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A Parametric Study of Energy Efficiency Measures Used in Deep Energy Retrofits for Two Building Types and U.S. Climate Zones

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ABSTRACT

One of the critical tasks of the International Energy Agency's Energy Conservation in Buildings and Communities Program's (IEC ECBC's) Annex 61 Business and Technical Concepts for Deep Energy Retrofit (DER) of Public Buildings is to develop bundles of core technologies (measures), which, when applied in major renovation projects to older, pre-1980 buildings, allow site energy reduction by 50% or better compared to the pre-renovation baseline. A short list of these technologies has been generated through analysis of DER projects (Zhivov et al. 2015). Characteristics of some of these "core technologies" depend on technologies available on an individual nation's market, minimum requirements of national standards, and life-cycle cost (LCC) analysis. In addition to these factors, requirements for building envelope-related technologies (e.g., insulation levels, windows), depend on specific climate conditions. This paper presents the results of computational modeling analysis conducted by the U.S. Army Engineer Research and Development Center team to determine the performance potential of the core technologies for two categories of buildings with relatively low internal loads in 15 U.S. climates using the net zero planner tool. This tool enabled simultaneous simulation of multiple building types and multiple technology bundles of energy efficiency measures in different climate zones. This research supported development of requirements for building envelope characteristics and typical equipment best practices for DER projects. Information presented in the paper along with results of similar studies conducted in Denmark, Estonia, Austria, Germany, China, and the UK (Riel et al. 2016; Yao et al. 2016; Zhivov 2016) for their nation-specific climate conditions have been used to develop general guidelines for technology bundles to be used in DER projects (Zhivov et al. 2016). Results of these studies show that 50% of site energy use reduction can be achieved in most climate conditions using a limited number of technologies readily available on the market. It is easier to reduce energy consumption in heating-dominated climates than in climates requiring cooling and humidity control. Additional energy efficiency technologies and measures specific to the building type and use, as well as to specific climate conditions, can further reduce energy use intensity of the building and allow achievement of even higher performance buildings (e.g., passive house standard or even net zero energy).

INTRODUCTION

Research conducted under the International Energy Agency's Energy Conservation in Buildings and Communities Program Annex 61 generated a limited number of "core technology bundles" that can be used in DER projects (Table 1). Characteristics of some of these "core technologies" depend on technologies available on an individual nation's market, minimum requirements of national standards, and economics (LCC analysis). In addition to these factors, requirements for building envelope-related technologies (e.g., insulation levels, windows, vapor and water barriers, requirements to building airtightness, etc.) depend on specific climate conditions.

Building envelope insulation levels and window characteristics for the core bundle of technologies have been optimized through computational modeling by the Annex 61 modeling team that conducted simulation of representative buildings for different climate zones of participating countries. The U.S. Army Engineer Research and Development Center modeling team conducted this study using two types of

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Table 1. Core Technologies Bundles for DER

Category	Name
Building Envelope	Roof insulation
	Wall insulation
	Slab Insulation
	Windows
	Doors
	Thermal bridges remediation
	Air tightness
	Vapor Barrier
	Building envelope quality assurance
Lighting and Electrical Systems	Lighting design, technologies, and controls
HVAC	High performance motors, fans, furnaces, chillers, boilers, etc.
	Dedicated outdoor air system (DOAS)
	HR (dry and wet)
	Duct insulation
	Duct airtightness
	Pipe insulation

typical Army buildings: a barracks (Unaccompanied Enlisted Personnel Housing [UEPH]) and an office building (Battalion Headquarters [BNHQ]) in 15 U.S. climate zones (ASHRAE 2010b). These results have been compared with results obtained through modeling by teams from Austria, China, Denmark, Estonia, Germany, and the UK (Rose et al. 2016; Riel et al. 2016; Yao 2016), and summarized in (Zhivov et al. 2016).

BUILDING DESCRIPTION

Barracks. An Army barracks is a cross between an apartment building and college dormitory. Within the Army, the different sizes of barracks are based on the number of soldiers living in them. The representative model of the barracks building used for this study is based on the information provided by the U.S. Army Corps of Engineers (USACE) Fort Worth District, which houses the Center of Standardization for barracks. The model used for this study contained 56 double-occupancy units. Each apartment unit has two bedrooms with a storage area, one shared bathroom, a kitchen, a mechanical room, and a storage area (Figure 1). The first floor has 18 units, a laundry room, a common area, a mechanical room, and a storage area. The second and third floors have 19 units. Each floor is 18,257 ft^2 (1696 m^2), and the building is 54,771 ft^2 (5088.4 m^2).

Office Building. A BNHQ building has been used as a representative example of an office building that primarily provides administrative space for battalion operations. Compared to a Brigade Headquarters, this type of building is smaller and does not contain any of the secure areas and equipment that generate high internal thermal loads. The representative model of the office building is based on a standard design defined by the Department of the Army Facilities Standardization Program (USACE 2015) (Figure 2). The model used for this study is a two-story building with a total floor area of 32,670 ft^2 (2940 m^2). The building aspect ratio is 1:1.375. It has a hip roof with an attic insulated at the roof level. The building has steel frame walls and a window to wall ratio of 10.3%. Thirteen percent of the windows are on the south facade.

LOCATIONS

Fifteen locations were selected to represent 15 Department of Energy climate zones in the United States (Briggs et al. 2003). Energy efficiency measures (EEMs) were modeled for each building type across all locations. The locations selected were representative cities for each of the climate zones. Colorado Springs was selected for Climate Zone 5B instead of Boise, ID, to more closely align with the location of Fort Carson, CO, a U.S. Army installation. Table 2 lists the 15 climate zones and the cities used to represent them.

SIMULATION SCENARIOS

Scenario 1: Baseline. Baseline energy performance is modeled using requirements of ASHRAE Standard 90.1-1980 (ASHRAE 1980) with parameters listed in Table 3. For the U.S. Army, it is safe to assume that most buildings that will be required to undergo major renovation were built to the requirements of this standard or to less stringent energy requirements. It is also assumed that upgrades to the building and its systems made during the building's life are offset by systems degradation. An exception to this assumption is that most of the buildings will have undergone some level of lighting upgrade so baseline buildings are modeled at the same lighting density as base case buildings.

Scenario 2: Base case (ASHRAE Standard 90.1-2010 [ASHRAE 2010b]). It is assumed that major renovation will be designed to meet minimum requirements to the building systems listed in the ASHRAE Standard 90.1-2010. Because neither designer nor contractor has control over the plug loads, they remain the same as in the baseline.

Scenario 3: Deep energy retrofit (DER)—50% energy use reduction compared to the baseline. This scenario represents site energy use reduction of about 50% compared to the baseline (when feasible). In this scenario, an attempt is made to achieve 50% site energy use reduction using only the bundle of core technologies: building envelope insulation, increased airtightness, heat recovery, improved lighting design and technologies, and increased efficiency of heating, ventilating, and air-conditioning (HVAC) and electrical systems.

