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Estimates of Energy Consumption by Building Type and End Use at U.S. Army Installations

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A Report Prepared for
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Abstract

This report discusses the application of the Lawrence Berkeley National Laboratory's (LBNL) End-use Disaggregation Algorithm (EDA) to 12 U.S. Army installations nation-wide in order to obtain annual estimates of electricity use for all major building types and end uses. The building types include: barrack, dining hall, gymnasium, administration, vehicle maintenance, hospital, residential, warehouse, and miscellaneous. Up to 8 electric end uses for each building type were considered for EDA application. These electric end uses include space cooling, ventilation (air-handling units, fans, chilled and hot water pumps), cooking, miscellaneous/plugs, refrigeration, exterior and interior lighting, and process loads. Through building simulations, we also obtained estimates of natural gas space heating energy use.

The average electricity use by end use for these 12 installations and Fort Hood are as follows. HVAC, miscellaneous, and indoor lighting end uses consumed the most electricity, with 28, 27, and 26% of the total use, and 3.8, 3.5, and 3.3 kWh/ft^2, respectively. Refrigeration, street lighting, exterior lighting, and cooking end uses consumed 7, 7, 3, and 2% of the total electricity use, and 0.9, 0.9, 0.4, and 0.3 kWh/ft^2, respectively.

Key to Bar Graphs

Installations

Fort Dix	Dix
Fort Belvoir	Bvr
Fort Bragg	Brg
Fort Benning	Bng
Fort Polk	Plk
Fort Benjamin Harrison	Bhn
Fort Leonard Wood	Lwd
Fort Irwin	Iwn
Fort Sill	Sll
Yuma Pg	Yma
Fort Bliss	Bls
Fort Sam Houston	Shn
Fort Hood	Hood

End Uses

Street Lighting	st lit
Interior Lighting	in lit
Exterior Lighting	ex lit
Refrigeration	refr
Miscellaneous	misc
Cooking	cook
HVAC	hvac

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Executive Summary

In 1993, the U.S. Army Construction Engineering Research Laboratory (CERL) contracted with the Lawrence Berkeley National Laboratory (LBNL) to perform an analysis of existing building and energy use data and obtain energy use intensity (EUI) by end use for major building types in U.S. Army installations. Since most buildings in Army installations are not individually metered, energy use data by building type are scarce. The majority of installations typically have one utility meter measuring electricity and gas energy use for the entire installation, where the electric utility meters usually record consumption at half-hour or one-hour intervals. LBNL was to use their End-use Disaggregation Algorithm (EDA) to disaggregate the hourly whole-installation electricity use into major end uses for major building types.

The objectives of the project were:

- to develop an energy database by building type and by end use for U.S. Army facilities;
- to enhance the DoD energy office's ability to track energy use by end use;
- to establish a vehicle for transferring the analytical methodologies for end-use energy analysis developed at LBNL to CERL.

The project was divided into two phases. In Phase I, the methodology was successfully pilot-tested and a database developed for one Army installation at Fort Hood, Texas. The results of the Phase I study were summarized in an LBNL report prepared for CERL (Akbari and Konopacki, 1995). This report summarizes the results of the Phase II project to obtain EUIs, by end use and major building types, for 12 other Army facilities nation-wide. These 12 facilities are Fort Dix, Fort Belvoir, Fort Bragg, Fort Benning, Fort Polk, Fort Benjamin Harrison, Fort Leonard Wood, Fort Irwin, Fort Sill, Yuma Pg, Fort Bliss, and Fort Sam Houston.

In the Phase I project, we carried out detailed hourly EDA reconciliations for over 12 electricity feeders, which distribute electricity to various areas in the Fort Hood installation. Also, 22 detailed prototypical buildings were developed from a comprehensive survey of selected buildings at Fort Hood. In the current phase (Phase II), because of a lack of detailed quality data for other installations, we decided to achieve the objectives of the project with a hybrid method integrating reconciled end-use data for Fort Hood, a general building type profile in each installation, and monthly and annual electrical utility bills for each installation. Prototypical building characteristics are understood to be uniform across the Army nation-wide; therefore, prototypes developed for Fort Hood were applied at all installations with few modifications.

The building types at Army facilities examined in this project cover a wide spectrum of commercial and residential buildings, which include: barrack, dining hall, gymnasium, large administration, small administration (old and new vintage), vehicle maintenance, hospital, residential, warehouse, and miscellaneous. Up to 9 end uses were estimated for each building type, consisting of 8 electric and gas heating; however, only the electric end uses were scaled with Fort Hood EDA results. Space heating EUIs were estimated using the DOE-2 building simulation program. Electric end-use EUIs were also estimated on an installation level using electrical utility billing data. The electric end uses include space cooling, ventilation (air-handling units, fans, chilled and hot water pumps), cooking, miscellaneous/plugs, refrigeration, exterior and interior lighting, and process loads. Street lighting was also estimated for each facility. Hot water consumption data were not available for these installations.

Electricity use estimates for 7 end uses (miscellaneous and process end uses are combined) summed for all building types for an entire installation are presented in **Figures EX-1** and **EX-2**, where Fort Hood estimates are included in the presentation. The average electricity use by end use for these 13 installations (12 installations studied in Phase II and Fort Hood studied in Phase I) are as follows. HVAC,

miscellaneous, and indoor lighting end uses consumed the most electricity, with 28, 27, and 26 % of the total use, and 3.8, 3.5, and 3.3 kWh/ft^2, respectively. Refrigeration, street lighting, exterior lighting, and cooking end uses consumed 7, 7, 3, and 2 % of the total electricity use, and 0.9, 0.9, 0.4, and 0.3 kWh/ft^2, respectively.

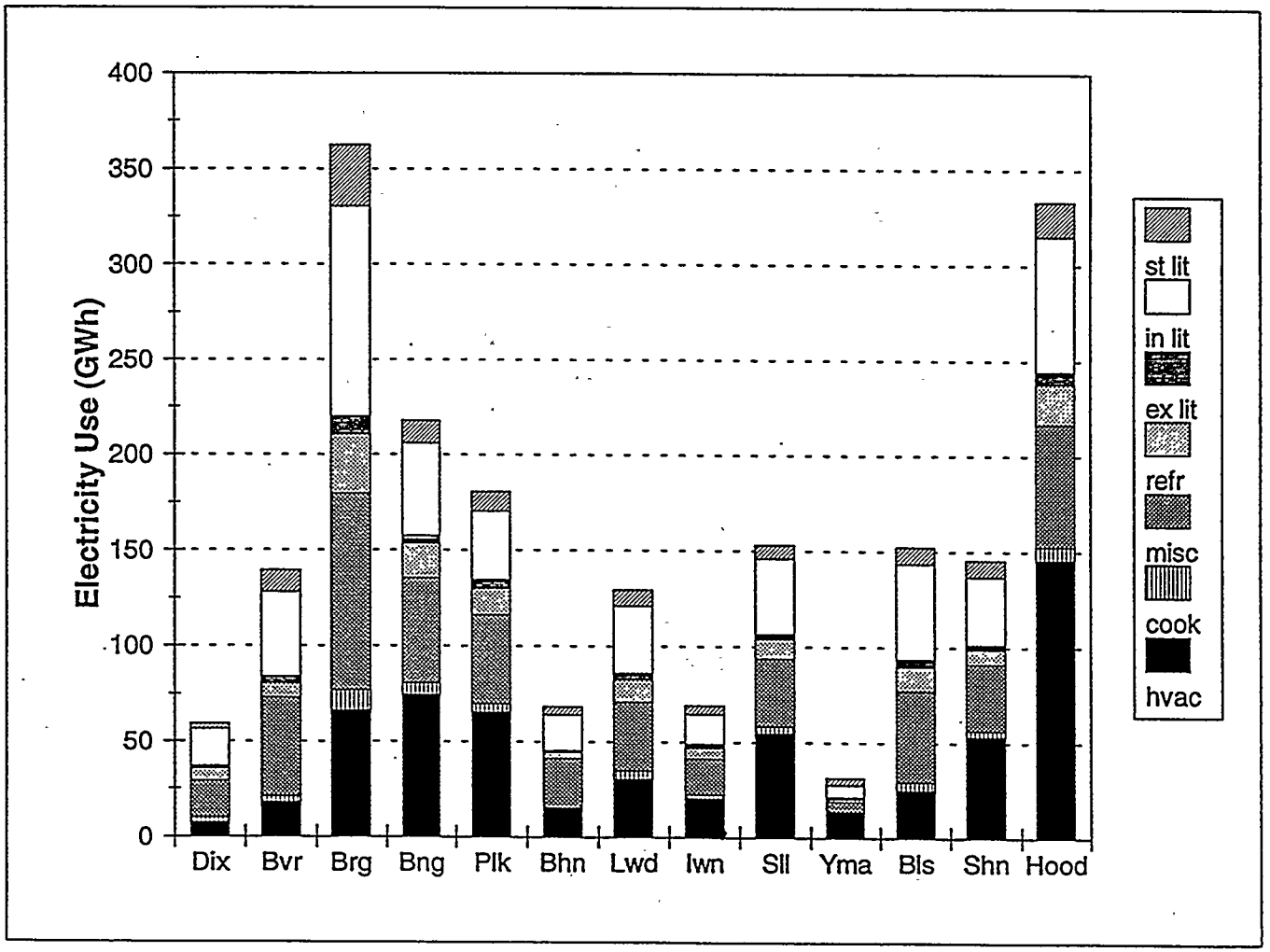
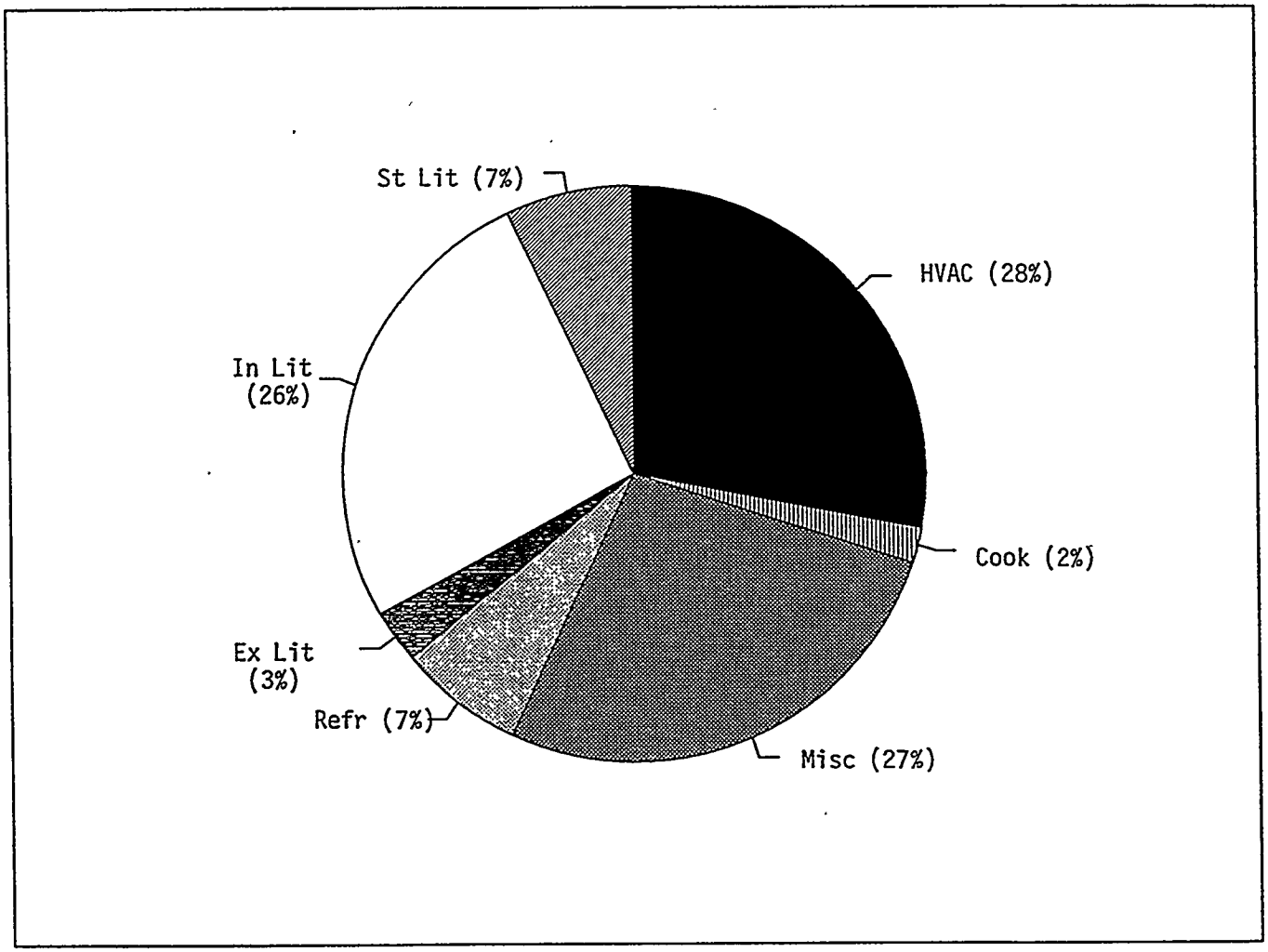


Figure EX-1. 1993 Electricity Consumption Estimates by End Use for 13 U.S. Army Installations (GWh).

Figure EX-2. 1993 Electricity Consumption Estimates by End Use for Average of 13 U.S. Army Installations (% of Total).



1. Introduction

Background

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, the 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 Lawrence Berkeley National Laboratory (LBNL) was designed specifically for this purpose. In EDA, computer simulations are reconciled hourly against measured energy consumption in order to obtain end-use consumption data (Akbari, 1996).

In addition, DoD and government agencies have developed numerous energy analysis tools and energy analysis techniques on a "piecemeal" basis or for specific applications, and have compiled property databases for facilities management (real property databases). This project has drawn upon and brought together these disparate sources of information into an integrated form that can be used for DoD-wide energy end-use characterization.

Objectives

The objectives of the project were:

- to develop an energy database by building type and by end use for U.S. Army facilities;
- to enhance the DoD energy office's ability to track energy use by end use;
- to establish a vehicle for transferring the analytical methodologies for end-use energy analysis developed at LBNL to the U.S. Army Construction Engineering Research Laboratory (CERL).

