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January 3, 2012

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Extremely Low-Energy Design for Army Buildings: Dining Facility

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ABSTRACT

The U.S. Army Corps of Engineers, in collaboration with the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), academia, and private sector subject matter experts, recently completed an energy study to evaluate potential site and source energy-use reduction in new Army buildings. The study was completed in response to the mandates for energy savings in federal buildings enacted by the U.S. Energy Independence and Security Act of 2007 (U.S. Congress 2007). The building types studied included an Unaccompanied Enlisted Personnel Housing (UEPH or barracks), a brigade headquarters (administrative building), a company operation facility, a maintenance facility, and a dining facility (DFAC). The study was conducted for representative locations in all 15 DOE identified climate zones in the United States with building designs adapted to these climatic conditions.

This paper presents the results of the energy analysis for a typical Army dining facility. It discusses energy efficiency measures and combinations used to reduce both internal and external loads on the building and overall energy use. The largest load in a DFAC is the cooking, and the currently available best-in-class kitchen equipment is included in the final design. The potential site energy savings compared to the energy code range from 21% to 38%. The potential source energy savings compared to Commercial Building Energy Consumption Survey ranges from 37% to 42%. Additional savings may be obtained if an efficient cogeneration system is used and the building is considered as a part of the building cluster or community to fully utilize the energy from the cogeneration system.

INTRODUCTION

The U.S. Army spends more than $1 billion annually in building-related energy expenses. The U.S. Army Energy Security Implementation Strategy sets the general direction for the United States. The Army, including elimination of energy waste in existing facilities, increased energy efficiency in new construction and renovations and reduced dependence on fossil fuels. Moreover, the Army's long-term goal is to foster net-zero/low-energy installations through a combination of energy efficiency, utilization of waste energy including co- and tri-generation, and energy from renewable resources. There are several federal regulations, executive orders, and internal orders related to the energy consumption and sustainability of buildings. The most important of these initiatives related to energy are summarized in the next three paragraphs.

The 2005 Energy Policy Act (EPAct) (U.S. Congress 2005) requires that federal facilities be built to achieve at least a 30% energy savings over the 2004 International Energy Conservation Code (ICC 2004) or ASHRAE Standard 90.1-2004 (ASHRAE 2004a) as appropriate and that energy-efficient designs must be cost effective throughout the life cycle. From 2006–2008, the U.S. Army Corps of Engineers (ACE) collaborated with the National Renewable Energy Laboratory (NREL), and the ASHRAE Military Technology Group to develop baseline and target energy budgets and design guides with a prescriptive path for achieving EPAct 2005 energy goals. The results of this study were published in the Whole Building Design Guide Web site and as a series of ASHRAE technical papers (Deru et al. 2009; Herron et al. 2009; and Zhivov et al. 2009).

The ACE Engineering Construction Bulletin (ECB) 2010-14 includes a requirement to reduce building site energy

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consumption with new construction and major renovation projects by 40% compared to a facility designed in accordance with ASHRAE Standard 90.1-2007 (ASHRAE 2007), which supersedes the requirements for EPAct (ACE 2010).

The U.S. Energy Independence and Security Act of 2007 (EISA) (U.S. Congress 2007) mandates that new federal buildings and federal buildings undergoing major renovations shall be designed so that consumption of energy generated on- or off-site using fossil fuels is reduced—as compared with such energy consumption by a similar building in the 2003 Commercial Building Energy Consumption Survey (CBECS) for the building type specified—by 55% in 2010, 80% by 2020, and 100% by 2030. This raises the bar considerably from the EPAct 2005 and ACE ECB 2010-14. The EISA requirement is not a comparison between a baseline and an energy-efficient simulation, but a direct comparison with the actual results from the final simulation with the EISA target.

The ACE Engineering Research and Development Center-Construction Engineering Research Laboratory (ERDC-CERL), in collaboration with U.S. Department of Energy's (DOE) NREL, academia, and private sector subject matter experts, recently completed an energy study (ACE 2011) which evaluated potential site and source energy use reduction in new Army buildings. The building types studied included an Unaccompanied Enlisted Personnel Housing (UEPH or barracks), a brigade headquarters (administrative building), a company operation facility, a maintenance facility, and a dining facility (DFAC). As a reference, the study used recent building designs developed by ACE in collaboration with industry experts and architectural/engineering firms. The study was conducted for representative locations in all 15 DOE identified climate zones in the United States with building designs adapted to these climatic conditions.

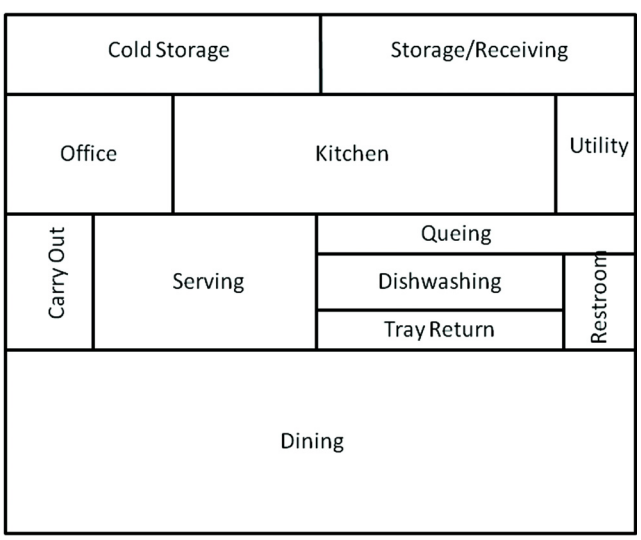

Figure 1 *Thermal zoning for the DFAC (Courtesy of Rois Langner).*

This paper presents the results of the energy analysis for a typical Army dining facility. It discusses the combinations of energy-efficiency measures used to reduce both internal and external loads on the building and overall energy use. It shows potential energy savings both on a building site basis and energy source basis. It also shows further energy use reduction opportunities when energy improvements are made and when a building is considered as a part of a cluster or community.

BUILDING DESCRIPTION

The U.S. Army has developed standard designs for its dining facilities, based on the number of meals served in a single meal time. These range in size from 251–500, 501–800, 801–1300, and 2600 meals. Most of the building elements scale with the size of the building. However, the kitchen is nearly the same size across all models to fit a standard set of food preparation equipment. The basic design is a single-story building with spaces for food preparation, serving, dining, dishwashing, carry-out food, employee breaks, storage, and utilities. The design must facilitate feeding the maximum number of meals in an hour and a half. Many short orders are cooked in the serving area on broilers or griddles, range tops, and in ovens. Several ventilation hoods are required to service the cooking equipment. A walk-in cooler, a walk-in freezer, and several reach-in refrigerators and other ancillary equipment are similar to those typically found in commercial food service. This report focuses on the dining facility sized to serve between 801 and 1300 meals during a 1 ½ hour serving period.

The thermal model of the DFAC used for this study is a one story, 23,384 ft^2 (2172 m^2) building shown in Figure 1 with the rendered view of the energy simulation model shown in Figure 2. The DFAC model was based on drawings for the 108th ADA Complex – DFAC in Fort Bragg, North Carolina.

The building is occupied seven days a week starting with food preparation at 3 a.m. and finishing with the cleaning at 8 p.m. There are three high-occupancy periods for breakfast (0600–0800 hours), lunch (1100–1300 hours), and dinner (1600–1800 hours). The baseline building model parameters are summarized in Table 1, a summary of the

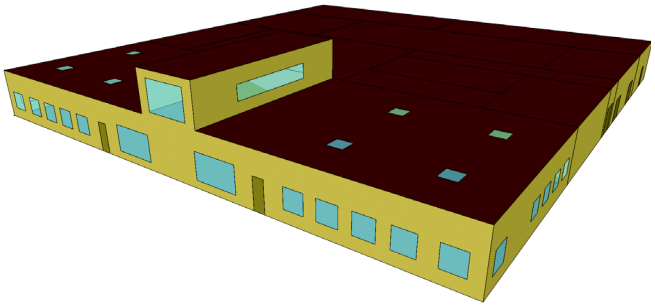

Figure 2 *Rendering of the energy simulation model for the DFAC (Courtesy of Rois Langner).*

zones and thermal loading is listed in Table 2, and the baseline envelope parameters are defined in Table 3.

LOCATIONS

Fifteen locations were selected to represent the various climate zones in the United States. The locations were selected as representative cities for each climate zone by the Pacific Northwest National Laboratory (Briggs et al. 2003). We selected Colorado Springs for climate zone 5B instead of Boise, Idaho to more closely align with the installations at Fort Carson in Colorado Springs. The 15 climate zones and the cities with the heating and cooling degree days (HDD and CDD) used to represent the climate zones are shown in Table 4.

ENERGY MODELING

The energy simulations were completed with the NREL analysis platform and EnergyPlus 5.0 (DOE 2010). A baseline model was developed from drawings for the 108th ADA Complex – DFAC in Fort Bragg, North Carolina, with envelope and energy system parameters set to values from Standard 90.1-2007 for each location. Unfortunately, there were no measured energy data available from a similar DFAC to use for calibrating the energy model. The energy model inputs were reviewed carefully to check for alignment with the drawings and the results were compared with previous energy modeling efforts to ensure that the model was an accurate representation of the real building. Energy-efficiency measures (EEMs) were analyzed and the best combinations were selected for each climate zone. The list of EEMs to consider was developed in consultation with the Army engineers and subject matter experts. The methods used to model the building and the systems are discussed in the following sections.

