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Author

Akbari, H.

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H. Akbari, S. Konopacki, L. Lister, and L. DeBaille
Energy and Environment Division

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Hashem Akbari and Steven Konopacki

Energy & Environment Division
Lawrence Berkeley National Laboratory
University of California
Berkeley, CA 94720

and

Larry Lister and Lee DeBaille

U. S. Army Construction Engineering
Research Laboratories (CERL)
Champaign, IL 61826

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Energy End-Use Characterization at Fort Hood, Texas

Hashem Akbari, Ph.D.
Member ASHRAE

Steven J. Konopacki

Larry D. Lister
Member ASHRAE

Lee P. DeBaillie
Associate Member ASHRAE

ABSTRACT

This paper discusses the application of a national laboratory's end-use disaggregation algorithm (EDA) to a Department of Defense (DOD) installation and presents hourly reconciled end-use data for all major building types and end-uses. The goals of the effort were to develop an energy database by building type and by end use for DOD facilities and to enhance the DOD energy office's ability to track energy use by end use.

The authors initially focused on achieving these objectives and pilot-testing the methodology at Fort Hood, Texas. Fort Hood is located near the town of Killeen and, with more than 5,000 buildings, was determined to have representative samples of nearly all of the major building types in use on DOD installations. More than 20 prototypes were developed for all major building types. Up to 11 end uses were considered for each prototype, consisting of 9 electric and 2 gas; however, only the electric end uses were reconciled against measured electricity-use data and weather conditions.

The EDA was applied to 10 separate feeders from the three substations at Fort Hood. The results from the analyses of these 10 feeders were extrapolated to estimate energy use by building type and end use for the entire installation and validate the results with an independent utility's billing data for electricity use for the installation. The results show that administration, residential, and barracks buildings are the largest consumers of electricity for a total of 250 GWh per year (74% of the Fort Hood annual consumption of 330 GWh). By end-use, cooling, ventilation, miscellaneous uses, and indoor lighting consume almost 84% of total electricity use. The contribution to the peak power demand is highest by the residential sector (35%, 24 MW out of 70 MW), followed by administration buildings (30%), and barracks (14%). For the entire Fort Hood installation, cooling is 54% of the peak demand (38 MW out of 70 MW), followed by interior lighting at 18%, and miscellaneous end-uses by 12%.

INTRODUCTION

Defense Energy Program Policy Memorandum (DEPPM) 91-2 requires, through energy-efficiency strategies, Department of Defense (DOD) facilities to reduce energy consumption and costs by 20% from 1985 to 2000. The strategies include both improved operation and maintenance and enhanced energy-efficiency measures.

The proper analytical tools, methodologies, and a database of energy consumption by end-use for DOD facilities are not readily available to implement energy-efficiency programs. The model energy installation program (MEIP) was developed to prove the concept that DOD could cost-effectively save energy while simultaneously improving both working and living conditions at DOD facilities. Tools are required to perform end-use energy analysis to predict and forecast future energy scenarios and to evaluate and recommend cost-effective energy conservation technologies and opportunities.

Historically, DOD has addressed these objectives by energy audits of the installations and by development of prototypical buildings and assessment of conservation potentials through building energy simulations. Although prototypical studies can result in some general understanding of energy consumption by end-use, they must be reconciled against measured energy use for reliable estimates. The end-use disaggregation algorithm (EDA), developed at a national laboratory, was designed specifically for this purpose. In EDA, computer simulations are reconciled hourly against measured energy consumption to obtain end-use consumption data (Akbari 1995).

In addition DOD and government agencies have developed numerous energy analysis tools and techniques on a piecemeal basis or for specific applications and have compiled property databases for facilities management (real property databases). This study has drawn upon and brought together these disparate

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Hashem Akbari is a staff scientist and **Steven J. Konopacki** is a principal research associate in the Energy Analysis Program, Energy and Environment Division, Lawrence Berkeley National Laboratory, Berkeley, Calif. **Larry D. Lister** is a research engineer and **Lee P. DeBaillie** is a principal investigator with the U.S. Army Construction Engineering Research Laboratory, Champaign, Ill.

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sources of information into an integrated form that can be used for DOD-wide energy end-use characterization.

One of the objectives of this study was to develop an energy database by building type and by end-use for DOD facilities. The project has focused on achieving this objective by developing a methodology and pilot-testing it at one DOD installation: Fort Hood, Texas. It is anticipated that the methodology and much of the database developed for Fort Hood can be easily transferred to other installations.

APPROACH

The building types at Fort Hood cover a wide spectrum of commercial and residential buildings. The commercial buildings include offices, administration buildings, vehicle maintenance, shops, a hospital, grocery stores, retail stores, car washes, churches, restaurants, etc. The residential buildings include single-family detached units, two- and four-plexes (both single- and double-story) units, and apartment buildings. In addition, there are barracks that combine the commercial and residential functions. Some buildings have dedicated air-conditioning systems, some have central systems, while others have none.