The project was divided into two phases. In Phase I, the methodology was successfully pilot-tested and a database developed for one Army installation at Fort Hood, Texas. The results of the Phase I study were summarized in an LBNL report prepared for CERL (Akbari and Konopacki, 1995). This report summarizes the results of the Phase II project to obtain EUIs, by end use and major building types, for 12 other Army facilities nation-wide. These 12 facilities are Fort Dix, Fort Belvoir, Fort Bragg, Fort Benning, Fort Polk, Fort Benjamin Harrison, Fort Leonard Wood, Fort Irwin, Fort Sill, Yuma Pg, Fort Bliss, and Fort Sam Houston.

In the Phase I project, we carried out detailed hourly EDA reconciliations for over 12 electricity feeders, which distribute electricity to various areas in the Fort Hood installation. Also, 22 detailed prototypical buildings were developed from a comprehensive survey of selected buildings at Fort Hood. In the Phase II project, because of a lack of detailed quality data for other installations, it was decided to achieve the

objectives of the project with a hybrid method integrating reconciled end-use data for Fort Hood, a general building type profile in each installation, and monthly and annual electrical utility bills for each installation. Prototypical building characteristics are understood to be uniform across the Army nation-wide; therefore, prototypes developed for Fort Hood were applied at all installations with few modifications.

The building types at Army facilities examined in this project cover a wide spectrum of commercial and residential buildings, which include: barrack, dining hall, gymnasium, large administration, small administration (old and new vintage), vehicle maintenance, hospital, residential, warehouse, and miscellaneous. Up to 9 end uses were estimated for each building type, consisting of 8 electric and gas heating; however, only the electric end uses were scaled with Fort Hood EDA results. Space heating EUIs were estimated using the DOE-2 building simulation program. Electric end-use EUIs were also estimated on an installation level using electrical utility billing data. The electric end uses include space cooling, ventilation (air-handling units, fans, chilled and hot water pumps), cooking, miscellaneous/plugs, refrigeration, exterior and interior lighting, and process loads. Street lighting was also estimated for each facility. Hot water consumption data were not available for these installations. The scope of the Phase II project is shown in **Table 1-1**, which presents the building types and end uses examined.

Overview of the Report

This final report summarizing Phase II activities is organized into five sections. In section 2, we provide an overview of the selected U.S. Army installations. Section 3 reviews input data and analysis performed. In section 4 we discuss the methodology for analysis of data and an approach to end-use data analysis. In section 5 we summarize estimated electricity end-use intensities (EUIs) and electricity use for all major building types and end uses.

Table 1-1. Project Scope

The scope includes 11 building types, 8 electric end uses, and gas space heating. We did not study domestic hot water gas energy use, since these data were unavailable.

Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Heat†
Barrack	X	X	X	X	X	X	X		X
Dining Hall	X	X	X		X	X	X		X
Gymnasium	X	X		X		X	X	X	X
Admin Large	X	X		X		X	X		X
Admin Small Old	X	X		X		X	X		X
Admin Small New	X	X		X		X	X		X
Vehicle Maintenance	X	X		X		X	X	X	X
Hospital	X	X	X	X	X	X	X		X
Residential	X	X	X	X	X	X	X		X
Warehouse	X	X		X		X	X		X
Miscellaneous	X	X	X	X	X	X	X		X

† Space heating is a gas end-use and was estimated with DOE-2 simulations.

2. Site Selection

The Army has more than 90 major installations nation-wide of mission types, Forces Command (FORSCOM), Military District of Washington (MDW), Training and Doctrine Command (TRADOC), and Army Material Command (AMC). FORSCOM are installations with combat-ready forces. The mission of MDW facilities are to provide general oversight and administration. In a TRADOC base, forces are trained for combat-readiness. The purpose of an AMC facility is weapons production and storage and proving grounds for testing.

Twelve installations were selected for analysis in this project and the criteria for choosing them were:

- they should represent all four major mission types;
- they should include the influence of building types and scheduling particular to each mission type;
- they should be larger bases that include most major building types;
- they should represent all major climate regions with emphasis on regions with high concentrations of Army installations.

The selected installations and weather sites used for DOE-2 simulations are shown in **Table 2-1**. The weather locations were the closest available and are illustrated in **Figure 2-1**. The weather tapes were of the Typical Meteorological Year (TMY) format for Philadelphia, St. Louis, Barstow, and Needles, and of the Weather Year for Energy Computation (WYEC) format for Washington DC, Raleigh, Atlanta, Lake Charles, Indianapolis, Oklahoma City, El Paso, and San Antonio.

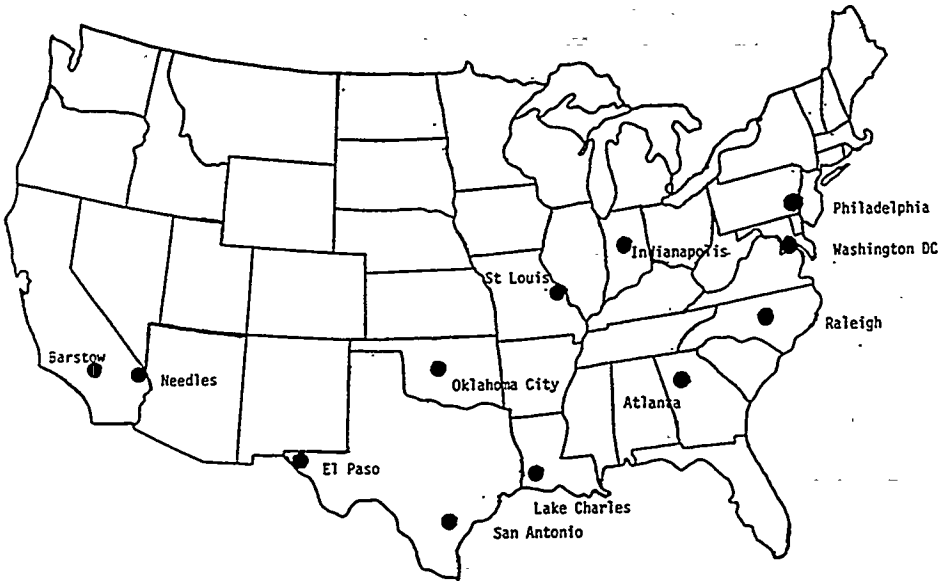


Figure 2-1. Weather Sites Representing the 12 U.S. Army Installations, where the northeast, midwest, southeast, and southwest regions represented areas with a high concentration of installations. Fort Lewis near Seattle was to represent the northwest region, however the quality of electrical utility billing data was inadequate.

Table 2-1. U.S. Army Installation Sites and Annual Weather Statistics

(HDH = Heating Degree Hours, CDH = Cooling Degree Hours, LEH = Latent Enthalpy Hours)

Installation Site			Weather Site			
Name	Type	Location	Location	HDH/24 (base 65 ° F)	CDH/24 (base 65 ° F)	LEH (btuh/lb dry air)
Northeast						
Fort Dix	FORSCOM	Wrightstown, NJ	Philadelphia, PA	5113	1185	3668
Southeast						
Fort Belvoir	MDW	Springfield, VA	Washington DC	4410	1494	3734
Fort Bragg	FORSCOM	Fayetteville, NC	Raleigh, NC	3779	1507	4790
Fort Benning	TRADOC	Columbus, GA	Atlanta, GA	3215	1602	4931
Fort Polk	FORSCOM	Leesville, LA	Lake Charles, LA	1718	2686	†
Midwest						
Fort Benjamin Harrison	TRADOC	Indianapolis, IN	Indianapolis, IN	5831	1133	2745
Fort Leonard Wood	TRADOC	Waynesville, MO	St Louis, MO	5069	1588	6210
California						
Fort Irwin	FORSCOM	Barstow, CA	Barstow, CA	2751	3213	‡
Southwest						
Fort Sill	TRADOC	Lawton, OK	Oklahoma City, OK	4036	2019	5001
Yuma Pg	AMC	Yuma, AZ	Needles, CA	1446	4613	‡
Fort Bliss	TRADOC	El Paso, TX	El Paso, TX	2866	2429	70
Fort Sam Houston	FORSCOM	San Antonio, TX	San Antonio, TX	1805	2913	12953

† Data were unavailable: New Orleans 17754 and Shreveport, LA 12312

‡ Data were unavailable: Bakersfield, CA 15

3. Input Data

There were four sources of input data; IFS building inventory data, building prototypes, electrical utility billing data, and Fort Hood data. The Fort Hood data included DOE-2 simulated HVAC EUIs and EDA reconciled HVAC and non-HVAC EUIs by building type.

IFS Building Inventory

The IFS building inventory data included building category code, floor area, year of construction, HVAC system type, and electricity connection status. These data were categorized into the 11 building types identified in **Table 1-1** and 4 additional types (non-building, utility, pump, and fuel station) based on the category code, floor area, and year of construction. Non-building, utility, pump, and fuel station buildings were grouped into the miscellaneous building type for the remainder of the analyses. Data identifying the HVAC system type for most of the entries were either missing (represented by an "X") or indicated no cooling (also represented by an "X"), which provided for unreliable estimates of air-conditioning system types and saturations. Each of the building types were represented by all 12 Army bases with the exception of Fort Irwin (no large administration) and Yuma Pg (no large administration or hospital). Building types and building floor area of each installation are listed in **Table 3-1**. Buildings listed in IFS as without electrical connection were not included in **Table 3-1** and the subsequent analyses.

Building Prototypes

In Phase II, data identifying building characteristics were scarce. The only source was the IFS building inventory data base, which listed category code, floor area, and year of construction. Information identifying HVAC system type was not available. Therefore, the 22 building types from Phase I were condensed into the 11 building types identified in **Table 1-1**. The small-old (new vintage) administration prototype with a packaged HVAC system from Phase I represented all small-old (new) administration buildings in Phase II. The hammerhead barrack represented all barracks. The large vehicle maintenance with a packaged HVAC system represented all vehicle maintenance buildings and hangars. The detached residence represented all residences. The warehouse with a packaged HVAC system represented all warehouses. Building prototypical characteristics are summarized in detail in Akbari and Konopacki (1995).

The building prototypes for Fort Hood differed from those of the other installations only in HVAC system characteristics. In Fort Hood, cooling was available from April 11 through October 22 and heating for the rest of the year; where in the other installations, cooling was available during temperature-dependent months as defined in Utility Billing Data in this section. Also, the temperature controlled economizer was replaced with an enthalpic control device to better model outside-air control in humid climates, and DOE-2 was allowed to automatically size HVAC equipment.

Table 3-1. IFS Building Inventory Data Floor Area by Building Type

Building Type	Fort Dix		Fort Belvoir		Fort Bragg		Fort Benning		Fort Folk		Fort Harrison	
	Number	Floor Area kft^2	Number	Floor Area kft^2	Number	Floor Area kft^2	Number	Floor Area kft^2	Number	Floor Area kft^2	Number	Floor Area kft^2
Barrack	67	1961	33	629	308	4703	161	4961	239	2414	30	881
Dining Hall	76	181	4	119	76	488	48	462	50	226	3	54
Gymnasium	2	38	4	68	12	218	2	61	2	50	3	49
Admin. Large	6	320	15	1584	19	1364	18	1409	2	70	11	1882
Admin. Small Old	147	825	174	1157	809	3510	355	1877	278	1144	44	308
Admin. Small New	62	118	13	83	205	1216	46	397	119	979	7	29
Vehicle Maintenance	45	301	81	1048	237	2615	123	1225	162	1261	11	77
Hospital	1	427	1	260	1	413	1	393	1	367	1	105
Residential	600	1882	753	3048	2225	7387	1376	6039	1293	8508	89	593
Warehouse	188	606	180	909	434	1855	345	967	345	939	62	298
Miscellaneous	40	430	43	520	110	944	80	796	75	585	38	277
Non-Building	253	1624	60	74	848	576	387	443	140	66	243	28
Utility	79	61	32	26	116	129	134	95	145	57	7	26
Pump	32	9	11	5	26	21	15	7	40	10	2	4
Fuel Station	14	2	5	2	47	12	27	24	19	5	2	0
Total	1612	8785	1409	9532	5473	25451	3118	19156	2910	16681	553	4611

Building Type	Fort Wood		Fort Irwin		Fort Sill		Yuma Pg		Fort Bliss		Fort Houston	
	Number	Floor Area kft^2	Number	Floor Area kft^2	Number	Floor Area kft^2	Number	Floor Area kft^2	Number	Floor Area kft^2	Number	Floor Area kft^2
Barrack	149	2405	64	732	198	3277	12	118	183	2856	54	1726
Dining Hall	26	339	14	95	40	387	1	13	36	271	7	189
Gymnasium	2	101	1	23	2	62	1	12	5	154	4	92
Admin. Large	11	544	0	0	21	1535	0	0	18	1010	12	1100
Admin. Small Old	269	1136	97	246	381	2120	41	204	449	2651	212	1279
Admin. Small New	89	452	120	607	163	588	9	50	70	266	21	131
Vehicle Maintenance	54	554	69	504	107	1072	21	96	93	1231	19	316
Hospital	1	404	1	64	2	498	0	0	2	675	6	636
Residential	1149	3556	818	3183	820	2356	197	436	2197	4359	605	1746
Warehouse	166	603	102	413	325	1103	87	163	214	1028	61	1082
Miscellaneous	110	478	154	15	272	270	71	117	110	208	276	151
Non-Building	74	679	33	286	93	778	24	127	92	856	47	643
Utility	77	72	40	18	79	107	21	7	37	26	48	49
Pump	6	9	12	5	17	8	8	2	24	21	3	10
Fuel Station	11	1	3	1	22	7	2	0	21	6	2	4
Total	2194	11333	1528	6192	2542	14168	495	1345	3551	15618	1377	9154

Utility Billing Data

The monthly electrical utility data for 1993 are plotted in **Figures 3-1(a)** through **3-1(l)** for 12 U.S. Army facilities. These data illustrated the temperature-dependent load behavior of each facility, where prototypical HVAC seasonal schedules were derived. Observed in these plots were two distinct regions, winter and summer. The winter load was defined as temperature-independent. The summer was characterized by a component of temperature-dependent load behavior (air-conditioning use) and of temperature-independent load behavior. The temperature-dependent component was assumed to be all air-conditioning use, and the temperature-independent component included air-conditioning and fans and pumps attributed to space heating, as well as non-HVAC end uses. The information derived from the utility billing data are displayed in **Table 3-2**, which included temperature-dependent HVAC, temperature-independent HVAC, temperature-independent non-HVAC, and months of loads with temperature-dependent behavior. See section 4, Utility Estimated Approach, for further discussion of these data.

