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# Characteristics of Energy Consumption by building type of a U.S. Navy Installation in Hot and Humid Climate

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## ABSTRACT

In fiscal year 2014, the facility energy consumption of the Department of Defense (DOD) amounted to 214,164 billion British thermal units (Btus), which was about 1.2 percent of the total U.S. commercial sector's energy consumption (Department of Defense 2015). DOD spent $4.2 billion on facility energy, which included $4 billion to power, heat, and cool buildings. Several research works have been conducted to save energy and study the energy consumption of military installations in a general view. However, few research works discussed the characteristics of energy consumption by building type in a high temperature and high relative humidity climate.

This paper will investigate the characteristics of energy consumption by building type under the specific hot and humid climate at a selected U.S. Navy installation. The building types comprise of office building, residential building, supermarket and data center. Utility bills of electricity and natural gas for each building will be analyzed to show the actual energy consumption status. Weakness of current building operation in the selected military installation will be discussed based on field test data. Aiming to the weakness discussed, energy conservation measures will be proposed and the estimated energy savings will be presented.

## 1. INTRODUCTION

Facility energy comprised approximately 19 percent of the total Federal energy consumption in fiscal year 2014 which was 1.2 percent of the total U.S. commercial sector's energy consumption. DoD spent $4.2 billion on facility energy, including $4 billion to power, heat and cool buildings and $0.2 billion to supply fuel to the fleet of NTVs. Facility energy represented 23 percent of the Department's total energy expenditures. In FY 2014, DoD consumed approximately 187,00 billion Btus of energy in its goal-subject buildings (Department of Defense 2015).

The majority of DoD investments are in the military departments' operations and maintenance accounts, to be used for sustainment and recapitalization projects. Such projects typically involve retrofits to incorporate improved lighting, high-efficiency heating, ventilation, and air conditioning (HVAC) systems, double-pane windows, energy management control systems, and new roofs.

LBNL analyzed the energy consumption by building type and end use at 12 U.S. army installations nation-wide by End-use Disaggregation Algorithm (EDA) (Konopacki and Akbari 1996). NREL investigated an assessment and planning process to examine military installations for net zero energy potential for military installations. The work summarized the problems in developing the military installations to net zero energy sites (Booth et al. 2010; Callahan et al. 2011). PNNL investigated the energy reduction goals for federal buildings by analyzing the past performance of buildings, future energy savings potential from retrofits and alternative approaches (Judd et al. 2014).

DoD will give greater focus to more capital-intensive projects that yield greater life-cycle savings, because the low- and no-cost energy efficiency and conservation initiatives continue to diminish and the decreasing budget. This paper will study the energy consumption characteristics of several building types under the specific hot and humid climate at a selected U.S. Navy installation. The building types comprise of office building, residential building, supermarket and data center. Based on the study, low- and no-cost energy saving measures still can be easily acquired.

## 2. BUILDING DESCRIPTION

The four representative buildings investigated in this study are residential, office, supermarket and data center. Their basic information including building type, schedules and HVAC systems are summarized in Table 1.

**Table 1**: Basic information of the five investigated buildings at NASK

| Building Type | HVAC System | Occupancy Schedule | HVAC Schedule |
|---|---|---|---|
| Residential | Air handling unit, fan coil unit, chiller, boiler | 24/7 | 24/7 |
| Office | Air handling unit, VAV box, chiller, boiler | 8 AM to 5 PM | 24/7 |
| Data Center | Air handling unit, VAV box, chiller, boiler | 7:35 AM to 11:45 PM (M-TR)<br>7:35 AM to 5 PM (F) | 24/7 |
| Supermarket | Air handling unit, split system heat pump, heat pump | 7 AM to 6 PM | 24/7 |

### 2.1 Residential building

The residential building is a 3-floor unaccompanied housing for NASK military. It has around 53 rooms serviced by four handling units (AHUs) and fan coil units (FCUs) for both heating and cooling purpose. The chilled water system consists of one high efficiency air cooled scroll chiller with a total capacity of 60 tons. The chilled water loop is a traditional primary only configuration with a two way valves installed on the return pipe of each Air Handling Unit (AHU). One primary chilled water loop pump is installed and dedicated to the air-cooled chiller at a constant speed.

The heating system consists of one gas fired water heating boiler with a total capacity of 1.2 MMBtu/hr. The hot water is directly sent to heating coils and fan coils. The building has one hot water loop. One primary hot water pump with no VFD installed for this boiler.