Given the complexity of the building types, we decided to analyze energy end-use characteristics of buildings by functions of buildings or building groups. We developed a list of building types and end-uses to be analyzed (see Table 1). For each building in the scope we developed a prototype. Up to 11 end-uses were developed for each prototype, consisting of 9 electric and 2 gas; however, only the electric end-uses were reconciled. The electric end uses are space cooling, ventilation (air-handling units [AHU], fans, chilled- and hot water pumps), cooking, miscellaneous/plugs, refrigeration, exterior lighting, interior lighting, process loads, and street lighting. The gas end-uses are space heating and hot water heating. Only space-heating Energy Une Intensity (EUIs) were simulated. Hot-water-heating EUIs were taken from previous laboratory studies and the MEIP surveys.

INPUT DATA

Numerous databases were available for use in this project, which include on-site surveys, measured electrical consumption data, building inventory data, and weather data. The primary source of these data was The U.S. Army Construction Engineering Research Laborities (CERL). We supplied supplementary information from previous EDA studies carried out there.

The data were carefully inspected and reviewed by us with advice from CERL. It was then decided which data would be used in the project. The databases outlined in Table 2 were integrated for use in the study.

METHODOLOGY

The project involved detailed analysis of existing DOD data on facilities' energy use and characteristics, in conjunction with other databases and application of a previously developed reconciliation model to estimate end-use load shapes and intensities. We first analyzed the databases for consistency and completeness. Implementation and validation of the methodology were the heart of this project. We refined the previously developed model to meet the requirements of the new application. We then applied the refined method to the above databases to extract end-use load shape information from them. The method consists of five steps, as depicted in Figure 1.

EDA Description

The end-use disaggregation algorithm (EDA) is a tool designed to improve the hourly estimates of building electric energy consumption from that of simulations. In EDA, the sum of the end uses is constrained at hourly intervals to be equal to the measured whole-building electricity use. This constraint provides a reality check that is not possible with pure simulation.

EDA is a deterministic method that primarily utilizes the statistical characteristics of the measured hourly feeder load and its inferred dependence on temperature. Simulation is only used to supply information that is not evident from the load/temperature relationship, including the ratios of one end use to another by hour and the temperature-independent cooling load. In addition, the load/temperature relationship helps to characterize the conditioning end use, providing an additional constraint on the remaining end uses and preventing some of the errors possible with simple proration. EDA can give more weight to any given end use for any scheduled hour with use of a confidence factor. For example, if lighting were metered, confidence in that end-use would be high, so EDA would not alter the initial estimate.