Table 3-2. 1993 Electricity Use at U.S. Army Installations from Utility Billing Data

Installation	HVAC			Non-HVAC	Total	Months of Loads w/
	Temperature-Dependent (GWh)	Temperature-Independent (GWh)	Total (GWh)	(GWh)	(GWh)	Temperature-Dependent Behavior
Fort Dix	4.4	3.2	7.6	54.9	62.5	Jul, Aug, Sep
Fort Belvoir	10.4	7.6	18.0	129.3	147.3	Jul, Aug, Sep
Fort Bragg	38.4	28.0	66.4	315.0	381.4	Jun, Jul, Aug, Sep, Oct
Fort Benning	43.2	31.5	74.7	153.9	228.6	Jun, Jul, Aug, Sep, Oct
Fort Polk	37.9	27.7	65.6	124.9	190.5	Jun, Jul, Aug, Sep, Oct, Nov
Fort Benjamin Harrison	8.2	6.0	14.2	57.8	72.0	Jun, Jul, Aug, Sep
Fort Leonard Wood	17.6	12.8	30.4	105.9	136.3	Jun, Jul, Aug, Sep
Fort Irwin	11.8	8.6	20.4	52.4	72.8	May, Jun, Jul, Aug, Sep, Oct
Fort Sill	31.6	23.1	54.7	106.2	160.9	May, Jun, Jul, Aug, Sep
Yuma Pg	7.7	5.6	13.3	19.6	32.9	May, Jun, Jul, Aug, Sep, Oct
Fort Bliss	14.4	10.5	24.9	135.3	160.2	Jun, Jul, Aug, Sep
Fort Sam Houston	30.9	22.6	53.5	99.6	153.1	May, Jun, Jul, Aug, Sep, Oct

Figure 3-1(a-f). 1993 Monthly Utility Billing Data for 12 U.S. Army Installations.

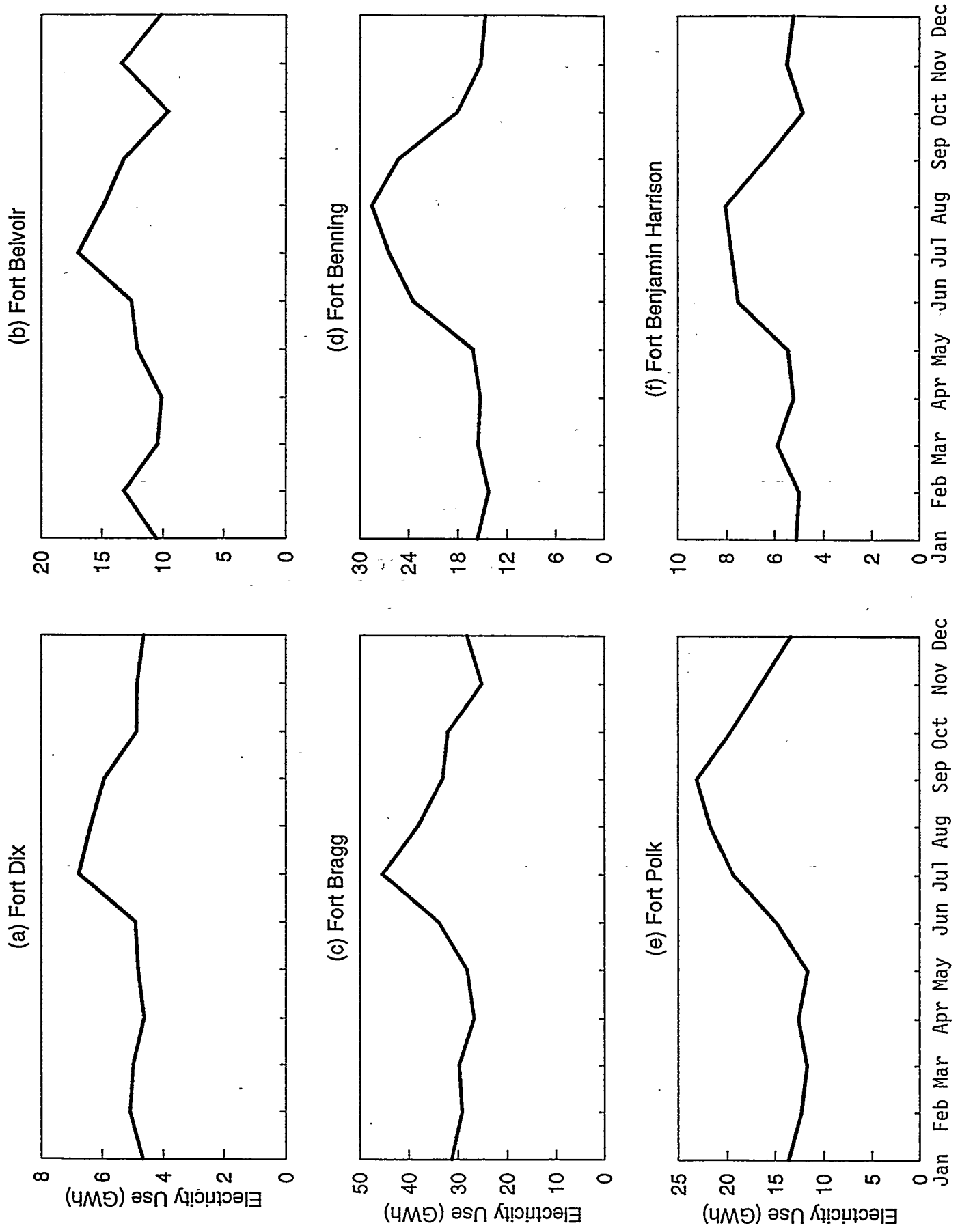
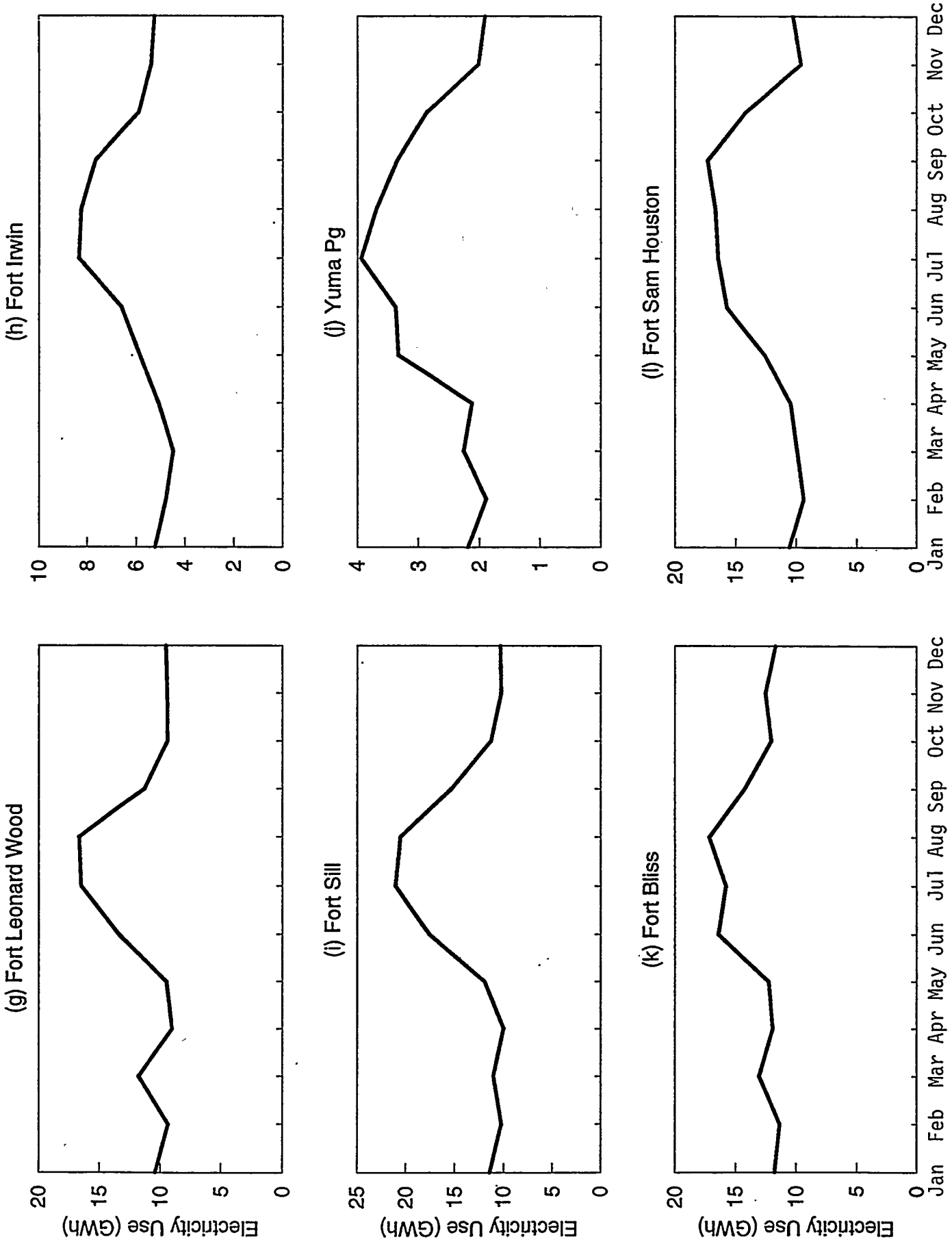


Figure 3-1(g-l). 1993 Monthly Utility Billing Data for 12 U.S. Army Installations.



Fort Hood Data Base

Data from Phase I analyses at Fort Hood include annual DOE-2 simulated HVAC EUIs and EDA reconciled HVAC and Non-HVAC electric EUIs, and the ratio of EDA reconciled temperature-independent to temperature-dependent HVAC. The 22 prototypes developed at Fort Hood were condensed into the 11 building types identified in **Table 1-1**, since regional prototypical characteristics were not available.

Annual DOE-2 simulated HVAC EUIs and EDA reconciled HVAC and Non-HVAC electric EUIs derived at Fort Hood are shown in **Tables 3-3** and **3-4**. These were obtained by weighting together by floor area similar building types (hammer head, rolling pin, modular, and small barrack were weighted into a single barrack type; packaged and central system type small administration into a single small administration type; small and large vehicle maintenance and hangar into a single vehicle maintenance type; detached, two-plex, and four-plex residential into a single residential type; packaged and non-cooled warehouse into a single warehouse type). The non-HVAC EUIs (cooking, miscellaneous/plug, refrigeration, exterior and interior lighting, and process) were assumed to be uniform nation-wide. The Fort Hood Data base for 22 prototypes can be found in Akbari and Konopacki (1995). The ratio of EDA reconciled temperature-independent to temperature-dependent HVAC annual electricity use was 0.73 at Fort Hood.

Table 3-3. Annual DOE-2 Simulated and EDA Reconciled HVAC EUIs at Fort Hood

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	3.51	1.16	3.80	3.83	2.07
Dining Hall	5.62	0.96	7.35	5.28	2.09
Gymnasium	1.59	0.69	28.59	2.32	0.90
Administration Large	4.29	3.79	0.18	2.85	3.18
Administration Small Old	6.68	3.18	20.29	5.82	4.17
Administration Small New	4.93	2.42	11.87	5.73	2.54
Vehicle Maintenance	0.47	0.23	29.44	0.49	0.57
Hospital	8.13	2.83	13.28	6.24	1.72
Residential	5.71	0.45	12.63	4.98	0.41
Warehouse	0.70	0.29	12.39	1.16	0.34
Miscellaneous	4.50	1.19	5.62	4.64	0.84

Table 3-4. Annual EDA Reconciled Electric End-use EUIs at Fort Hood [kWh/ft^2/yr]

Prototype	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	3.83	2.07	0.30	1.55	2.05	0.16	1.74	-	11.70
Dining Hall	5.28	2.09	5.94	-	4.60	0.13	3.69	-	21.73
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	-	20.07
Administration Small Old	5.82	4.17	-	1.40	-	0.12	4.70	-	16.21
Administration Small New	5.73	2.54	-	1.54	-	0.14	5.22	-	15.17
Vehicle Maintenance	0.49	0.57	-	0.43	-	0.24	2.21	0.04	3.98
Hospital	6.24	1.72	0.68	11.81	0.61	0.33	9.40	-	30.79
Residential	4.98	0.41	0.21	3.51	0.79	0.35	0.73	-	10.98
Warehouse	1.16	0.34	-	0.59	-	0.32	2.20	-	4.61
Miscellaneous	4.64	0.84	0.06	1.91	0.22	0.29	5.99	-	13.95

4. Methodology

Two approaches were employed to estimate electricity use at Army installations. The first was called 'EDA estimated', which utilized DOE-2 simulations of HVAC electricity use in combination with Fort Hood DOE-2 simulated and EDA reconciled EUIs, and IFS building inventory data to obtain electricity use data by building type and end use. The second was called 'utility estimated', which integrated electrical utility billing data, the Fort Hood EDA temperature-independent to temperature-dependent HVAC electricity use ratio, and non-HVAC EDA estimates from the first approach to determine electricity use by end use for the entire facility. These two approaches are illustrated in **Figure 4-1** with EDA estimated shown on the left (1) and utility estimated on the right (2).

EDA Estimated Approach

The 11 building prototypes identified in **Table 1-1** were simulated with the building energy simulation program DOE-2.1D (BESG, 1990) using nearby weather data for each installation to obtain annual simulated HVAC EUIs (cooling, ventilation, and gas heating). The annual simulated HVAC electric end-use EUIs (cooling and ventilation) for each installation and building type were divided by the annual simulated HVAC electric end-use EUIs from Fort Hood of like building type, to obtain simulation scaling ratios as in equation [1], where the subscript 'i' identifies the installation, 'j' the building type, and 'k' the enduse.

$$\text{DOE2\_EUI\_RATIO}_{\text{annual,hvac,i,j,k}} = \frac{\text{DOE2\_EUI}_{\text{annual,hvac,i,j,k}}}{\text{DOE2\_EUI}_{\text{annual,hvac,FtHood,j,k}}} \quad [1]$$

The simulation scaling ratios were then multiplied by the annual EDA reconciled electric HVAC EUIs from Fort Hood for each installation and building type to obtain EDA estimated EUIs as in equation [2]. The EDA non-HVAC end-use EUIs were assumed to be uniform for all installations, and hence were not modified from the Fort Hood EDA reconciled EUIs, equation [3]. EDA reconciled EUIs from Phase I applicable to Phase II are shown in **Table 3-4**.

$$\text{EDA\_EUI}_{\text{annual,hvac,i,j,k}} = \text{DOE2\_EUI\_RATIO}_{\text{annual,hvac,i,j,k}} \times \text{EDA\_EUI}_{\text{annual,hvac,FtHood,j,k}} \quad [2]$$

$$\text{EDA\_EUI}_{\text{annual,nhvac,i,j,k}} = \text{EDA\_EUI}_{\text{annual,nhvac,FtHood,j,k}} \quad [3]$$

The EDA estimated annual HVAC and non-HVAC electricity use by building type and end use were calculated by multiplying the EDA estimated EUIs by the total building floor area from **Table 3-1** as in equation [4].

$$\text{EDA\_EU}_{\text{annual,i,j,k}} = \text{EDA\_EUI}_{\text{annual,i,j,k}} \times \text{Floor\_Area}_{\text{i,j}} \quad [4]$$

Utility Estimated Approach

The 1993 monthly utility billing data were separated into three components; temperature-dependent HVAC, temperature-independent HVAC, and non-HVAC, for each installation as shown in **Figure 4-2.**

Two seasons were observed; winter and summer. The winter season exhibited temperature-independent behavior, therefore a winter average was defined as the mean load during these months. The summer season exhibited both temperature-dependent and temperature-independent behavior. The summer temperature-independent component was defined as equal to the winter average load and the summer temperature-dependent component was defined as the total load less the summer temperature-independent component. The summer temperature-dependent component was attributed completely to HVAC use. The temperature-independent component was divided into HVAC and non-HVAC components. Since the temperature-dependent HVAC component was known, the temperature-independent HVAC component could be found from the ratio of EDA temperature-independent HVAC to temperature-dependent HVAC at Fort Hood. The total HVAC electricity use of the installation was the sum of the temperature-dependent HVAC component and the temperature-independent HVAC component. The non-HVAC component was the total less the HVAC component.