ENERGY-EFFICIENCY MEASURES

A previous study completed by CERL and NREL to determine solutions for 30% site energy savings for the Energy Policy Act of 2005 served as the starting point for this analysis (Deru et al. 2009). EEMs considered for EISA 2007 analyzed the building envelope construction, lighting, and plug load design and power densities, as well as heating, ventilation, and air-conditioning strategies. The final list of applied EEMs is summarized in Table 5.

Envelope

The baseline building envelope features are modeled as steel frame wall construction, roof insulation entirely above deck, and door and fenestration types that meet the requirements of ASHRAE Standard 90.1-2007. Door, window, and skylight size and distribution match the drawings for the Fort Bragg design. This design has a skylight-to-floor area (SFA) ratio in the dining area of 1.7% and a roof monitor in the middle of the dining area to provide further daylighting in the space.

To enhance the daylighting in the building, the SFA fraction was increased to 3% over office, dining, and servery areas, following recommendations found in the 30% Advanced Energy Design Guide for Small Retail Buildings (ASHRAE 2004b). Daylighting controls were not included in the baseline model. However, the energy-efficient models utilize daylighting controls that are dimmable to off with a 500 lux minimum set point in all day-lit areas. Fenestration details are listed in Tables 3 and 6. This analysis showed savings from daylighting in all climates, but a more detailed analysis for each space type and climate should be conducted to optimize the designs for overall performance.

Significant energy use reduction by buildings can be achieved by minimizing the impact of the external environment on the building loads for heating, cooling, or both. While the current advanced building practice in the United States is based on ASHRAE Standards 90.1 (2010a) and 189.1 (2010b), the most rigorous standards for building energy efficiency resulting in ultra-low energy buildings are the German Passive House (Passivhaus) standards developed by professors Bo Adamson of Lund University, Sweden, and Wolfgang Feist of the *Institut für Wohnen und Umwelt* (Institute for Housing and the Environment, Germany) (Passivhaus 2011). ERDC-CERL researchers, in collaboration with Georg Zielke, Architekturburo Zielke Passivhauser, and Dr. Berthold Kauffman, Passivhaus Institut, Germany, developed an interpretation of the Passive House characteristics of the building envelope to be applied to U.S. construction specifics and all 15 DOE climate zones (ACE 2011).

Typical Passive House characteristics for central European locations include:

- Airtight building shell ≤ 0.6 air changes per hour @ 50 Pa (0.2 in w.g.) (~0.0006 $m^3/s/m^2$ (0.11cfm/ft^2) of the building envelope area at 75 Pa (0.3 in w.g.) measured by a blower-door test)
- Annual heat requirement ≤ 15 kWh/m^2•year (< 4.75 kBtu/ft^2•year)
- Primary energy ≤ 120 kWh/m^2•year (38.1 kBtu/ ft^2•year)
- Window U-factor ≤ 0.8 W/m^2•K (0.14 Btu/ ft^2•h• °F)
- Ventilation system with heat recovery with ≤ 75% efficiency and low electric consumption @ 0.45 W•h/m^3 (0.43 Btu/ft^3)
- Thermal bridge free construction ≤ 0.01 W/m•K (0.005 Btu/ft•h•°F)

In addition to energy efficiency, improved building insulation and airtightness result in a more stable room temperature between day and night, higher internal wall surface temperature in winter, and lower component internal wall temperature in summer. Higher wall temperatures in the winter reduce the risk that mold or mildew may occur on the internal wall surfaces and improve the quality of life in a building.

Baseline insulation values and window U-factors for Army DFACs are described in Table 3. Table 6 shows the Passive House insulation requirements (R-values) for walls and the roof in different climate conditions used in this study.

LIGHTING

Recommendations to reduce the lighting energy use include various applications of different lighting technologies as well as zone-by-zone control strategies. The control strategies include vacancy, occupancy, and daylighting sensors. Vacancy sensors are manually controlled on, and automatically controlled off when occupants are no longer present in the space. Occupancy sensors have automatic controls for both the on and off settings, and were recommended for the dining, kitchen, corridor, and stairwell areas. Daylighting sensors were also applied in areas where daylighting is accessible. These areas include the dining, servery, and office areas. In each of these areas, the skylight-to-floor area fraction was increased to 3%. Table 7. *Lighting Power Density Reduction, Control, Technologies, and Approach Per ZoneTable 7 shows a summary of the lighting power density (LPD) reduction as well as recommended control strategies, technologies, and lighting approach for each zone. A detailed lighting report for the DFAC can be found in Appendix F of the ACE energy study (ACE 2011).

Plug and Process Loads

Process loads for a commercial kitchen are very large and have a significant impact on the heating, ventilating, and air conditioning (HVAC) and overall building energy use. The 2007 *DOE Buildings Energy Data Book* estimates that the cooking and refrigeration loads in a typical "food service" building is approximately 45% of the total energy use (DOE 2007). Significantly reducing the energy consumption associated with kitchen equipment is a challenging task; however, a number of energy-efficiency measures can be implemented and were considered in this analysis.

Given that there is very little detailed information on the plug and process loads in Army dining facilities, assumptions had to be made in order to include them in our models. The Army supplied the standard layout of the kitchen, the equipment specification sheets, a 21-day menu, and the number of meals served per meal. The cooking energy for each piece of equipment was then estimated based on the menus, and aggregated schedules were created for each space including warm-up and idle times.

Recommendations for using a combination of best-in-class, high-efficiency, gas and electric kitchen equipment were made based on the current kitchen design. The use of high-efficiency equipment reduces the energy demand of the kitchen area and potentially reduces the amount of heat entering the space. For instance, induction stove tops generate heat directly in the cookware, mitigating wasted energy from a heating coil or gas burner that is not directly interacting with the cookware. The heat is generated by an induced electric current, which enables the unit to monitor when a pot or pan is in contact with the stove top. When cookware is removed, the unit turns off immediately. As a result, the amount of heat generated at the stove top is less than traditional appliances, and exhaust and makeup air requirements can be reduced—especially when paired with proper exhaust hood design, layout, and flow control.

A second design specifying all-electric kitchen equipment was also considered. This design uses less site energy than the combination of energy-efficient gas and electric equipment and positions the facility to have the flexibility to operate using 100% renewable electricity. Table 8 describes the equipment power density for each zone of the baseline kitchen design, the energy-efficient gas and electric kitchen design, and the energy-efficient all-electric kitchen design.

Selecting the best kitchen equipment to meet mission needs can be a difficult task, and selecting the most efficient equipment while still meeting the mission needs is even more difficult. Hiring a commercial kitchen consultant with experience in low-energy design can be very beneficial. The kitchen consultant for this project provided several alternatives for the major pieces of food preparation equipment. Tables 9 and 11 show equipment specifications in inch-pound (IP) and System International (SI) units for the best-in-class and two alternatives equipment type options. Tables 10 and 12 show the gas appliances that were replaced by equivalent electric ones for the all-electric kitchen design in IP and SI units. The high-efficiency all-electric kitchen also included the electric appliances listed in Tables 9 and 11.

The modeling results show that the kitchen and refrigeration equipment account for a significant percentage of total building energy consumption. Table 13 illustrates that, for most climate zones, the kitchen and refrigeration equipment represent close to 50% or more of the total site energy. For most of the climate zones, this fraction of total energy use increases for the energy-efficient designs because other EEMs were more effective at reducing energy use associated with the rest of the building. Figure 3 shows the detailed breakout of end-use data for the three cases for climate zone 1A.

Infiltration

ACE Engineering Construction Bulletin 2009-29 states that the air leakage rate of a building envelope shall not exceed 0.25 cfm/ft^2 (0.00127 m^3/s/m^2) at a pressure differential of 0.3 in w.g. (75 Pa) for new and renovation construction projects (ACE 2009). In 2010, more than 200 buildings were constructed and renovated to meet or exceed this requirement (achieving airtightness of 0.10 cfm/ft^2 (0.0005 m^3/s/m^2) or better was not uncommon) at no or minimum additional cost. Based on this experience and industry consensus, the level for airtightness for this study was lowered to 0.15 cfm/ft^2 (0.00076 m^3/s/m^2) at a pressure differential of 0.3 in w.g. (75 Pa).

Exhaust Hoods and Ventilation

The outdoor air requirements for a large dining facility such as those for the Army represent a significant portion of the overall energy use. The outdoor air requirements for the high volume of occupants during meal times and the makeup air for the exhaust hoods are both significant. The peak outdoor air requirement for this building is approximately

10,000 cfm (4.72 m^3/s) and the peak exhaust flow for the baseline building design is over 31,000 cfm (14.63 m^3/s). Some of the 10,000 cfm (4.72 m^3/s) outdoor air can be transferred to the food preparation zones to off-set some of the makeup air requirements for the exhaust hoods, but the total air flow requirement is still very large.

The high-efficiency and all-electric appliances will not significantly reduce exhaust air requirements as stand-alone EEMs. However, adding side panels and changing hood style will allow for significant reductions in exhaust and makeup air flow rates. Modifying exhaust hood design to include side and back panels directs exhaust air more effectively into the exhaust hood aperture, reducing the need for higher exhaust and makeup air flow rates. In return, this reduces the heating, cooling, and fan energy required for the space. Close proximity hoods should be considered for low-profile appliances (e.g., griddles and fryers). With a close proximity hood, the hood aperture is positioned close to the cooking surface and can more effectively exhaust air from the space with a lower flow rate. Various flow control strategies can also be applied to further reduce the total exhaust flow rates. The most energy-efficient controls include temperature and particulate sensors to modulate air flow based on the amount of heat, smoke, and grease that is discharged from the appliance. The control strategies must be linked to the makeup air units to realize the full energy savings.