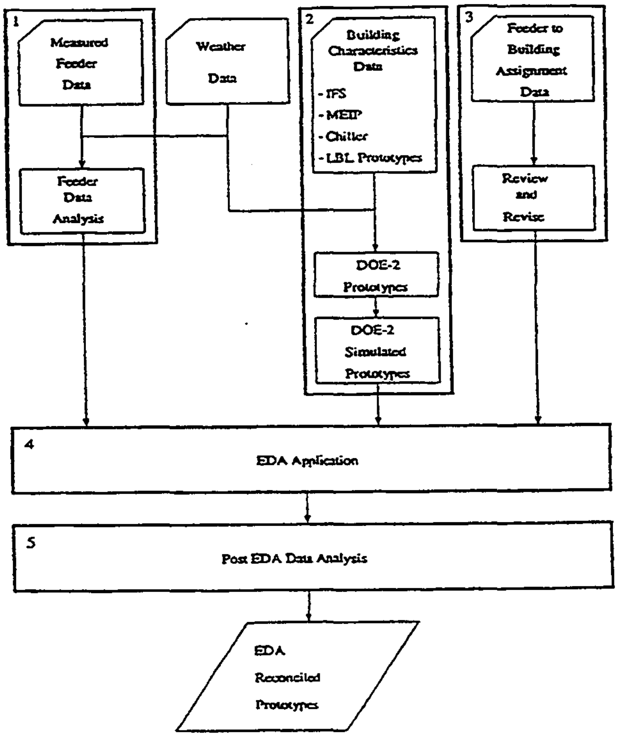

Figure 1 *Fort Hood end-use characterization methodology.*

TABLE 1 Building Types and End Use

Prototype	Cool	Fan/Vent[*]	Cook	Misc/Plug	Refrig	Ex_Lit	In_Lit	Press	Heat[†]	Hot[†] Water
Barrack										
Hammer head	X	X	X	X	X	X	X		X	X
Rolling pin	X	X	X	X	X	X	X		X	X
Modular	X	X	X	X	X	X	X		X	X
Small	X	X	X	X	X	X	X		X	X
Dining hall	X	X	X		X	X	X		X	X
Gymnasium	X	X		X		X	X	X	X	X
Administration										
Large	X	X		X		X	X		X	X
Small—old w/ split DX	X	X		X		X	X		X	X
Small—old w/ chiller	X	X		X		X	X		X	X
Small—new w/ split DX	X	X		X		X	X		X	X
Small—new w/ chiller	X	X		X		X	X		X	X
Vehicle Maintenance										
Small w/ no A/C		X		X		X	X	X	X	
Large w/ split DX	X	X		X		X	X	X	X	
Large w/ chiller	X	X		X		X	X	X	X	
Hangar	X	X		X		X	X	X	X	
Hospital	X	X	X	X	X	X	X		X	X
Residential										
Detached	X	X	X	X	X	X	X		X	X
Two plex	X	X	X	X	X	X	X		X	X
Four plex	X	X	X	X	X	X	X		X	X
Other										
Retail—large	X	X	X	X	X	X	X		X	X
Warehouse										
w/ no A/C		X		X		X	X		X	
w/ split DX	X	X		X		X	X		X	
Miscellaneous[‡]										
Bowling center	X	X		X		X	X		X	
Church	X	X		X		X	X		X	
Grocery store	X	X	X	X	X	X	X		X	X
Library	X	X		X		X	X		X	
Restaurant—fast food	X	X	X	X	X	X	X		X	X
Restaurant—sitdown	X	X	X	X	X	X	X		X	X
Retail—small	X	X	X	X	X	X	X		X	X
Youth center	X	X		X		X	X		X	
Water pump[**]										
Street lighting						X				

[*] The fan/vent end-use includes chilled and heated water pumps.

[†] Space heating and hot water heating are gas end-uses and are not reconciled.

[‡] The end-use characterization for the miscellaneous prototypes are provided by simulations only.

[**] EDA is not applied to the water pump prototype; only measured load data are available.

The reconciliation is done hourly for two seasons (winter and summer) and for two day types (standard and nonstandard). Standard days include normal weekdays, and nonstandard days include weekends and holidays.

In its original form EDA was limited to reconciling end-use data for a single building. The technique was documented and validated with metered end-use data from an office building and a retail store (Akbari 1995). The next generation of EDA was applied to prototypical buildings (Akbari et al. 1989, 1991, 1993), where the characteristics and measured whole-building electricity-use data from many buildings of a similar type were averaged. The prototype simulations were reconciled with the average whole-building measured electricity-use data. In this project, EDA was refined so that it reconciles several prototypes on a given feeder with feeder hourly electrical load data (Akbari and Konopacki 1995).

The present generation of EDA is implemented using the hourly measured load for the feeder and the estimated temperature-independent and temperature-dependent components, the initial estimated end-use loads from the simulations, and the feeder-to-prototype assignment as input to obtain reconciled hourly end-use loads for all prototypes on the feeder. Confidence factors were not used because information did not exist that provided more confidence in one end use over another.

Feeder Data Analysis

The feeder data were analyzed to obtain information on daily load shape by day-of-week and season (winter and summer). Scatter plots of feeder load vs. outdoor dry-bulb temperature were developed by day type (standard and nonstandard days) and season, by hour-of-day. During the winter, the hourly loads were constant for the entire season. However, during the summer a strong positive relationship between feeder load and outdoor dry-bulb temperature was observed.

Based on the multi-variable regression of the hourly data, the summer load was divided into temperature-independent (ti) and temperature-dependent (td) loads. The technique regresses feeder summer load vs. outdoor dry-bulb temperature and assumes a single slope adequately represents the 24 hourly

TABLE 2 Input Data Sources

1. *IFS Building Inventories*
   Containing 40 building characteristics (such as category code, floor area, number of floors, year of construction, HVAC system type) of all 5,122 buildings in Fort Hood.
2. *MEIP On-site Survey Data of 25 Nonresidential Buildings*
   A detailed on-site survey of 25 buildings, including small and large administration buildings, hangar, barracks, gymnasium, vehicle maintenance shop, and dining hall in Fort Hood.
3. *MEIP On-site Survey Data of 11 Residential Buildings at Fort Hood*
4. *Chiller Survey Data*
   A visual inspection/recording of installed chiller nameplate data of 463 chillers, including manufacturer, model number, building number, number of chillers, tonnage, airflow, air handler power, and condenser power.
5. *Mechanical Equipment Survey Data*
   A visual inspection/recording of installed motor and equipment (pumps, cooling towers, air handlers, boilers, and domestic water heaters) nameplate data of 1127 motors and equipment for about 230 buildings.
6. *Feeder Hourly Electric Load Data*
   Fort Hood receives electrical power from three substations: main, west, and north substations. These substations distributed the power through 16 feeders connected to the main substation, 6 to the west, and 3 to the north for the period of September 1992 through December 1993. Of the 16 feeders connected to the main substation, one feeder was not monitored, three feeders had missing data for 6 months, and four feeders were missing a month. Of the six feeders connected to the west substation, three were missing data for one month. In this study, we primarily considered analysis of feeders that had one calendar year of complete data.
7. *Feeder to Building Assignment Data*
   A database listing the buildings connected to each feeder for the main and west substations except for two feeders.
8. *Hourly Weather Data for 1993 (Waco, Texas)*

9 *Texas Utility 1993 Hourly Electrical Consumption Data for the Main and West Substations*

slopes. In Figure 2, the 24 hourly plots show slopes of equal magnitude.