The ratio of the utility non-HVAC component and the sum of EDA estimated non-HVAC end uses for an entire installation was defined as whole-installation non-HVAC electricity use saturation. The 'Utility Estimated' non-HVAC end-use electricity consumption was calculated by scaling the 'EDA Estimated' non-HVAC electricity use by end use of the entire installation by the whole-installation non-HVAC saturation as in equation [5].

$$\text{Utility\_EU}_{\text{annual,nhvac,i,all\_bldgs,k}} = \text{EDA\_EU}_{\text{annual,nhvac,i,all\_bldgs,k}} \times \text{Non\_HVAC\_Saturation}_{i} \qquad [5]$$

Figure 4-1. Two approaches to estimating electricity use at U.S. Army installations; (1) EDA Estimated and (2) Utility Estimated.

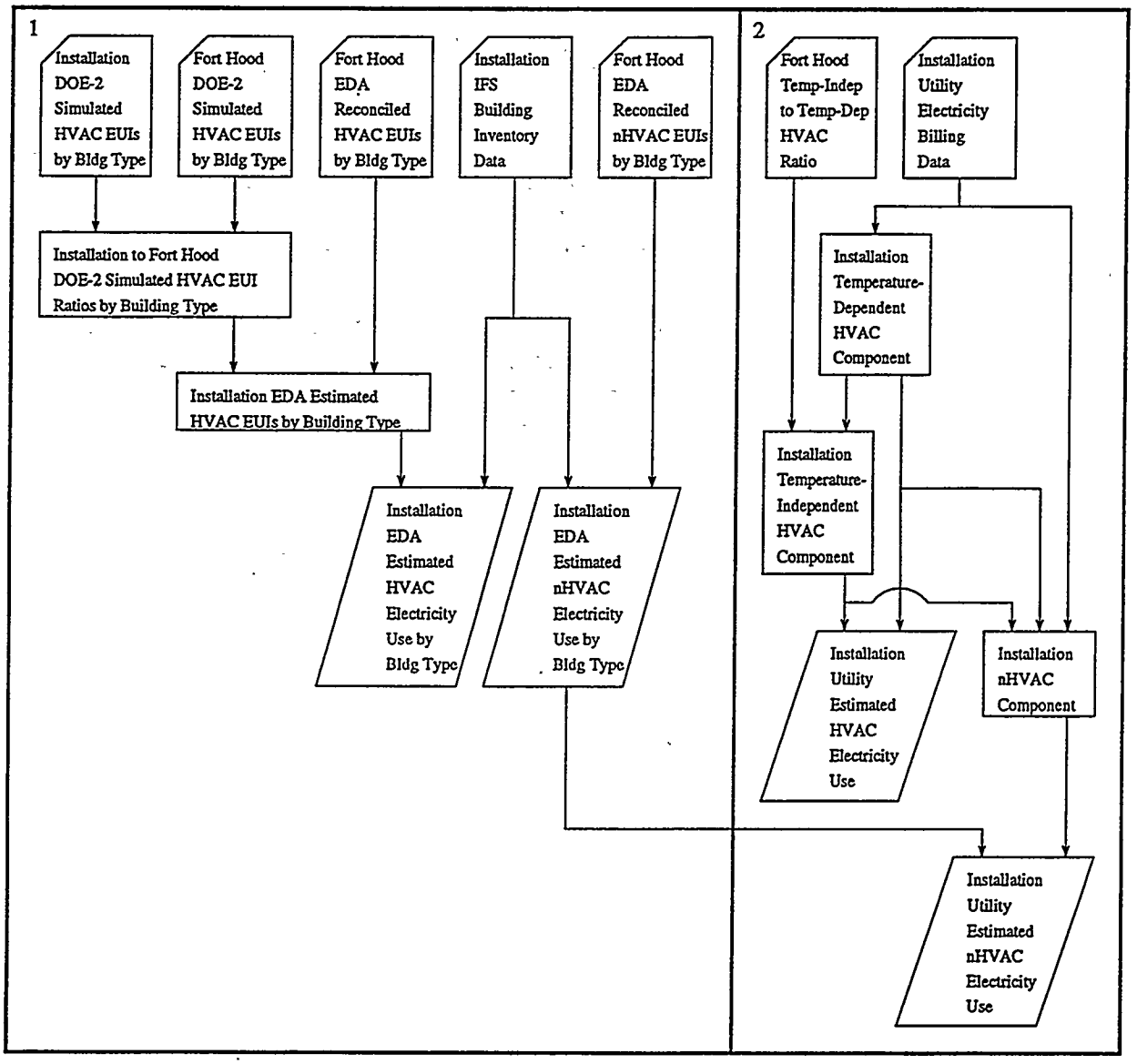
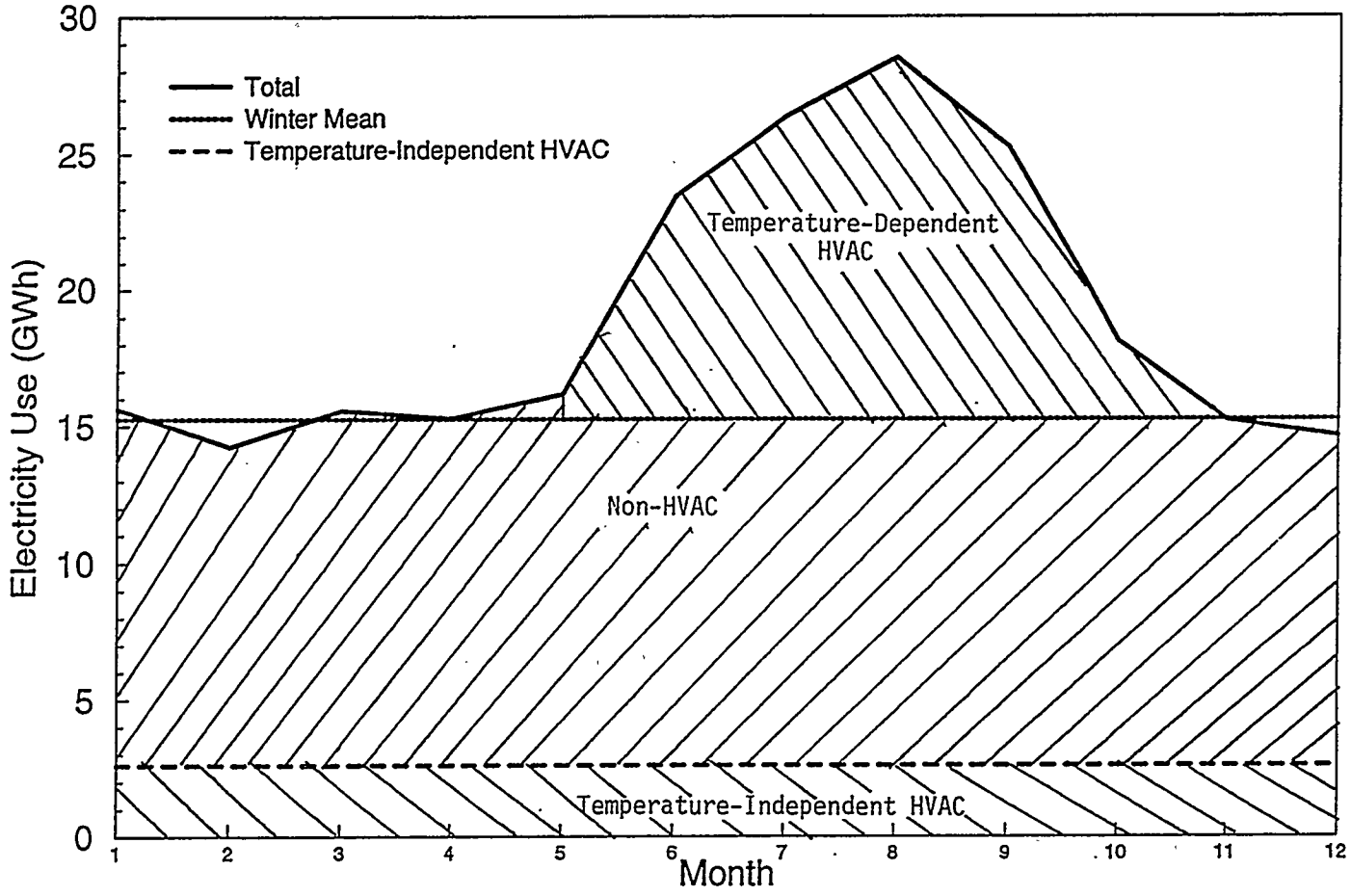


Figure 4-2. Monthly electrical utility billing data for Fort Benning depicting temperature-dependent HVAC, temperature-independent HVAC, and non-HVAC annual components.



5. Results

Annual DOE-2 Simulated and EDA Estimated HVAC EUIs

Annual HVAC end-use EUIs from DOE-2 simulations and EDA estimates are shown in **Tables 5-1** through **5-12.** The electric cooling and ventilation end uses are presented for simulations and EDA estimates. The gas heating end use was simulated only, since measured gas use data were not available. The EDA estimates were those derived from equation [2] in section 4.

Annual EDA Estimated Electricity Use

Annual HVAC and Non-HVAC end-use electricity consumption estimates are shown in **Tables 5-13** through **5-24.** These estimates were obtained by scaling the EDA estimated end-use EUIs by the floor area of each building type, per equation [4] in section 4.

Comparison of Utility Billing Data and EDA Estimates

A comparison of utility billing data divided into HVAC and non-HVAC components with EDA estimated electricity usage divided into HVAC and Non-HVAC end uses is shown in **Table 5-25.** Additionally, the relative error of the total utility data versus the total EDA estimated electricity use is displayed as is the whole-installation non-HVAC electricity use saturation. The non-HVAC estimates included street lighting and transmission losses, which each accounted for 5% of the annual utility billing data (Akbari and Konopacki, 1995). The comparison is also displayed in **Figure 5-1**, where the first column in each pair are utility billing data components and the second column are EDA estimates.

An air-conditioning saturation of 100% was assumed in all building types for all locations along with location-dependent HVAC schedules. Typically, residences and hospitals are the only buildings with 100% saturation, some administration type buildings have ventilation only, and many warehouse and vehicle maintenance buildings do not have air-conditioning. It is reasonable to assume that air-conditioning saturation was less than 100%, but there were no data to estimate this quantity. A comparison of Utility and EDA HVAC estimates revealed that the EDA estimated HVAC end use was always greater than the utility billing HVAC component, except for Yuma Pg, which was the location of highest cooling-degree-days. This indicated that air-conditioning saturation was less than 100% for these installations. The HVAC electricity use estimated by EDA was within 1% of the utility billing HVAC component for Fort Sam Houston, which is located in San Antonio due south a couple hundred miles from Fort Hood, within 15% for Fort Benning, within 36% for 4 others, and within 84% for 4 others.

The EDA estimated non-HVAC end use was less (except for Fort Dix and Fort Sill) than the utility billing non-HVAC component because of the non-representation of industrial process end uses within the EDA estimates, and/or the Fort Hood non-HVAC EUIs were not applicable. The industrial process end uses may account for a substantial portion of electricity consumption, however there were no data available to estimate these. The non-HVAC electricity use estimated by EDA was within 5% of the utility billing non-HVAC component for three installations, Fort Dix, Fort Benning, and Fort Polk, within 18% for 5 others, and within 48% for the rest.

There were 6 installations where the 1993 electricity consumption was estimated to within 11%, Fort Benning, Fort Polk, Fort Benjamin Harrison, Fort Leonard Wood, Fort Irwin and Fort Sam Houston. There were 4 installations where the 1993 electricity consumption was estimated to within 25%, Fort Belvoir, Fort Bragg, Fort Sill, and Fort Bliss. There was 1 installation where the 1993 electricity consumption was estimated to within 34%, Fort Dix.

