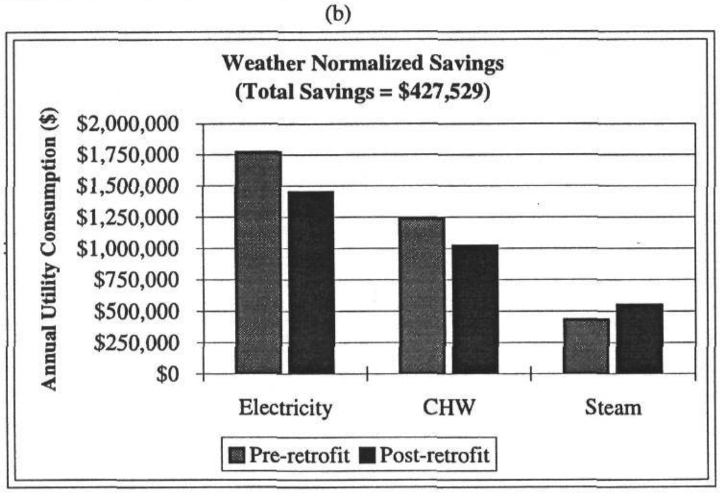
Actually charged utility bills	(a)			
Energy source	Pre-retrofit	Post-retrofit	$ Change	% Change
Electricity	$1,819,147	$1,540,662	($278,485)	-15%
CHW	$878,237	$853,923	($24,314)	-3%
Steam	$428,415	$529,879	$101,464	24%
Total	$3,125,799	$2,924,464	($201,335)	-6%
(b) Utility Bills based only on pre-retrofit billing rates				
Energy source	Pre-retrofit	Post-retrofit	$ Change	% Change
Electricity	$1,819,147	$1,475,679	($343,468)	-19%
CHW	$878,237	$1,020,676	$142,439	16%
Steam	$428,415	$549,374	$120,959	28%
Total	$3,125,799	$3,045,730	($80,069)	-3%
(c) Weather Normalized Savings (Bin: Electricity, 4P: CHW, 4P: Steam) Based on pre-retrofit billing rates				
Energy source	Pre-retrofit	Post-retrofit	$ Change	% Change
Electricity	$1,771,342	$1,446,637	($324,705)	-18%
CHW	$1,238,797	$1,020,676	($218,121)	-18%
Steam	$434,078	$549,374	$115,297	27%
Total	$3,444,217	$3,016,688	($427,529)	-12%
(d) Weather Normalized Savings (Bin: Electricity, 3P: CHW, 3P: Steam) Based on pre-retrofit billing rates				
Energy source	Pre-retrofit	Post-retrofit	$ Change	% Change
Electricity	$1,771,342	$1,446,637	($324,705)	-18%
CHW	$1,208,970	$1,020,676	($188,294)	-16%
Steam	$437,643	$549,374	$111,732	26%
Total	$3,417,955	$3,016,688	($401,267)	-12%
(e) Weather Normalized (Bin: Electricity, 4P: CHW, Bin: Steam) Based on pre-retrofit billing rates				
Energy source	Pre-retrofit	Post-retrofit	$ Change	% Change
Electricity	$1,771,342	$1,446,637	($324,705)	-18%
CHW	$1,238,797	$1,020,676	($218,121)	-18%
Steam	$413,215	$549,374	$136,160	33%
Total	$3,423,354	$3,016,688	($406,666)	-12%



(a)

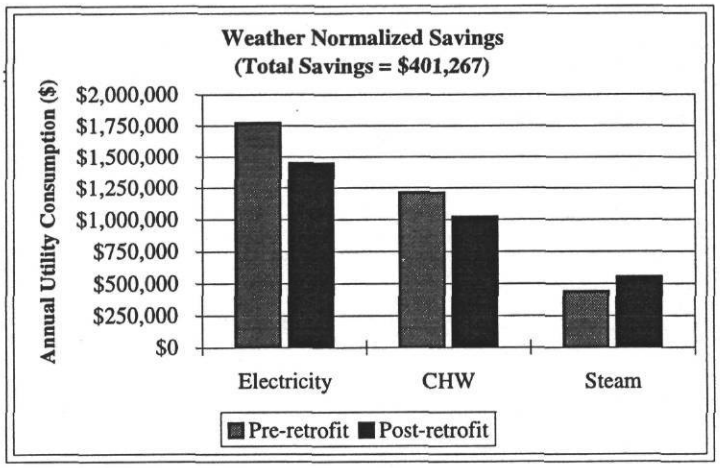


(b)

