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Steven Konopacki, Hashem Akbari,
Larry Lister, and Lee DeBaille
Energy and Environment Division

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Steven Konopacki and Hashem Akbari

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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Steven J. Konopacki

Hashem Akbari
Member ASHRAE

Larry D. Lister
Member ASHRAE

Lee P. DeBaillie
Associate Member ASHRAE

ABSTRACT

The U.S. Department of Defense (DOD) has been mandated to reduce energy consumption and costs by 20% from 1985 to 2000 and by 30% from 1985 to 2005. Reduction of electrical energy consumption at DOD facilities requires a better understanding of energy consumption patterns and energy and financial savings potential. This paper utilizes two independent studies—EDA (End-Use Disaggregation Algorithm) and MEIP (Model Energy Installation Program)—and whole-installation electricity use data obtained from a state utility to estimate electrical energy conservation potential (ECP) and cost savings potential (CSP) at the Fort Hood, Texas, military installation and at DOD nationwide. At Fort Hood, we estimated an annual electricity savings of 62.2 GWh/yr (18%), a peak demand savings of 10.1 MW (14%), and an annual energy cost savings of $6.5 million per year. These savings could be attained with an initial investment of $41.1 million, resulting in a simple payback of 6.3 years. Across the DOD, we estimated an annual electricity savings of 4,900 GWh/yr, a peak demand savings of 694 MW, and an annual energy cost savings of $316 million per year. The estimated cost savings is 16% of the total nationwide DOD 1993 annual energy costs. These savings could be attained with an initial investment of $1.23 billion, resulting in a simple payback of 3.9 years.

INTRODUCTION

Background

Defense Energy Program Policy Memorandum (DEPPM) 91-2 requires, through energy-efficiency strategies, that Department of Defense (DOD) facilities reduce energy consumption and costs by 20% from 1985 to 2000, while Executive Order 12902 has mandated a 30% reduction over that of 1985 by 2005. The DOD owns more than 1.6 billion square feet of facilities with energy costs totaling more than $1.93 billion in 1993. The potential for energy reduction and cost savings is enormous. Possible conservation strategies include both improved operations and maintenance and enhanced energy-efficiency measures. To implement these strategies, it is important to characterize energy consumption patterns and estimate energy and cost savings potential to develop optimal conservation programs.

The Model Energy Installation Program (MEIP), created and managed by the U.S. Army's Construction Engineering Research Laboratories (CERL) under the DOD Strategic Environmental Research and Development Program, was designed to demonstrate the cost-saving potential of energy-efficiency measures applied at a large military installation. A 20% reduction in total energy consumption and cost has been established as a goal for a demonstration project at Fort Hood, Texas.

Objectives

The objectives of this study were to (1) estimate electrical energy conservation potential (ECP) at Fort Hood, Texas; (2) estimate the cost savings potential (CSP) at Fort Hood; and (3) extrapolate ECP and CSP to all DOD installations nationwide. These objectives were met in this paper from the integration of two independent studies—EDA (End-Use Disaggregation Algorithm) and MEIP—and whole-installation electricity use data obtained from a Texas utility. The ECP and CSP estimates were based on annual electrical energy, peak demand, and indirect gas savings.

The ECP and CSP were estimated for air-conditioning (compressors, fans, chilled and hot water pumps) and indoor lighting energy conservation opportunity (ECO) retrofits for the following building types: barracks, dining halls, gymnasiums, small and large administration buildings, vehicle maintenance shops and hangars, hospitals, residential buildings, warehouses, and miscellaneous structures.

Steven J. Konopacki is a principal research associate and Hashem Akbari is a staff scientist at Lawrence Berkeley National Laboratory, Berkeley, Calif. Larry D. Lister is a research engineer and Lee P. DeBaillie is a principal investigator at U.S. Army CERL, Champaign, Ill.