Table 5-1. Annual DOE-2 Simulated and EDA Estimated HVAC EUIs at Fort Dix

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	1.79	1.15	14.67	1.95	2.05
Dining Hall	2.70	0.96	28.70	2.54	2.09
Gymnasium	0.67	0.93	62.17	0.98	1.21
Administration Large	2.34	3.67	0.80	1.55	3.08
Administration Small Old	2.84	3.43	53.75	2.47	4.50
Administration Small New	2.12	2.49	34.26	2.46	2.61
Vehicle Maintenance	0.20	0.34	83.54	0.21	0.84
Hospital	5.64	2.77	27.42	4.33	1.68
Residential	2.55	0.23	30.51	2.22	0.21
Warehouse	0.36	0.39	35.01	0.60	0.46
Miscellaneous	1.83	1.36	19.77	1.89	0.96

Table 5-2. Annual DOE-2 Simulated and EDA Estimated HVAC EUIs at Fort Belvoir

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	2.06	1.19	11.79	2.25	2.12
Dining Hall	2.92	0.88	21.94	2.74	1.92
Gymnasium	0.73	0.88	54.55	1.07	1.15
Administration Large	2.62	3.76	0.62	1.74	3.15
Administration Small Old	3.19	3.40	48.77	2.78	4.46
Administration Small New	2.39	2.53	31.01	2.78	2.66
Vehicle Maintenance	0.22	0.27	68.22	0.23	0.67
Hospital	6.34	2.79	23.63	4.87	1.70
Residential	2.61	0.24	24.72	2.28	0.22
Warehouse	0.38	0.39	29.08	0.63	0.46
Miscellaneous	2.10	1.44	17.18	2.17	1.02

Table 5-3. Annual DOE-2 Simulated and EDA Estimated HVAC EUIs at Fort Bragg

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	2.59	1.14	7.38	2.83	2.03
Dining Hall	3.89	0.88	14.02	3.65	1.92
Gymnasium	1.02	0.83	41.26	1.49	1.08
Administration Large	2.96	3.66	0.39	1.97	3.07
Administration Small Old	4.37	3.23	32.88	3.81	4.24
Administration Small New	3.25	2.38	21.17	3.78	2.50
Vehicle Maintenance	0.30	0.24	44.55	0.31	0.59
Hospital	6.88	2.78	18.21	5.28	1.69
Residential	3.82	0.31	17.06	3.33	0.28
Warehouse	0.50	0.37	20.07	0.83	0.43
Miscellaneous	2.89	1.31	11.38	2.98	0.92

Table 5-4. Annual DOE-2 Simulated and EDA Estimated HVAC EUIs at Fort Benning

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	3.05	1.14	6.43	3.33	2.03
Dining Hall	4.79	0.88	12.58	4.50	1.92
Gymnasium	1.07	0.83	36.78	1.56	1.08
Administration Large	3.14	3.76	0.31	2.09	3.15
Administration Small Old	4.59	3.27	29.32	4.00	4.29
Administration Small New	3.41	2.41	18.82	3.96	2.53
Vehicle Maintenance	0.32	0.24	41.73	0.33	0.59
Hospital	7.24	2.79	15.57	5.56	1.70
Residential	3.93	0.33	14.85	3.43	0.30
Warehouse	0.51	0.37	18.14	0.85	0.43
Miscellaneous	3.04	1.35	9.60	3.13	0.95

Table 5-5. Annual DOE-2 Simulated and EDA Estimated HVAC EUIs at Fort Polk

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	3.83	1.22	1.79	4.18	2.18
Dining Hall	5.85	0.88	4.62	5.50	1.92
Gymnasium	1.35	0.64	15.17	1.97	0.83
Administration Large	5.11	4.04	0.22	3.39	3.39
Administration Small Old	5.89	3.41	8.82	5.13	4.47
Administration Small New	4.44	2.60	5.45	5.16	2.73
Vehicle Maintenance	0.41	0.23	16.14	0.43	0.57
Hospital	9.42	2.82	9.64	7.23	1.71
Residential	4.92	0.38	7.50	4.29	0.35
Warehouse	0.62	0.24	6.23	1.03	0.28
Miscellaneous	4.09	1.39	2.44	4.22	0.98

Table 5-6. Annual DOE-2 Simulated and EDA Estimated HVAC EUIs at Fort Benjamin Harrison

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	1.91	1.11	19.92	2.08	1.98
Dining Hall	2.94	0.88	36.07	2.76	1.92
Gymnasium	0.90	1.13	75.09	1.31	1.47
Administration Large	2.34	3.54	1.36	1.55	2.97
Administration Small Old	3.65	3.50	73.62	3.18	4.59
Administration Small New	2.68	2.50	47.04	3.11	2.62
Vehicle Maintenance	0.25	0.35	98.52	0.26	0.87
Hospital	5.51	2.78	31.76	4.23	1.69
Residential	3.09	0.31	38.52	2.69	0.28
Warehouse	0.45	0.48	42.31	0.75	0.56
Miscellaneous	2.33	1.65	29.73	2.40	1.16

Table 5-7. Annual DOE-2 Simulated and EDA Estimated HVAC EUIs at Fort Leonard Wood

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	2.50	1.15	14.88	2.73	2.05
Dining Hall	4.16	0.88	27.84	3.91	1.92
Gymnasium	1.00	1.01	61.68	1.46	1.32
Administration Large	2.61	3.73	1.08	1.73	3.13
Administration Small Old	4.22	3.49	56.65	3.68	4.58
Administration Small New	3.08	2.54	36.16	3.58	2.67
Vehicle Maintenance	0.29	0.33	77.88	0.30	0.82
Hospital	6.44	2.81	26.68	4.94	1.71
Residential	3.63	0.33	29.39	3.17	0.30
Warehouse	0.49	0.46	32.68	0.81	0.54
Miscellaneous	2.71	1.50	21.27	2.79	1.06

Table 5-8. Annual DOE-2 Simulated and EDA Estimated HVAC EUIs at Fort Irwin

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	3.14	1.46	2.25	3.43	2.61
Dining Hall	5.93	1.23	5.23	5.57	2.68
Gymnasium	1.42	0.74	25.32	2.07	0.97
Administration Large	3.59	4.53	0.15	2.38	3.80
Administration Small Old	6.41	4.10	13.99	5.58	5.38
Administration Small New	4.67	2.97	9.67	5.43	3.12
Vehicle Maintenance	0.46	0.30	11.62	0.48	0.74
Hospital	8.02	2.99	9.27	6.16	1.82
Residential	7.14	0.43	7.62	6.23	0.39
Warehouse	0.71	0.32	8.54	1.18	0.38
Miscellaneous	4.13	1.49	4.00	4.26	1.05

Table 5-9. Annual DOE-2 Simulated and EDA Estimated HVAC EUIs at Fort Sill

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	2.75	1.24	8.67	3.00	2.21
Dining Hall	4.48	0.96	17.92	4.21	2.09
Gymnasium	1.29	0.86	46.73	1.88	1.12
Administration Large	3.40	3.89	0.51	2.26	3.26
Administration Small Old	5.45	3.51	36.43	4.75	4.60
Administration Small New	3.99	2.57	23.75	4.64	2.70
Vehicle Maintenance	0.39	0.33	67.25	0.41	0.82
Hospital	7.31	2.83	19.40	5.61	1.72
Residential	4.76	0.41	19.56	4.15	0.37
Warehouse	0.61	0.38	25.48	1.01	0.45
Miscellaneous	3.53	1.35	12.61	3.64	0.95

Table 5-10. Annual DOE-2 Simulated and EDA Estimated HVAC EUIs at Yuma Pg

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	3.50	1.55	0.88	3.82	2.77
Dining Hall	6.75	1.23	4.35	6.34	2.68
Gymnasium	1.86	0.70	11.57	2.71	0.91
Administration Large	4.05	4.74	0.03	2.69	3.98
Administration Small Old	7.94	4.29	4.46	6.92	5.63
Administration Small New	5.81	3.09	3.26	6.75	3.24
Vehicle Maintenance	0.59	0.32	7.96	0.62	0.79
Hospital	9.72	3.00	7.72	7.46	1.82
Residential	8.03	0.52	5.26	7.00	0.47
Warehouse	0.87	0.29	3.72	1.44	0.34
Miscellaneous	5.20	1.62	0.87	5.36	1.14

Table 5-11. Annual DOE-2 Simulated and EDA Estimated HVAC EUIs at Fort Bliss

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	2.61	1.34	2.95	2.85	2.39
Dining Hall	4.41	0.96	7.67	4.14	2.09
Gymnasium	0.93	0.73	27.99	1.36	0.95
Administration Large	2.99	4.43	0.14	1.99	3.72
Administration Small Old	4.32	3.82	14.35	3.76	5.01
Administration Small New	3.19	2.82	10.14	3.71	2.96
Vehicle Maintenance	0.30	0.30	25.82	0.31	0.74
Hospital	7.55	2.91	8.31	5.79	1.77
Residential	4.37	0.29	8.47	3.81	0.26
Warehouse	0.49	0.32	11.82	0.81	0.38
Miscellaneous	2.81	1.56	5.39	2.90	1.10

Table 5-12. Annual DOE-2 Simulated and EDA Estimated HVAC EUIs at Fort Sam Houston

Building	DOE-2			EDA	
	Cooling kWh/ft^2	Ventilation kWh/ft^2	Heating kBtu/ft^2	Cooling kWh/ft^2	Ventilation kWh/ft^2
Barrack	3.45	1.26	1.86	3.76	2.25
Dining Hall	5.68	0.96	5.07	5.34	2.09
Gymnasium	1.55	0.70	17.60	2.26	0.91
Administration Large	4.09	4.10	0.09	2.72	3.44
Administration Small Old	6.65	3.47	10.53	5.79	4.55
Administration Small New	4.94	2.61	6.47	5.74	2.74
Vehicle Maintenance	0.47	0.24	16.48	0.49	0.59
Hospital	9.11	2.86	9.12	6.99	1.74
Residential	5.87	0.45	7.68	5.12	0.41
Warehouse	0.69	0.31	6.60	1.14	0.36
Miscellaneous	4.53	1.35	2.45	4.67	0.95

Table 5-13. Annual EDA Estimated Electricity Use at Fort Dix [GWh/yr]

Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	3.82	4.02	0.59	3.04	4.02	0.31	3.41	-	19.21
Dining Hall	0.46	0.38	1.07	-	0.83	0.02	0.67	-	3.43
Gymnasium	0.04	0.05	-	0.02	-	0.01	0.22	0.00	0.33
Administration Large	0.50	0.99	-	2.90	-	0.04	1.56	-	5.98
Administration Small Old	2.04	3.71	-	1.15	-	0.10	3.88	-	10.88
Administration Small New	0.29	0.31	-	0.18	-	0.02	0.62	-	1.42
Vehicle Maintenance	0.06	0.25	-	0.13	-	0.07	0.66	0.01	1.19
Hospital	1.85	0.72	0.29	5.04	0.26	0.14	4.02	-	12.32
Residential	4.18	0.40	0.40	6.61	1.49	0.66	1.37	-	15.10
Warehouse	0.36	0.28	-	0.36	-	0.19	1.33	-	2.52
Miscellaneous	0.81	0.41	0.03	0.82	0.09	0.12	2.58	-	4.87
Total	14.41	11.51	2.38	20.25	6.69	1.68	20.32	0.01	77.25

Table 5-14. Annual EDA Estimated Electricity Use at Fort Belvoir [GWh/yr]

Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	1.42	1.33	0.19	0.98	1.29	0.10	1.10	-	6.41
Dining Hall	0.33	0.23	0.71	-	0.55	0.02	0.44	-	2.28
Gymnasium	0.07	0.08	-	0.04	-	0.01	0.40	0.01	0.61
Administration Large	2.76	4.99	-	14.33	-	0.19	7.71	-	29.97
Administration Small Old	3.22	5.16	-	1.62	-	0.14	5.44	-	15.58
Administration Small New	0.23	0.22	-	0.13	-	0.01	0.43	-	1.02
Vehicle Maintenance	0.24	0.70	-	0.45	-	0.25	2.32	0.04	4.00
Hospital	1.27	0.44	0.18	3.07	0.16	0.09	2.45	-	7.66
Residential	6.95	0.67	0.64	10.70	2.41	1.07	2.22	-	24.66
Warehouse	0.57	0.42	-	0.54	-	0.29	2.00	-	3.82
Miscellaneous	1.13	0.53	0.03	0.99	0.11	0.15	3.11	-	6.05
Total	18.18	14.78	1.75	32.85	4.52	2.32	27.62	0.05	102.06

Table 5-15. Annual EDA Estimated Electricity Use at Fort Bragg [GWh/yr]

Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	13.31	9.55	1.41	7.29	9.64	0.75	8.18	-	50.13
Dining Hall	1.78	0.94	2.90	-	2.24	0.06	1.80	-	9.72
Gymnasium	0.32	0.24	-	0.13	-	0.04	1.27	0.02	2.02
Administration Large	2.69	4.19	-	12.34	-	0.16	6.64	-	26.01
Administration Small Old	13.37	14.88	-	4.91	-	0.42	16.50	-	50.08
Administration Small New	4.60	3.04	-	1.87	-	0.17	6.35	-	16.03
Vehicle Maintenance	0.81	1.54	-	1.12	-	0.63	5.78	0.10	9.98
Hospital	2.18	0.70	0.28	4.88	0.25	0.14	3.88	-	12.31
Residential	24.60	2.07	1.55	25.93	5.84	2.59	5.39	-	67.97
Warehouse	1.54	0.80	-	1.09	-	0.59	4.08	-	8.10
Miscellaneous	2.81	0.87	0.06	1.80	0.21	0.27	5.65	-	11.67
Total	68.01	38.80	6.20	61.36	18.18	5.82	65.52	0.12	264.01

Table 5-16. Annual EDA Estimated Electricity Use at Fort Benning [GWh/yr]

Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	16.52	10.07	1.49	7.69	10.17	0.79	8.63	-	55.36
Dining Hall	2.08	0.89	2.75	-	2.13	0.06	1.71	-	9.62
Gymnasium	0.09	0.07	-	0.04	-	0.01	0.35	0.01	0.57
Administration Large	2.95	4.44	-	12.76	-	0.17	6.86	-	27.18
Administration Small Old	7.51	8.05	-	2.63	-	0.23	8.82	-	27.24
Administration Small New	1.57	1.00	-	0.61	-	0.06	2.07	-	5.32
Vehicle Maintenance	0.40	0.72	-	0.53	-	0.29	2.71	0.05	4.71
Hospital	2.19	0.67	0.27	4.64	0.24	0.13	3.69	-	11.82
Residential	20.71	1.81	1.27	21.20	4.77	2.11	4.41	-	56.28
Warehouse	0.82	0.42	-	0.57	-	0.31	2.13	-	4.25
Miscellaneous	2.49	0.76	0.05	1.52	0.18	0.23	4.77	-	10.00
Total	57.33	28.89	5.83	52.19	17.49	4.39	46.15	0.06	212.34

Table 5-17. Annual EDA Estimated Electricity Use at Fort Polk [GWh/yr]

Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	10.09	5.26	0.72	3.74	4.95	0.39	4.20	-	29.35
Dining Hall	1.25	0.43	1.35	-	1.04	0.03	0.84	-	4.94
Gymnasium	0.10	0.04	-	0.03	-	0.01	0.29	0.00	0.47
Administration Large	0.24	0.24	-	0.64	-	0.01	0.34	-	1.47
Administration Small Old	5.87	5.11	-	1.60	-	0.14	5.38	-	18.10
Administration Small New	5.05	2.67	-	1.51	-	0.14	5.11	-	14.48
Vehicle Maintenance	0.54	0.72	-	0.54	-	0.30	2.79	0.05	4.94
Hospital	2.65	0.63	0.25	4.34	0.22	0.12	3.45	-	11.66
Residential	36.50	2.98	1.79	29.86	6.72	2.98	6.21	-	87.04
Warehouse	0.97	0.26	-	0.55	-	0.30	2.06	-	4.14
Miscellaneous	2.47	0.57	0.04	1.12	0.13	0.17	3.50	-	8.00
Total	65.72	18.92	4.15	43.93	13.06	4.59	34.17	0.05	184.59