It is common for the makeup air units to introduce the air at the face of the exhaust hood through a perforated plate. However, the most efficient method is to provide the air at a low velocity further away from the exhaust hood through ceiling-mounted perforated plate or fabric diffusers. The makeup air units should be located at least 10 feet from the hood, if possible, to provide the best capture of cooking effluent.

The flow rates and exhaust fan characteristics for the baseline and efficient kitchen designs are described in Tables 14 and 15. The total exhaust flow rate was reduced by 42% in the efficient design, and the total fan power was reduced by nearly 80% as a result of the cubic relationship between fan power and flow.

HVAC Systems

The current HVAC design for the building specifies rooftop units with standard efficiency constant volume fans, hot-water heating coils, and direct expansion cooling coils with efficiencies of approximately 3.3 coefficient of performance (COP). In the energy-efficient models, the HVAC design and systems remained the same; however, the efficiencies were improved. The cooling coil COP was increased from 3.3 to 3.85 to reflect current high-efficiency rooftop units. Fan efficiencies were increased similarly to meet these rooftop unit specifications.

Makeup air units and exhaust fans are located in the kitchen, servery, and carry out zones. As mentioned in the previous section, makeup air and exhaust hood flow rates were reduced by assuming a flow reduction based on the effects of adding side and back panels to the exhaust hoods.

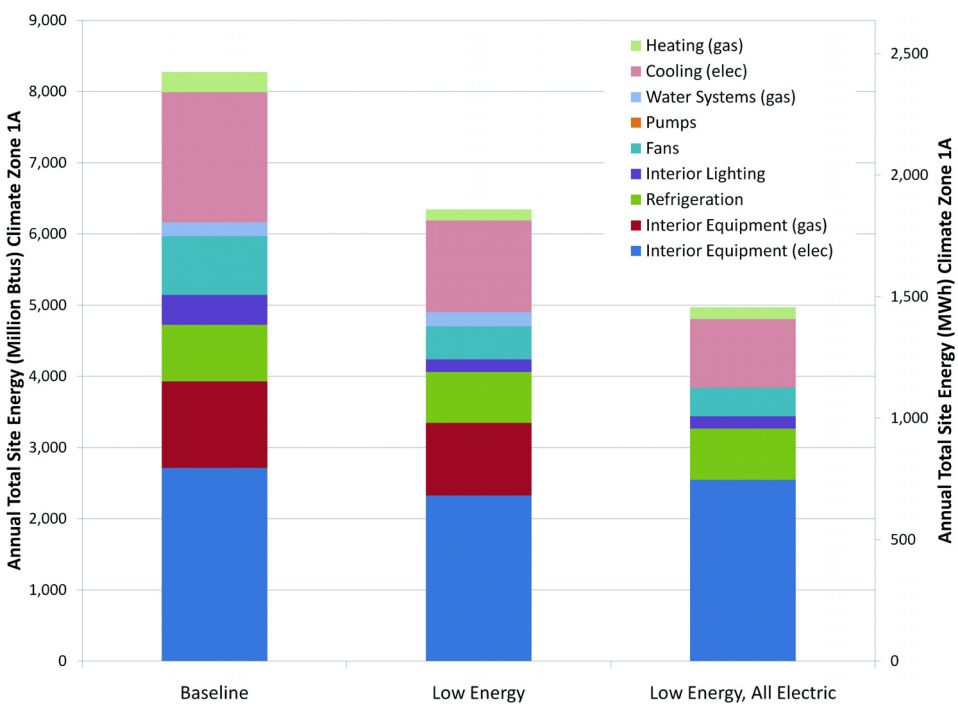

Figure 3 *Total site energy consumed by end use for climate zone 1A.*

Percent flow reduction for each exhaust fan is noted in Table 15. Demand control ventilation strategies based on temperature and particulates in the air from smoke or grease were applied to the exhaust hoods to further reduce exhaust flow rates.

Passive House insulation levels were recommended for climate zones 4A to 8. Adhering to Passive House specifications and a tighter envelope construction also reduced the infiltration rates. These envelope improvements contribute to an overall reduction in heating and cooling loads for the building.

Refrigeration

The current design for the kitchen area includes two walk-in freezers and two walk-in coolers. The efficiency measures considered were to increase the efficiency of the compressor/condensers and reduce the lighting power. Light-emitting diodes (LEDs) are recommended to replace the currently specified fluorescent fixtures. LEDs have proven to provide better quality light and controllability in cold temperatures. The reach-in refrigerators are included in the plug and process loads.

Other refrigeration efficiency measures that were not modeled but should be implemented in future designs include strip curtains and door alarms for the walk-in coolers and freezers. The strip curtains buffer heat loss emitted from walk-ins when the walk-in door is open. Door alarms alert an employee that the walk-in door has been left open for excessive periods of time.

ENERGY BUDGETS

The annual energy use intensity (EUI) for the baseline DFAC in each climate was determined by EnergyPlus and compared to EUI data for a similar building type measured by the Commercial Buildings Energy Consumption Survey (CBECS) 2003 (EIA 2007) as required by EISA 2007. The EUIs from CBECS are based on the median value for each building category (Sharp 2010). The median source energy EUIs were calculated with conversion factors of 11.4 kBtu/kWh (12.0MJ/kWh) for electricity and 1.047 kBtu/kBtu for natural gas. The EUIs for each climate zone were calculated by adjusting the CBECS median values with climate zone multipliers for each building type from energy simulations of the DOE Reference Building Models (Deru et al. 2011).

The fast food CBECS building category was chosen for comparison with the DFAC. The target energy budget is 65% energy savings over the baseline CBECS source EUI values (also referred to as the 2015 EISA 2007 target). Site and source EUIs for the baseline and target energy budgets are shown in Table 16 for each climate zone. A breakdown of the baseline site energy consumption by end use is shown in Figure 4 for each climate zone.

RESULTS

Energy efficiency measures (EEMs) considered for the DFAC were analyzed individually, and EEMs with the highest

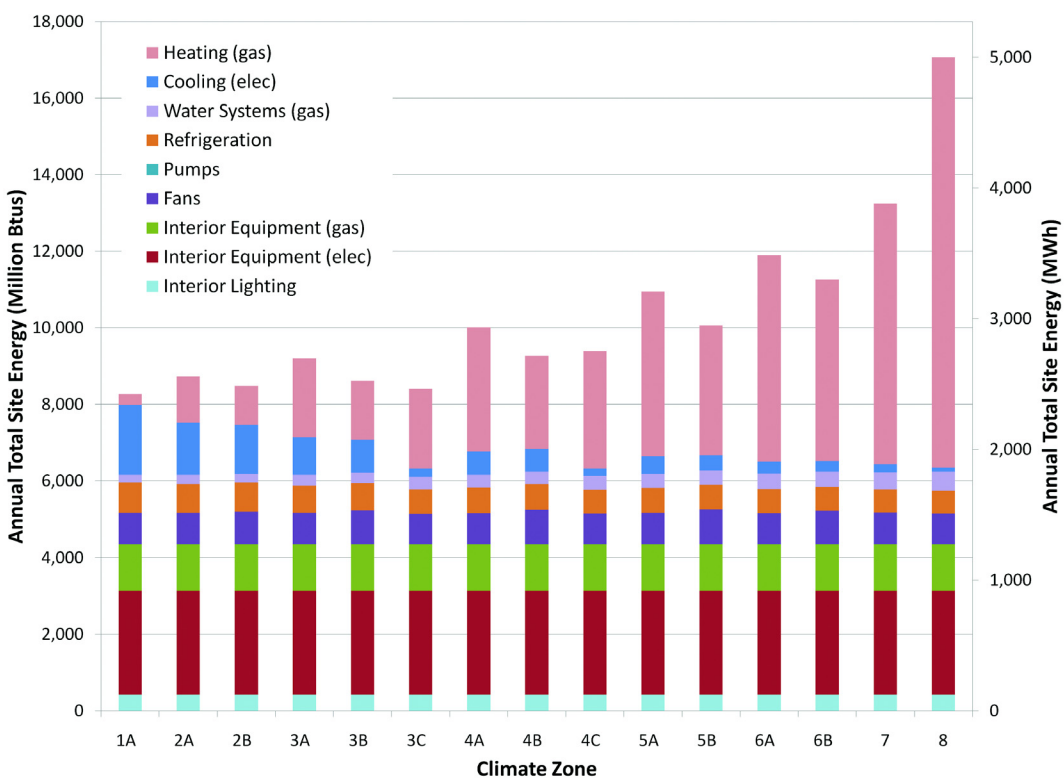

Figure 4 *Energy use by end use for the baseline building.*

energy savings were chosen to be included in a low-energy package (Package 1) for the DFAC with high-efficiency gas and electric kitchen equipment for each climate zone. A second package (Package 2) was considered, exploring the effects of using all-electric kitchen equipment. A description of the two packages is described in Table 17 and results showing energy use intensity and percent savings are presented in Tables 18 and 19. Note that these results assume that each DFAC utilizes a gas-fired boiler for heating and an electric chiller for cooling.

Implementation of the EEMs in Package 2, including reduced infiltration, improved HVAC efficiencies, demand-controlled makeup air, improved kitchen exhaust hoods, and the use of all-electric kitchen cooking equipment is recommended for all climate zones. Use of Passive House-level envelope insulation values is recommended for DFACs in climate zones 4A–8. Figures 5 and 6 graphically display site energy by end use for the two low-energy packages compared to the baseline for each climate zone. Figure 5 emphasizes the savings associated with heating, cooling, and fan energy. This is attributed to the reduction in exhaust and makeup air flow rates as well as the Passive House insulation standards. The aggressive lighting power density reduction strategy presented in Table 7 also shows notable energy savings.