Previous Studies

Independent studies have been done to meet these objectives, which include MEIP and the REEP (Renewables and Energy Efficiency Planning) software and database. The MEIP study simulated energy consumption by building type and end-use and estimated ECP and CSP at Fort Hood for 25 nonresidential (CDI/EMC 1993) and 11 residential (AEC 1993) buildings. Prototypical buildings were surveyed to determine construction, system, and use characteristics. Metering and blower door tests were also performed. These buildings were modeled using an energy simulation program and calibrated to historical meter data to provide energy baselines. ECOs were applied to each building type at baseline conditions and evaluated with regard to energy and life-cycle financial savings. Finally, ECO implementation strategies were recommended along with corresponding ECPs and CSPs.

The REEP (Nemeth et al. 1993) software and database assesses the economic potential for investment in energy-efficient and renewable resource technologies. REEP can estimate the energy and financial saving potentials at 250 domestic DOD installations. The life-cycle cost analysis adheres to the U.S. Army's Energy Conservation Investment Program guidelines (ECIP 1993). REEP generalizes ECOs and applies them to a minimum amount of specific installation data. This generalized approach allows analysis nationwide by avoiding the immense data set necessary for more detailed studies yet provides accuracy suitable for planning purposes. REEP and MEIP utilize similar, but not identical, energy conservation technologies and different cost assumptions (i.e., REEP does not include maintenance cost savings while MEIP does). REEP estimates also include the effect of installations with substantially less cooling requirements. Therefore, energy and cost savings potentials presented in this paper cannot be directly compared to REEP savings potentials.

The REEP software and database were applied to Fort Hood and at 250 DOD installations (DeBaillie 1995) for similar energy conservation technologies as recommended by MEIP. At Fort Hood, REEP estimated an annual electricity savings of 59.7 GWh/yr (17%), a peak demand savings of 14.7 MW (21%), and an annual energy cost savings of $3.8 million per year. These could be attained with an initial investment of $18.2 million, resulting in a simple payback of 4.8 years. Across the DOD, REEP estimated an annual electricity savings of 2,730 GWh/yr (18%), a peak demand savings of 628 MW (9%), and an annual energy cost savings of $183 million per year. The estimated cost savings is 9% of the total nationwide DOD 1993 annual energy cost. These could be attained with an initial investment of $1.03 billion, resulting in a simple payback of 5.6 years. Additionally, electricity consumption savings of 27% and peak demand savings of 40% at Fort Hood were estimated from application of all 85 ECOs contained in REEP.

METHODOLOGY—RESULTS

The methodology is an integrated technique for the estimation of ECP and CSP that relies on whole-installation electricity use data, estimates of electricity consumption by building type and end-use, and estimates of electrical energy and financial savings. First, the annual whole-installation electricity-use data for Fort Hood are divided into annual cooling and noncooling components based on analyses of the annual electricity use hourly load shape. Second, each component is divided among all the building types and end-uses using proration derived from EDA results to obtain end-use consumption estimates. Third, estimated electrical and demand savings percentages from the MEIP study by building type for air-conditioning and indoor lighting end-uses are applied to the building-level end-use consumption estimates to produce ECP for the installation. Fourth, MEIP energy and maintenance cost savings and investment costs per square foot are scaled up to a base-wide level based on total floor area for each building type to produce CSP for the installation. Finally, the savings potentials at Fort Hood are extrapolated across the DOD to produce national savings estimates. Figure 1 illustrates the methodology in detail.

EDA Application to Fort Hood

The EDA (Akbari 1995) was developed at a national laboratory to characterize electricity consumption by end-use for commercial and residential buildings. In EDA, computer simulations of prototypical building types estimate energy consumption by hour and end-use; these are then reconciled hourly against measured electricity consumption data. EDA is a deterministic method that utilizes the statistical characteristics of measured electricity data and their inferred dependence on temperature, which helps to characterize the air-conditioning end-use. EDA has been successfully applied to the DOD installation at Fort Hood, Texas (Akbari and Konopacki 1995) and to commercial buildings in northern and southern California (Akbari et al. 1989, 1991, 1993).