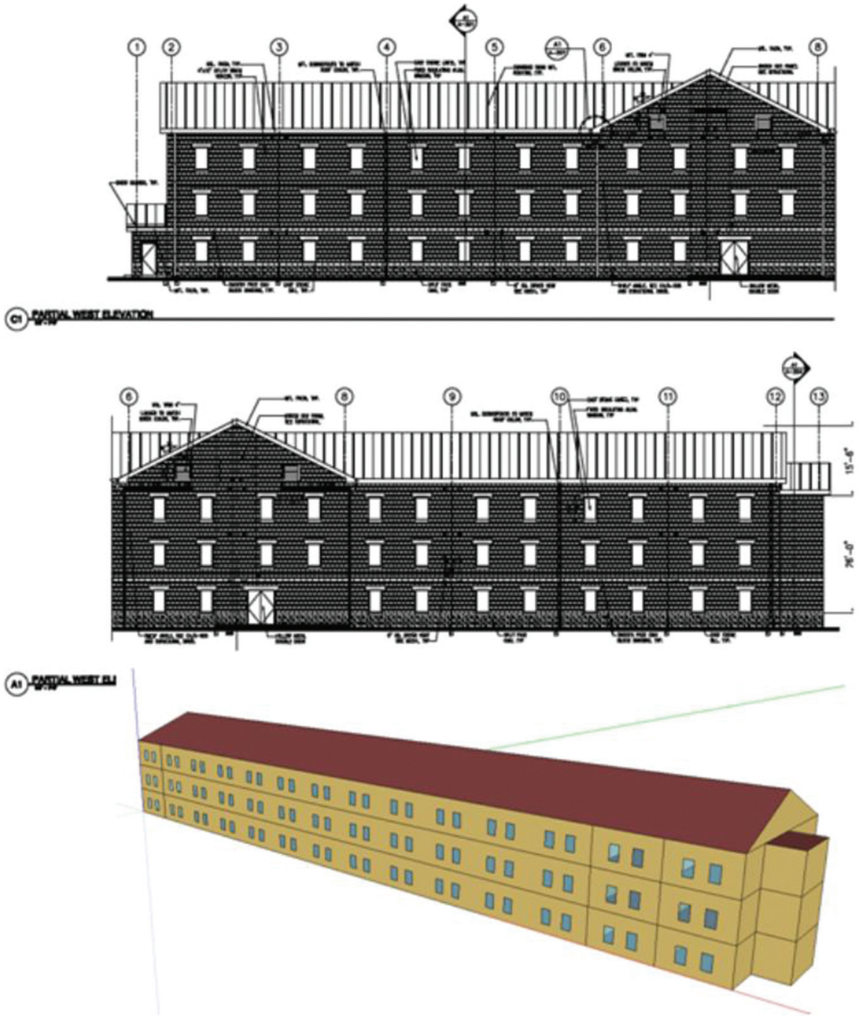


Figure 1 *Elevation view and rendering of the barracks energy simulation model.*

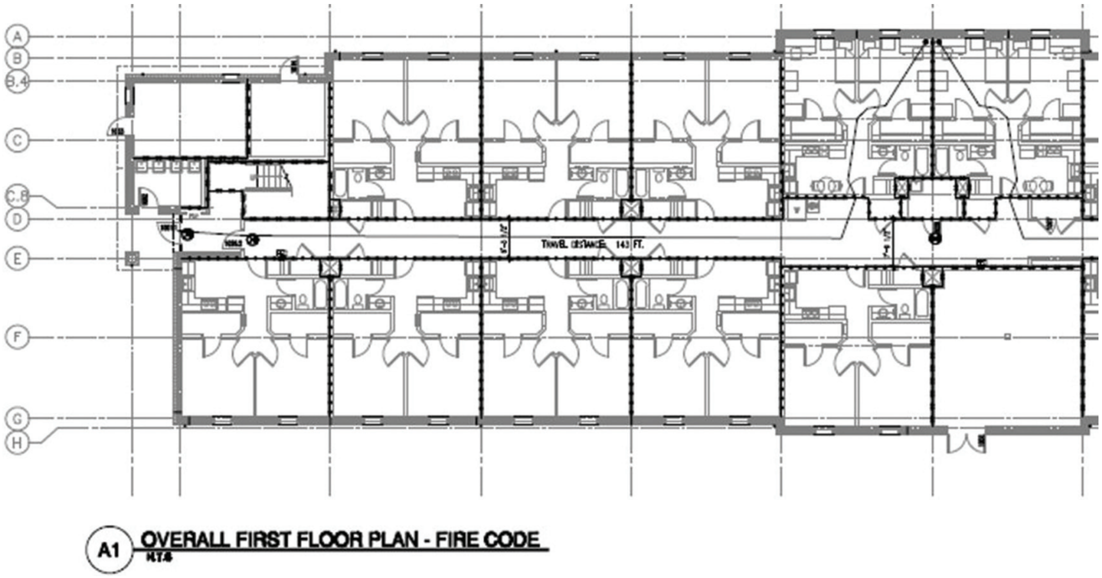


Figure 2 *A first floor plan and rendering of the office energy simulation model.*

Scenario 4: High Performance Buildings. The final scenario is intended to push the envelope further than 50% reduction using additional energy efficiency technologies such as high-efficiency equipment (lower plug loads), domestic hot-water (DHW) reduction measures, and even more advanced HVAC equipment.