Table 5-18. Annual EDA Estimated Electricity Use at Fort Benjamin Harrison [GWh/yr]

Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	1.83	1.74	0.26	1.37	1.81	0.14	1.53	-	8.69
Dining Hall	0.15	0.10	0.32	-	0.25	0.01	0.20	-	1.03
Gymnasium	0.06	0.07	-	0.03	-	0.01	0.29	0.00	0.47
Administration Large	2.92	5.59	-	17.03	-	0.23	9.17	-	34.94
Administration Small Old	0.98	1.41	-	0.43	-	0.04	1.45	-	4.31
Administration Small New	0.09	0.08	-	0.05	-	0.00	0.15	-	0.37
Vehicle Maintenance	0.02	0.07	-	0.03	-	0.02	0.17	0.00	0.31
Hospital	0.44	0.18	0.07	1.24	0.06	0.03	0.99	-	3.01
Residential	1.59	0.17	0.12	2.08	0.47	0.21	0.43	-	5.07
Warehouse	0.22	0.17	-	0.18	-	0.10	0.66	-	1.33
Miscellaneous	0.66	0.32	0.02	0.53	0.06	0.08	1.66	-	3.34
Total	8.98	9.90	0.79	22.97	2.65	0.87	16.70	0.00	62.86

Table 5-19. Annual EDA Estimated Electricity Use at Fort Leonard Wood [GWh/yr]

Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	6.57	4.93	0.72	3.73	4.93	0.38	4.18	-	25.44
Dining Hall	1.33	0.65	2.01	-	1.56	0.04	1.25	-	6.84
Gymnasium	0.15	0.13	-	0.06	-	0.02	0.59	0.01	0.96
Administration Large	0.94	1.70	-	4.93	-	0.07	2.65	-	10.30
Administration Small Old	4.18	5.20	-	1.59	-	0.14	5.34	-	16.45
Administration Small New	1.62	1.21	-	0.70	-	0.06	2.36	-	5.95
Vehicle Maintenance	0.17	0.45	-	0.24	-	0.13	1.22	0.02	2.23
Hospital	2.00	0.69	0.27	4.77	0.25	0.13	3.80	-	11.91
Residential	11.27	1.07	0.75	12.48	2.81	1.24	2.60	-	32.22
Warehouse	0.49	0.33	-	0.36	-	0.19	1.33	-	2.69
Miscellaneous	1.90	0.72	0.04	1.30	0.15	0.20	4.07	-	8.38
Total	30.60	17.09	3.79	30.16	9.70	2.60	29.39	0.03	123.35

Table 5-20. Annual EDA Estimated Electricity Use at Fort Irwin [GWh/yr]

Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	2.51	1.91	0.22	1.13	1.50	0.12	1.27	-	8.66
Dining Hall	0.53	0.26	0.57	-	0.44	0.01	0.35	-	2.16
Gymnasium	0.05	0.02	-	0.01	-	0.00	0.14	0.00	0.22
Administration Large	-	-	-	-	-	-	-	-	-
Administration Small Old	1.37	1.32	-	0.34	-	0.03	1.15	-	4.21
Administration Small New	3.30	1.89	-	0.93	-	0.08	3.17	-	9.37
Vehicle Maintenance	0.24	0.37	-	0.22	-	0.12	1.11	0.02	2.08
Hospital	0.39	0.12	0.04	0.75	0.04	0.02	0.60	-	1.96
Residential	19.83	1.24	0.67	11.17	2.51	1.11	2.32	-	38.85
Warehouse	0.49	0.16	-	0.24	-	0.13	0.91	-	1.92
Miscellaneous	1.22	0.30	0.02	0.55	0.06	0.08	1.71	-	3.94
Total	29.93	7.59	1.52	15.34	4.55	1.70	12.73	0.02	73.38

Table 5-21. Annual EDA Estimated Electricity Use at Fort Sill [GWh/yr]

Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	9.83	7.24	0.98	5.08	6.72	0.52	5.70	-	36.07
Dining Hall	1.63	0.81	2.30	-	1.78	0.05	1.43	-	8.00
Gymnasium	0.12	0.07	-	0.04	-	0.01	0.37	0.01	0.62
Administration Large	3.47	5.00	-	13.89	-	0.18	7.48	-	30.02
Administration Small Old	10.07	9.75	-	2.97	-	0.25	9.96	-	33.00
Administration Small New	2.73	1.59	-	0.91	-	0.08	3.07	-	8.38
Vehicle Maintenance	0.44	0.88	-	0.46	-	0.26	2.37	0.04	4.45
Hospital	2.80	0.86	0.34	5.88	0.30	0.16	4.68	-	15.01
Residential	9.78	0.87	0.49	8.27	1.86	0.82	1.72	-	23.81
Warehouse	1.11	0.50	-	0.65	-	0.35	2.43	-	5.04
Miscellaneous	2.83	0.74	0.05	1.49	0.17	0.23	4.66	-	10.17
Total	44.80	28.31	4.16	39.64	10.83	2.91	43.87	0.05	174.56

Table 5-22. Annual EDA Estimated Electricity Use at Yuma Pg [GWh/yr]

Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	0.45	0.33	0.04	0.18	0.24	0.02	0.21	-	1.47
Dining Hall	0.08	0.03	0.08	-	0.06	0.00	0.05	-	0.31
Gymnasium	0.03	0.01	-	0.01	-	0.00	0.07	0.00	0.12
Administration Large	-	-	-	-	-	-	-	-	-
Administration Small Old	1.41	1.15	-	0.29	-	0.02	0.96	-	3.83
Administration Small New	0.34	0.16	-	0.08	-	0.01	0.26	-	0.85
Vehicle Maintenance	0.06	0.08	-	0.04	-	0.02	0.21	0.00	0.41
Hospital	-	-	-	-	-	-	-	-	-
Residential	3.05	0.20	0.09	1.53	0.34	0.15	0.32	-	5.68
Warehouse	0.24	0.06	-	0.10	-	0.05	0.36	-	0.80
Miscellaneous	0.68	0.14	0.01	0.24	0.03	0.04	0.76	-	1.90
Total	6.34	2.16	0.22	2.47	0.67	0.31	3.20	0.00	15.37

Table 5-23. Annual EDA Estimated Electricity Use at Fort Bliss [GWh/yr]

Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	8.14	6.83	0.86	4.43	5.86	0.46	4.97	-	31.55
Dining Hall	1.12	0.57	1.61	-	1.25	0.04	1.00	-	5.59
Gymnasium	0.21	0.15	-	0.09	-	0.03	0.90	0.01	1.39
Administration Large	2.01	3.76	-	9.14	-	0.12	4.92	-	19.95
Administration Small Old	9.97	13.28	-	3.71	-	0.32	12.46	-	39.74
Administration Small New	0.99	0.79	-	0.41	-	0.04	1.39	-	3.62
Vehicle Maintenance	0.38	0.91	-	0.53	-	0.30	2.72	0.05	4.89
Hospital	3.91	1.19	0.46	7.97	0.41	0.22	6.34	-	20.50
Residential	16.61	1.13	0.92	15.30	3.44	1.53	3.18	-	42.11
Warehouse	0.83	0.39	-	0.61	-	0.33	2.26	-	4.42
Miscellaneous	2.48	0.94	0.05	1.63	0.19	0.25	5.12	-	10.66
Total	46.65	29.94	3.90	43.82	11.15	3.64	45.26	0.06	184.41

Table 5-24. Annual EDA Estimated Electricity Use at Fort Sam Houston [GWh/yr]

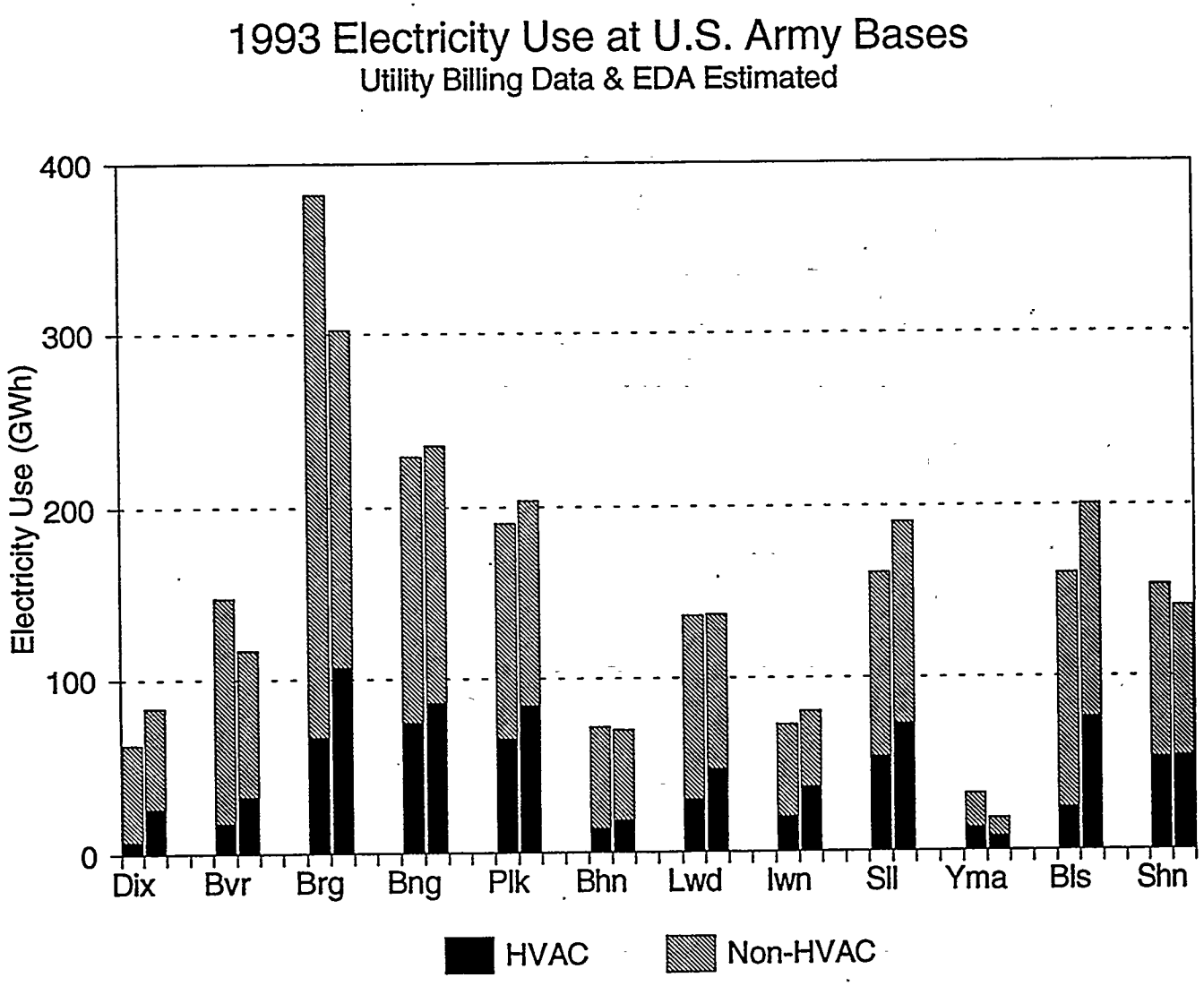
Building	Cool	Vent	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	Total
Barrack	6.49	3.88	0.52	2.68	3.54	0.28	3.00	-	20.40
Dining Hall	1.01	0.39	1.12	-	0.87	0.02	0.70	-	4.11
Gymnasium	0.21	0.08	-	0.06	-	0.02	0.54	0.01	0.92
Administration Large	2.99	3.79	-	9.96	-	0.13	5.36	-	22.23
Administration Small Old	7.40	5.82	-	1.79	-	0.15	6.01	-	21.17
Administration Small New	0.75	0.36	-	0.20	-	0.02	0.69	-	2.02
Vehicle Maintenance	0.15	0.19	-	0.14	-	0.08	0.70	0.01	1.27
Hospital	4.45	1.11	0.43	7.52	0.39	0.21	5.98	-	20.09
Residential	8.94	0.72	0.37	6.13	1.38	0.61	1.27	-	19.41
Warehouse	1.23	0.39	-	0.64	-	0.35	2.38	-	4.99
Miscellaneous	3.00	0.61	0.04	1.23	0.14	0.19	3.85	-	9.07
Total	36.64	17.34	2.48	30.35	6.32	2.06	30.48	0.02	125.68

Table 5-25. 1993 Electricity Use at U.S. Army Installations from Utility Billing Data and EDA Estimates

Installation	Utility Billing Data (U)			EDA Estimate			(U - EDA) / U * 100			U / EDA †
	HVAC (GWh)	Non-HVAC (GWh)	Total (GWh)	HVAC (GWh)	Non-HVAC (GWh)	Total (GWh)	HVAC (%)	Non-HVAC (%)	Total (%)	Non-HVAC
Fort Dix	7.6	54.9	62.5	25.9	57.6	83.5	-240	-5	-34	0.95
Fort Belvoir	18.0	129.3	147.3	33.0	83.9	116.9	-83	35	21	1.59
Fort Bragg	66.4	315.0	381.4	106.8	195.3	302.1	-61	38	21	1.68
Fort Benning	74.7	153.9	228.6	86.2	149.0	235.2	-15	3	-3	1.04
Fort Polk	65.6	124.9	190.5	84.6	119.0	203.6	-29	5	-7	1.05
Fort Benjamin Harrison	14.2	57.8	72.0	18.9	51.2	70.1	-33	11	3	1.14
Fort Leonard Wood	30.4	105.9	136.3	47.7	89.3	137.0	-57	16	-1	1.20
Fort Irwin	20.4	52.4	72.8	37.5	43.1	80.6	-84	18	-11	1.24
Fort Sill	54.7	106.2	160.9	73.1	117.5	190.6	-34	-11	-18	0.90
Yuma Pg	13.3	19.6	32.9	8.5	10.2	18.7	36	48	43	2.10
Fort Bliss	24.9	135.3	160.2	76.6	123.9	200.5	-207	8	-25	1.10
Fort Sam Houston	53.5	99.6	153.1	54.0	87.0	141.0	-1	13	8	1.16

† Whole-installation non-HVAC electricity use saturation

Figure 5-1. 1993 Electricity Use at U.S. Army Installations by Utility Billing Data and EDA Estimates (first column are utility billing data estimates and second column are EDA estimates).