Additional energy savings are seen as a result of reduced interior equipment load including those associated with kitchen equipment. Figure 5 shows the savings between the baseline standard efficiency equipment and the low-energy high-efficiency equipment. Figure 6 shows the savings between the baseline and the all-electric kitchen equipment case.

Source energy usage for the recommended DFAC designs for each climate zone was calculated using the conversion of 11.4 kBtu/kWh for electricity (12.0 MJ/kWh) and 1.047 kBtu/kBtu for gas. The source energy use intensity for the recommended low energy DFAC in each climate zone was compared to source energy data from CBECS 2003 for "fast food" building types. This comparison is shown in Table 20.

A cogeneration (cogen) system was evaluated as an additional EEM to see the effects of simultaneously generating both electricity and heat to further reduce fuel consumption. The cogen system was not included in the whole building energy simulation, but was modeled post-simulation with an electric and hot-water multiplier. The multipliers assumed 37% electric efficiency and 80% overall efficiency and all of the thermal and electric energy was used by the building. The multiplier values used were 1.521 kBtu/kBtu for electricity and 1.126 kBtu/kBtu for hot water and were derived from values associated with the GE Jenbacher combined heat and power (CHP) system. Source energy savings associated with the cogen system are referenced in the last column of

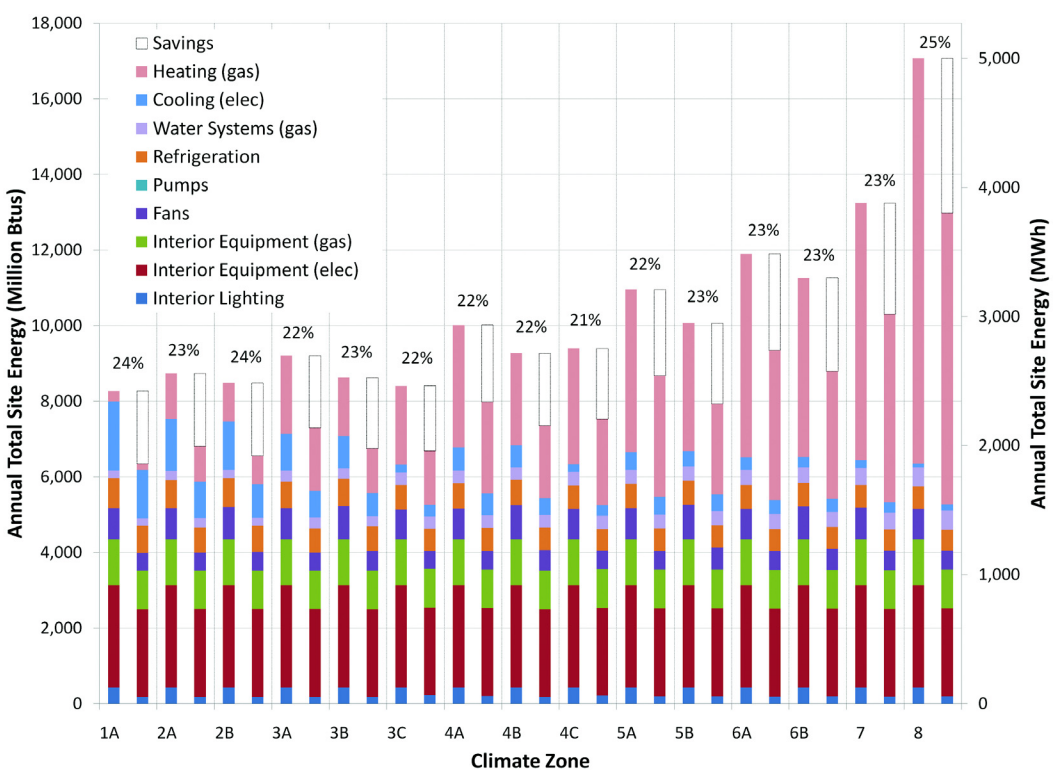

Figure 5 *Comparison of site energy by end use for Low-Energy Package 1 to the baseline building.*

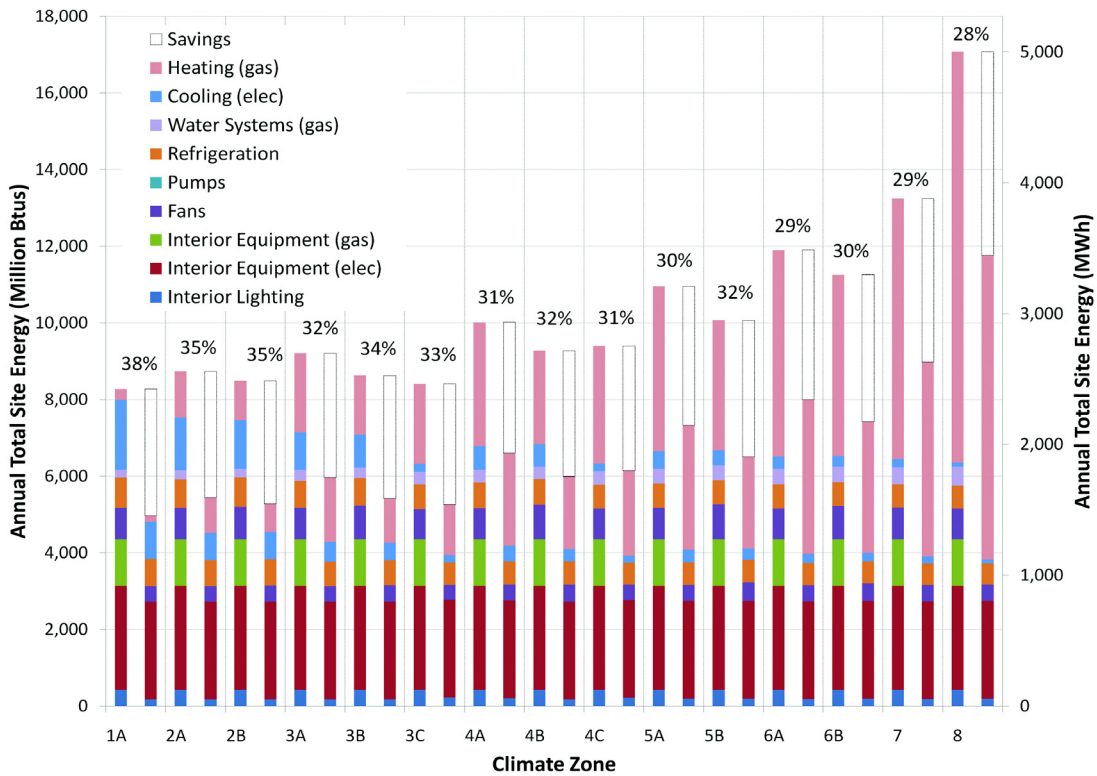

Figure 6 *Comparison of site energy by end use for Low-Energy Package 2 to the baseline building.*

Table 20. Note that the cogen system EEM assumed that all of the thermal and electric energy was consumed. This assumption is aggressive, for it is rare that a single building can use all of the thermal energy produced. A cogen system may be more effective for a building or network of buildings that has a diversification of loads and high operating hours, which would maximize heat and energy consumption.

CONCLUSION

This study showed that the use of best-in-class, all-electric kitchen equipment, improved ventilation and exhaust systems, advanced lighting strategies, efficient HVAC systems, and aggressive envelope strategies results in significant energy savings (site and source) in new Army dining facilities in all climates. Source energy consumption was reduced by 37%–42% depending on the climate zone, which is not sufficient to meet the current (55%) or future (65% in 2015, 100% in 2030) required reduction in source (fossil fuel) energy mandated by EISA 2007. Applying cogeneration technology in addition to the building EEMs identified above results in a reduction of source energy by 57%–73% which will nearly satisfy the 2015 source reduction requirements (65%) of EISA 2007 in all climate zones. However, this is not enough to meet future source reduction requirements.

Further savings may be achieved by simultaneously optimizing the life-cycle cost and energy performance of the whole building, which would drive the solutions to the most efficient and lowest cost results. Furthermore, some of the building features were fixed, such as the building form and window geometries. Allowing for variation in these components could lead to additional energy savings.

This building will always struggle to be a very low or net zero energy building due to the fact that a large fraction of the DFAC energy consumption results from the DFAC "mission" load of the kitchen equipment. Significant use of renewable energy sources will be required in Army DFACs to comply with future EISA 2007 source energy reduction goals.

