Energy Efficiency Opportunities in Highway Lodging Buildings: Development of 50% Energy Savings Design Technology Packages

Wei Jiang, W&J Environment and Energy Technology Ltd.
Krishnan Gowri, Brian Thornton, and Bing Liu, Pacific Northwest National Laboratory

ABSTRACT

This paper presents the process, methodology, and assumptions for development of the *50% Energy Savings Design Technology Packages for Highway Lodging Buildings*, a design guidance document that provides specific recommendations for achieving 50% site energy savings in roadside motels (highway lodging) above the requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004. This 50% solution represents a further step toward realization of the U.S. Department of Energy's net-zero energy building goal, and exceeds the 30% savings in the *Advanced Energy Design Guide* series (upon which this work was built). This work can serve as the technical feasibility study for the development of a 50% saving *Advanced Energy Design Guide for Highway Lodging,* and thus should greatly expedite the development process.

The design technology package provides user-friendly design assistance to designers, developers, and owners of highway lodging properties. It is intended to encourage energy-efficient design by providing prescriptive energy-efficiency recommendations for each climate zone in the United States and to help new construction of highway lodging attain the 50% energy savings target.

This paper describes the steps that were taken to demonstrate the technical feasibility of achieving a 50% reduction in whole-building energy use with practical and commercially available technologies. The energy analysis results are presented, indicating the recommended energy-efficient measures achieved a national-weighted average energy savings of 55%, relative to Standard 90.1-2004. The cost-effectiveness of the recommended technology package is evaluated, and the result shows an average simple payback of 11.3 years. Finally, suggestions for improving future 50% (or beyond) design technology package work are discussed.

Introduction

Buildings account for over 40% of total energy use and over 70% of electricity use in the United States. To tackle this challenge, the Department of Energy (DOE) has, through its Building Technologies (BT) Program, established a strategic goal to reduce energy consumption as well as energy expenditures in commercial buildings: *To create technologies and design approaches that enable net-zero energy buildings (NZEB) at low incremental cost by 2025.*

To reach the NZEB goal by 2025, DOE-BT has implemented a strategy to develop information packages and tools to support realization of 30%, 50% and 70% more energy-efficient buildings, relative to the Standard 90.1-2004 (ANSI/ASHRAE/IESNA 2004a). By 2009, ASHRAE and its partners have published a series of design guides focused on small commercial buildings (ASHRAE 2004, 2006, 2008a, 2008b, 2009a, 2009b).[1] These guides are intended to provide recommendations for achieving at least 30% energy savings over the

---

[1] The published *Advanced Energy Design Guide* guides are available for free download at http://www.ashrae.org/technology/page/938.

minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-1999 (ANSI/ASHRAE/IESNA 1999). A *Technical Support Document* for each of the guides, describing the assumptions and methodologies used to achieve the targeted levels of energy performance, was also published along with the guides (Jarnagin et al. 2006; Liu et al. 2006; Liu et al. 2007; Pless et al. 2007, Jiang et al. 2008).

The 30% energy savings target is the first step toward achieving net-zero commercial buildings. Having proven the feasibility of 30% energy savings across a variety of building types, DOE now exits the 30% design guide area and focuses on the informational products to realize 50% and 70% whole-building energy savings goals. The highway lodging and three other building types, i.e., medium office, general merchandise stores, and grocery stores, were selected on a prioritized basis for the 50% design technology packages development in FY2009. The objective of this project (referred to Technical Support Document for 50% Design Technology Packages, or TSD) is to provide design technology packages that indicate, measure by measure, how to achieve 50% energy savings relative to Standard 90.1-2004 for highway lodging properties. The design technology packages provide a sensible, hands-on approach to design through the use of "off-the-shelf" technologies and products that are practical and commercially available from major manufacturers. DOE's decision to develop the TSDs first would greatly expedite the process with which the final design guides are published by ASHRAE to impact actual design decisions in new commercial buildings. This paper summarizes the methodology and assumptions for development of the 50% design technology package for highway lodging. More detailed descriptions of the work can be found in the TSD (Jiang et al. 2009).