An attempt to improve the regression statistics was made by regressing the feeder load against dry-bulb temperature and absolute humidity. This yielded no significant improvement in the regression statistics due to the colinearity of dry-bulb temperature and absolute humidity. This finding is consistent with an earlier study (Akbari 1995).

Prototype Development

The 5,122 buildings of Fort Hood were grouped into 23 prototypes based on the functions and characteristics of the facilities. These prototypes were developed from the IFS building inventory, MEIP on-site surveys, a chiller survey, previously developed national laboratory prototypes, and feeder schedule databases. A prototype is described by floor area from IFS data; shell characteristics; interior loads; heating, ventilating, and air-conditioning (HVAC) system characteristics; schedules from either MEIP or national laboratory prototypes; and additional schedule information from the feeder analysis. The hospital prototype also uses the chiller survey data.

The barracks group consists of four types of billets (barracks), a dining hall, and a gymnasium (the billets are classified as hammerhead, rolling pin, modular, or small). The modular and small billets function as residential units. The hammerhead and rolling pin billets function as commercial units as well as residential since they include administrative zones in addition to billeting. All the prototypes are heated with natural gas hot water boilers. The gymnasium and small billets are cooled by packaged direct expansion units and the dining hall and remaining billets by central chillers with cooling towers.

The administrative group is made up of five prototypes: a large and four small varieties. The large administrative prototype is modeled as three floors of a 168,500 ft^2 (15,654 m^2) building with a central chiller with a cooling tower and hot water boiler. The four small administrative prototypes are either of old or modern construction with a packaged direct expansion or