This building has 4 AHUs serving the conditioned spaces. The total installed fan power is 7 hp with the total designed airflow rate of 7600 CFM. They are all single duct fresh air only units. Two of them are cooling only units. The building has a total of 63 fan coil units which are five-pipe type. The cold air supplied by AHUs mix with return air at fan coil units and then can be further cooled down or heated up before entering the room.

To save energy, two energy recovery units (ERVs) are installed to exchange heat between outdoor air and exhaust air from the building. However, they are not in use now because of technician reason.

### 2.2 Office building

The office building is a three-floor building. There are currently about 20 people working in the building. The chilled water system consists of two high efficiency air cooled scroll chiller with a capacity of 110 tons each. The chilled water system configuration is primary system only. The chilled water system and hot water system share the same supplying water pipe. Two chilled water pumps are constant speed pumps. The heating system consists of one gas fired water heating boiler with a total capacity of 3103 MBtu/hr.

There are three AHUs in this building, each serves one floor. Each AHU has fresh air duct, return air duct and supply air duct and is a unit which cannot provide heating and cooling simultaneously. They all have bypass pipe with three-way valve and electronic controlled actuator.

### 2.3 Data center building

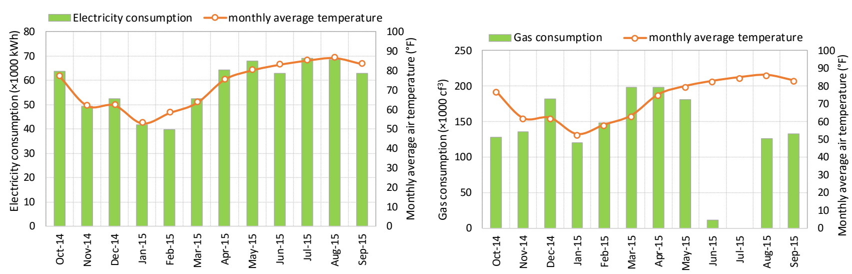
The data center building has mixed usage of office area and data center. There are two air handling units in its mechanical room: one for the data center and the other one for the rest area of the building. The control system used in this building is Johnson Control. The chilled water system consists of two high efficiency air cooled scroll chillers with a capacity of 40 tons each. The chilled water loop is a traditional primary only configuration. Two chilled water pumps with VFDs are installed in parallel. The heating system consists of two gas fired water heating units with a total capacity of 748 MBtu/hr. The hot water pump is a constant speed pump. This building has 2 AHUs serving the conditioned spaces. One of them is cooling only unit and the other one is heating and cooling unit. The fans of both AHUs are equipped with VFD. The building has in total 11 VAV boxes, 6 of which are fan powered VAV boxes. They are all equipped with reheat hot water coil.

### 2.4 Supermarket

The last investigated building is a medium size supermarket. It has large glazed façade facing east and south. The whole building is divided into the main shopping area, office area (with several offices) and a storage area. The main cooling system in this building is comprised of two split system heat pump units. The split system heat pump unit has one air handler unit and one outdoor condenser unit. The cooling capacity of the two split system heat pump units are 15 Tons and 20 Tons, respectively. Supply air duct has two split branches as observed in the mechanical room, one branch of which has gas heating unit for reheat purpose. Each AHU is equipped with an electrical heater installed before supply air duct split point.

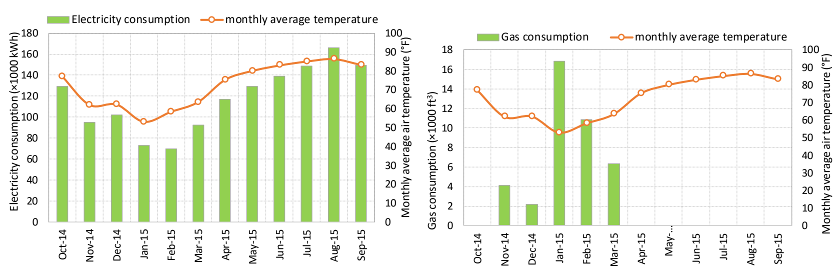
## 3. UTILITY DATA ANALYSIS

Figures 1 to 4 present one-year period electricity energy consumption and natural gas consumption for four buildings. The metered data at 15-minute interval is processed and plotted as monthly electricity consumption and natural gas consumption. Monthly average outdoor air temperatures were obtained from underground weather website for local installation and plotted in the same figures as well.