ENERGY MODELING

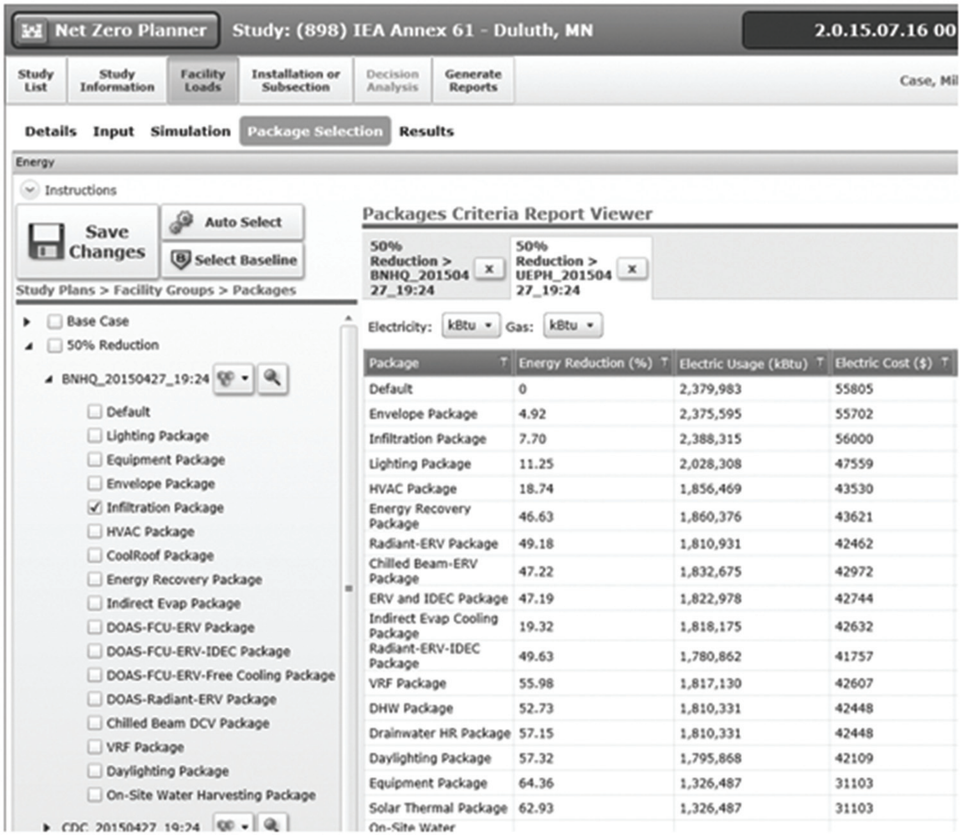
Energy simulations were conducted using the net zero planner (NZP) tool (Case et al. 2014). Within NZP, building energy simulation is performed by a combination of EnergyPlus, Version 8 (DOE 2008) and a pre- and post-processor developed as part of net zero planner called PARAMS (i.e., "parametric service"). NZP maintains a set of 37 EnergyPlus models based on a combination of building designs maintained by the USACE Centers of Standardization and selected buildings from the Energy Information Administration (EIA) CBECS (EIA 2012) database. PARAMS uses a set of parameters to describe the building based on a subset of input parameters accepted by EnergyPlus. It narrows the set of parameters that can be changed by the user to a subset that the authors consider practical at an installation planning level. These parameters are described in an extensible markup language (XML) master definition file that contains default parameter values and technology bundles of EEMs for each building type and climate zone. A project is created in NZP for each climate zone using TMY3 weather data for the city being considered. Within each project, each of the two building types is modeled using parameters tuned to the baseline (ASHRAE 1980). Each building type is also modeled using parameters for the base case (ASHRAE 2010b). NZP then modifies the base case parameters to reflect the application of various combinations of technology bundles (referred to as *packages* in the tool). When NZP requests simulation of a building from its simulation server farm, the simulation server passes the job to PARAMS, which generates input files, launches EnergyPlus, tracks the status of the job, retrieves the results, and post processes the results into a set of XML and comma-delimited loads files that are retrieved by the core as part of a data set. For each reference model, PARAMs specifies default values of parameters such as orientation, window, wall, and roof overall heat transfer coefficient values (U), lighting types, roof emittance, equipment efficiency, and presence of lighting controls; the user is allowed to change these values to suit conditions. Each reference model has an associated conditioned area, the intent being that the results be scaled to the actual area of the building. Figure 3 shows the package selection screen from NZP that includes the energy savings compared to the base case (shown as default in the figure). This screen is used to compare simulation results for different scenarios and building types. The energy reduction shown is generally cumulative, where one package (bundle) includes packages above it. Not all results are cumulative, however. A future improvement to NZP will be to include the baseline comparison in this screen. For this paper, the bundle of core technologies that brought the energy reduction closest to a 50% reduction was selected to create the 50% reduction scenario. It was not possible in all cases to achieve 50% reduction using only the core technology bundles. In these cases, the closest to 50% that could be achieved using only core technology measures was selected. Finally, the high-performance building scenario ("National Dream" in Figure 3) was created by selecting the highest performing set of technology bundles in the tool. This included the use of high-efficiency equipment, reducing plug loads by 30%. Table 3 lists example modeling assumptions used for the barracks building baseline, base case, and a 50% more energy efficient model. The office baseline is modeled with a variable-air-volume system.

Table 2. Climate Zones and Cities Used for Simulations

Climate Zone	City
1A	Miami, FL
2A	Houston, TX
2B	Phoenix, AZ
3A	Memphis, TN
3B	El Paso, TX
3C	San Francisco, CA
4A	Baltimore, MD
4B	Albuquerque, NM
4C	Seattle, WA
5A	Chicago, IL
5B	Colorado Springs, CO
6A	Burlington, VT
6B	Helena, MT
7A	Duluth, MN
8A	Fairbanks, AK

Improved Building Envelope

Significant energy use reduction in buildings can be achieved by minimizing the impact of the external environment on the building heating and/or cooling loads. While the current advanced buildings practice in the United States is based on ASHRAE Standard 90.1-2010 and ASHRAE Standard 189.1-2009, the highest levels of insulation, windows, and air infiltration for building energy envelope efficiency for obtaining ultra-low energy buildings are found in the German Passive House (Passivhaus 2015) standard. A well-insulated, airtight building envelope is important for building energy use



☐ Base Case
☐ 50% Reduction
BNHQ_20150427_19:24
☐ Default
☐ Lighting Package
☐ Equipment Package
☐ Envelope Package
☑ Infiltration Package
☐ HVAC Package
☐ CoolRoof Package
☐ Energy Recovery Package
☐ Indirect Evap Package
☐ DOAS-FCU-ERV Package
☐ DOAS-FCU-ERV-IDEC Package
☐ DOAS-FCU-ERV-Free Cooling Package
☐ DOAS-Radiant-ERV Package
☐ Chilled Beam DCV Package
☐ VRF Package
☐ Daylighting Package
☐ On-Site Water Harvesting Package
CDC_20150427_19:24

Electricity: kBtu Gas: kBtu

Package	Energy Reduction (%)	Electric Usage (kBtu)	Electric Cost ($)
Default	0	2,379,983	55805
Envelope Package	4.92	2,375,595	55702
Infiltration Package	7.70	2,388,315	56000
Lighting Package	11.25	2,028,308	47559
HVAC Package	18.74	1,856,469	43530
Energy Recovery Package	46.63	1,860,376	43621
Radiant-ERV Package	49.18	1,810,931	42462
Chilled Beam-ERV Package	47.22	1,832,675	42972
ERV and IDEC Package	47.19	1,822,978	42744
Indirect Evap Cooling Package	19.32	1,818,175	42632
Radiant-ERV-IDEC Package	49.63	1,780,862	41757
VRF Package	55.98	1,817,130	42607
DHW Package	52.73	1,810,331	42448
Drainwater HR Package	57.15	1,810,331	42448
Daylighting Package	57.32	1,795,868	42109
Equipment Package	64.36	1,326,487	31103
Solar Thermal Package	62.93	1,326,487	31103
On-Site Water			