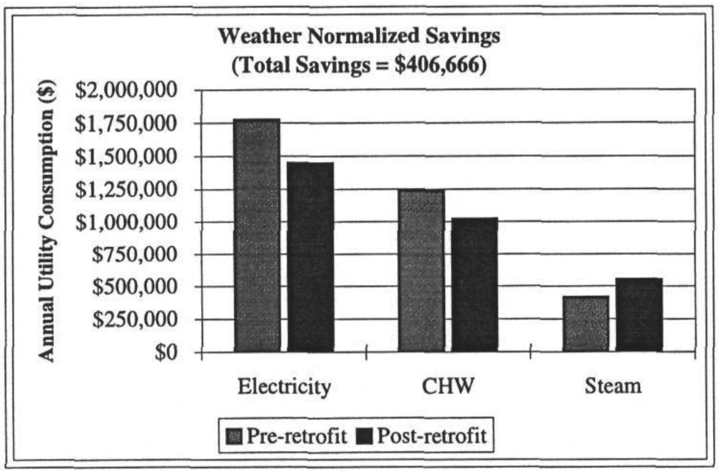


(c)

FIGURE A-6A,B,C,D,E: COMPARISON OF THE ELECTRICITY, CHILLED WATER, AND STEAM MONETARY SAVINGS DUE TO THE LIGHTING RETROFIT.



(d)



(e)

FIGURE A-6A,B,C,D,E (Cont'd): COMPARISON OF THE ELECTRICITY, CHILLED WATER, AND STEAM MONETARY SAVINGS DUE TO THE LIGHTING RETROFIT.

APPENDIX B

The statistical indices used to evaluate the daytype models are modified versions of those used in Kreider and Haberl (1994a, 1994b) using additional information found in (SAS 1990):

The coefficient of variation of the root mean square error CV-RMSE is defined in percent (%) as:

$$\text{CV-RMSE} = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(y_{pred,i} - y_{data,i}\right)^2}{n-p}}}{\bar{y}_{data}} \times 100 \qquad \text{(A2)}$$

and the mean bias error (MBE) is given by:

$$\text{MBE} = \frac{\dfrac{\sum_{i=1}^{n}\left(y_{pred,i} - y_{data,i}\right)}{n-p}}{\bar{y}_{data}} \times 100 \qquad \text{(A3)}$$

where:

- $y_{data,i}$ = is the data value of the dependent variable corresponding to a particular set of the independent variables,
- $y_{pred,i}$ = is the predicted dependent variable value for the same set of independent variables above,
- $\bar{y}_{data}$ = is the mean value of the dependent variable of the data set,
- n = is the number of data points in the data set,
- p = is the total number of regression parameters in the model (which was arbitrarily assigned to 1 for all models).

The R^2 is given by:

$$R^2 = 1 - \frac{\sum_{n}\left(y - \hat{y}\right)^2}{\sum_{n}\left(y - \bar{y}\right)^2} \qquad \text{(A4)}$$

APPENDIX C

Appendix C contains the monthly billing data used in Figure 4. It includes the month and year, the electric energy data (GWh/mo of billion Wh/mo), the demand data (MWh/mo or megawatts/mo), the steam data (GBtu/mo or billion Btu/mo), the chilled water data (GBtu/mo or billion Btu/mo), and the monthly average temperature. Average monthly temperatures were obtained from the NWS.

Mon-yr	GWh/mo Energy	MW/mo Demand	GBtu/mo Steam	GBtu/mo CHW	Avg Mon temp
Oct-84	1.966135		4.167		65
Nov-84	1.925533		6.585		46
Dec-84	2.275031		10.889		46
Jan-85	2.49421		14.972		31
Feb-85	2.166189		5.5		38
Mar-85	1.960809		4.3		48
Apr-85	1.967148		0.794		62
May-85	1.890727		0.52	3.209991	68
Jun-85	2.030403		0.5	5.842863	73
Jul-85	2.198618		0.4	7.822749	79
Aug-85	2.092753		0.683	12.18199	77
Sep-85	2.075019		0.747	9.184265	72
Oct-85	1.934445		1.895	1.330464	61
Nov-85	2.080442		6.287		55
Dec-85	2.238006		14.19		37
Jan-86	2.456901		11.727		36
Feb-86	2.389961		8.648		36
Mar-86	2.10733		3.837		48
Apr-86	2.037685		1.481		56
May-86	1.994291		1.154		68
Jun-86	2.181348		1.208		77
Jul-86	2.12208		1.417		81
Aug-86	2.092483		1.508		75
Sep-86	2.12326		1.694		71
Oct-86	1.438374		2.244		61
Nov-86	2.041966		4.846		47
Dec-86	2.220597		6.481		40
Jan-87	2.403194		8.398		35
Feb-87	2.024453		6.236		37
Mar-87	2.149352		2.965		48
Apr-87	2.038371		1.983		55
May-87	2.040176		0.735	0.904493	68
Jun-87	2.267195		0.694	6.437346	77
Jul-87	2.399512		0.518	8.825972	83
Aug-87	2.311992		0.557	9.769005	79
Sep-87	2.205285		1.012	6.52346	72
Oct-87	2.06288		2.815		55
Nov-87	2.09018		5.287		50
Dec-87	2.334309		9.083		42
Jan-88	2.417439		7.303		31
Feb-88	2.235631		5.021		39
Mar-88	2.127443		4.291		48
Apr-88	2.161676		2.639		54
May-88	2.282618		0.56		66
Jun-88	2.540964		0.471		74
Jul-88	2.324434		0.48		82
Aug-88	2.15284		0.514		81
Sep-88	2.08684		0.52		69
Oct-88	2.132177		0.875		54
Nov-88	2.416844		2.891		50
Dec-88	2.449663		6.473		39