Utility Billing Data Estimated HVAC and Non-HVAC Electricity Use

The utility billing HVAC estimates shown in **Table 5-25** were the sum of temperature-dependent and temperature-independent HVAC components from utility billing data analyses. The utility billing non-HVAC estimates were derived by scaling the annual EDA estimated non-HVAC end uses on an installation level by the whole-installation non-HVAC electricity use saturation, as in equation [5] of section 4. This operation distributed the non-HVAC utility billing component proportionally to the EDA estimated non-HVAC end uses.

Electricity use estimates by end use have been summed for all building types for an entire installation and are presented in **Table 5-26** and **Figures 5-2** through **5-7**. Fort Hood estimates are included in the presentation. Electricity use for the process end use was negligible and was not included in the figures.

The average electricity use by end use for these 12 installations and Fort Hood are as follows. HVAC, miscellaneous, and indoor lighting end uses consumed the most electricity, with 28, 27, and 26 % of the total use, and 3.8, 3.5, and 3.3 kWh/ft^2, respectively. Refrigeration, street lighting, exterior lighting, and cooking end uses consumed 7, 7, 3, and 2 % of the total electricity use, and 0.9, 0.9, 0.4, and 0.3 kWh/ft^2, respectively.

Table 5-26. 1993 Electricity Consumption Estimates by End Use for 13 U.S. Army Installations

Installation	HVAC	Cook	Misc	Ref	Ex Lit	In Lit	Prcss	St Lit	Total
	GWh								
Fort Dix	7.6	2.3	19.2	6.4	1.6	19.3	0.0	3.0	59.3
Fort Belvoir	18.0	2.8	52.2	7.2	3.7	43.9	0.1	11.7	139.6
Fort Bragg	66.4	10.4	103.1	30.5	9.8	110.1	0.2	32.0	362.5
Fort Benning	74.7	6.1	54.3	18.2	4.6	48.0	0.1	11.9	217.8
Fort Polk	65.6	4.4	46.1	13.7	4.8	35.9	0.1	10.0	180.6
Fort Benjamin Harrison	14.2	0.9	26.2	3.0	1.0	19.0	0.0	4.1	68.4
Fort Leonard Wood	30.4	4.5	36.2	11.6	3.1	35.3	0.0	8.2	129.4
Fort Irwin	20.4	1.9	19.0	5.6	2.1	15.8	0.0	4.5	69.4
Fort Sill	54.7	3.7	35.7	9.8	2.6	39.5	0.1	7.2	153.3
Yuma Pg	13.3	0.5	5.2	1.4	0.7	6.7	0.0	3.5	31.2
Fort Bliss	24.9	4.3	48.2	12.3	4.0	49.8	0.1	8.8	152.3
Fort Sam Houston	53.5	2.9	35.2	7.3	2.4	35.4	0.0	8.9	145.6
Fort Hood	145.8	6.8	64.2	21.1	6.4	70.7	0.2	18.1	333.3
	kWh / ft^2								
Fort Dix	0.9	0.3	2.2	0.7	0.2	2.2	0.0	0.3	6.7
Fort Belvoir	1.9	0.3	5.5	0.8	0.4	4.6	0.0	1.2	14.7
Fort Bragg	2.6	0.4	4.0	1.2	0.4	4.3	0.0	1.3	14.2
Fort Benning	3.9	0.3	2.8	0.9	0.2	2.5	0.0	0.6	11.3
Fort Polk	3.9	0.3	2.8	0.8	0.3	2.1	0.0	0.6	10.8
Fort Benjamin Harrison	3.1	0.2	5.7	0.7	0.2	4.1	0.0	0.9	14.9
Fort Leonard Wood	2.7	0.4	3.2	1.0	0.3	3.1	0.0	0.7	11.5
Fort Irwin	3.3	0.3	3.1	0.9	0.3	2.5	0.0	0.7	11.2
Fort Sill	3.9	0.3	2.5	0.7	0.2	2.8	0.0	0.5	10.8
Yuma Pg	10.2	0.4	4.0	1.1	0.5	5.2	0.0	2.7	24.0
Fort Bliss	1.6	0.3	3.1	0.8	0.3	3.2	0.0	0.6	9.8
Fort Sam Houston	5.8	0.3	3.8	0.8	0.3	3.8	0.0	1.0	15.8
Fort Hood	5.7	0.3	2.5	0.8	0.3	2.8	0.0	0.7	13.1
	% of Total								
Fort Dix	13	4	32	11	3	33	0	4	100
Fort Belvoir	13	2	37	5	3	31	0	9	100
Fort Bragg	18	3	28	8	3	30	0	10	100
Fort Benning	34	3	25	8	2	22	0	6	100
Fort Polk	36	2	26	8	3	20	0	5	100
Fort Benjamin Harrison	21	1	38	4	1	28	0	7	100
Fort Leonard Wood	23	3	28	9	2	27	0	8	100
Fort Irwin	29	3	27	8	3	23	0	7	100
Fort Sill	36	2	23	6	2	26	0	5	100
Yuma Pg	43	2	17	4	2	21	0	11	100
Fort Bliss	16	3	32	8	3	33	0	5	100
Fort Sam Houston	37	2	24	5	2	24	0	6	100
Fort Hood	45	2	19	6	2	21	0	5	100

Figure 5-2. 1993 Electricity Consumption Estimates by End Use for 13 U.S. Army Installations (GWh).

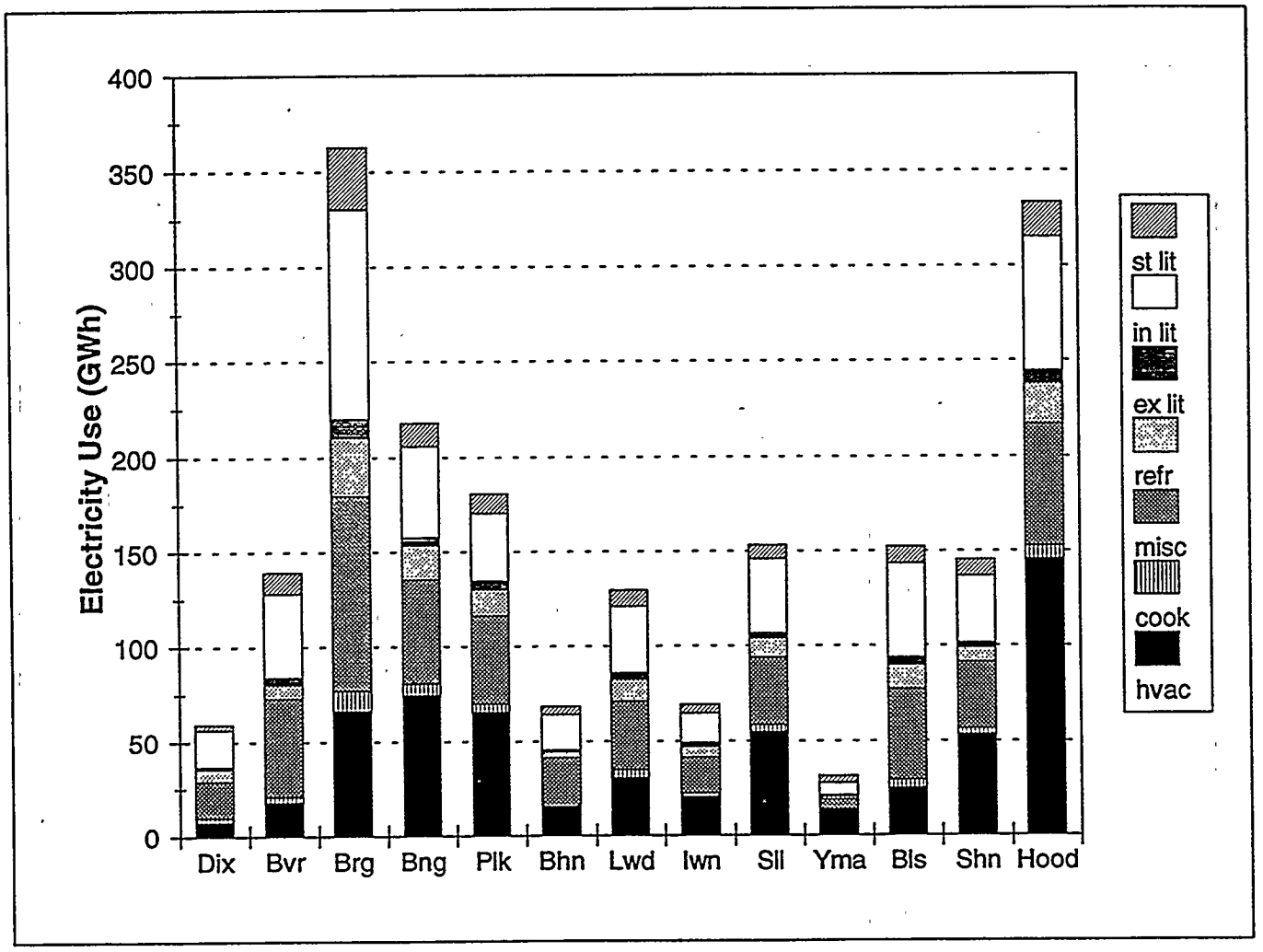


Figure 5-3. 1993 Electricity Consumption Estimates by End Use for 13 U.S. Army Installations (kWh/ft²).

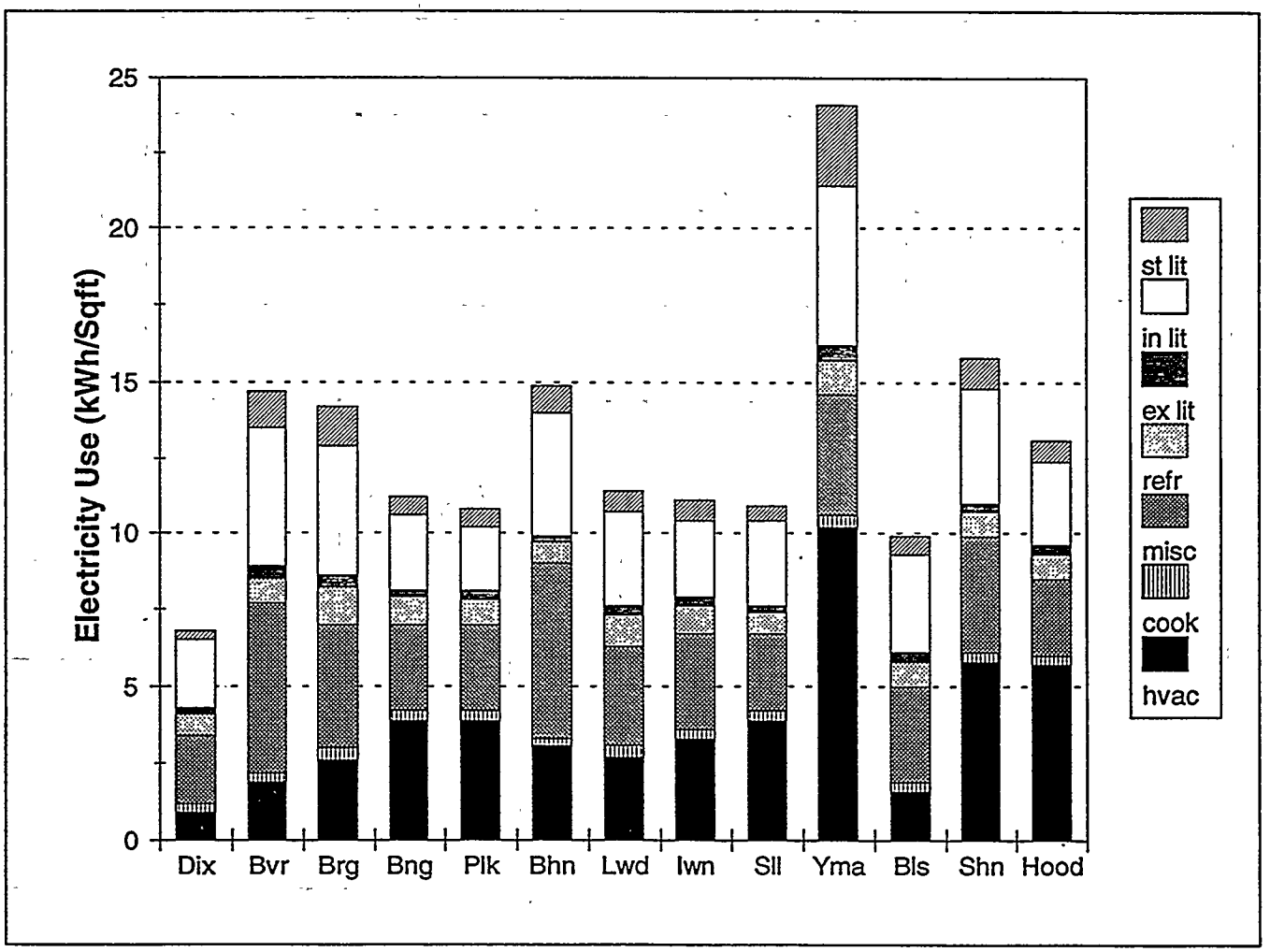


Figure 5-4. 1993 Electricity Consumption Estimates by End Use for 13 U.S. Army Installations (% of Total).