(a) (b)

**Figure 1:** Monthly total electricity consumption and natural gas consumption of residential building and monthly average local outdoor air temperature, Oct 2014 – Sep 2015




(a) (b)

**Figure 2:** Monthly total electricity consumption and natural gas consumption of office building and monthly average local outdoor air temperature, Oct 2014 – Sep 2015

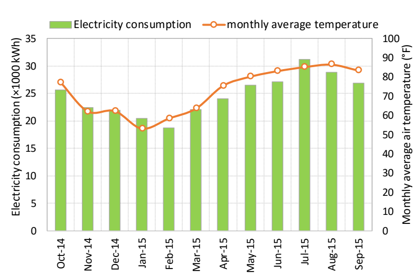
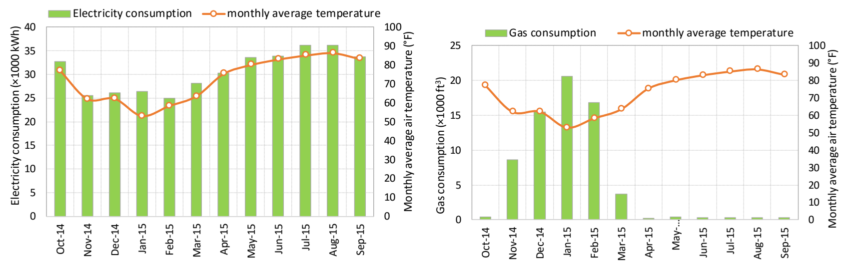



**Figure 3:** Monthly total electricity consumption and natural gas consumption of data center building and monthly average local outdoor air temperature, Oct 2014 – Sep 2015




(a) (b)

Figure 4: Monthly total electricity consumption and natural gas consumption of supermarket building and monthly average local outdoor air temperature, Oct 2014 – Sep 2015

Based on the figures 1(a) to 4(a), the monthly electricity consumption varies with the change of local outdoor air temperature. The change curve of monthly electricity consumption matches the change curve of outdoor air temperature. Different building type has different change magnitudes. The office building has the largest difference between maximum and minimum of electricity consumption, which is 95 thousand kWh. The residential building has the second largest difference and supermarket building has the smallest difference. The minimum electricity consumption can be regarded as the base load. Generally, base load keeps constant and is not affected by outdoor air. So, the difference indicates the energy consumption for cooling load. Larger difference represents larger cooling load. It also indicates the potential energy savings on reducing energy consumption for cooling load.

Figures 1(b) to 4(b) show the variation of natural gas consumption with the change of local outdoor air temperature. Unlike the electricity consumption, gas was consumed only in limited time period (winter). For the office building and data center building, natural gas was consumed from November to January and the peak natural gas consumption occurred in January. For residential building, natural gas was demanded whole year except July and the peak consumption occurred in June.

For commercial buildings, heating, cooling and hot water account for almost 70% of the total building energy (Book 2010). The ratio of the maximum electricity consumption to the minimum presents the total energy savings potential. Smaller ratio means that the base load is comparably large and this part can be further reduced. The ratio of four buildings are 1.75 for the residential building), 2.357 for the office building, 1.78 for the data center building and 1.48 for the supermarket building. The office building has the largest ratio. It means its base load can be reduced in a smaller magnitude compared with the other three buildings. The next section of this paper will discuss the ways to reduce energy consumption from the viewpoints of reducing energy consumption for base load and cooling/heating load.

## 4. ENERGY CONSERVATION MEASURES (ECMs)

Currently, major energy efficiency improvement investments in this installation focus on replacing old heating/cooling units with new units. Replacing old HVAC equipment with higher efficiency equipment will save energy. However, it is costly and may not bring the expected energy savings if the control strategies of HVAC system are not carefully addressed. This section discusses the common control strategies, necessary capital investment and the energy savings potential due to the implementation.

### 4.1 Energy conservation measures for saving total energy consumption

(a) Install central control system

The control system of the four buildings are not integrated and most of them do not work properly. Table 2 summarizes the control systems of each building and their problems.