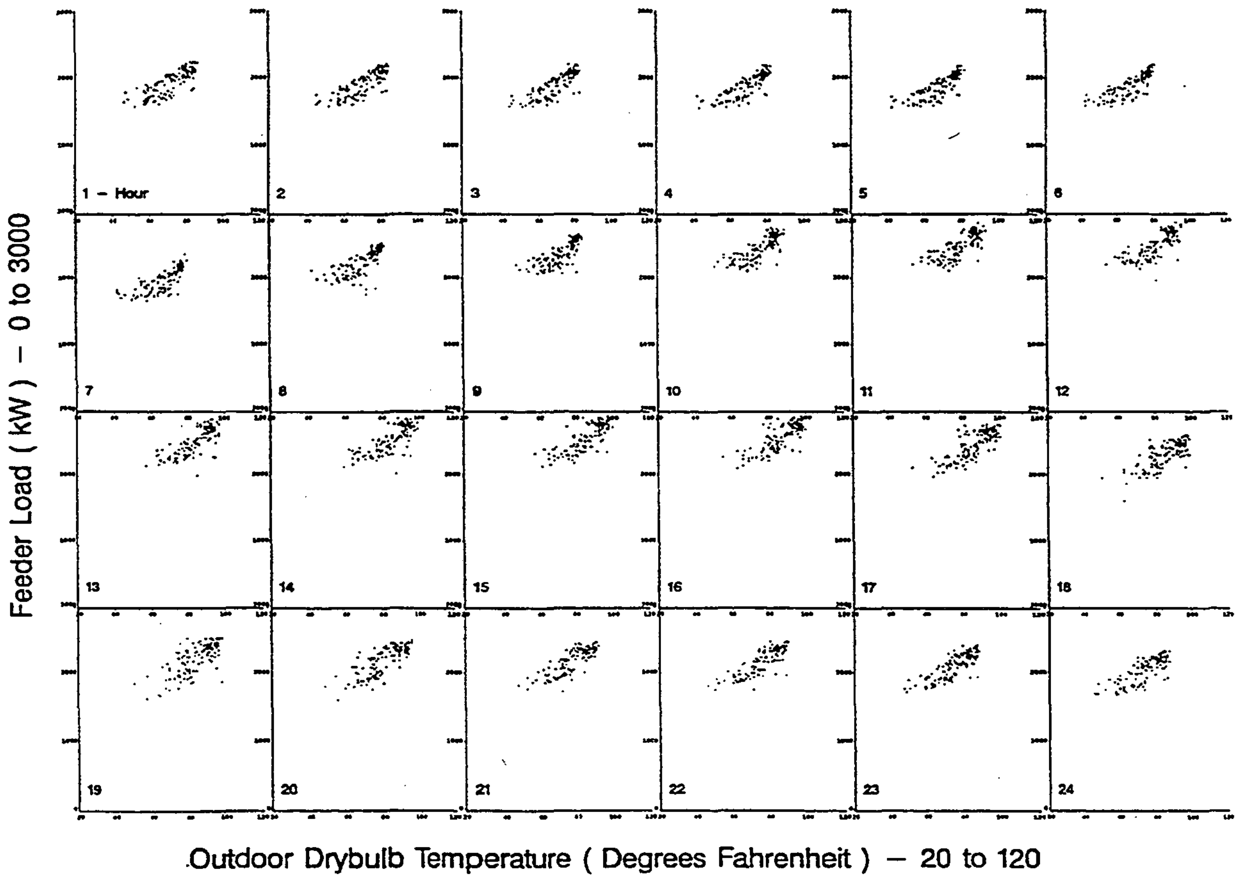

Figure 2 Feeder 2 data analysis—feeder load vs. outdoor dry-bulb temperature—summer, standard day.

chilled-water cooling system. They are modeled as a single story with approximately 5,000 ft^2 (464 m^2).

The vehicle maintenance group consists of four prototypes: a small shop, two large shops, and a hangar. Each of these prototypes is modeled with an office zone and a bay zone, where the office is about 5% of the total floor area. The bay zones are not cooled but are heated with gas-fired unit heaters. The office zones are heated with a hot water boiler. The small vehicle maintenance shop is modeled without an air-conditioned office. The large vehicle maintenance shops have air-conditioned offices that are cooled with either a packaged direct expansion unit or a chiller. The hangar has office cooling provided by a chiller. Also, these prototypes have a process (air compressor) load.

There is only one major hospital (Darnell) at Fort Hood and it is individually modeled as a prototype. Dental clinics, which for all practical purposes are operated like office buildings (with well-defined schedules and a similar working environment), are modeled as administrative prototypes.

The residential group consists of three prototypes: detached, two-plex, and four-plex of 1,330, 2,940, and 6,770 ft^2 (123, 273, and 628 m^2), respectively. All are modeled as single-story units heated with a gas-fired furnace and cooled with central air-direct expansion units.

The other building group includes a large retail store, two warehouses, and a miscellaneous category. The large retail store is modeled as a single story of 128,000 ft^2 (11,891 m^2), where cooling is provided by a chiller/cooling tower and heating by a hot water boiler. The warehouses are modeled with an office space and a storage space, in which the office is about 5% of the total floor area. The storage zone has no cooling but is heated with a gas-fired unit heater. The office is heated with a hot water boiler. One warehouse is modeled without office cooling and the other is cooled with a packaged direct expansion unit. For the miscellaneous category, consisting of a bowling center, a church, a grocery store, a library, restaurants (fast food and sit down), a small retail store, and a youth center, only DOE-2 simulated results were obtained.

A single streetlight pole was assumed to consist of a mixture of single and double lamps with 1.3 lamps per pole and where each lamp is rated at 150 W. These poles are placed every 50 feet (15 m). The street length for each feeder was estimated from the Fort Hood base map. This provided the initial estimate for the EDA application.

EDA requires initial estimates of hourly end-use loads for each prototype. For HVAC end uses (cooling and fans), initial estimates result from simulation of the prototype using the DOE-2.1D (BESG 1990) building energy simulation program with Waco, Texas, weather data. For non-HVAC end uses (miscellaneous equipment, refrigeration, cooking, process, exterior and interior lighting), the estimates are generated with the non-HVAC load generator, also known as NELDIG (Akbari et al. 1989). NELDIG combines the peak intensity for each end use (equipment/lighting/etc.) with a fraction derived from prototypical schedules. This results in an annual hourly load profile for each non-HVAC end use.

Feeder-to-Prototype Assignment

The feeder-to-building assignment database was integrated with the IFS building inventories data to determine the floor area per prototype on each feeder. The feeders were assigned the prototypes that cover 90% to 100% of the floor area of the feeder. This ranged from 1 prototype to 10 prototypes on a single feeder. The remaining 5% to 10% of the floor area was composed of prototypes that each represented less than 1% or 2% of the floor area (in most cases less than 1%). The feeder-to-prototype assignment was then used as input to EDA.

EDA Application

The first step was to disaggregate the winter temperature-independent hourly component from the feeder data analysis into end uses for each prototype. Cooling had been set equal to zero for the winter season since the measured load data suggested there was no temperature-dependent component and the MEIP survey indicated cooling systems were off during the winter (the exception is the hospital). The winter fan and pump load was attributed to moving heated and ventilated air and hot water. The winter hourly component was distributed proportionally based on the initial simulated hourly end-use loads for each prototype and street lighting.