Mon-yr	GWh/mo Energy	MW/mo Demand	GBtu/mo Steam	GBtu/mo CHW	Avg Mon temp
Jan-89	2.197861		7.384		40
Feb-89	2.266526		6.925		38
Mar-89	2.280079		5.012		46
Apr-89	2.123024		2.426		55
May-89	2.228646		0.798		64
Jun-89	2.388011		0.599		77
Jul-89	2.204389		0.589		78
Aug-89	2.242985		0.669		77
Sep-89	2.120469		0.694		71
Oct-89	2.14504		0.547		61
Nov-89	2.31245		1.065		48
Dec-89	2.405627		5.059		28
Jan-90	2.206514		6.812		44
Feb-90	2.305073		4.15		45
Mar-90	2.21765		3.351		50
Apr-90	2.163925		2.112		57
May-90	2.265744		0.764	3.3313	64
Jun-90	2.43838		0.679		75
Jul-90	2.29769		0.554	9.36	79
Aug-90	2.312037		0.515	8.0006	77
Sep-90	2.312037		0.386	5.7735	70
Oct-90	2.3227	5.2848			63
Nov-90	2.046421	5.279			52
Dec-90	2.262762	5.2186			45
Jan-91	2.406756	5.3021			39
Feb-91	2.316074	5.2618			43
Mar-91	2.313582	5.1889			49
Apr-91					58
May-91	2.193925	5.3241			73
Jun-91	2.4576	5.3395			77
Jul-91	2.381088	5.3712			81
Aug-91	2.373733	5.4778			80
Sep-91	2.493607	5.4662			71
Oct-91	2.208984	5.377			60
Nov-91	2.319378	5.3942			49
Dec-91	2.424023	5.4691			42
Jan-92	2.654375	5.5382	3.524		38
Feb-92	2.491367	5.688	6.032		41
Mar-92	2.166693	5.6304	3.335		45
Apr-92	2.441166	5.5901	3.1		55
May-92	2.469551	5.5382	0.545	0.6356	62
Jun-92	2.387796	5.6419	0.361	3.6853	72
Jul-92	2.552896	5.7773	0.29	7.4933	80
Aug-92	2.462147	5.6534	0.276	9.8303	74
Sep-92	2.655715	5.7744	0.31	6.9978	69
Oct-92	2.380244	5.6218	0.344		56
Nov-92	2.235887	5.6016	1.6707		49
Dec-92	2.534937	5.665	3.5892		40
Jan-93	2.432189	5.6794	4.7556		40
Feb-93	2.367671	5.7139	5.8484		34
Mar-93	2.439976	5.6909	6.5497		42

Mon-yr	GWh/mo Energy	MW/mo Demand	GBtu/mo Steam	GBtu/mo CHW	Avg Mon temp
Apr-93	2.289571	5.3338	3.5455		55
May-93	2.308402	5.4259	1.1936	0.2771	67
Jun-93	2.210436	5.1178	0.472	3.806	75
Jul-93	2.312235	4.8182	0.5675	10.1839	83
Aug-93	2.171109	4.6944	0.276	9.4934	80
Sep-93	2.150546	4.6771	0.4298	7.0938	71
Oct-93	1.872685	4.4784	0.5524		58
Nov-93	1.983824	4.5014	1.7295		49
Dec-93	1.838133	4.4957	3.5396		38
Jan-94	2.165273	4.5043	8.2164		29
Feb-94	1.731429	4.5014	9.411		36
Mar-94	1.913079	4.5446	5.7966		45
Apr-94	1.780789	4.4986	3.5204		62
May-94	1.858445	4.5418	0.5853	0.97	63
Jun-94	2.078466	4.7635	0.5939	5.0991	79
Jul-94	2.35686	4.6426	0.5853	10.5762	82
Aug-94	2.055398	4.6454	0.4833	9.0509	76
Sep-94	2.092716	4.5418	0.5738	5.5623	70
Oct-94	1.993443	4.5821	0.6173	1.9371	59
Nov-94	1.433955	4.5389	1.0899	0.2591	53
Dec-94	1.966276	4.6512	3.564		44
Jan-95	2.0462	4.648	6.1133		40
Feb-95	1.4209		8.8681		
Mar-95	2.16		5.5559		49
Apr-95	2.0544		3.4496		56
May-95	2.1358	4.628	1.5561	1.0839	66
Jun-95	2.1696	4.761	0.8392	4.7108	75
Jul-95	2.2289	4.83	0.6736	6.6336	82
Aug-95	2.5142	4.841	0.7749	11.6638	81
Sep-95	2.1654	4.743	0.7464	6.7437	71