Energy Savings Analysis Methodology

This section describes the energy savings evaluation approach, simulation tools, and U.S. climate locations that were used to assess and quantify the 50% energy savings by implementing the energy efficiency measures (EEMs) in the design package.

Evaluation Approach

The energy savings evaluation approach was similar to the one used for the *Advanced Energy Design Guides* (AEDGs), where prototypical buildings were selected, and then simulated in various climate locations covering the eight climate zones contained in ASHRAE Standard 90.1 and the International Energy Conservation Code (IECC) (IECC 2006). The analysis results established that the EEM recommendations in the design package meet the 50% energy savings target. Cost effectiveness of the recommended EEMs was then assessed using incremental costs data and simple payback period analysis.

The energy savings goal of the design package was based on whole-building site energy savings between minimally code-compliant (baseline) highway lodging buildings and advanced highway lodging buildings that used the EEMs in the design package. The baseline buildings in this design package were based on the requirements of ASHRAE Standard 90.1-2004. The selection of ASHRAE 90.1-2004 for the baseline was because the standard was the most recent for which DOE had issued a formal determination of energy savings. The whole-building energy savings metrics was also in line with the current ASHRAE practices specified in Appendix G of ASHRAE Standard 90.1. The site energy metric was adopted to retain the consistency with previous AEDGs.

Simulation Tool Description

EnergyPlus Version 3.0 (released in November 2008) was used to assess the energy savings potential of the recommended EEMs. All energy simulations were performed with Pacific Northwest National Laboratory's (PNNL) Linux energy simulation infrastructure, which manages inputs and outputs of the *EnergyPlus* simulations. This infrastructure includes creating *EnergyPlus* input files by a PNNL-developed program known as gparm, submitting input files to an 80-central processing unit (CPU) computing cluster for batch simulation, and energy end-use results extraction.

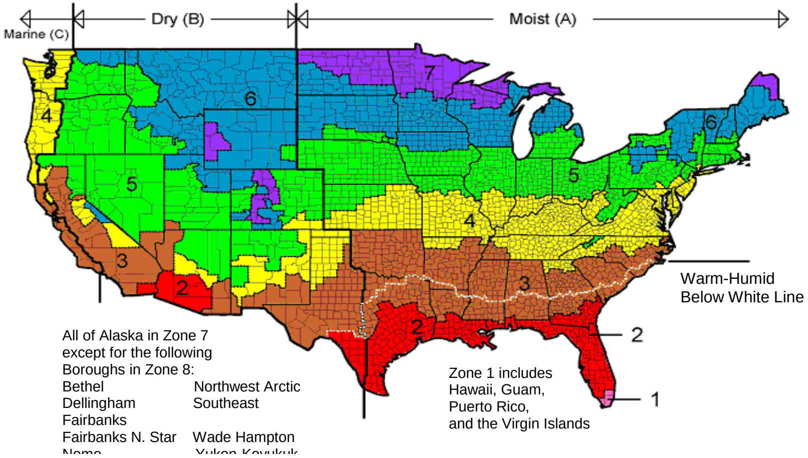
Climate Zones and Construction Weights

The previously released 30% *AEDGs* have standardized climate zones that have been adopted by IECC as well as ASHRAE for both residential and commercial building applications. This results in a common set of climate zones for use in codes and standards. The common set of climate zones includes eight zones covering the entire United States, as shown in Figure 1 (Briggs et al. 2003). The climate zones are categorized from 1 to 8, with increasing heating degree days and decreasing cooling degree days, and further divided into moist and dry regions. A specific climate location (city) is selected as a representative of each climate zone.