The prototypical buildings developed for Fort Hood were barracks, dining halls, gymnasiums, small and large administration buildings, vehicle maintenance shops and hangars, hospitals, residential buildings, warehouses, and miscellaneous structures. Additionally, water pump and street light electrical energy consumption and transformer and feeder losses were estimated. Up to eight electric end-uses were developed for each building type: space cooling, ventilation (fans, chilled and hot water pumps), cooking, miscellaneous/plugs, refrigeration, exterior lighting, interior lighting, and process loads.

Utility's Annual Hourly Electricity Consumption at Fort Hood

Figure 2 displays the utility's hourly electricity consumption at Fort Hood during 1993. Two distinct regions are observed: winter (January 1 to April 10 and October 23 to December 31) and summer (April 11 to October 22). Figure 3 shows the hourly dry-bulb temperature of Waco, Texas, during 1993 (Fort Hood is approximately 50 miles north of Waco). When Figures 2 and 3 are observed together, the electricity use clearly exhibits temperature-dependent behavior.

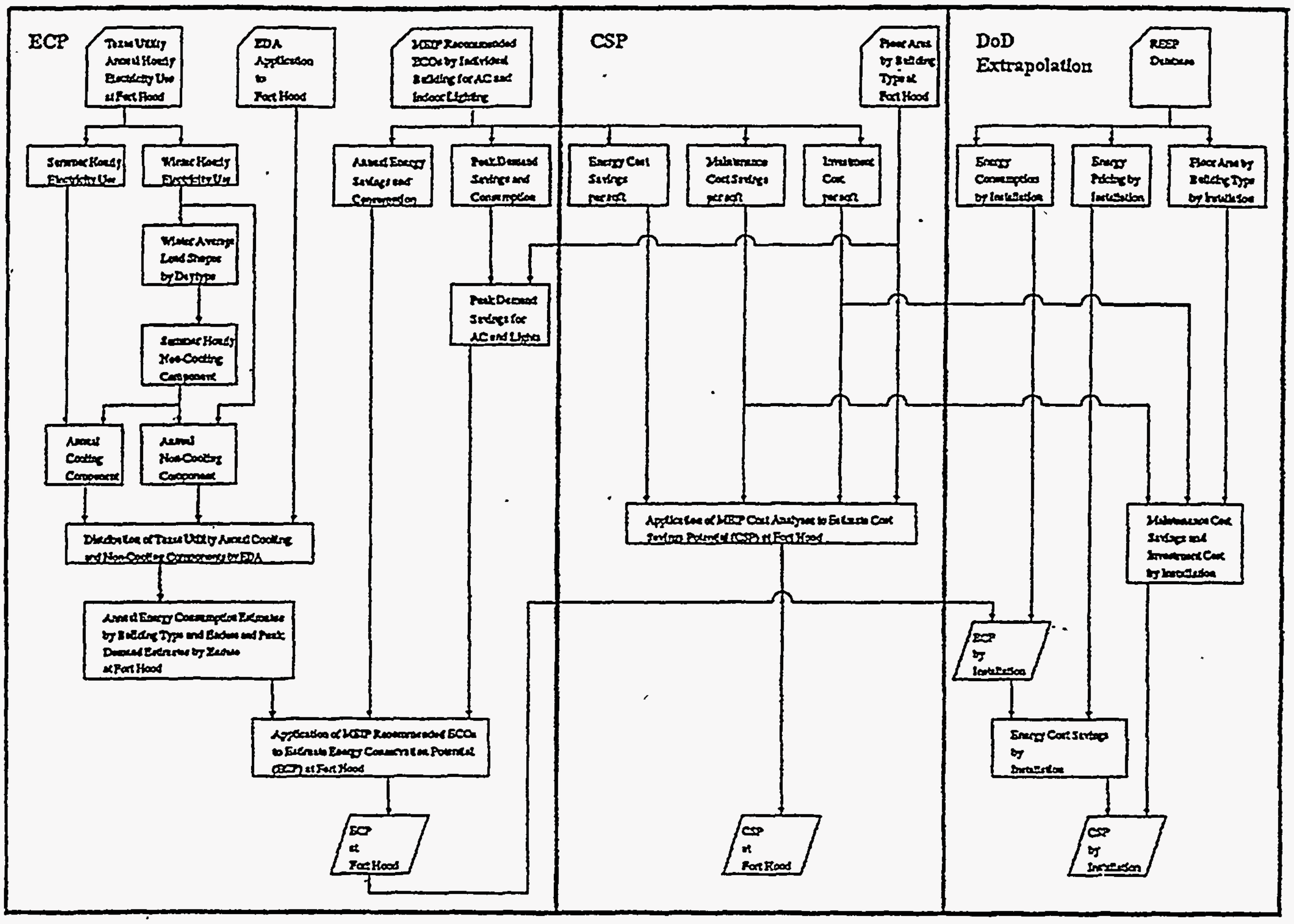

Figure 1 Methodology to estimate ECP and CSP at Fort Hood and extrapolate to DOD installations nationwide.

The winter region load was characterized by two average daily load shape types: standard (weekday) and nonstandard (weekend/holiday) and temperature-independent behavior. The winter standard day average minimum (nighttime) load was 24.6 MW and the average peak (daytime) demand was 36.3 MW. The winter average daily loads were calculated for each hour of the day and day type (standard and nonstandard days).