Figure 3 *The NZP EEM package selection screen.*

reduction. U.S. and European energy prices differ by approximately a factor of two, with U.S. energy prices being less expensive. Considering this, Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) researchers in collaboration with Georg Zielke, Architekturburo Zielke Passivhauser, and Dr. Berthold Kauffman, Passivhaus Institut, Germany (Liesen et al. 2012) have developed cost-effective parameters for building envelope elements to be applied to U.S. construction specifics for all 15 DOE climate zones. The types of insulation materials used depend on construction practices, the climate, and other factors. Typical insulating materials used in the United States include wood-fiber boards, cellulose, foam glass, mineral wool, fiberglass, extruded polystyrene, expanded polystyrene, polyurethane boards, perlite, etc. The most commonly used materials are wood-fiber boards (λ = 0.045 W/m·K), mineral wool (λ = 0.035 – 0.040 W/m·K) and expanded polystyrene (λ = 0.035 – 0.040 W/m·K). These low-cost materials are well suited for most new construction and retrofit situations. Table 4 lists insulation requirements (R-values) for walls, roofs, and floors in different climate conditions resulted from this study, compared to current Army requirements (Liesen et al. 2012) as well as requirements from ASHRAE Standard 90.1 (2010, 2007), ASHRAE Standard 189.1 (2009), and the ASHRAE Advanced Energy Guides.

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

"Business as usual" conditions provide the least first cost insulation level. ASHRAE determines the minimum insulation level that will be mandated by code using a LCC optimization algorithm. The ASHRAE optimization parameters used for ASHRAE Standard 90.1-2010 development were national average combined heating fuel prices at $1.22/therm ($0.042/kWh), a blended cooling fuel price at $0.09/kWh, and a scalar ratio of 20. However, for an energy security planning and risk analysis, it is necessary to look at increased fuel prices to see the recommended insulation levels at higher energy prices. To explore exposure to risk, this scenario arbitrarily assumed fuel prices were triple, or $3.50/therm ($0.119/kWh and $0.30/kWh). This energy security scenario captures risk, because wall and roof insulation level cannot be cost effectively retrofitted to these levels later. In this example, the ASHRAE LCC curves recommended for Climate Zone 2 range from R-25 to R-50 (R-4.4 to R-8.8) for roof insulation entirely above deck and from R-13 +

Table 3. Example of Model Assumptions for Barracks

Component	Baseline Building Model	Base Case Building Model	DER Building Model
Area	54,771 ft^2 (5088.4 m^2)	Same as baseline	Same as baseline
Floors	3	Same as baseline	Same as baseline
Orientation	Long axis running E and W	Same as baseline	Same as baseline
Window/wall ratio	15% on N and S facades	Same as baseline	Same as baseline
Window type	Standard 90.1-1980	Standard 90.1-2010	See Table 4
Wall construction	Steel frame	Same as baseline	Same as baseline
Wall insulation	Standard 90.1-1980	Standard 90.1-2010	See Table 4
Roof construction	Sloped roof and attic with insulation at the roof level	Sloped metal roof and attic with insulation at the ceiling level	Sloped metal roof and attic with insulation at the ceiling level
Roof insulation	Standard 90.1-1980 equivalent “insul. entirely above deck”	Standard 90.1-2010 equal to the “insulation entirely above deck”	See Table 3
Infiltration	1.2 cfm/ft^2 @ 0.3 in. w.c.	0.4 cfm/ft^2 @ 0.3 in. w.c.	0.25 cfm/ft^2 @ 0.3 in. w.c.
Lighting per (Liesen et al. 2012)	Room—1.1 W/ft^2 (11.8 W/m^2) Corrid—1.1 W/ft^2 (11.8 W/m^2) See Table 6	Rooms—1.0 W/ft^2 (10.8 W/m^2) Corridors—0.5 W/ft^2 (5.4 W/m^2) See Table 6	Rooms—0.6 W/ft^2 (6.5 W/m^2) Corridors—0.35 W/ft^2 (3.8 W/m^2)
Plug loads per USACE 2013	1.7 W/ft^2 (18.3 W/m^2) plus refrigerator and range	Same as baseline	Same as baseline
Temperature setpoints	70°F (21.1°C) heating; 75°F (23.9°C) cooling, no set back	Same as baseline	Same as baseline
HVAC	Packaged single zone air-conditioning (PSZ-AC) units (COP 2.1) with a natural gas furnace (0.80 Et) in each room or zone.	DOAS (2.87 COP), central natural gas boiler hot water system (0.80 Et), four-pipe FCUs for zone temperature control	DOAS (4.4 COP), central natural gas boiler hot water system (0.95 Et), four-pipe FCUs for zone temperature control

Table 4. Recommended Wall, Roof, and Floor Insulation Values

Item	CZ 1, Btu/(h·ft^2·F) (W/m^2·K)	CZ 2, Btu/(h·ft^2·F) (W/m^2·K)	CZ 3, Btu/(h·ft^2·F) (W/m^2·K)	CZ 4, Btu/(h·ft^2·F) (W/m^2·K)	CZ 5, Btu/(h·ft^2·F) (W/m^2·K)	CZ 6, Btu/(h·ft^2·F) (W/m^2·K)	CZ 7, Btu/(h·ft^2·F) (W/m^2·K)	CZ 8, Btu/(h·ft^2·F) (W/m^2·K)
Roof, U-factor	0.029 (0.164)	0.025 (0.14)	0.022 (0.126)	0.022 (0.126)	0.02 (0.11)	0.0167 (0.095)	0.0154 (0.307)	0.0133 (0.0755)
Wall, U-factor	0.067 (0.38)	0.067 (0.38)	0.05 (0.284)	0.04 (0.227)	0.033 (0.187)	0.029 (0.165)	0.025 (0.142)	0.02 (0.114)
Wall below grade, U-factor	0.2 (1.14)	0.1 (0.57)	0.10 (0.57)	0.067 (0.38)	0.067 (0.38)	0.05 (0.284)	0.04 (0.22)	0.028 (0.159)
Floors over unconditioned space, U-factor	0.1 (0.57)	0.0416 (0.236)	0.0416 (0.236)	0.033 (0.187)	0.033 (0.187)	0.025 (0.142)	0.022 (0.125)	0.020 (0.114)
Windows (assembly) thermal transmittance, U-factor	<0.35 (<1.98)	<0.35 (<1.98)	<0.3 (<1.7)	<0.3 (<1.7)	<0.27 (<1.53)	<0.24 (<1.36)	<0.22 (<1.25)	<0.18 (1.02)
Windows, SHGC	<0.25	<0.25	0.25	<0.3	<0.4	NR	NR	NR

R-7.5ci to R-13 + R-28.1ci (R-2.29 + R-1.32ci to R-2.29 + R-4.95ci) (Figure 4). This level would exceed the insulation levels proposed by ERDC that are listed in Table 3, indicating that these levels are justified when higher energy prices are considered as part of the risk analysis.