The second step was to disaggregate the summer temperature-dependent and temperature-independent hourly components into end uses for each prototype. The temperature-dependent cooling was determined by prorating the estimated temperature-dependent hourly component by the initial simulated cooling hourly loads. The same was done to estimate temperature-dependent hourly loads for fans.

The temperature-independent (base) cooling and fan hourly loads were calculated by prorating the summer temperature-independent hourly component with the non-HVAC end uses and simulated base cooling and fans. The total cooling load was the sum of the hourly temperature-dependent cooling and the base cooling (likewise for fans). The summer temperature-independent hourly component was then adjusted by subtracting out the base cooling and fan hourly loads. The hourly non-HVAC end-use loads were found by proportionately distributing the adjusted summer temperature-independent hourly component. Then the difference (error) between the total measured feeder hourly load and the sum of the estimated temperature-dependent and temperature-independent hourly components was distributed. This was done for summer only. If the error was greater than zero (regression underestimate), it was then distributed proportionately based on the relative floor area of the prototype to the feeder. However, if the error was less than zero (regression overestimate), the error was still distributed proportionately, but if this distribution caused any end use to become less than zero, then the error was redistributed with the relative floor area decreased by 50% for any end use less than zero. This process was repeated until all reconciled hourly end-use loads were greater than zero. The error was then added to the previously calculated summer hourly end-use loads.

At the completion of this step, the raw EDA-reconciled hourly loads by end use and prototype were determined. These raw EDA-reconciled hourly loads were then averaged by season and day type to produce average load shapes. The data in both the hourly and average daily forms were utilized in the post-EDA data analysis.

Post-EDA Data Analysis

The raw EDA-reconciled hourly loads, annual EUIs, and load shapes were inspected for acceptance. The method used to check the validity of EUIs was to compare the end-use EUIs derived from the analysis of a feeder to similar EUIs obtained from other feeders. If the EUIs were not accepted, then the feeder-to-prototype assignments were adjusted based on a remapping of buildings to feeders and the EDA application was repeated for those feeders affected. If they were accepted, then the raw EDA-reconciled hourly loads were scaled down by the fraction of floor area utilized by the feeder.

The criterion used for the acceptance of the load shapes was based on the visual inspection of data and ensuring that the load shapes did not have any erratic features such as high hour-to-hour variations during the shoulder hours. We examined the load shapes for such unrealistic behavior in the shoulder hours. Because the prototype schedules do not ideally reflect the load behavior in the reconciled load shapes, the shoulder hours periodically exhibited spikes for some end use. These spikes were smoothed with a linear fit within the scaled EDA-reconciled hourly loads for whatever end uses were necessary.

At this point the scaled and smoothed annual EUIs and load shapes were examined for a final time to determine which would be implemented in the final weighting step. The prototypes accepted were combined into a final weighted, reconciled prototype based on the relative floor area of like prototypes from different feeders.

RESULTS

As was stated in the methodology, first we simulated the hourly electricity end-use consumption data using an hourly simulation program. The simulated end-use data were then reconciled with the measured feeder data using EDA. Finally, we averaged the reconciled prototypical end-use EUIs for all feeders to obtain average EUIs for the entire fort. Table 3 summarizes the final weighted EDA-reconciled annual electric end-use EUIs. We believe that the results for the hospital have a high degree of accuracy since the hospital is the only building on the feeder. The feeders serving the residential neighborhoods do not provide electricity to other major nonresidential buildings and, hence, we believe the resulting end-use EUIs and load shapes for the residences are reliable. This reliability was noted by observing that the residential EUIs obtained from different feeders agree with each other within 20%. Similarly, the resulting EUIs for administration buildings and barracks from different feeders agree within 20%. EUIs for large retail buildings are believed to be grossly overestimated because of building-to-feeder misassignment.

The total energy consumption for similar prototypes for all the feeders analyzed is displayed in column 3 of Table 4. These values were obtained by combining EUIs and floor area for all feeders. These results were then extrapolated to the entire base, and they are displayed in column 5 of Table 4. Also, extrapolated results by end-use are shown in column 2 of Table 5. The EDA-predicted annual hourly electrical use for the entire base is illustrated in the upper portion of Figure 3.

The utility's annual hourly electrical use data were used to check EDA results extrapolated to the entire base. The difference between the utility's annual hourly electrical use and the EDA-predicted annual hourly electrical use is shown in the lower portion of Figure 3. In this plot, the larger fluctuations occur during shoulder hours, which are inherently less stable than normal operating hours. If the fluctuations in the lower portion of Figure 3 are ignored, the EDA-predicted use is always less than that shown in the utility's data (the last 10 days of the year excluded). The comparison for the last 10 days of the year reveals that EDA overpredicts use because some nonstandard days are being modeled as standard days. The utility's data should exceed the EDA-predicted use because the utility measures on the high side of the transformer, while feeder data are measured on the low side. Also, feeder line loss was not accounted for in EDA.