The summer region load, on the other hand, was characterized by temperature-dependent behavior and was further divided into two components: cooling and noncooling. The summer hourly noncooling load component was assumed to be equal to the winter average daily hourly load, which assumes that non-heating, ventilating, and air-conditioning (HVAC) schedules and consumption levels were identical for winter and summer seasons. The summer hourly cooling load component was determined by subtracting the summer hourly noncooling (winter average) load component from the summer hourly total load.

The annual total electricity consumption for Fort Hood was 349.6 GWh, where 16.3 GWh (4.7%) was attributed to transformer and feeder losses by EDA (Akbari and Konopacki 1995). The annual noncooling electricity consumption was the sum of the integrated winter hourly load and summer hourly noncooling load components, which was 247.3 GWh (70.7%). The annual cooling electricity consumption was the integrated summer hourly cooling load component, which was 86.0 GWh (24.6%).

The summer peak demand was 73.0 MW, where 3.4 MW (4.7%) was attributed to losses. The summer noncooling peak demand component was the winter standard day average peak (daytime) less losses, which was 34.6 MW (47.4%). Since the summer peak demand corresponds with the summer peak temperature, the summer cooling peak demand component was the difference of the total demand less the noncooling peak demand and losses, which was 35.0 MW (47.9%).

Distribution of Utility Data by EDA

The annual cooling electricity consumption was disaggregated into space-cooling and ventilation (fans, hot and chilled-water pumps) end-uses, and the annual noncooling electricity consumption was disaggregated into non-HVAC (cooking, miscellaneous/plugs, refrigeration, exterior lighting, interior lighting, and process loads) end-uses for each building based on proration from EDA. The water pump and street light were included as non-HVAC end-uses. The upper-left quadrant of Table 1 summarizes EDA's disaggregation of the utility's annual electricity consumption for air-conditioning (space cooling and