The *AEDGs* selected 15 cities as the representative climate locations. For this project we selected a revised set of 16 cities that balance the representation of the climate zones and the number of buildings in the climate zones. The modified representative cites are also consistent with those used in DOE's commercial benchmark buildings (Torcellini et al. 2008). The 16 cities representing the climate zones are:

1A: Miami, Florida (hot, humid)
2A: Houston, Texas (hot, humid)
2B: Phoenix, Arizona (hot, dry)
3A: Atlanta, Georgia (hot, humid)
3B-CA: Los Angeles, California (hot, dry)
3B-other: Las Vegas, Nevada (hot, dry)
3C: San Francisco, California (marine)
4A: Baltimore, Maryland (mild, humid)
4B: Albuquerque, New Mexico (mild, dry)
4C: Seattle, Washington (marine)
5A: Chicago, Illinois (cold, humid)
5B: Denver, Colorado (cold, dry)
6A: Minneapolis, Minnesota (cold, humid)
6B: Helena, Montana (cold, dry)
7: Duluth, Minnesota (very cold)
8: Fairbanks, Alaska (extreme cold)

Figure 1. DOE-Developed Climate Zone Map



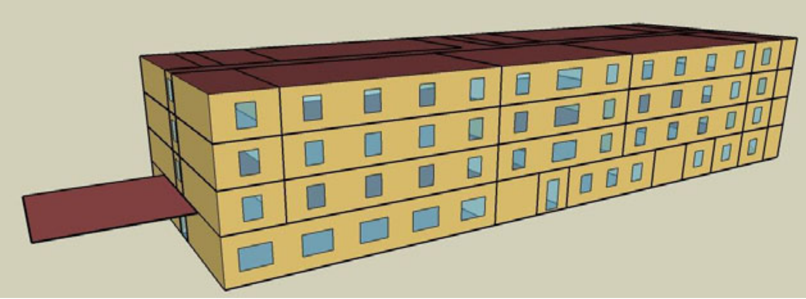
These representative climate locations were assigned construction weights based on the square footage of construction from 2003 to 2007, as presented in a PNNL study that utilizes the McGraw-Hill Construction Projects Starts Database (Jarnagin and Bandyopadhyay 2010). The weights for highway lodging by climate locations were used in this project to calculate weighted-average energy savings for the whole country.

Development of Prototypical Building

The first step of the energy savings analysis is to develop prototypical buildings. The highway lodging prototype is a theoretical building with characteristics of a typical building of this size and end-use. The building prototype used for this study is the 43,000 ft^2 highway lodging prototype, one of two prototypes, developed during the development of *Advanced Energy Design Guide for Highway Lodging* (AEDG-HL).

This highway lodging prototype is a wide, rectangular, four-story building with a total floor area of 43,000 ft^2, aspect ratio of 3.0 and window-to-wall ratio of 11%. There are 77 guest rooms accounting for 63% of the total floor area, and it includes public use areas for lobby, office, meeting room, laundry room, exercise room, etc. The data sets that were used to form the highway lodging building prototype include 2003 Commercial Building Energy Consumption Survey (CBECS) (EIA 2005), F.W. Dodge Database, New Commercial Construction Characteristics (NC^3) Database (Richman et al. 2008), 2008 Lodging Industry Profile (AHLA 2008), and additional data sets from the AEDG-HL project committee, which includes actual floor plans for Hampton Inn Prototype (Hampton Inn 2008), plug loads data, etc.

Figure 2. Axonometric View of Highway Lodging Prototype



Development of Baseline Building Models

In the baseline models, building components that are regulated by ASHRAE Standard 90.1-2004 were assumed to “just meet” the minimum prescriptive requirements of that standard. Components that are not regulated by Standard 90.1 are assumed to be designed as is standard practice for a highway lodging building. Standard practice is determined from various sources including a review of CBECS data and the inputs of various design and construction industry professionals.

Envelope

The baseline building envelope characteristics were developed to meet the prescriptive design requirements in accordance with ASHRAE Standard 90.1-2004 Section 5.3, Prescriptive

Building Envelope Option. Most of the spaces in lodging buildings are guest rooms, which are defined as residential spaces according to the Standard. Because 84% of the spaces on the ground floor of the prototype are non-residential spaces and 79% of the spaces on floors two through four are guest rooms, it was decided that the envelope requirements for the spaces on the ground floor shall meet the criteria for non-residential conditioned space, and the envelope requirements for the spaces on the remaining floors shall meet the criteria for residential conditioned space.