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Table 1. Building Description

Building Component	Baseline Building Model
Area	23,384 ft^2 (2172 m^2)
Floors	1
Aspect ratio	1.1
Fenestration type	Standard 90.1-2007 (ASHRAE 2007)
Wall construction	Steel frame
Wall insulation	Standard 90.1-2007 steel frame
Roof construction	Flat built-up roof
Roof insulation	Standard 90.1-2007 insulation entirely above deck
Roof albedo	0.3
Infiltration	0.4 cfm/ft^2 @ 0.3 in w.g. (2.0 L/s·m^2 @ 75 Pa)
Temperature setpoints	68ºF (20°C) heating; 78ºF (25.6°C) cooling Kitchen: 68ºF (20°C) heating; 80ºF (26.7°C) cooling set back/up to 55ºF (12.8°C) heating; 90ºF (32.2°C) cooling
HVAC	PSZ with DX-AC (3.3 COP) and gas furnace (0.8 Et);
DHW	Natural gas boiler (0.8 Et)

Table 2. Building Zones and Internal Loads

Zone	Area ft^2 (m^2)	Volume ft^3 (m^3)	Max People	Lights W/ft^2 (W/m^2)	Electric Equipment W/ft^2 (W/m^2)	Gas Equipment W/ft^2 (W/m^2)
Dining	7400 (687)	453,219 (12,834)	600	0.7 (7.2) 4958 W	0.9 (10.2) 7026 W	
Carry out	990 (92)	13,860 (392)	6	1.4 (15.0) 1,376 W	29.3 (315.2) 28,990 W	
Servery	2880 (268)	40,320 (1142)	50	1.5 (16.3) 4368 W	27.1 (292.1) 78,154 W	1.4 (15.0) 4013 W
Tray Return	560 (52)	7840 (222)	35	2.2 (23.4) 1215 W		
Queing	620 (58)	8680 (246)	35	0.7 (7.4) 422 W		
Restroom	770 (72)	10,780 (305)	6	2.5 (26.8) 1917 W		
Kitchen	3060 (284)	42,840 (1213)	12	1.0 (11.1) 3152 W	13.5 (144.9) 41,193 W	46.9 (505.3) 143,648 W
Utility	756 (70)	10,584 (300)	0	1.4 (14.6) 1021 W		
Cold Storage	1998 (186)	27,972 (792)	5	0.5 (5.3) 999 W	7.8 (84.5) 15,677 W	
Storage Receiving	1998 (186)	27,972 (792)	5	0.7 (7.9) 1479 W		
Office	1512 (140)	21,168 (599)	6	0.8 (9.1) 1285 W	0.7 (8.1) 1134 W	
Dishwashing	840 (78)	11,760 (333)	5	1.2 (13.1) 1025 W	53.5 (575.5) 44,911 W	
Total	**23,384 (2172)**	**676,998 (19,170)**	**765**	**23,226 W**	**217,086 W**	**147,662 W**

Table 3. Envelope Baseline Values (90.1-2007 [ASHRAE 2007])

Zone	Wall Ins. $ft^2 \cdot h \cdot {}^\circ F/Btu$ ($m^2 \cdot C/W$)	Roof Ins. $ft^2 \cdot h \cdot {}^\circ F/Btu$ ($m^2 \cdot C/W$)	Slab Ins. $ft^2 \cdot h \cdot {}^\circ F/Btu$ ($m^2 \cdot C/W$)	Skylights		Windows	
				U-factor Btu/ $ft^2 \cdot h \cdot {}^\circ F$ ($W/m^2 \cdot C$)	SHGC	U-factor Btu/$ft^2 \cdot h \cdot {}^\circ F$ ($W/m^2 \cdot C$)	SHGC
1A	13 (2.29)	15 ci (2.64 ci)	NR	1.98 (11.24)	0.19	1.20 (6.81)	0.25
2A & B	13 (2.29)	20 ci (3.52 ci)	NR	1.98 (11.24)	0.19	0.70 (3.97)	0.25
3A & B	13 + 3.8 ci (2.29 + 0.67 ci)	20 ci (3.52 ci)	NR	1.17 (6.64)	0.19	0.60 (3.41)	0.25
3C	13 + 3.8 ci (2.29 + 0.67 ci)	20 ci (3.52 ci)	NR	1.17 (6.64)	0.19	0.60 (3.41)	0.25
4A, B, & C	13 + 7.5 ci (2.29 + 1.32 ci)	20 ci (3.52 ci)	NR	1.17 (6.64)	0.39	0.50 (2.84)	0.40
5A & B	13 + 7.5 ci (2.29 + 1.32 ci)	20 ci (3.52 ci)	NR	1.17 (6.64)	0.39	0.45 (2.56)	0.40
6A & B	13 + 7.5 ci (2.29 + 1.32 ci)	20 ci (3.52 ci)	10 (1.76)	1.17 (6.64)	0.49	0.45 (2.56)	0.40
7	13 + 7.5 ci (2.29 + 1.32 ci)	20 ci (3.52 ci)	15 (2.64)	1.17 (6.64)	0.64	0.40 (2.27)	0.45
8	13 + 7.5 ci (2.29 + 1.32 ci)	20 ci (3.52 ci)	15 (2.64)	0.98 (5.56)	None	0.40 (2.27)	0.45

ci: continuous insulation
NR: no recommendation
SHGC: solar heat gain coefficient
U-factor: thermal transmittance

Table 4. Climate Zones and Cities Used for Simulations

Climate Zone	City	HDD Base 65ºF (18ºC)	CDD Base 50ºF (10ºC)
1A	Miami, FL	200 (111)	9474 (5263)
2A	Houston, TX	1599 (888)	6876 (3820)
2B	Phoenix, AZ	1350 (750)	8425 (4681)
3A	Memphis, TN	3082 (1712)	5467 (3037)
3B	El Paso, TX	2708 (1504)	5488 (3049)
3C	San Francisco, CA	3016 (1676)	2883 (1602)
4A	Baltimore, MD	4707 (2615)	3709 (2061)
4B	Albuquerque, NM	4425 (2458)	3908 (2171)
4C	Seattle, WA	4908 (2727)	1823 (1013)
5A	Chicago, IL	6536 (3631)	2941 (1634)
5B	Colorado Springs, CO	6415 (3564)	2312 (1284)
6A	Burlington, VT	7771 (4317)	2228 (1238)
6B	Helena, MT	7699 (4277)	1841 (1023)
7	Duluth, MN	9818 (5454)	1536 (853)
8	Fairbanks, AK	13,940 (7744)	1040 (578)

Table 5. Building Description and EEM Summary

Building Component	Baseline Building Model	Efficient Building Model
Envelope	ASHRAE 90.1-2007-compliant envelope constructions (ASHRAE 2007)	Passive House insulation and Passive House-rated windows applied to whole building. Reduced infiltration rates from 0.4 cfm/ft^2 (0.002 m^3/s/m^2) to 0.15 cfm/ft^2 (0.00076 m^3/s/m^2)
Lighting	Lighting power densities calculated from drawings	Lighting power density reduction and improved control strategies
Daylighting	No daylighting controls	Increased skylight-to-floor area (SFA) fraction to 3% over office, dining, and servery areas and added daylighting controls with 50 fc (500 lux) setpoint
HVAC	Standard efficiency CV fans Cooling coil efficiencies: 3.3 (COP) Makeup air units in the kitchen, servery, and carry out Exhaust fans in the kitchen, servery, and carry out	Increased fan efficiencies Cooling coil efficiencies increased to 3.85 (COP) Reduced flow in exhaust hoods by 1) adding side panels (~26% reduction) and 2) adding side panels with demand controls (~41% reduction)
Refrigeration	4 walk-in freezers/coolers	Increased efficiency of units and lower lighting power density
Food Prep. Equipment	Equipment power calculated from drawings and schedules taken from EPAct 2005 study	Best-in-class kitchen equipment All-electric equipment option also considered

Table 6. Efficient Envelope Parameters—Passive House Insulation Specifications

Zone	Wall Ins. $ft^2 \cdot h \cdot °F/Btu$ ($m^2 \cdot C/W$)	Roof Ins. $ft^2 \cdot h \cdot °F/Btu$ ($m^2 \cdot C/W$)	Slab-On-Grade (Unheated) $ft^2 \cdot h \cdot °F/Btu$ ($m^2 \cdot C/W$)	Slab-On-Grade (Heated) $ft^2 \cdot h \cdot °F/Btu$ ($m^2 \cdot C/W$)	Skylights		Windows	
					U-factor $Btu/ft^2 \cdot h \cdot °F$ ($W/m^2 \cdot C$)	SHGC	U-factor $Btu/ft^2 \cdot h \cdot °F$ ($W/m^2 \cdot C$)	SHGC
1A	19 + 7.5 ci (3.34 + 1.32 ci)	25 (4.4)	NR	7.5 for 12 in.+ 5 ci (1.32 for 0.3 m + 0.88ci)	1.36 (7.72)	0.19	0.26 (1.48)	0.25
2A & B	19 + 15 ci (3.34 + 2.64 ci)	30 (5.28)	NR	10 for 24 in.+ 5 ci (1.76 for 0.6 m + 0.88ci)	1.36 (7.72)	0.19	0.26 (1.48)	0.25
3A & B	19 + 20 ci (3.34 + 3.52 ci)	35 (6.16)	10 for 24 in. (1.76 for 0.6 m)	15 for 24 in.+ 5 ci (2.64 for 0.6 m + 0.88 ci)	0.69 (3.92)	0.19	0.26 (1.48)	0.39
3C	19 + 10 ci (3.34 + 1.76 ci)	25 (4.4)	NR	15 for 24 in.+ 5 ci (2.64 for 0.6 m + 0.88 ci)	0.69 (3.92)	0.19	0.26 (1.48)	0.39
4A & B	19 + 25 ci (3.34 + 4.4 ci)	45 (7.92)	15 for 24 in. (2.64 for 0.6m)	20 for 24 in.+ 5 ci (3.52 for 0.6m + 0.88 ci)	0.69 (3.92)	0.34	0.18 (1.02)	0.39
4C	19 + 20 ci (3.34 + 3.52 ci)	35 (6.16)	10 for 24 in. (1.76 for 0.6 m)	20 for 24 in.+ 5 ci (3.52 for 0.6 m + 0.88 ci)	0.69 (3.92)	0.34	0.18 (1.02)	0.39
5A & B	19 + 30 ci (3.34 + 5.28 ci)	55 (9.68)	20 for 24 in. (3.52 for 0.6 m)	20 for 48 in.+ 5ci (3.52 for 1.2 m + 0.88 ci)	0.69 (3.92)	0.39	0.18 (1.02)	0.49
6A & B	19 + 40 ci (3.34 + 7.04 ci)	70 (12.32)	20 for 48 in. (3.52 for 1.2 m)	20 for 48 in.+ 5 ci (3.52 for 1.2 m + 0.88 ci)	0.69 (3.92)	0.49	0.18 (1.02)	0.49
7	19 + 50 ci (3.34 + 8.8 ci)	80 (14.08)	20 for 48 in.+ 5ci (3.52 for 1.2 m + 0.88ci)	25 for 48 in.+ 5 ci (3.52 for 1.2 m + 0.88 ci)	0.69 (3.92)	0.64	0.18 (1.02)	0.49
8	19 + 60 ci (3.34 + 10.56 ci)	90 (15.84)	20 for 48 in.+ 5ci (3.52 for 1.2 m + 0.88ci)	25 for 48 in.+ 5 ci (3.52 for 1.2 m + 0.88 ci)	0.58 (3.29)	0.64	0.18 (1.02)	0.49