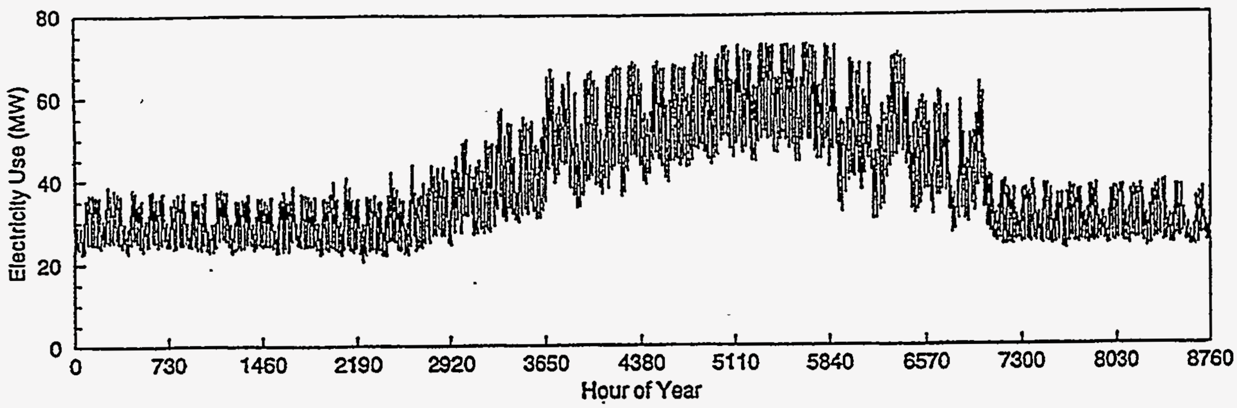

Figure 2 1993 Texas utility hourly electricity use at Fort Hood.

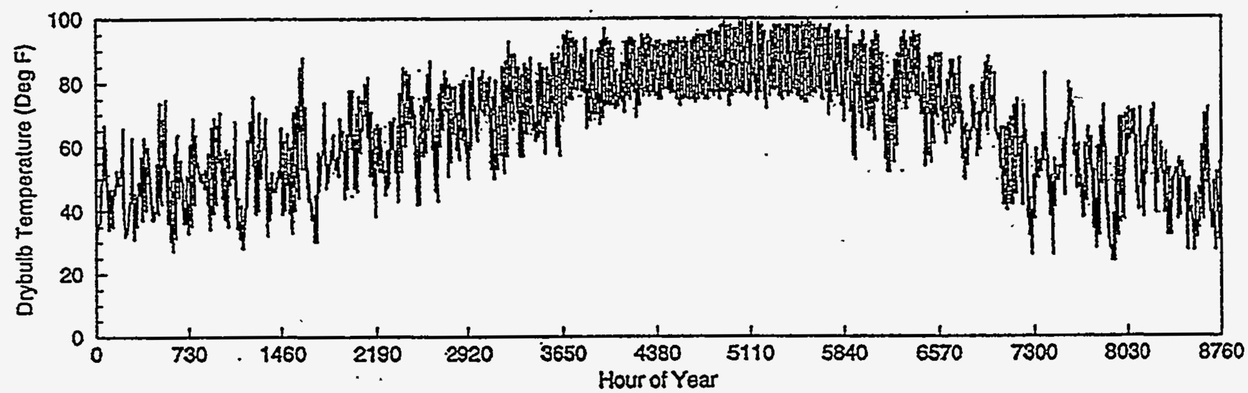

Figure 3 1993 Waco, Texas, hourly dry-bulb temperature at Fort Hood.

ventilation combined) and indoor lighting by building type at Fort Hood.

The peak demand was disaggregated into space-cooling and ventilation end-uses and is shown in the lower-left quadrant of Table 1. The peak air-conditioning demand was determined through utility data analysis to be 35.0 MW. The peak indoor lighting demand was 51% of the peak non-HVAC demand as determined by EDA (Akbari and Konopacki 1995), or 17.8 MW.