The exterior walls are constructed of 8-in. medium weight concrete blocks with a density of 115 lb/ft³ and solid grouted cores. The flat roof consists of a roof membrane over rigid insulation, uninterrupted by framing, over a structural metal deck. The base assembly for the ground floor is carpet over 6-in. concrete slab-on-grade floor poured directly on to the earth. Insulation R-values for exterior walls, roofs and slab-on-grade floors were selected to create a construction assembly that just meets the maximum U-value and F-factor required in Tables 5.5.1 through 5.5.8 of the Standard, as defined by climate zones. The baseline window U-factor and solar heat gain coefficient were determined to match the fenestration performance criteria outlined in Tables 5.5.1 through 5.5.8 of the Standard, by climate, based on an estimated weighting of 22% operable and 78% fixed windows.[2]

Internal Loads

Lodging buildings are generally occupied 24 hours a day, 365 days a year. However, the building contains a variety of space types with differing usage patterns. The baseline internal load schedules for the guest rooms were adapted from those used in Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment (DOE 2000), and separate schedules were developed for rented and unrented guest rooms. Schedules for lighting and plug loads were matched to the occupancy schedules. The schedules for other spaces were derived based on the AEDG-HL project committee's inputs. To model energy-efficient control technologies for lighting and plug loads, the lighting and plug loads schedules were assumed to be different for baseline buildings and advanced buildings.

The highway lodging prototype was modeled such that 65% of the guest rooms were rented throughout the year based on the occupancy rate reported in the 2008 Lodging Industry Profile (AHLA 2008). It was also assumed that there were, on average, 1.5 persons in each of those rented rooms. The values of the peak occupancy for the common areas were based on occupant densities listed in ASHRAE Standard 62-1999 (ANSI/ASHRAE 1999) and Standard 62.1-2004 (ANSI/ASHRAE 2004).

The baseline interior lighting system was assumed to be a system that just meets the lighting power density (LPD) requirements of the space-by-space method described in Standard 90.1-2004, Table 9.6.1. The baseline LPD values are summarized in Table 2. The lighting diversity schedules were used in the building energy models to reflect the inclusion of the required mandatory lighting controls. Table 9.4.5 of Standard 90.1-2004 specifies permitted maximum LPDs for building exteriors. Those values together with the Hampton Inn Prototype plans were used to derive the installed exterior lighting power for the baseline building models. The baseline models also simulated the use of an astronomical time switch to automatically control the exterior lighting as required by the Standard.

---

[2] ASHRAE SSPC 90.1 Envelope Subcommittee provided the estimated weighting factor based on the Ducker Fenestration Market Data.

The peak power densities of plug loads in the building energy models were calculated by adding the peak power of all typically used appliances in that space and multiplying the peak power by the appliance usage diversity factor, as summarized in Table 2. The peak power for common appliances and office equipment was obtained from several sources, including the 2005 ASHRAE Handbook of Fundamentals (ASHRAE 2005), ENERGY STAR website, web search, etc. The laundry equipment gas and electricity energy use data were derived based on lodging industry practices, manufacturers' data, etc.

HVAC Systems

Based on the 2003 CBECS data and Ducker's packaged terminal air conditioner (PTAC) market research report (Ducker Worldwide 2001), it was assumed that in the baseline building, each guest room was served by a PTAC with electric resistance of 9,000 Btu/h cooling capacity, and the common areas were served by split type air-conditioning units with gas furnace. Detailed review of the 2003 CBECS data and Ducker's report can be found in the TSD (Jiang et al. 2009). It was also assumed that unit heaters were used to condition semi-heated spaces, such as the mechanical room and stairs. The efficiency of baseline HVAC equipment was assumed to meet the Standard 90.1-2004 requirements, based on their actual required heating and cooling capacities.

In the baseline building, the HVAC systems were assumed to run continuously in the rented guest rooms and common areas. For the unrented guest rooms, it was assumed that the PTAC units cycle on and off to maintain the setback thermostat temperature. Based on the lodging industry practice, rented guest rooms were assumed to maintain 70°F for both heating and cooling year around. For unrented guest rooms, thermostat control was assumed with a 4°F temperature setback. The common areas are maintained at 70°F heating setpoint and 75°F cooling setpoint year around. The semi-heated mechanical room and stairs are heated to 45°F.