**Table 2:** Control system status

| Building type | Control system | Problems |
|---|---|---|
| Residential | Trane IQ3xcite | Access to the control system is lost. Boiler and chiller are not connected to the system. |

| | | |
|---|---|---|
| Office | Dos-based Honeywell system | Access to the control system is lost. System cannot work properly. |
| Supermarket | No control system | Units are controlled by thermostats. |
| Data center | Johnson Control System | Control platform only permit limited functions without the ability to optimize control strategies and record trend data. |

According to the problems and current status of control systems in the four buildings, following measures are proposed. A functional control system will be the platform to conduct optimal energy conservation measures.

- Replace old malfunctioning control system with new control system.
- Integrate the control system across the whole campus buildings.

**4.2 Energy conservation measures for saving base energy consumption**

(a) Optimize operation schedule

Reduce the operation time of HVAC equipment is very important to avoid unnecessary energy consumption and will extend the service life through reducing operation time of equipment. The data center building requires all units to be on for 24/7 for safety concerns. And the supermarket building adopts split heat pump system. So, considering the functions and the types of HVAC systems of each building, only residential building and office building have the potential to optimize the operation schedule.

**Table 3:** Operation schedule optimization

| **Buildings** | **Equipment** | **Original** | **Proposed** |
|---|---|---|---|
| Residential | Chiller | On for 24/7 | Shut down chillers when outdoor air temperature is below 50 $^{o}$F. |
| | Boiler | On for 24/7 | Shut down boilers when outdoor air temperature is below 50 $^{o}$F. |
| | Pump | On for 24/7 | Pump will be off as the chiller is off. |
| Office | Chiller | Manually turn off and changeover | Chillers will changeover every month and will be shut down when outdoor air temperature drops below 50 F or when the boiler is on. |

**4.3 Energy conservation measures for saving cooling/heating energy consumption**

Optimize the operation strategies of HVAC system in buildings will greatly save energy consumption and avoid high capital cost in the meanwhile. Therefore, field test was conducted from December to April in all the four buildings to get their current system operations and energy performance. HOBO data loggers were adopted and deployed to measure major operation parameters including supply air temperature, return air temperature and outdoor air temperature of AHUs, chilled water supply/return temperature (CHWS/RT) and hot water supply/return temperature (HWS/RT). Three weeks test data was collected for each test point. This section discusses the proper energy conservation measures for each type of buildings based on their specific HVAC systems and field test data.

Figures 5 to 7 show the chilled water temperature difference between CHWS and CHWR and hot water temperature difference between HWS and HWR. For all buildings, the chilled water temperature difference is very small. This means the cooling load was very low during the testing period and the pump should not fully run. However, the chilled water pumps were always in operation according to current operation schedule. Hot water temperature difference of the residential building and data center building varies with outdoor air temperature. The smallest difference was around 4 $^{o}$F indicating that the HW pump was fully running in partial load situation. Installing VFDs on hot water pumps of these two buildings should increase the temperature difference to reduce energy consumption of pumps.

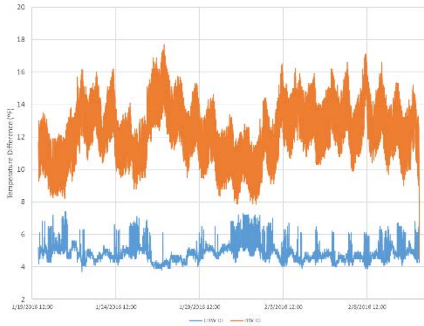


**Figure 5:** CHW and HW Temperature difference of residential building

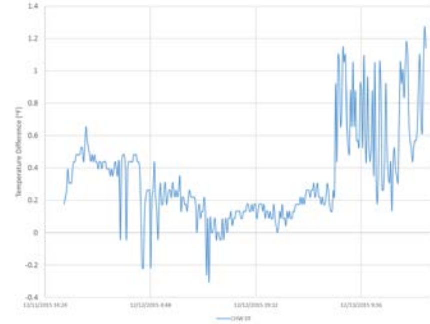


**Figure 6:** CHW Temperature difference of office building

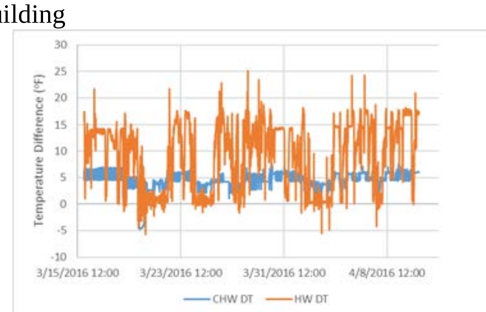



**Figure 7:** CHW and HW Temperature difference of data center building

According to the walk-through and field test data, the Tables 4 to 7 summarize the optimized control strategies in four types of buildings.