MEIP Energy Conservation Opportunities

MEIP summarized simulated annual electrical energy consumption and savings, indirect annual gas energy savings, peak demand and savings, annual energy and maintenance cost savings and expenditures, investment cost, simple payback period, and a savings-to-investment ratio (SIR) for a variety of ECOs and buildings. The ECOs specified and recommended in the MEIP study are shown in Table 2. The MEIP-recommended ECOs, which were used in this paper, were either in the form of air-conditioning (compressors, fans, hot and chilled-water pumps) or indoor lighting retrofits for both nonresidential and residential buildings. The recommended ECOs met the ECIP requirements of a SIR of more than 1.25 and a simple payback period of less than 10 years. We did not calculate ECO simple payback periods to determine which to implement but relied on MEIP recommendations.

Electrical energy consumption and peak demand savings percentages for each building were calculated from ratios of simulated annual electrical energy savings to annual electrical energy consumption and peak electrical savings to peak electrical demand, respectively, from MEIP. The energy savings percentages are shown in the upper-right quadrant of Table 1 in parentheses and were utilized to estimate ECP. The percent savings for the small administration building was used in estimates for the miscellaneous building, since it was not available from the MEIP study. We believe these are low savings estimates for the air-conditioning end-use (with the exception of large administration and residential buildings, which are too high), since more cost-effective air-conditioning ECOs could be implemented than those recommended by MEIP. A database of measured commercial energy-use data has documented that with existing technologies, energy-efficient 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). The peak demand savings percentages listed by end-use in the lower-

TABLE 1 Annual Electricity Consumption and Potential Savings at Fort Hood

Energy						
Building Type	Electricity Consumption (GWh/yr)			Potential Electricity Savings (GWh/yr)		
	A/C	Lighting	Total	A/C	Lighting	Total
Barrack						
Barrack	17.8	11.7	56.7	1.2 (7%)	2.2 (19%)	3.4
Dining hall	2.2	2.5	11.8	0.2 (7%)	0.6 (22%)	0.8
Gymnasium	0.4	1.7	2.2	0.0 (5%)	0.2 (13%)	0.2
Administration						
Large	2.3	4.4	14.9	1.0 (42%)	2.3 (53%)	3.3
Small	22.5	25.1	55.7	2.5 (11%)	12.6 (50%)	15.1
Vehicle Maintenance						
Shop	1.1	6.6	10.7	0.0 (0%)	1.8 (28%)	1.8
Hangar	1.4	3.4	5.2	0.1 (4%)	0.9 (27%)	1.0
Hospital	2.4	6.2	17.5	0.1 (6%)	3.1 (50%)	3.2
Residential	28.5	8.2	89.8	17.1 (60%)	4.9 (60%)	22.0
Other						
Warehouse	0.6	3.6	5.7	0.1 (21%)	0.7 (19%)	0.8
Miscellaneous	6.8	19.8	35.1	0.7 (11%)	9.9 (50%)	10.6
Water pump	—	—	4.2	—	—	—
Street light	—	—	23.9	—	—	—
Loss	—	—	16.3	—	—	—
Fort Hood	86.0	93.2	349.6	23.0 (27%)	39.2 (42%)	62.2
Power						
Fort Hood	Demand Consumption (MW)			Potential Demand Savings (MW)		
	35.0	17.8	73.0	7.4 (21%)	2.7 (15%)	10.1

The potential electricity savings in parentheses were based on MEIP-recommended ECOs. We believe these are low savings estimates for the air-conditioning end-use (with the exception of large administration and residential, which are too high), since more cost-effective air-conditioning ECOs could be implemented than those recommended by MEIP. A database of measured commercial energy-use data has documented that with existing technologies, energy-efficient 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).

right quadrant of Table 1 are average percentages by building and end-use from the MEIP analysis weighted by total building floor area and were utilized to estimate ECP. Annual energy and maintenance cost savings and investment cost were determined per square foot for each building for calculation of CSP.

Application of MEIP ECOs to Estimate Energy Conservation Potential at Fort Hood

The ECP consists of two components estimated from MEIP ECOs: annual electrical energy and peak demand savings. Since this paper is focused on electrical savings potential, the indirect natural gas savings that occur from application of the ECOs have not been stated explicitly. However, the financial savings that result from gas savings have been included in the overall financial analysis.