Outdoor ventilation air is supplied to the guest rooms by a central make-up air unit (MAU) with direct expansion (DX) coil and gas furnace. Each guest room is served by a central toilet exhaust system that operates continuously. Outdoor air ventilation rates were modeled per the requirements of ASHRAE Standard 62.1-2004, which specifies minimum ventilation rates based on space types. According to Section 6.4.3.4 of Standard 90.1-2004, gravity dampers were assumed for all systems in the baseline buildings, and the ventilation air was supplied to the spaces continuously. The baseline HVAC systems were simulated with economizers when required by Standard 90.1- 2004 based on the cooling capacities and climate zones. All PTAC units are below the cooling capacity threshold and air economizers are not required. For the systems servings the common areas, some are large enough to require economizers, based on the thermal zone served and the climate.

Service Water Heating

The hot water consumption in hotel buildings that do not contain substantial food service facilities are from two major users: guest room hot water use and laundry hot water use. The baseline service water heating system consists of two hot water circulation loops: a circulation loop for guest rooms and a separate circulation loop for laundry. Each circulation loop is served by gas-fired storage water heaters. The hot water supply temperatures were assumed to be 140°F for laundry and 120°F for guest rooms, respectively. The typical hot water consumption was derived from *2007 ASHRAE Handbook: HVAC Applications* (ASHRAE 2007) and lodging industry data. Gas storage water heaters were chosen based on the inputs from the lodging industry experts as well as the 2003 CBECS data, which shows the most typical fuel used for water heating in small hotels/motels is natural gas. The efficiency of baseline water heaters was set to match the minimum performance requirement in Standard 90.1-2004.

Energy Efficiency Measures Recommendations

The starting points to determining the candidate EEMs were those recommendations in the published AEDG-HL and the approved and proposed addenda to ASHRAE Standard 90.1-2007, and they were further evaluated and developed with the following major considerations.

- The EEMs are based on technologies that are commercially available from multiple sources. Technologies or techniques that are one-of-a-kind or available from a single manufacturer are not recommended.
- The EEMs can be modeled by the current version of the *EnergyPlus* simulation program.
- The EEMs address five building components: building envelope, HVAC, service water heating, lighting, and plug loads.

Envelope

The envelope EEMs, as summarized in Table 1, were derived based on the more-stringent envelope recommendations from the AEDG-HL and the public review draft of Addendum bb to ASHRAE Standard 90.1-2007. Consistent with the movement from the hotter to colder zones, the insulation requirements (R-value) increase as the climates get colder, and corresponding thermal transmittance (U-factor) decreases. Control of solar loads is more important in the hotter, sunnier climates, and thus the solar heat gain coefficient of the high-performance windows tends to be more stringent (lower) in zone 1 and higher in zone 8. Cool roofs are recommended in climate zones 1 through 3 because a cool roof that reflects solar energy can be an effective energy-efficiency measure in hot climates.

Table 1. Energy Efficiency Measures Recommendations – Envelope

Item	Component	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
Roof (Insulation entirely above deck)	R-value, °F·h·ft^2 /Btu	R-25 c.i.	R-25 c.i.	R-25 c.i.	R-30 c.i.	R-30 c.i.	R-30 c.i.	R-35 c.i.	R-35 c.i.
	SRI	78	78	78	NR	NR	NR	NR	NR
Exterior walls (Mass wall)	R-value, °F·h·ft^2 /Btu	R-5.7 c.i.	R-7.6 c.i.	R-11.4 c.i.	R-13.3 c.i.	R-19.5 c.i.	R-19.5 c.i.	R-19.5 c.i.	R-19.5 c.i.
Slabs (Unheated)	R-value, ft·°F·h/Btu	NR	NR	R-10 for 24 in.	R-15 for 24 in.	R-20 for 24 in.	R-20 for 48 in.	R-20 for 48 in.	R-25 for 48 in.
Vertical glazing (Including doors)	U-value, Btu/h·ft^2·°F	U-0.56	U-0.45	U-0.41	U-0.38	U-0.35	U-0.35	U-0.33	U-0.25
	SHGC	0.28	0.24	0.24	0.24	0.23	0.38	0.38	0.37