Airtightness. According to USACE ECB 2014-16 (USACE 2014), the air leakage rate of a building envelope shall not exceed 0.25 cfm/ft^2 (1.27 L/s/m^2) at a pressure differential of 0.3 in. w.c. (75 Pa) for new and renovation construction projects. Since 2010, more than 450 buildings on Army Installations were constructed and renovated to meet or exceed this requirement (achieving airtightness of 0.10 cfm/ft^2 (0.51 L/s/m^2) or better was not uncommon) at no or minimal additional cost. Based on this experience and on industry consensus, the new level for airtightness in high-performance buildings was proposed to be lowered to 0.15 cfm/ft^2 (0.76 L/s/m^2) at a pressure differential of 0.3 in. w.c. (75 Pa).

Infiltration at these leakage rates and pressures is calculated based on the total wall and flat roof area of the building and is then converted to a pressure of 5 Pa from 75 Pa, assuming a flow coefficient of 0.65 (5 cfm [2.36 L/s/person], 0.06 cfm/ft^2 [0.3 L/s/m^2]). Note, the area referenced is per area of conditioned space in square feet or square meters. We assumed that the average pressure drop across the building envelop is 0.02 in. w.c. (5 Pa). Wind pressure and temperature differentials across the building envelope drive the infiltration, and these driving forces vary throughout the year; however, these variations are not modeled in the simulations. We assume that a constant rate of air changes per hour will model the average effects over the year. Table 5 lists the infiltration at these two leakage rates. The mechanical ventilation system pressurizes the building by providing outside air equal to the building exhaust, plus the air leakage at 0.02 in. w.c. (5 Pa). Infiltration is often assumed to go to zero when buildings are pressurized. This assumption is usually made to compensate for the lack of evidence about what really happens and about how to model it in an energy simulation. We assume that the average uncontrolled infiltration when the building is pressurized is reduced to 10% of the value calculated at 0.02 in. w.c. (5 Pa). The difference in the leakage rates between the two airtightness levels was accounted for in the outdoor ventilation rates for the baseline and energy efficient models.

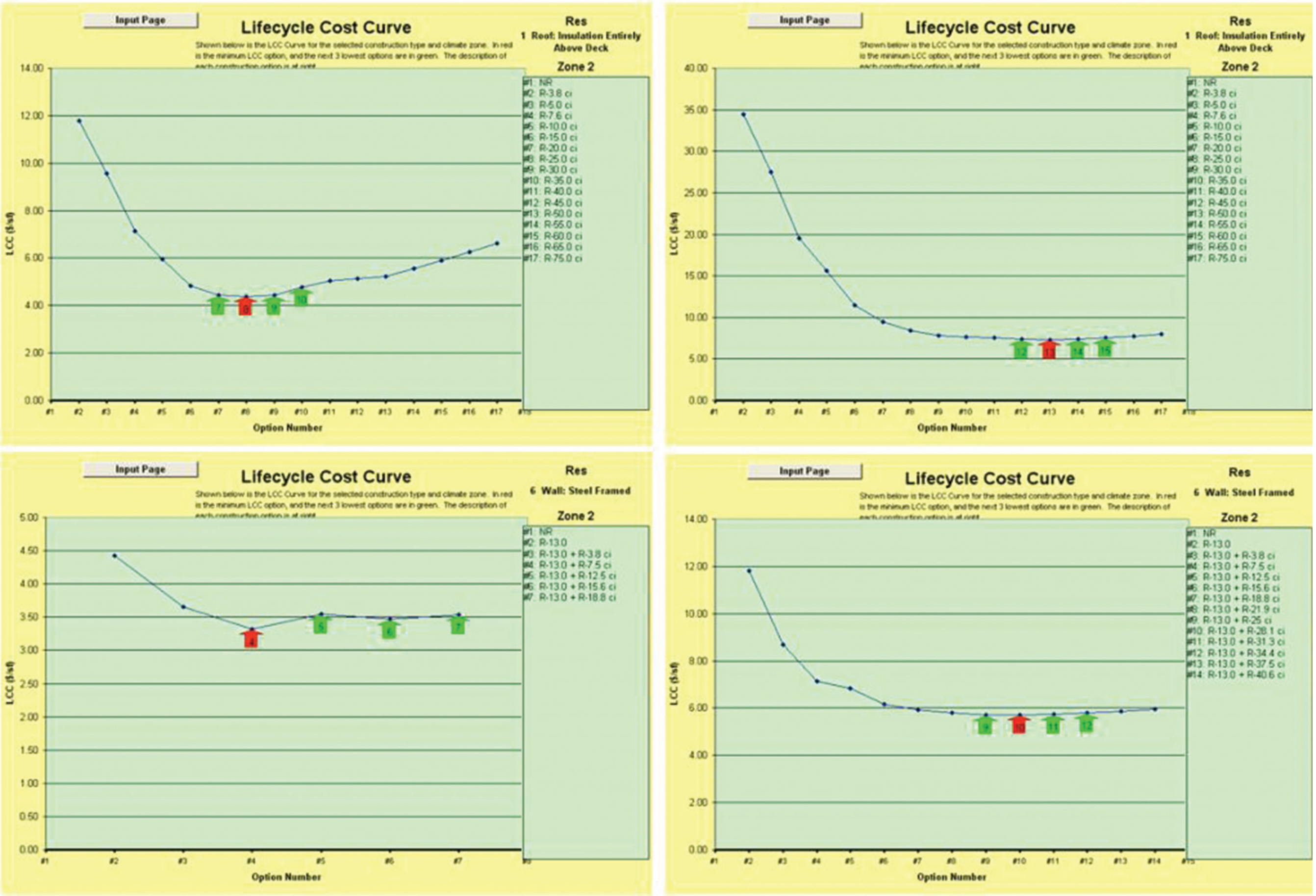


Figure 4 *Insulation life-cycle cost for business as usual and DER.*

VENTILATION

The ventilation rate for the barracks was set to provide 90 cfm (42.5 L/s) of outside air to each apartment unit to make up for the bathroom exhaust and control humidity, which is greater than the ventilation requirements from ASHRAE Standard 62.1 (ASHRAE 2010a) for the baseline model. This level of ventilation is based on experience with Army barracks. Additional outdoor air was added to the whole building to make up for the leakage rate at 0.02 in. w.c. (5 Pa) pressurization (Table 5). For the DER scenario, the ventilation air was reduced to 65 cfm (30.7 L/s) per living unit with excess ventilation air per Table 5. The 65 cfm (30.7 L/s) was based on the standard design provided by the Center of Standardization.

The ventilation rate for the office building was set to provide 5 cfm/person and 0.06 cfm/ft^2 of outdoor air to the conditioned spaces in the building per ASHRAE Standard 62.1-2010, accounting for occupancy, floor area, and restrooms for office buildings. During unoccupied setback hours, the ventilation air was scheduled to turn off. Both the baseline and DER cases were set to the same values to maintain proper indoor air quality.