Table 7. Lighting Power Density Reduction, Control, Technologies, and Approach Per Zone

Zone	Area ft^2 (m^2)	Baseline LPD W/ft^2 (W/m^2)	Energy Efficient LPD W/ft^2 (W/m^2)	Control Strategy	Technologies	Lighting Approach
Dining	7400 (687)	0.67 (7.21)	0.50 (5.38)	Occupancy and daylight	Linear fluorescent, CFL, ceramic metal halide, LED	Overhead general, wall wash/perimeter lighting
Carry out	990 (92)	1.39 (14.96)	0.65 (7.00)	Vacancy	Linear fluorescent	Overhead general lighting
Servery	2880 (268)	1.52 (16.36)	0.70 (7.53)	Daylight	Linear fluorescent, CFL, ceramic metal halide, LED	Overhead general, task, adjustable accent lighting
Tray Return	560 (52)	2.17 (23.36)	0.50 (5.38)	Occupancy	Linear fluorescent	Overhead general lighting
Queing	620 (58)	0.68 (7.32)	0.50 (5.38)	Occupancy	Linear fluorescent	Overhead general, wall wash/perimeter lighting
Restroom	770 (72)	2.49 (26.80)	0.80 (8.61)	Vacancy	Linear fluorescent, CFL, LED	Overhead general, wall wash/perimeter lighting
Kitchen	3060 (284)	1.03 (11.09)	0.65 (7.00)	Occupancy	Linear fluorescent	Overhead general lighting
Utility	756 (70)	1.35 (14.53)	0.70 (7.53)	Vacancy	Linear fluorescent	Overhead general lighting
Cold Storage	1998 (186)	0.50 (5.38)	0.50 (5.38)	Vacancy	Linear fluorescent	Overhead general lighting
Storage/ Receiving	1998 (186)	0.74 (7.97)	0.70 (7.53)	Vacancy	Linear fluorescent	Overhead general, adjustable accent lighting
Office	1512 (140)	0.85 (9.15)	0.85 (9.15)	Vacancy and daylight	Linear fluorescent, LED	Overhead ambient, task lighting
Dishwashing	840 (78)	1.22 (13.13)	0.65 (7.00)	Vacancy	Linear fluorescent	Overhead general lighting
Total	**23,384 (2,172)**	**23.208 W**	**14,313 W**			

Table 8. Plug and Process Load Power Density Per Zone

Zone	Area ft^2 (m^2)	Baseline Gas and Electric Kitchen Equipment W/ft^2 (W/m^2)	Energy-Efficient Gas and Electric Equipment W/ft^2 (W/m^2)	Energy-Efficient All-Electric Kitchen Equipment W/ft^2 (W/m^2)
Dining	7400 (687)	0.95 (10.23)	0.95 (10.23)	0.95 (10.23)
Carry out	990 (92)	29.28 (315.18)	14.14 (152.21)	14.14 (152.21)
Servery	2880 (268)	28.53 (307.10)	27.15 (292.25)	25.75 (277.18)
Tray Return	560 (52)			
Queing	620 (58)			
Restroom	770 (72)			
Kitchen	3060 (284)	60.41 (650.27)	48.25 (519.38)	17.09 (183.96)
Utility	756 (70)			
Cold Storage	1998 (186)	7.85 (84.50)	7.85 (84.50)	7.85 (84.50)
Storage/Receiving	1998 (186)			
Office	1512 (140)	0.75 (8.07)	0.50 (5.38)	0.50 (5.38)
Dishwashing	840 (78)	53.47 (575.57)	64.06 (689.56)	64.34 (692.57)
Total	**23,384 (2172)**	**364,771 W**	**317,116 W**	**217,970 W**

Table 9. High-Efficiency Kitchen Equipment Specifications (IP units)

Equipment	Best-in-Class				Alternate 1				Alternate 2			
	Eff.	Energy	Capacity	Water	Eff.	Energy	Capacity	Water	Eff.	Energy	Capacity	Water
Ice Machine		4.00 kWh/ 100 lb	1030 lb/d	12 gal/100 lb		4.12 kWh/ 100 lb	1120 lb/d	12 gal/ 100 lb		4.8 kWh/ 100 lb	1120 lb/d	12 gal/ 100 lb
Refrigerator, Reach-In, 25 ft^3		2.64 kWh/d				2.71 kWh/d				2.64 kWh/d		
Refrigerator, Reach-in, 52 ft^3		4.25 kWh/d				4.51 kWh/d				4.51 kWh/d		
Refrigerator. Pass-thru, 48 ft^3		4.25 kWh/d				6.07 kWh/d				6.49 kWh/d		
Refrigerator, Reach-In		6.67 kWh/d				6.74 kWh/d				6.68 kWh/d		
Convection Oven, Gas (full size)	0.54	12280 Btu/h idle	85 lb/h		0.48	11360 Btu/h idle	89 lb/h		0.44	12280 Btu/h idle	99 lb/h	
Combi Oven-Steamer, Gas (20 pan)	0.55	20929 Btu/h idle	148.5 lb/h	30 gph	0.54	30000 Btu/h idle	390 lb/h	20 gph	0.55	40000 Btu/h idle	390 lb/h	30 gph
Combi Oven-Steamer, Gas (6 pan)	0.54	10540 Btu/h idle	75 lb/h	25 gph	0.53	12285 Btu/h idle	125 lb/h	5.7 gph	0.5	17500 Btu/h idle	130 lb/h	11 gph
Pressureless Convection Steamer, Gas (10 pan)	0.4	5766 Btu/h idle	182 lb/h	7.5 gph	0.49*	14000 Btu/h idle	192 lb/h	6 gph	0.47*	16700 Btu/h idle	278 lb/h	6 gph
Pressureless Convection Steamer, Elec. (10 pan)	0.67	430 W idle	159 lb/h	5.9 gph	0.74*	160 W idle	220 lb/h	6 gph	0.69*	300 W idle	194 lb/h	6 gph
Pass-Through Heated Cabinets		347 W				359 W				771 W		
Hot Holding Cabinets		122 W				183 W				219 W		

Table 9. High-Efficiency Kitchen Equipment Specifications (IP units) *(continued)*

Equipment	Best-in-Class				Alternate 1				Alternate 2			
	Eff.	Energy	Capacity	Water	Eff.	Energy	Capacity	Water	Eff.	Energy	Capacity	Water
Heavy-duty Griddles, Elec. (5 ft)	0.77	3.32 W idle	68 lb/h		0.72	2.46 W idle	50 lb/h		0.77	3.32 W idle	68 lb/h	
Heavy-duty Griddles. Elec. (3 ft)	0.76	1.93 W idle	41 lb/h		0.73	2.44 W idle	57 lb/h		0.72	1.5 W idle	30 lb/h	
Tilting Skillet, Gas (no pilot, 40 gal)	0.54	15779 Btu/h idle	152 lb/h		0.53	16000 Btu/h idle	113 lb/h		0.5	16000 Btu/h idle	120 lb/h	
Deep Fat Fryer, Gas	0.66	4072 Btu/h idle	82 lb/h		0.552	5604 Btu/h idle	68.9 lb/h		0.54	8510 Btu/h idle	67 lb/h	
Deep Fat Fryer, Elec.	0.87	770 W idle	70 lb/h		0.82	700 W idle	71 lb/h		0.85	990 W idle	77 lb/h	
Dishwasher, 292 gpm wash, 5.4 gpm rinse with waste heat recovery			14,300 dish/hr	132 gph								

*Alternates 1 and 2 are connectionless steamers, which are more efficient than connected steamers. The original appliance is a connected steamer, therefore, the best-in-class is the same type. Note that ranking (best-in-class, alternate 1, and alternate 2) is based on overall energy efficiency only; reliability and other features, which may be very important in final appliance selection, are not part of the ranking.