The electrical energy savings were estimated by applying the annual electrical energy savings percentages from the MEIP analysis to the EDA disaggregated consumption estimates for air-conditioning and indoor lighting end-uses for the entire applicable building stock at Fort Hood. The potential annual electricity savings are displayed in the upper-right quadrant of Table 1 in GWh/yr. From Table 1 it is estimated that an annual electricity savings of 62.2 GWh/yr could result from the implementation of the MEIP-recommended ECOs, which is 18% of the total annual electricity use at Fort Hood.

The peak demand savings were estimated by applying the peak demand savings percentages from the MEIP analysis to the disaggregated peak consumption estimates for air-conditioning and indoor lighting end-uses. The potential peak demand savings are displayed in the lower-right

TABLE 2 Model Energy Installation Program Recommended Energy Conservation Opportunities

Nonresidential	Residential
AC	
Albedo modification	Albedo modification
Ceiling insulation	Attic radiant barrier
Cooling options	**Duct Doctoring**
Direct digital controls	**High EER A/C (7 to 13)**
Exterior Shading	Storm windows
Gas-fired cooling	Wall insulation
High-efficiency fans	
Ice storage	
Lower supply airflow	
Peak shaving	
Premium efficiency motors	
Reflective window film	
Rooftop DX units	
Tune VAV system	
Variable-air-volume conversion	
Variable-speed drives	
Window replacement	
Lighting	
Compact fluorescent lamps	**Compact fluorescent lamps**
Daylighting	Kitchen electronic ballasts
Occupancy sensors	**Occupancy sensors**
T-8 fluorescent lamps	
Other (includes heating)	
Boiler Modifications	Efficient water heater
Gas-fired radiant heat	Electronic ignition (gas furnace)
HID lamps	Flue damper (gas furnace)
Plug load modification	High-efficiency gas furnace (0.90)
Vending machine modification	
ECOs recommended by MEIP and considered in the paper are boldfaced	

quadrant of Table 1 in MW. From Table 1 it is estimated that a peak demand savings of 10.1 MW (14%) could result from the implementation of the MEIP-recommended ECOs.

Application of MEIP Cost Analyses to Estimate Cost Savings Potential at Fort Hood

The CSP is a function of energy and maintenance cost savings, where the energy savings are the sum of annual electricity, peak demand, and natural gas components. CSP was estimated for Fort Hood based on MEIP-recommended ECOs. First, the MEIP per-square-foot savings and investment were calculated by building type, which are shown in the left half of Table 3. Then the MEIP per-square-foot savings and investment were scaled up installation-wide by the total floor area of each building. CSP and total investment estimates are shown in the right half of Table 3 for all of Fort Hood. The total annual cost savings potential for Fort Hood was estimated to be $6.5 million per year with an initial investment cost of $41 million, resulting in a simple payback of 6.3 years. Table 4 summarizes ECP and CSP at Fort Hood.

Estimated Energy and Cost Savings Potential at All DOD Installations

The ECP, CSP, and investment cost for all of the DOD were estimated using information contained in the REEP database, although not using the REEP software. Specifically, for each installation, 1993 annual energy consumption data, energy pricing, and total floor area by building type were used. The Fort Hood estimates of percent annual electrical savings (18%) and demand savings (14%) were applied to the 1993 annual energy consumption of 250 domestic DOD installations. These energy savings were then applied to their respective local energy prices to provide energy cost savings estimates. The MEIP estimates of investment cost and maintenance savings per square foot by building type were then applied to the total floor area by building type at each installation. From this approach, estimates of domestic DOD ECP, CSP, and investment cost were derived. The estimates reveal a DOD-wide ECP of 4,900 GWh/yr and 694 MW and a CSP of $316 million per year with an initial investment of $1.23 billion, resulting in a simple payback of 3.9 years. The estimated cost savings is 16% of the total nationwide DOD 1993 annual energy costs.