LIGHTING

The lighting improvements for all building types were based on recommendations from the Lighting Design Guide for Low Energy Buildings–New and Retrofits (USACE 2013) developed in collaboration with Atelier Ten. The focus was on efficient lighting design and not just on improving the efficiency of existing fixtures. Table 6 lists example control strategies for barracks. Lighting efficiency measures including lighting power density reductions with control strategies for each zone were modeled. Although the baseline models were based on relatively old buildings, it is assumed that lighting has been upgraded to meet ASHRAE 90.1-2010 standards so there will not be a difference between the baseline and base-case lighting densities.

PLUG LOADS

The modeling supports the findings of the previous ERDC study for each of the building types that plug loads are a major source of energy usage, particularly in the barracks. For example, in a barracks in Climate Zone 5A, the fraction of the total power consumed by plug loads increased from 18% in the baseline model to 37% in the DER model. This would represent all buildings where the overall energy usage is reduced without reducing the plug loads.

In the barracks, the bedroom has a computer, stereo, television, and other smaller electronic devices for a plug load density of 1.7 W/ft^2 (18.3 W/m^2). Each kitchen contains a refrigerator and an electric range. The refrigerator was assumed to be very efficient, with an average power consumption of 76 W, and the range was assumed to have a peak power of 1,500 W. There are 14 washing machines in the building (four on the first floor and five on the second and third floors). With a 90% occupancy rate for the building, there are 140 occupants. Plug load density in the office building for all scenarios through DER was assumed to be 1.7 W/ft^2 (18.3 W/m^2).

Table 5. Infiltration Leakage Rate Modeling Assumptions

Parameter	0.25 cfm/ft^2 (1.25 L/s/m^2)	0.15 cfm/ft^2 (0.75 L/s/m^2)
ACH at 0.3 in w.g. (75 Pa)	2.98	1.79
ACH at 0.02 in w.g. (5 Pa)	0.51	0.31
Excess ventilation flow at 0.02 in. w.c. (5 Pa)	5832 cfm (2752 L/s)	3499 (1651 L/s)

HVAC

The baseline HVAC system efficiency for both types of buildings is based on requirements of ASHRAE Standard 90.1-1980. The base case and DER scenarios include HVAC systems with efficiencies upgraded to the requirements of ASHRAE Standard 90.1-2010 adopted for the U.S. Federal sector. More stringent requirements of the next generation of the ASHRAE Standard 90.1 from 2013 can be used to achieve “national dream” scenarios.

For the barracks model, the baseline HVAC system used packaged single zone air-conditioning (PSZ-AC) units with a natural gas furnace in each room or zone. A DOAS with FCUs was considered for the base case (COP 2.87) and boiler with thermal efficiency of 0.80. For the DER case, the DOAS provided the building ventilation air, and zone-level FCUs were used to control zone loads. The DOAS included a packaged direct-expansion coil for cooling and humidity control, hot water coil for heating energy, and an energy recovery ventilator (ERV). The base case ERV was modeled with sensible heat recovery only at 75% to 70% effectiveness at 75% to 100% airflow. The DER simulations included latent heat recovery. Frost control for the ERV was handled with the exhaust only method in EnergyPlus, which bypasses the supply air around the ERV to avoid frost conditions. The system was operated with an outdoor air temperature (OAT) reset on supply air temperature (SAT). The SAT setpoint schedule was colder with higher OAT and warmer with colder OAT. The setpoint at high OAT was lower in the humid climates for better humidity control and higher in the dry climates for more energy savings. The space loads are met with four-pipe FCUs connected to a central chiller (COP 4.4) and boiler (thermal efficiency of 0.95).

For the office building, the baseline, base case, and DER HVAC configuration used fan-coil units for office zones and unit-heaters for the mechanical rooms. Chilled water was supplied by an air-cooled chiller (2.87 COP). Hot water was supplied by a natural gas boiler (0.80 Et). Heating and cooling setpoints were taken from the standard brigade design specification with heating at 70°F (21°C) and setback at 65°F (18°C) and with cooling at 75°F (24°C) with setup at 78°F (26°C). The offices spaces were modeled with setback during unoccupied hours on nights and weekends. The heating setpoint in the mechanical room was set at 60F. The "national dream" scenarios used a variable refrigerant flow system.

The HVAC strategy and modeling approach for the DER scenario was to provide high efficiency HVAC systems that offset the sensible heating and cooling loads in the spaces and to provide separate high-efficiency DOAS, which includes a total energy recovery exhaust air system to handle the ventilation requirements and the latent (moisture) load in the spaces. The outdoor air ventilation quantity provided by the DOAS maintained the building, including the hallways, at a slightly positive pressure relative to outdoors to eliminate uncontrolled infiltration into the building. High efficiency, variable-speed pumps and fans were used throughout the HVAC system, as well as high efficiency boilers and chillers for both building types.

RESULTS

Table 7 lists the results of the computational analysis of simulated buildings for barracks; Table 8 lists those results for an office building. Both tables show the energy use intensity (EUI) as a percentage of the baseline EUI prior to renovation. Site energy represents the EUI measured as if by a natural gas and electric meter on the building, while source EUI represents primary energy required to deliver energy to the site, including conversion and transmission losses (1.047 for gas and 3.34 for electricity). A review of the data in Table 7 and Table 8 reveals two interesting points. First, upgrading both types of buildings from a 1980 standard to a 2010 version of ASHRAE Standard 90.1 only results in a decreased of modeled energy usage by 12% to 36% in different climate zones. This is partly because lighting upgrades were already factored into the older buildings. Second, application of additional bundles of core technologies easily results in energy usage reduction by about 50% for office buildings, but it is a challenge to achieve 50% energy use reduction in some climates (generally those climates in which cooling requirements dominate) in the modeled barracks building.

A look at the energy resource breakdowns from the tool is instructive. Figures 5 and Figure 6 show the breakdown of energy use for Climate Zones 3A and 6B, respectively, for both office and barracks buildings. As improvements to the building envelope, lighting, and higher efficiency of HVAC equipment reduce the EUI, internal loads dominate energy usage more and more. In the office building, plug loads (interior equipment) are initially a much larger fraction of the

Table 6. Example of USACE Guide Lighting Recommendations for DER of Barracks (ASHRAE 2010a)