Table 10. High-Efficiency Electric Kitchen Appliances Substituted for Gas Appliances in the All-Electric Kitchen Design (IP units)

Equipment	Best-in-Class				Alternate 1				Alternate 2			
	Eff.	Energy	Capacity	Water	Eff.	Energy	Capacity	Water	Eff.	Energy	Capacity	Water
Convection Oven, Elec. (full size)	0.80	0.8 kW idle	77 lb/h		0.76	1.6 kW idle	96 lb/h		0.73	1.2 kW idle	72 lb/h	
Deck Oven, Elec. (4 cavities)	0.75	2.5 kW idle	200 lb/h		0.70	2.8 kW idle	200 lb/h		0.65	3.2 kW idle	180 lb/h	
Combi Oven-Steamer, Elec. (6-pan)	0.79	1.9 kW idle	136 lb/h	17.8 gph	0.70	2.9 kW idle	130 lb/h	5 gph	0.70	3.1 kW idle	130 lb/h	2 gph
Combi Oven-Steamer, Elec. (20-pan)	0.80	2.5 kW idle	390 lb/h	18 gph	0.70	2.5 kW idle	390 lb/h	12 gph	0.70	12 kW idle	390 lb/h	20 gph
Kettle, Elec. (40 gal)	0.77	2.3 kW idle	1050 lb/h		0.75	2.5 kW idle	1000 lb/h		0.75	2.5 kW idle	1000 lb/h	
Kettles, Modular Base	0.85	1 kW idle	330 lb/h		0.80	1 kW idle	330 lb/h		0.80	1 kW idle	330 lb/h	
Range, Hot Top, (6-burner, heavy-duty)	0.80	0 W idle	210 lb/h		0.80	0 W idle	200 lb/h					
Range, Open Top (6-burner, heavy-duty)	0.80	0 kW idle	210 lb/h		0.80	0 kW idle	200 lb/h					
Pressureless Convection Steamer (10 pan)	0.67	430 W idle	159 lb/h	5.9 gph	0.74	160 W idle	220 lb/h	6 gph	0.69	300 W idle	194 lb/h	6 gph
Tilting Skillet, Elec. (40 gal)	0.80	2.5 kW idle	150 lb/h		0.75	2.6 kW idle	120 lb/h		0.78	2.5 kW idle	120 lb/h	
Deep Fat Fryer, Elec.	0.87	770 W idle	70 lb/h		0.82	700 W idle	71 lb/h		0.85	990 W idle	77 lb/h	

Note that the gas deck oven, kettles, open top range, and hot top range did not have high-efficiency gas alternatives and therefore were not included in Table 9.

Table 11. High-Efficiency Kitchen Equipment Specifications (SI units)

Equipment	Best-in-Class				Alternate 1				Alternate 2			
	Eff.	Energy	Capacity	Water	Eff.	Energy	Capacity	Water	Eff.	Energy	Capacity	Water
Ice Machine		8.8 kWh/100 kg	467 kg/d	1 l/kg		9.1 kWh/100 kg	508 kg/d	1 l/kg		10.6 kWh/100 kg	508 kg/d	1 l/kg
Refrigerator, Reach-In, 0.71 m^3		2.64 kWh/d				2.71 kWh/d				2.64 kWh/d		
Refrigerator, Reach-In, 1.47 m^3		4.25 kWh/d				4.51 kWh/d				4.51 kWh/d		
Refrigerator. Pass-Thru, 1.36 m^3		4.25 kWh/d				6.07 kWh/d				6.49 kWh/d		
Refrigerator, Reach-In		6.67 kWh/d				6.74 kWh/d				6.68 kWh/d		
Convection Oven, Gas (full size)	0.54	12.96 MJ/h idle	39 kg/h		0.48	11.98 MJ/h idle	40 kg/h		0.44	12.96 MJ/h idle	45 kg/h	
Combi Oven-Steamer, Gas (20 pan)	0.55	22.08 MJ/h idle	67 kg/h	114 l/h	0.54	31.65 MJ/h idle	177 kg/h	76 l/h	0.55	42.20 MJ/h idle	177 kg/h	114 l/h
Combi Oven-Steamer, Gas (6 pan)	0.54	11.12 MJ/h idle	34 kg/h	95 l/h	0.53	12.96 MJ/h idle	57 kg/h	22 l/h	0.5	18.46 MJ/h idle	59 kg/h	42 l/h
Pressureless Convection Steamer, Gas (10 pan)	0.4	6.08 MJ/h idle	83 kg/h	28 l/h	0.49*	14.77 MJ/h idle	87 kg/h	23 l/h	0.47*	17.62 MJ/h idle	126 kg/h	23 l/h
Pressureless Convection Steamer, Elec. (10 pan)	0.67	430 W idle	72 kg/h	22 l/h	0.74*	160 W idle	100 kg/h	23 l/h	0.69*	300 W idle	88 kg/h	23 l/h
Pass-Through Heated Cabinets		347 W				359 W				771 W		
Hot Holding Cabinets		122 W				183 W				219 W		
Heavy-Duty Griddles, Elec. (1524 cm)	0.77	3.32 W idle	31 kg/h		0.72	2.46 W idle	23 kg/h		0.77	3.32 W idle	31 kg/h	
Heavy-Duty Griddles. Elec. (914 cm)	0.76	1.93 W idle	19 kg/h		0.73	2.44 W idle	26 kg/h		0.72	1.5 W idle	14 kg/h	
Tilting Skillet, Gas (no pilot, 150 l)	0.54	16.65 MJ/h idle	69 kg/h		0.53	16.88 MJ/h idle	51 kg/h		0.5	16.88 MJ/h idle	54 kg/h	
Deep Fat Fryer, Gas	0.66	4.30 MJ/h idle	37 kg/h		0.552	5.91 MJ/h idle	31 kg/h		0.54	8.98 MJ/h idle	30 kg/h	
Deep Fat Fryer, Elec.	0.87	770 W idle	32 kg/h		0.82	700 W idle	32 kg/h		0.85	990 W idle	35 kg/h	
Dishwasher, 1105 l/m wash, 20 l/m rinse with waste heat recovery			14,300 dishes/hr	500 l/h								

*Alternates 1 and 2 are connectionless steamers, which are more efficient than connected steamers. The original appliance is a connected steamer and therefore the best-in-class is the same type. Note that ranking (best-in-class, alternate 1, and alternate 2) is based on overall energy efficiency only; reliability and other features, which may be very important in final appliance selection, are not part of the ranking.

Table 12. High-Efficiency Electric Kitchen Appliances Substituted for Gas Appliances in the All-Electric Kitchen Design (SI units)

Equipment	Best-in-Class				Alternate 1				Alternate 2			
	Eff.	Energy	Capacity	Water	Eff.	Energy	Capacity	Water	Eff.	Energy	Capacity	Water
Convection Oven, Elec. (full size)	0.80	0.8 kW idle	35 kg/h		0.76	1.6 kW idle	44 kg/h		0.73	1.2 kW idle	33 kg/h	
Deck Oven, Elec. (4 cavities)	0.75	2.5 kW idle	91 kg/h		0.70	2.8 kW idle	91 kg/h		0.65	3.2 kW idle	82 kg/h	
Combi Oven-Steamer, Elec. (6-pan)	0.79	1.9 kW idle	62 kg/h	67 l/h	0.70	2.9 kW idle	59 kg/h	19 l/h	0.70	3.1 kW idle	59 kg/h	8 l/h
Combi Oven-Steamer, Elec. (20-pan)	0.80	2.5 kW idle	177 kg/h	68 l/h	0.70	2.5 kW idle	177 kg/h	45 l/h	0.70	12 kW idle	177 kg/h	76 l/h
Kettle, Elec. (150 l)	0.77	2.3 kW idle	476 kg/h		0.75	2.5 kW idle	454 kg/h		0.75	2.5 kW idle	454 kg/h	
Kettles, Modular Base	0.85	1 kW idle	150 kg/h		0.80	1 kW idle	150 kg/h		0.80	1 kW idle	150 kg/h	
Range, Hot Top, (6-burner, heavy-duty)	0.80	0 W idle	95 kg/h		0.80	0 kW idle	91 kg/h					
Range, Open Top (6-burner, heavy-duty)	0.80	0 kW idle	95 kg/h		0.80	0 kW idle	91 kg/h					
Pressureless Convection Steamer (10 pan)	0.67	430 W idle	72 kg/h	22 l/h	0.74	160 W idle	100 kg/h	23 l/h	0.69	300 W idle	88 kg/h	23 l/h
Tilting Skillet, Elec. (150 l)	0.80	2.5 kW idle	68 kg/h		0.75	2.6 kW idle	54 kg/h		0.78	2.5 kW idle	54 kg/h	
Deep Fat Fryer, Elec.	0.87	770 W idle	32 kg/h		0.82	700 W idle	32 kg/h		0.85	990 W idle	35 kg/h	

Note that the gas deck oven, kettles, open top range, and hot top range did not have high-efficiency gas alternatives and therefore were not included in Table 11.

Table 13. Percentage of Total Site Energy Consumed by Kitchen and Refrigeration Equipment

Climate Zone	Baseline	Low-Energy Model with Best-in-Class Kitchen Equipment	Low-Energy Model with All-Electric, Best-in-Class Kitchen Equipment
1A	57%	64%	66%
2A	54%	59%	59%
2B	55%	62%	61%
3A	50%	55%	54%
3B	54%	59%	59%
3C	54%	59%	60%
4A	46%	50%	48%
4B	50%	54%	53%
4C	48%	52%	51%
5A	42%	45%	43%
5B	45%	50%	48%
6A	38%	42%	39%
6B	40%	45%	42%
7	34%	38%	35%
8	26%	30%	26%

Table 14. Baseline Exhaust Hood Schedule

Zone	Exhaust Fan No.	Flow cfm (m^3/s)	Static Press. in w.g. (Pa)	Fan Power HP (kW)	Total Fan Eff.
Kitchen	EF-1	6120 (2.89)	1.8 (448)	3 (2.24)	58%
	EF-2	6120 (2.89)	1.8 (448)	3 (2.24)	58%
	EF-3	3830 (1.81)	1.8 (448)	2 (1.49)	54%
	EF-5	1350 (0.64)	0.4 (100)	0.33 (0.25)	25%
Carry Out	EF-4	3575 (1.69)	1.8 (448)	2 (1.49)	51%
Dishwashing	EF-6	750 (0.35)	0.3 (75)	0.25 (0.19)	14%
Servery	EF-9	1020 (0.48)	1.8 (448)	0.75 (0.56)	39%
	EF-10	2380 (1.12)	1.8 (448)	1.5 (1.12)	45%
	EF-11	2100 (0.99)	1.8 (448)	1 (0.75)	59%
	EF-12	2380 (1.12)	1.8 (448)	1.5 (1.12)	45%
	EF-13	1530 (0.72)	1.8 (448)	1 (0.75)	43%
Total		**31,155 (14.71)**		**16.33 (12.18)**	