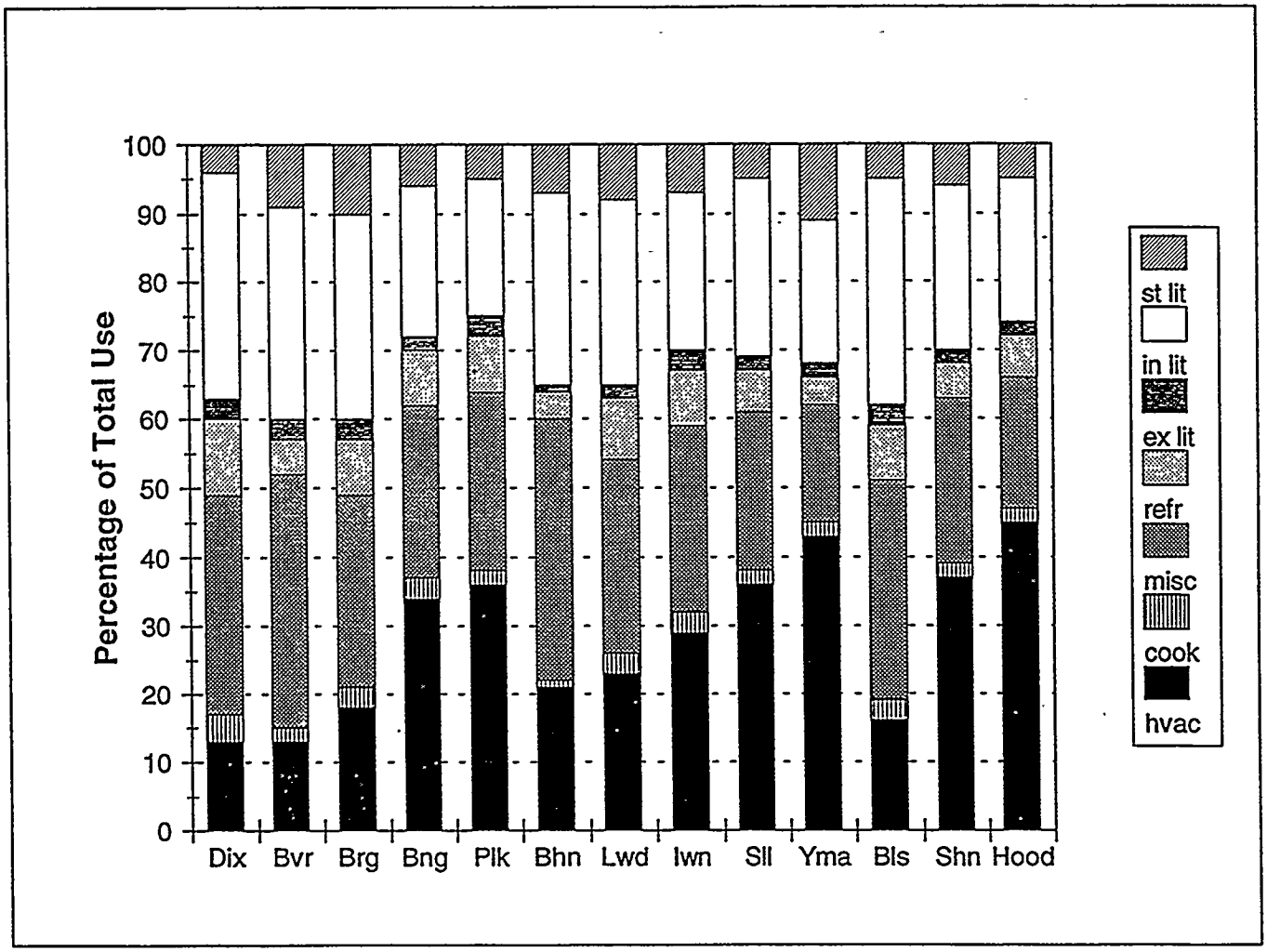


Figure 5-5. 1993 Electricity Consumption Estimates by End Use for 13 U.S. Army Installations, where minimum, maximum, 25% quartile, 75% quartile, mean, and median are shown (kWh/ft²).

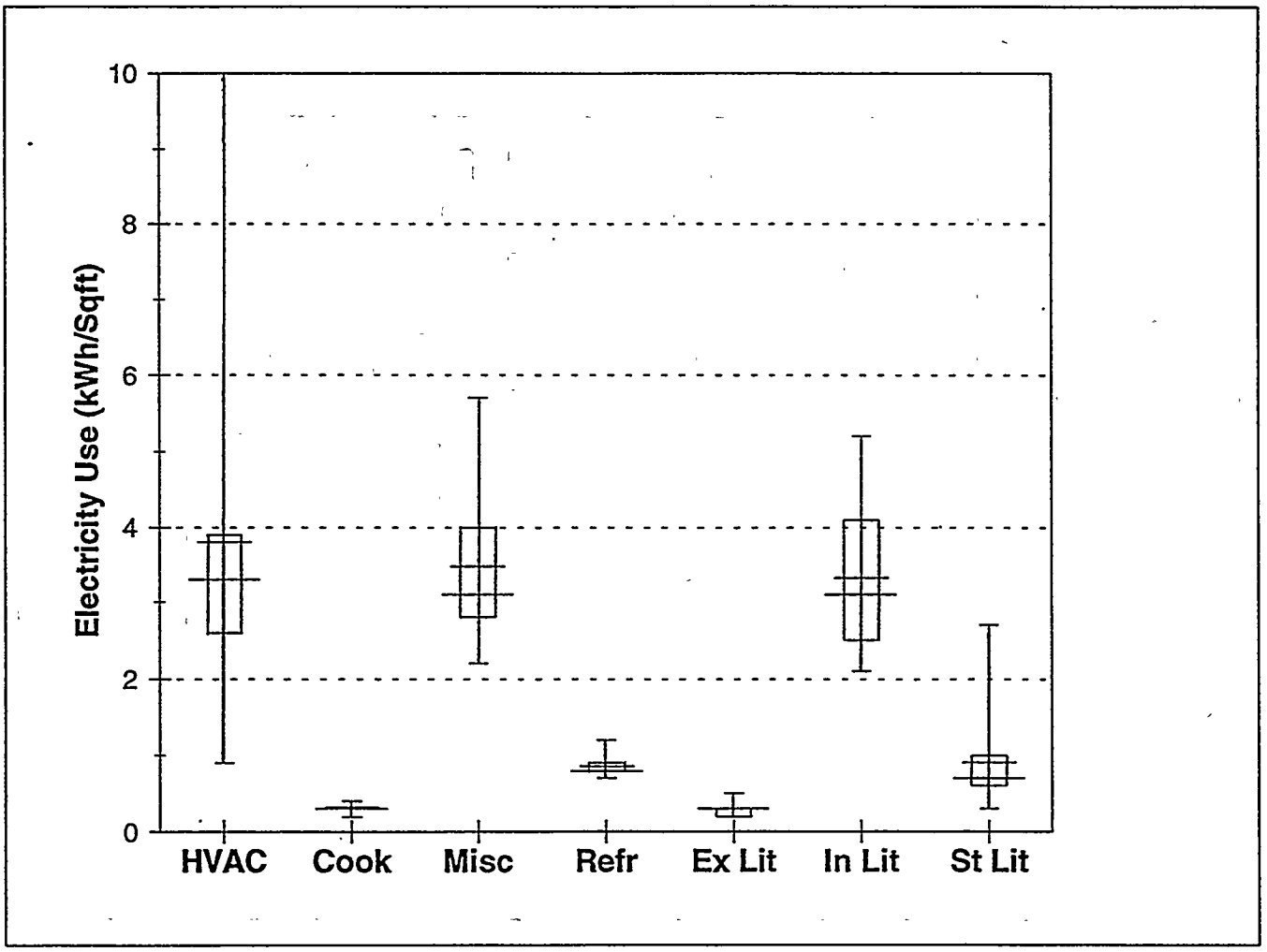


Figure 5-6. 1993 Electricity Consumption Estimates by End Use for 13 U.S. Army Installations, where minimum, maximum, 25% quartile, 75% quartile, mean, and median are shown (% of Total).

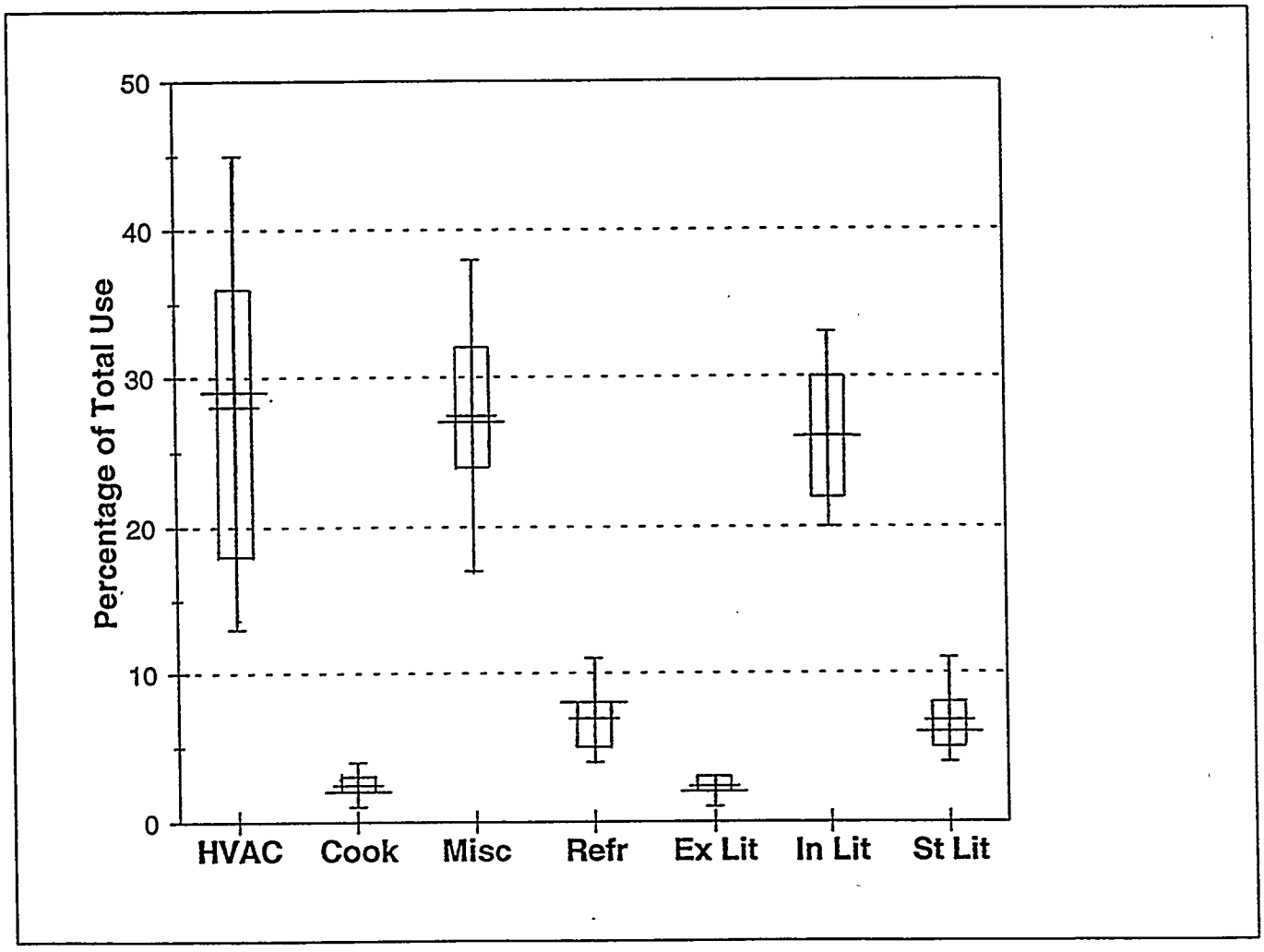
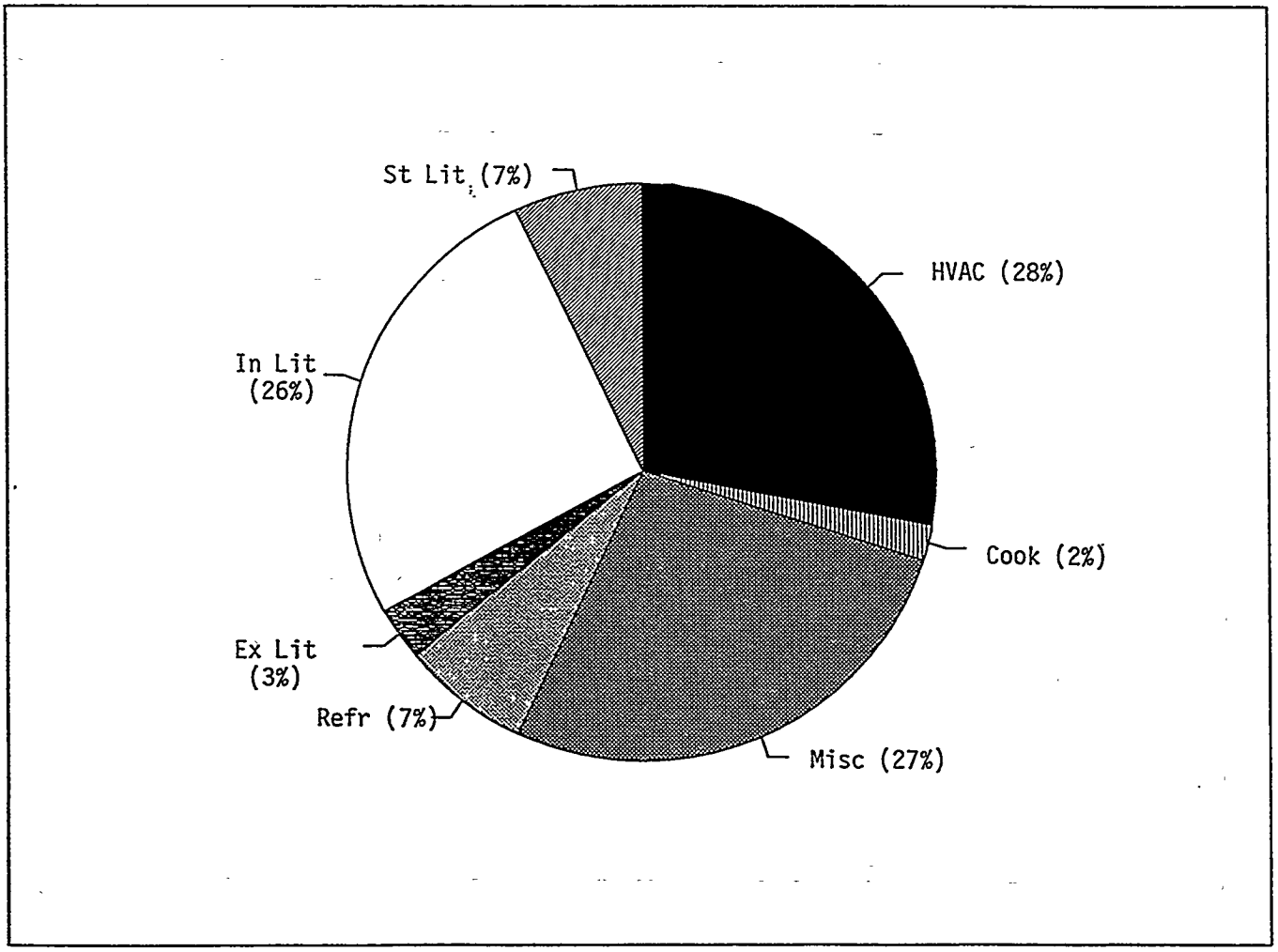


Figure 5-7. 1993 Electricity Consumption Estimates by End Use for Average of 13 U.S. Army Installations (% of Total).



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