Space	Design Criteria					Control Strategies				Technologies				Approach				
		IP		SI		Levels	Automatic Interface											
	Target Illuminance at Taskfc (Design Goal)	Target Lighting Power Density, W/ft^2 (Project Design Goal)	Allowable Lighting Power Density, W/ft^2 (ASHRAE/IESNA Std 90.1-2004/2007)	Target Lighting Power Density, W/m^2 (Project Design Goal)	Allowable Lighting Power Density, W/m^2 (ASHRAE/IESNA Std 90.1-2004/2007)	Switching—(blank) Multilevel—M Full Dimming—D	V—Vacancy [Manual ON/ Auto OFF] O—Occupancy [Auto ON/ Auto OFF]	Daylight (e.g., Photosensors)	Schedule (e.g., Astronomical time-clock)	Linear Fluorescent	Compact Fluorescent	Ceramic Metal Halide	Light Emitting Diodes	Overhead General Lighting	Overhead Ambient Lighting	Task Lighting	Wallwash/Perimeter Lighting	Adjustable Accent Lighting
Corridor	10	0.50	0.5	5.4	5.4		O			4				•			•	
Living Quarters	5–30	0.60	1.1	6.5	11.8		V			4	4		4	•	•	•		
Mechanical/ Electrical	30	0.70	1.5	7.5	16.1		V			4				•				
Restroom / Shower	20	0.80	0.9	8.6	9.7		V			4	4		4	•			•	
Stair	10	0.50	0.6	5.4	6.5	M	O			4				•				
Storage (General)	10	0.50	0.8	5.4	8.6		V			4				•				•

Table 7. Barracks

Climate Zone	Baseline						Base Case		DER			HPB	
	Site EUIh (100%), kWh/m²·yr (kBtu/ft² ·yr)		Site EUIt (100%), kWh/m²·yr (kBtu/ ft²·yr)		Source EUIt (100%), kWh/m²·yr (kBtu/ft²·yr)		Site energy, %	Source energy, %	Site energy, %	Site heating energy, %	Source energy, %	Site energy, %	Source energy, %
1A	1	(0)	398	(126)	1154	(366)	83%	81%	61%	41%	58%	41%	41%
2A	33	(10)	380	(121)	1025	(325)	83%	82%	59%	16%	58%	40%	41%
2B	17	(5)	365	(116)	1008	(320)	83%	82%	60%	20%	58%	39%	39%
3A	65	(21)	394	(125)	965	(306)	81%	82%	55%	16%	58%	37%	41%
3B	37	(12)	326	(103)	812	(258)	85%	86%	61%	18%	63%	40%	43%
3C	35	(11)	273	(87)	634	(201)	88%	91%	67%	30%	69%	54%	63%
4A	103	(33)	397	(126)	869	(276)	80%	84%	52%	15%	75%	35%	41%
4B	86	(27)	333	(106)	745	(236)	84%	88%	58%	12%	65%	38%	44%
4C	111	(35)	330	(105)	678	(215)	82%	88%	56%	14%	65%	38%	45%
5A	160	(51)	422	(134)	872	(277)	79%	83%	49%	13%	58%	33%	40%
5B	133	(42)	362	(115)	733	(233)	82%	87%	48%	12%	63%	35%	43%
6A	212	(67)	448	(142)	839	(266)	78%	84%	45%	12%	56%	30%	39%
6B	192	(61)	414	(131)	773	(245)	79%	86%	47%	11%	59%	31%	40%
7	283	(90)	508	(161)	878	(279)	76%	82%	41%	12%	53%	27%	37%
8	417	(132)	630	(200)	978	(310)	76%	82%	36%	8%	48%	23%	33%

(EUIh—heating energy use intensity; EUIt—total energy use intensity)

Table 8. Office Building

Climate Zone	Baseline						Base Case		DER			HPB	
	Site EUIh (100%), kWh/m²·yr (kBtu/ft²·yr)		Site EUIt (100%), kWh/m²·yr (kBtu/ft²·yr)		Source EUIt (100%), kWh/m²·yr (kBtu/ft²·yr)		Site energy, %	Source energy, %	Site energy, %	Site heating energy, %	Source energy, %	Site energy, %	Source energy, %
1A	24	(7)	261	(83)	815	(259)	70%	73%	52%	9%	55%	34%	36%
2A	60	(19)	285	(90)	814	(258)	68%	72%	54%	37%	57%	30%	35%
2B	81	(26)	314	(100)	862	(273)	64%	71%	51%	13%	59%	27%	9%
3A	82	(26)	288	(91)	771	(245)	66%	72%	53%	37%	57%	29%	36%
3B	68	(22)	251	(80)	680	(216)	70%	77%	49%	8%	59%	34%	42%
3C	45	(14)	183	(58)	507	(161)	74%	84%	59%	4%	70%	41%	49%
4A	96	(30)	271	(86)	685	(217)	65%	74%	50%	11%	62%	31%	40%
4B	71	(22)	227	(72)	593	(188)	69%	79%	50%	5%	63%	37%	46%
4C	76	(24)	206	(65)	513	(163)	69%	82%	52%	4%	67%	37%	48%
5A	107	(34)	270	(86)	656	(208)	65%	75%	50%	13%	63%	31%	42%
5B	83	(26)	223	(71)	552	(175)	69%	80%	50%	5%	65%	36%	47%
6A	121	(39)	265	(84)	606	(192)	64%	77%	48%	12%	64%	31%	45%
6B	118	(38)	254	(81)	575	(182)	66%	78%	49%	12%	66%	32%	45%
7	145	(46)	278	(88)	594	(189)	61%	76%	46%	13%	64%	29%	45%
8	218	(69)	340	(108)	634	(201)	58%	73%	41%	17%	61%	24%	42%

(EUIh—heating energy use intensity; EUIt—total energy use intensity)

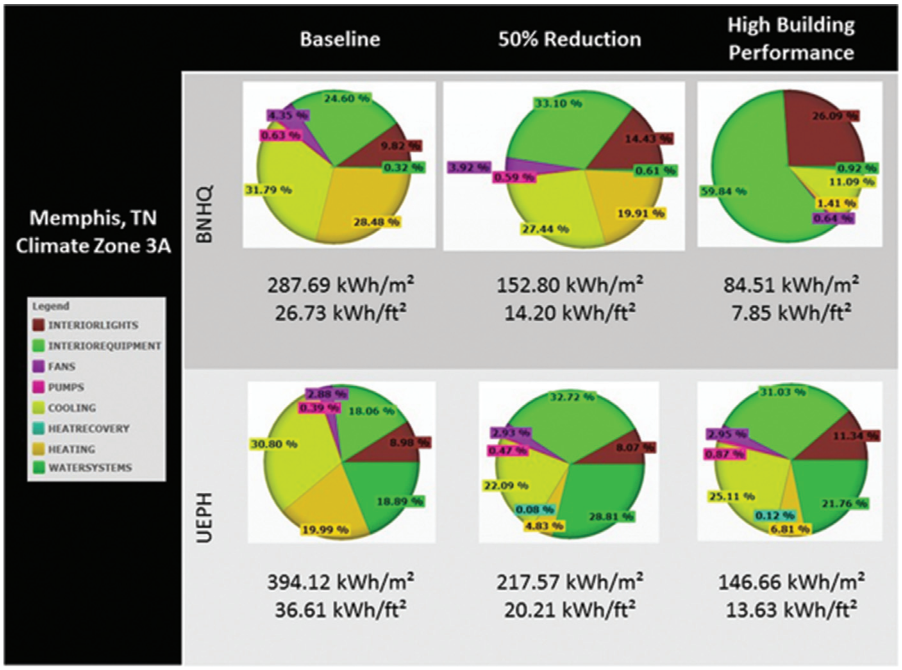


Figure 5 *Energy end use as percentage of total EUI in climate zone 3A, Memphis, TN.*