This approach assumes that the same energy savings percentages can be achieved at every installation and that investment cost and maintenance savings per square foot do not vary regionally. The cooling energy savings percentage may vary regionally due to climatic influence; however, the indoor lighting energy savings percentage may be uniform DOD-wide. Therefore, the DOD-wide estimates should be examined under these considerations.

CONCLUSIONS

ECP and CSP estimates were obtained through a unique methodology fusing a detailed analysis of energy consumption and savings data of actual surveyed buildings together with a detailed analysis of installation-wide energy consumption data disaggregated by building type and end-use. It was determined by this method that implementation of a few air-conditioning and indoor lighting ECOs can result in significant energy and cost savings at Fort Hood and other DOD installations. This study should be a useful tool for budget allocation and technology prioritization when assessing the energy conservation potential of large installations, which should lead to the establishment of successful energy conservation programs.

TABLE 3 MEIP Cost Savings Estimates by Building and Annual Cost Savings Potential at Fort Hood

Building Type	MEIP Estimate for Individual Building			Cost Savings Potential at Fort Hood		
	Energy Cost Savings ($yr/ft²)	Maintenance Cost Savings ($1000/yr)	Investment Cost ($/ft²)	Energy Cost Savings ($1000/yr)	Maintenance Cost Savings ($1000/yr)	Investment Cost ($1000)
Barrack						
Barrack	0.08	0.04	0.77	409	190	3806
Dining hall	0.08	0.05	0.95	40	25	482
Gymnasium	0.04	0.00	0.34	8	1	76
Administration						
Large	0.58	0.02	1.52	389	15	1024
Small	0.22	0.02	1.93	864	74	7534
Vehicle Maintenance						
Shop	0.11	0.03	1.00	282	73	2530
Hangar	0.09	0.02	0.68	67	16	507
Hospital	0.37	0.05	2.86	187	25	1441
Residential	0.40	0.00	2.40	3436	0	20561
Other						
Warehouse	0.04	0.00	0.15	59	3	217
Miscellaneous	0.22	0.02	1.93	332	28	2891
Fort Hood	—	—	—	6100	400	41100

TABLE 4 ECP and CSP Estimates at Fort Hood

Energy/Cost Savings Potential		
ECP	Annual Electric (GWh/yr)	62.2
	Peak Demand (MW)	10.1
CSP	Annual Energy ($M/yr)	6.1
	Annual Maintenance ($M/yr)	0.4
	Investment ($M)	41.1
	Simple Payback Period (yr)	6.3

At Fort Hood, we estimated an annual electricity savings of 62.2 GWh/yr (18%), a peak demand savings of 10.1 MW (14%), and an annual energy cost savings of $6.5 million per year. These could be attained with an initial investment of $41.1 million, resulting in a simple payback of 6.3 years. Across the DOD, we estimated an annual electricity savings of 4,900 GWh/yr, a peak demand savings of 694 MW, and an annual energy cost savings of $316 million per year. These could be attained with an initial investment of $1.23 billion, resulting in a simple payback of 3.9 years. The estimated cost savings is 16% of the total nationwide DOD 1993 annual energy costs. We have less confidence in the DOD-wide estimates than those for Fort Hood because of the reasons specified in the previous section.

The energy savings percentages at Fort Hood are lower than expected, since with existing technologies energy-efficient programs can be implemented to reduce energy consumption and peak demand by 30% with a payback time of less than two years. At Fort Hood, such a program could result in savings of more than 100 GWh/yr in energy consumption and 20 MW in peak power demand. The MEIP study recommended only a few ECOs to be implemented; this could be a primary reason for the lower-than-expected ECP. A study of the effect of ECO implementation on the national laboratory's prototypical building types may increase the number of feasible ECOs and, hence, increase ECP and CSP at Fort Hood.

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tutes of Health (NIH), the U.S. Geological Survey (USGS), and the National Aeronautics and Space Administration (NASA).

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