The EDA-predicted total annual electrical use is compared as a percentage to the total annual utility data by prototype in column 6 of Table 4 and by end-use in column 3 of Table 5. Clearly, the barracks, administration, and residential prototypes are the largest consumers of energy at 70%; by end use, cooling, ventilation, miscellaneous, and indoor lighting consume almost 80%. The total energy consumption of the main and west substations serving Fort Hood predicted by EDA is 95.3% of the utility's data. This excess difference of 4.7% can be attributed to transformer loss, feeder line loss, and any error within the input data or methodology.

CONCLUSION

The EDA was applied to 10 feeders in Fort Hood. The results from the analyses of these 10 feeders were extrapolated to estimate energy use by end use for the entire installation and validate the results with the independent utility billing data for electricity use for the installation.

Fort Hood is probably exceptional in having hourly electricity consumption data by distribution feeders. In those installations where electricity consumption data are not available by feeder, the EDA reconciliation can be applied to the utility's hourly data for the entire installation.

The extrapolation of the EDA results to the entire fort shows that the administration, residential, and barracks prototypes are the largest consumers of electricity for a total of 250 GWh per year (74% of the Fort Hood annual consumption of 330 GWh). By end use, cooling, ventilation, miscellaneous uses, and indoor lighting consume almost 84% of total electricity use. The contribution to the peak power demand is highest by residential sector (35%, 24 MW out of 70 MW), followed by administration buildings (30%) and barracks (14%). For the entire Fort Hood instal-

TABLE 3 Weighted EDA-Reconciled Electric Annual End-Use EUIs [kWh/ft^2·yr]

Prototype	Cool	Fan	Cook	Misc	Ref	Ex_Lit	In_Lit	Prcss	Total
Barrack									
Hammer head	3.41	1.40	0.28	1.73	2.05	0.19	1.83	—	10.90
Rolling pin	4.31	3.51	0.31	0.86	2.03	0.12	1.35	—	12.48
Modular	3.75	1.15	0.30	2.63	2.29	0.15	2.50	—	12.76
Small	5.10	1.36	0.16	0.99	1.16	0.19	1.03	—	9.99
Dining Hall	5.28	2.09	5.94	—	4.60	0.13	3.69	—	21.72
Gymnasium	2.32	0.90	—	0.60	—	0.19	5.85	0.09	9.95
Administration									
Large	2.85	3.18	—	9.05	—	0.12	4.87	—	20.06
Small—old w/ split DX	8.39	2.66	—	1.47	—	0.14	4.98	—	17.63
Small—old w/ chiller	4.98	4.65	—	1.37	—	0.12	4.61	—	15.75
Small—new w/ split DX	6.30	1.93	—	1.45	—	0.13	4.92	—	14.75
Small—new w/ chiller	4.35	4.02	—	1.74	—	0.18	5.92	—	16.21
Vehicle Maintenance									
Small w/ no A/C	—	0.48	—	0.45	—	0.26	1.82	0.04	3.03
Large w/ split DX	0.57	0.28	—	0.50	—	0.29	2.05	0.04	3.74
Large w/ chiller	0.47	0.43	—	0.57	—	0.34	2.33	0.05	4.19
Hangar	1.71	1.32	—	0.25	—	0.07	3.49	0.04	6.88
Hospital	6.24	1.72	0.68	11.81	0.61	0.33	9.40	—	30.80
Residential									
Detached	5.03	0.44	0.21	3.71	0.83	0.37	0.78	—	11.37
Two plex	4.65	0.40	0.21	3.59	0.80	0.35	0.75	—	10.76
Four plex	6.45	0.44	0.19	2.92	0.70	0.31	0.64	—	11.67
Other									
Retail—large	9.00	8.74	1.16	5.29	5.74	1.53	29.09	—	60.54
Warehouse									
w/ no A/C	—	0.16	—	0.44	—	0.22	1.67	—	2.49
w/ split DX	2.41	0.53	—	0.75	—	0.43	2.78	—	6.90

lation, cooling is 54% of the peak demand (38 MW out of 70 MW), followed by interior lighting at 18% and miscellaneous end-uses at 12%.

A database of measured commercial energy-use data has documented that, with existing technologies, energy-efficiency strategies can be designed to reduce energy and peak demand use by 20% with a payback time of less than three years (Greely et al. 1990). Such a program at Fort Hood could result in savings of more than 65 GWh per year in energy and 15 MW in peak power demand.