Table 15. Exhaust Hood Style and Control Recommendations

Zone	Exhaust Fan No.	Flow cfm (m^3/s)	Static Press. in w.g. (Pa)	Fan Power HP (kW)	Total Fan Eff.	Efficiency Measure
Kitchen	EF-1	3,427 (1.62)	0.56 (139)	0.53 (0.40)	57%	Add full end panels; 20% exhaust reduction. Note flow rate is based on one side of double island considered as two wall-mounted hoods (flow rate is 208 cfm/lf). Add variable demand controls.
	EF-2	3,427 (1.62)	0.56 (139)	0.53 (0.40)	57%	Add full end panels; 20% exhaust reduction. Add variable demand controls.
	EF-3	1,609 (0.76)	0.32 (80)	0.15 (0.11)	54%	Flow rate is high for appliances in baseline, reduced by 20%; add side panels, another 20% exhaust reduction. Add variable demand controls.
	EF-5	1,080 (0.51)	0.3 (75)	0.2 (0.15)	25%	Add side panels; 20% exhaust reduction
Carry Out	EF-4	2,002 (0.94)	0.56 (139)	0.35 (0.26)	50%	Add side panels; 20% exhaust reduction. Add variable demand controls.
Dishwashing	EF-6	750 (0.35)	0.3 (75)	0.25 (0.19)	14%	No change to flight conveyor dishwasher exhaust
Servery	EF-9	816 (0.39)	1.2 (299)	0.4 (0.30)	39%	Add quarter side panels; 20% exhaust reduction
	EF-10	1,190 (0.56)	0.5 (125)	0.2 (0.15)	47%	Change to proximity hood type; 50% exhaust reduction
	EF-11	1,050 (0.50)	0.5 (125)	0.2 (0.15)	41%	Change to proximity hood type; 50% exhaust reduction
	EF-12	1,190 (0.56)	0.5 (125)	0.2 (0.15)	47%	Change to proximity hood type; 50% exhaust reduction
	EF-13	1,530 (0.72)	1.2 (299)	0.5 (0.37)	58%	Add side panels; 20% exhaust reduction
Total		**18,071 (8.53)**		**3.51 (2.62)**		

Table 16. Energy Budgets by Climate Zone—kBtu/ft^2 (kWh/m^2)

Climate Zone	City	CBECS 2003 Site Energy Budget	Baseline Site Energy Budget	CBECS 2003 Source Energy Budget	CBECS 2003 Source Energy Target	Baseline Source Energy Budget
1A	Miami, FL	377 (1189)	354 (1116)	1244 (3923)	435 (1372)	1016 (3204)
2A	Houston TX	387 (1221)	373 (1176)	1212 (3823)	424 (337)	985 (3107)
2B	Phoenix, AZ	380 (1198)	363 (1145)	1187 (3744)	416 (1312)	972 (3066)
3A	Memphis, TN	396 (1249)	394 (1243)	1175 (3706)	411 (1296)	965 (3044)
3B	El Paso, TX	381 (1202)	369 (1164)	1161 (3662)	406 (1280)	934 (2946)
3C	San Francisco, CA	370 (1167)	359 (1132)	1067 (3365)	373 (1176)	846 (2668)
4A	Baltimore, MD	430 (1356)	428 (1350)	1221 (3851)	427 (1347)	961 (3031)
4B	Albuquerque, NM	400 (1262)	396 (1249)	1159 (3655)	406 (1280)	935 (2949)
4C	Seattle, WA	406 (1280)	402 (1268)	1142 (3602)	400 (1262)	888 (2801)
5A	Chicago, IL	463 (1460)	468 (1476)	1256 (3961)	440 (1388)	987 (3113)
5B	Colorado Springs, CO	426 (1344)	430 (1356)	1188 (3747)	416 (1312)	949 (2993)
6A	Burlington, VT	503 (1586)	509 (1605)	1311 (4135)	459 (1448)	1,013 (3195)
6B	Helena, MT	467 (1473)	481 (1517)	1242 (3917)	435 (1372)	985 (3107)
7A	Duluth, MN	540 (1703)	566 (1785)	1348 (4251)	472 (1489)	1,061 (3346)
8A	Fairbanks, AK	669 (2110)	730 (2302)	1539 (4854)	539 (1700)	1,218 (3841)

Table 17. Description of Low-Energy Modeling Packages for the DFAC

Low-Energy Package	EEMs
Package 1	Increased daylit area, added daylighting and occupancy controls, and reduced lighting power density Passive House insulation for climate zones 4A-8 VAV fans, increased fan and HVAC efficiency, reduced exhaust hood ventilation High efficiency gas and electric kitchen equipment Demand control ventilation on makeup air units
Package 2	Package 1 plus all-electric, high efficiency kitchen equipment

Table 18. Site Energy Use Intensity for DFAC Designs—kBtu/ft^2 (kWh/m^2)

Climate Zone	City	Baseline Site Energy Budget	Low-Energy Package 1: Gas and Elec. Kitchen Equipment	Low-Energy Package 2: All-Electric Kitchen Equipment
1A	Miami, FL	354 (1116)	268 (845)	221 (697)
2A	Houston, TX	373 (1176)	287 (905)	243 (766)
2B	Phoenix, AZ	363 (1145)	277 (874)	235 (741)
3A	Memphis, TN	394 (1243)	307 (968)	267 (842)
3B	El Paso, TX	369 (1164)	284 (896)	243 (766)
3C	San Francisco, CA	359 (1132)	281 (886)	239 (754)
4A	Baltimore, MD	428 (1350)	336 (1060)	297 (937)
4B	Albuquerque, NM	396 (1249)	309 (975)	270 (852)
4C	Seattle, WA	402 (1268)	316 (997)	278 (877)
5A	Chicago, IL	468 (1476)	365 (1151)	329 (1038)
5B	Colorado Springs, CO	430 (1356)	333 (1050)	294 (927)
6A	Burlington, VT	509 (1605)	393 (1239)	359 (1132)
6B	Helena, MT	481 (1517)	369 (1164)	335 (1057)
7A	Duluth, MN	566 (1785)	433 (1366)	403 (1271)
8A	Fairbanks, AK	730 (2302)	547 (1725)	525 (1656)

Table 19. DFAC Site Energy Savings Compared to the Baseline

Climate Zone	City	Low-Energy Package 1: Gas and Elec. Kitchen Equip.	Low-Energy Package 2: All-Electric Kitchen Equip.
1A	Miami, FL	24%	38%
2A	Houston, TX	23%	35%
2B	Phoenix, AZ	24%	35%
3A	Memphis, TN	22%	32%
3B	El Paso, TX	23%	34%
3C	San Francisco, CA	22%	33%
4A	Baltimore, MD	22%	31%
4B	Albuquerque, NM	22%	32%
4C	Seattle, WA	21%	31%
5A	Chicago, IL	22%	30%
5B	Colorado Springs, CO	23%	32%
6A	Burlington, VT	23%	29%
6B	Helena, MT	23%	30%
7A	Duluth, MN	23%	29%
8A	Fairbanks, AK	25%	28%

Table 20. DFAC Source Energy Savings Compared to CBECS Fast Food Restaurants – kBtu/ft^2 (kWh/m^2)

Climate Zone	City	CBECS 2003 Source Energy EUI	CBECS 2003 Source Energy EUI Target	Baseline Source Energy	Low-Energy DFAC Source Energy	Percent Savings from 2003 CBECS	Percent Savings with Cogen System
1A	Miami, FL	1244 (3923)	435 (1372)	1016 (3204)	722 (2277)	42%	73%
2A	Houston, TX	1212 (3823)	424 (1337)	985 (3107)	721 (2274)	40%	71%
2B	Phoenix, AZ	1187 (3744)	416 (1312)	972 (3066)	713 (2249)	40%	71%
3A	Memphis, TN	1175 (3706)	411 (1296)	965 (3044)	728 (2296)	38%	68%
3B	El Paso, TX	1161 (3662)	406 (1280)	934 (2946)	699 (2205)	40%	70%
3C	San Francisco, CA	1067 (3365)	373 (1176)	846 (2668)	669 (2110)	37%	68%
4A	Baltimore, MD	1221 (3851)	427 (1347)	961 (3031)	753 (2375)	38%	66%
4B	Albuquerque, NM	1159 (3655)	406 (1280)	935 (2949)	716 (2258)	38%	67%
4C	Seattle, WA	1142 (3602)	400 (1262)	888 (2801)	710 (2239)	38%	66%
5A	Chicago, IL	1256 (3961)	440 (1388)	987 (3113)	780 (2460)	38%	65%
5B	Colorado Springs, CO	1188 (3747)	416 (1312)	949 (2993)	748 (2359)	37%	66%
6A	Burlington, VT	1311 (4135)	459 (1448)	1013 (3195)	805 (2539)	39%	64%
6B	Helena, MT	1242 (3917)	435 (1372)	985 (3107)	782 (2466)	37%	64%
7A	Duluth, MN	1348 (4251)	472 (1489)	1061 (3346)	848 (2675)	37%	61%
8A	Fairbanks, AK	1539 (4854)	539 (1700)	1218 (3841)	974 (3072)	37%	57%