**Table 4:** Existing and proposed control strategies for residential building

| Equipment | Existing | Proposed |
|---|---|---|
| Chiller | Constant chilled water supply (CHWS) temperature setpoint | Reset CHWS temperature based on OAT |
| Chilled water pump | Constant speed | Install VFD and reset differential pressure (DP) setpoint based on VFD speed |
| Boiler | Constant hot water supply (HWS) temperature setpoint | Reset HWS temperature based on OAT |
| Hot water pump | Constant speed | Install VFD and reset differential pressure (DP) setpoint based on VFD speed |
| AHU | Constant supply air temperature (SAT) Setpoint | Reset SAT setpoint based on OAT |
| | Constant fan speed | Install VFD and reset static pressure (SP) setpoint based on average room temperature setpoint |
| Fan coil units (FCUs) | Reheat coil is controlled by the thermostat | Reset the reheat temperature setpoint based on room temperature setpoint and VFD speed |

**Table 5:** Existing and proposed control strategies for office building

| Equipment | Existing | Proposed |
|---|---|---|
| Chiller | Constant chilled water supply (CHWS) temperature setpoint | Reset CHWS temperature based on OAT |
| Chilled water pump | Constant speed | Install VFD and reset differential pressure (DP) setpoint based on VFD speed |
| Boiler | Constant hot water supply (HWS) temperature setpoint | Reset HWS temperature based on OAT |
| AHU | Constant supply air temperature (SAT) Setpoint | Reset SAT setpoint based on OAT |

| | | |
|---|---|---|
| | Constant fan speed | Install VFD and reset static pressure (SP) setpoint based on average room temperature setpoint |
| Variable air volume terminal box (VAVs) | Reheat coil is controlled by the thermostat | Reset the reheat temperature setpoint based on room temperature setpoint and VFD speed |

**Table 6:** Existing and proposed control strategies for supermarket building

| Equipment | Existing | Proposed |
|---|---|---|
| AHU | Constant supply air temperature (SAT) Setpoint | Reset SAT setpoint based on OAT |
| | Constant fan speed | Install VFD and reset static pressure (SP) setpoint based on average room temperature setpoint |

**Table 7:** Existing and proposed control strategies for data center building

| Equipment | Existing | Proposed |
|---|---|---|
| Chiller | Constant chilled water supply (CHWS) temperature setpoint | Reset CHWS temperature based on OAT |
| Chilled water pump | Pump speed is controlled to maintain constant differential pressure setpoint | Reset differential pressure (DP) setpoint based on VFD speed |
| Boiler | Constant hot water supply (HWS) temperature setpoint | Reset HWS temperature based on OAT |
| Hot water pump | Constant speed | |
| AHU | Constant supply air temperature (SAT) Setpoint | Reset SAT setpoint based on OAT |
| | Fan speed is controlled to maintain constant static pressure setpoint | Reset static pressure (SP) setpoint based on average room temperature setpoint |

## 5. ENERGY SAVINGS ESTIMATION

To estimate the potential energy savings upon the implementation of ECMs, bin method is applied. Tables 8 to 11 presents the energy savings estimation based on different ECMs.

**Table 8:** Energy savings based on operation schedule optimization

| Buildings | Equipment | Proposed | Energy Savings (kWh) |
|---|---|---|---|
| Residential | Chiller | Shut down chillers when outdoor air temperature is below 50 °F. | 24,317 |
| | Boiler | Shut down boilers when outdoor air temperature is below 50 °F. | 1,086,628 |
| Office | Chiller | Chillers will changeover every month and will be shut down with chilled water pumps when outdoor air temperature drops below 50 °F or when the boiler is on. | 23,379 |

Table 8 shows the significant energy savings via optimizing operation schedule. The total energy savings can be about 1.13 million kWh. The office building has the largest ratio as discussed above, so it has the smallest potential to save energy in operation schedule optimization.

As shown in Tables 9 to 12, without big capital investment, in total about 1.7 million kWh can be saved by optimizing control strategies.