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TABLE 4 EDA-Predicted Annual Energy Consumption by Prototype

Prototype	EDA Application		Extrapolated to Fort Hood		
	Area [ft^2]	EDA [GWh/yr]	Area [ft^2]	EDA [GWh/yr]	Percent of Texas Utility
Barrack					
Hammer head	1066798	11.6	1066798	11.6	3.3
Rolling pin	776986	9.7	1810654	22.6	6.5
Modular	355353	4.5	1647994	21.0	6.0
Small	84960	0.8	403967	4.0	1.2
Dining Hall	218660	4.7	505877	11.0	3.1
Gymnasium	41960	0.4	223595	2.2	0.6
Administration					
Large	587817	11.7	674113	13.5	3.9
Small—old w/ split DX	305103	5.3	1153551	20.3	5.8
Small—old w/ chiller	945802	14.9	2029777	32.0	9.1
Small—new w/ split DX	119835	1.7	373706	5.5	1.6
Small—new w/ chiller	49320	0.8	356215	5.8	1.7
Vehicle Maintenance					
Small w/ no A/C	457888	1.4	1034912	3.1	0.9
Large w/ split DX	301899	1.1	1037480	3.9	1.1
Large w/ chiller	58080	0.2	446072	1.9	0.5
Hangar	170010	1.2	743895	5.1	1.5
Hospital	504202	15.5	504202	15.5	4.4
Residential					
Detached	741594	8.4	1141815	13.0	3.7
Two plex	3243286	34.9	4936284	53.1	15.2
Four plex	686420	8.0	2490464	29.1	8.3
Other					
Retail—large	256116	15.5	256116	15.5	4.4
Warehouse					
w/ no A/C	60974	0.2	1137313	2.8	0.8
w/ split DX	56800	0.4	283407	2.0	0.6
Miscellaneous	470967	6.6	1245593*	17.5	5.0
Water pump	—	3.2	—	3.2	0.9
Street Lights	—	8.2	—	18.1	5.2
EDA Total	11560830	170.9	25503800	333.4	95.3
Texas Utility	—	—	—	349.6	100.0

* Miscellaneous floor area includes non-building, utility, water pump, and fuel station.

TABLE 5 EDA-Predicted Annual Energy Consumption by End-Use

End-use	EDA [GWh/yr]	Percent of Texas Utility
Cooling	107.4	30.7
Fans	38.4	11.0
Cooking	6.8	1.9
Miscellaneous	61.0	17.4
Refrigeration	21.1	6.0
Exterior lighting	6.4	1.8
Interior lighting	70.7	20.2
Process	0.2	0.1
Street lighting	18.1	5.2
Water pump	3.2	0.9
EDA total	333.4	95.3
Texas utility	349.6	100.0

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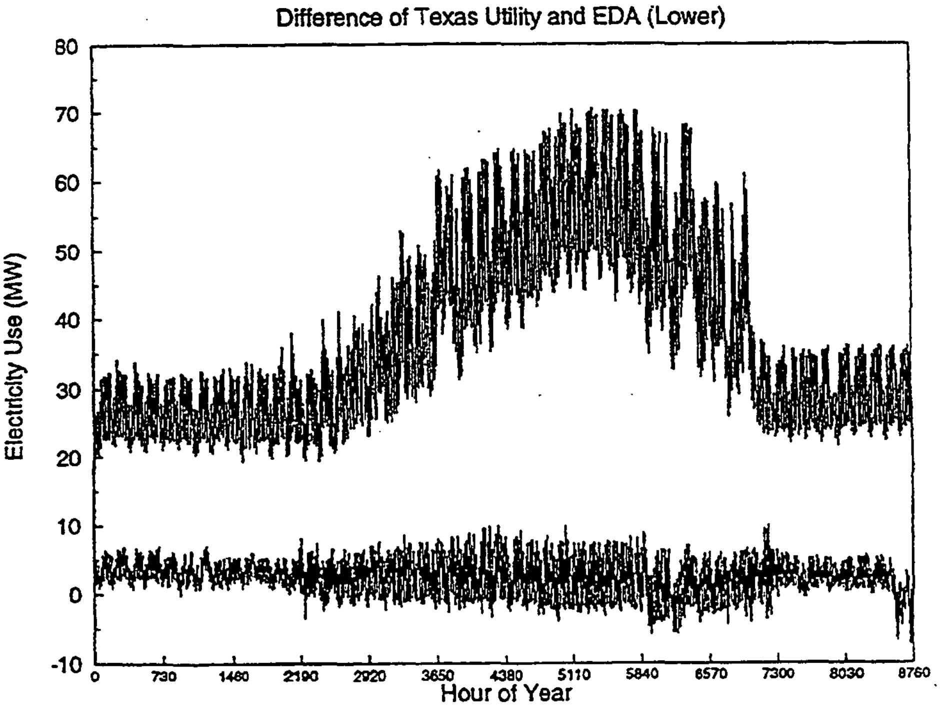

Figure 3 *EDA annual hourly electricity use (upper), difference of Texas utility and EDA (lower).*

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY
ONE CYCLOTRON ROAD | BERKELEY, CALIFORNIA 94720

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