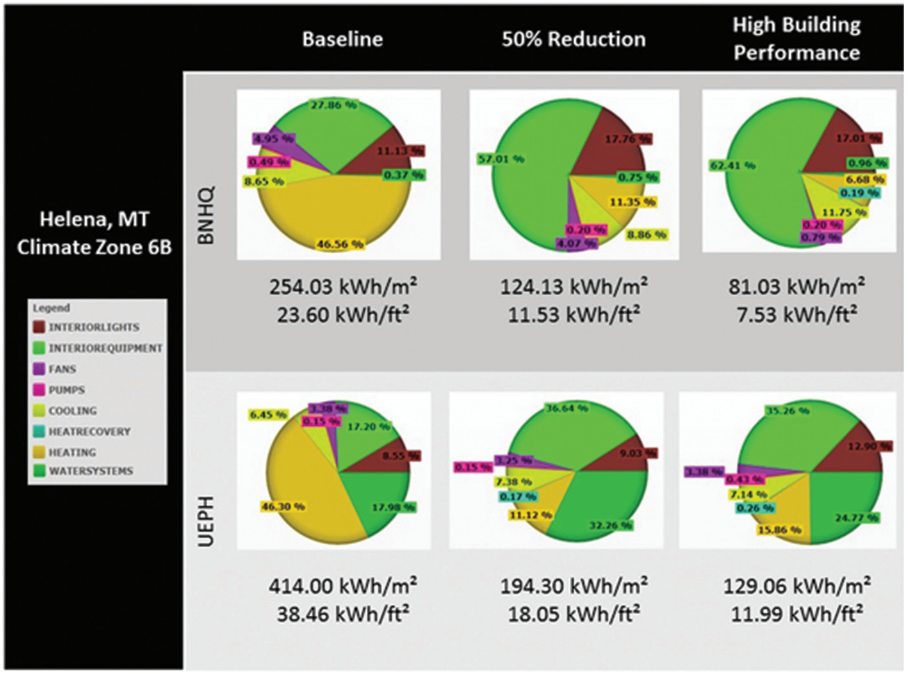


Figure 6 *Energy end use as percentage of total EUI in climate zone 6B, Helena, MT.*

EUI, leaving not as much potential for reduction in the other categories. In the barracks, plug loads are important, but a significant percentage of energy is used for domestic water heating (which provides an additional opportunity for energy use reduction, not included in the core technologies bundle). For the high performance building, according to assumed scenarios, other EEMs can be used in addition to core technologies bundles, including reduction in plug and domestic hot-water loads. These additional EEM technology bundles allow achievement of better than a 50% overall energy reduction.

Tables 9 and Table 10 show the cumulative impact of different EEM packages on energy use reduction in the DER scenario for barracks and office buildings in Climate Zones 3, 5, and 7, compared to the base case. Note: packages may be applied in a different order. Remember that the base case has already improved the building to ASHRAE 90.1-2010 standards.

CONCLUSION

The base case scenario, which describes major renovation to minimum requirements of ASHRAE Standard 90.1-2010 to building energy systems, improves building energy use in Climate Zones 1 through 8 by 12% to 24% compared to the baseline in barracks and by 26% to 42% in office buildings. The base case scenario achieves significant heating and cooling energy use energy reduction (Table 11). However, the reduction in total energy usage is much more modest (Tables 7 and Table 8) due to constant plug loads and lighting energy.

With a DER scenario using the core technology bundle (increased insulation of the buildings envelope, advanced windows, significantly improved building airtightness, improved lighting design and technologies, heat recovery, and high efficiency electrical and HVAC system), heating energy can be further reduced, reaching up to 87% to 90% reduction in barracks and by 63% to 87% in office buildings. Cooling energy can be reduced by 60% to 67% in barracks and by 51% to 58% in office buildings. Reduction of lighting energy in barracks and office buildings will be 50% and 22%, respectively. The major part of remaining energy consumption in barracks is due to energy use by plug loads and heating of DHW. In office buildings, the major remaining part is due to plug loads. Overall, application of the DER core technology bundle to barracks results in site energy use reduction by 45% in Climate Zone 3A, 51% in Climate Zone 5A, and 49% in Climate Zone 7. For office buildings, application of the DER core technology bundle results in site energy use reduction by 47% in Climate Zone 3A, 50% in Climate Zone 5A, and 54% in Climate Zone 7.

Table 9. Impact of Different Energy Conservation Measure (ECM) Packages on Energy Use Reduction DER of a Barracks Building

Package	Climate Zone 3A Energy Reduction, %	Climate Zone 5A Energy Reduction, %	Climate Zone 7 Energy Reduction, %
Base Case	0	0	0
Envelope and Infiltration	4	5	8
Lighting Package	10	10	11
HVAC Package	22	19	19
Energy Recovery Package	32	38	47

Table 10. Impact of Different ECM Packages on Energy Use Reduction in the DER Scenario of an Office Building

Package	Climate Zone 3A Energy Reduction, %	Climate Zone 5A Energy Reduction, %	Climate Zone 7 Energy Reduction, %
Base Case	0	0	0
Lighting Package	3	4	3
Envelope and Infiltration	34	24	26
HVAC Package	42.9	31.57	31
Energy Recovery Package	43.1	31.64	31

Table 11. Comparison of Heating, Cooling, and Lighting Energy Reduction in Modeled Building Types in Selected Climate Conditions

Building Type	Scenario	Heating Energy Reduction, %			Cooling Energy Reduction, %			Lighting Energy Reduction, %		
		CZ 3A	CZ 5A	CZ 7	CZ 3A	CZ 5A	CZ 7	CZ 3A	CZ 5A	CZ 7
Barracks	Base Case	42%	41%	39%	31%	27%	21%	0%	0%	0%
	DER	87%	87%	90%	60%	58%	67%	50%	50%	53%
Office	Base Case	57%	61%	64%	48%	45%	39%	0%	0%	0%
	DER	63%	87%	87%	54%	58%	51%	22%	22%	22%

To further reduce site energy, water conservation technologies (e.g., low-flow shower heads), plug load reduction, and more advanced HVAC strategies (e.g., variable refrigerant flow) can be used. This can result in an additional site energy use reduction of approximately 20%. While the first group of technologies can be included in the scope of a major renovation project, plug load reduction is more of a challenge. It can be achieved by establishing energy conservation polices and procurement of high-efficiency appliances (refrigerators, ovens, computers, monitors, etc.) by the building owner or tenants, by implementation of smart power strips, and by introducing dedicated sockets with occupancy control. Additional energy savings can be achieved by introducing building-based or building cluster-wide energy power and thermal energy generation from renewable sources.

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