**Table 9:** Energy savings based on control strategies optimization - Residential Building

| Equipment | ECMs | Energy Savings (kWh) |
|---|---|---|
| Chiller | Reset CHWS temperature based on OAT | 32,836 |

| | | |
|---|---|---|
| Chilled water pump | Install VFD and reset differential pressure (DP) setpoint based on VFD speed | 13,153 |
| Boiler | Reset HWS temperature based on OAT | 15,109 |
| Hot water pump | Install VFD and reset differential pressure (DP) setpoint based on VFD speed | 5,833 |
| AHU | Reset SAT setpoint based on OAT | 8,350 |
| | Install VFD and reset static pressure (SP) setpoint based on average room temperature setpoint | 27,696 |
| Fan coil units (FCUs) | Reset the reheat temperature setpoint based on room temperature setpoint and VFD speed | 98,389 |

**Table 10:** Energy savings based on control strategies optimization - office building

| Equipment | Proposed | Energy Savings (kWh) |
|---|---|---|
| Chiller | Reset CHWS temperature based on OAT | 77,770 |
| Chilled water pump | Install VFD and reset differential pressure (DP) setpoint based on VFD speed | 43,844 |
| Boiler | Reset HWS temperature based on OAT | 13,944 |
| | | 5,584 |
| AHU | Reset SAT setpoint based on OAT | 10,417 |
| | Install VFD and reset static pressure (SP) setpoint based on average room temperature setpoint | 169,606 |
| Variable air volume terminal box (VAVs) | Reset the reheat temperature setpoint based on room temperature setpoint and VFD speed | 347,878 |

**Table 11:** Energy savings based on control strategies optimization - supermarket building

| Equipment | Proposed | Energy Savings (kWh) |
|---|---|---|
| AHU | Reset SAT setpoint based on OAT | 6,526 |
| | Install VFD and reset static pressure (SP) setpoint based on average room temperature setpoint | 69,648 |
| | Reheat Savings | 278,908 |

**Table 12:** Energy savings based on control strategies optimization - data center building

| Equipment | Proposed | Energy Savings (kWh) |
|---|---|---|
| Chiller | Reset CHWS temperature based on OAT | 52,050 |
| Chilled water pump | Reset differential pressure (DP) setpoint based on VFD speed | 9,810 |
| Boiler | Reset HWS temperature based on OAT | 15,109 |
| Hot water pump | | 5,833 |
| AHU | Reset SAT setpoint based on OAT | 7,081 |
| | Reset static pressure (SP) setpoint based on average room temperature setpoint | 78,715 |
| | Reheat savings | 294,495 |

## 6. CONCLUSIONS

This paper investigates the characteristics of energy consumption by building type under the specific hot and humid climate at a selected U.S. Navy installation. Utility data of four types of buildings is analyzed and shows two main ways to conserve energy: reduce base energy consumption and heating/cooling energy consumption. Based on walk-through and field data, energy conservation measures are proposed for each type of buildings and potential energy savings are estimated by bin method. There is a great improvement of saving energy consumption of buildings in an easy and quick way. This will be a good addition to the energy conservation program conducted by DoD.

## REFERENCES

Book, Buildings Energy Data. 2010. *US Department of Energy, 2011*.

Booth, Samuel, John Barnett, Kari Burman, Josh Hambrick, and Robert Westby. 2010. *Net Zero Energy Military Installations: A Guide to Assessment and Planning*.

Callahan, M., K. Anderson, S. Booth, J. Katz, and T. Tetreault. 2011. “Lessons Learned from Net Zero Energy Assessments and Renewable Energy Projects at Military Installations.” National Renewable Energy Laboratory (NREL), Golden, CO.

Department of Defense. 2015. “Annual Energy Management Report, Fiscal Year 2014.” http://www.acq.osd.mil/eie/Downloads/Reports/Tab%20B%20-%20FY%202014%20AEMR_FINAL.pdf.

Judd, K. S., J. A. Dirks, D. M. Anderson, B. E. Ford, and D. B. Belzer. 2014. “Analysis of Federal Agency Facility Energy Reduction Potential and Goal-Setting Approaches for 2025.”

Konopacki, Steven J., and Hashem Akbari. 1996. “Estimates of Energy Consumption by Building Type and End Use at US Army Installations,” August. http://www.escholarship.org/uc/item/4bd685cx.