Lighting

The lighting measures are not climate dependent. As such, the same recommendations are provided for all climate zones. The design package includes recommended values for the reduced interior lighting power density levels, as shown in Table 2, based on lighting modeling studies performed by the lighting experts in Seattle Lighting Design Lab. The area-weighted average lighting level reductions in the advanced building models were about 30% relative to the 90.1-2004 baseline buildings.

For guest rooms, the recommended lighting control measures include occupancy-based guest room energy management system and bathroom lighting vacancy control. The impact of occupancy controls was modeled by reducing the baseline guest room lighting levels by 80% during the unoccupied hours and sleep time, and 20% during the occupied hours (CEC 2005). For stairs, luminaires with an integrated occupancy sensor on all fixtures that provides a bi-level, low light level when the space is unoccupied and full light when occupied are recommended. Ceiling-mounted or wall-switch-mounted occupancy sensors for laundry rooms, offices, exercise rooms, meeting rooms, employee lounge, mechanical/electrical rooms and storage rooms are also recommended in the design package, and, therefore, included in the simulation for the advanced building models. Based on various studies (Jarnagin et al. 2006; Galasiu et al. 2007; VonNeida et al. 2000; LRC 2004), the impact of various occupancy-based controls was modeled by reducing the baseline lighting levels by 15% for offices, 28% for exercise rooms, 40% for storage rooms and mechanical/electrical rooms, and 26% for restroom, to account for typical occupancy densities.

The design package also includes recommendations for the reduced exterior lighting power density levels according to the lighting power allowances prescribed by Addendum i to Standard 90.1-2007. And, the lighting power allowance for building facades is further reduced in the advanced buildings to 50% of the 90.1-2007 Addendum i allowance because other than helping attract attention for road-side motels, façade lighting is a purely decorative effect and should be eliminated or reduced in buildings attempting to save energy. On top of the measures of reduced exterior lighting power allowances, the design package includes reducing the parking area lighting energy use by using integrated bi-level control that reduces the power by 50% between midnight and 5 am. In addition, installed façade lighting was assumed to be programmed to turn off between the hours of midnight and 5 am in the advanced building models. In contrast, for the baseline buildings, exterior lights are fully energized whenever it is dark outside.

Miscellaneous Equipment

The design package includes using an absorption type of refrigerator in guest rooms, ENERGY STAR labeled products if available, and high-efficiency washers and dryers. The plug load peak power densities used in the advanced building models are summarized in Table 2. The recommended control strategies for plug loads include occupancy-based control to turn off receptacles in guest rooms when unoccupied, power management software for networked computers, vending machine occupancy sensor controls and timer switches for equipment that do not need to be on during off-hours, such as coffee makers and water coolers. The measures also include using washer/extractors that generate high G forces to reduce the retained moisture content of the clothes before going through the dryer cycle, thus greatly reducing the dryer energy use. High-performance washers can generate G forces over 300 G, which can reduce the retained water percentage to 52.5%, compared with 87.5% for conventional washers.

Table 2. Space-by-Space Interior Lighting Power Density and Plug Load Density

Space Type	Interior LPD W/ft^2		Plug Loads Density W/ft^2	
	Baseline	Advanced	Baseline	Advanced
Guest room	1.1	0.71	1.01	0.97
Office	1.1	0.85	1.24	0.71
Lobby	1.1	0.77	2.59	1.83
Employee lounge	1.2	0.82	2.00	1.95
Meeting room	1.3	1.14	0.57	0.57
Exercise room	0.9	0.78	1.77	1.53
Laundry room	0.6	0.52	2.57 (electric)/38.08 (gas)	3.04 (electric)/22.85 (gas)
Restroom	0.9	0.74	0	0
Mechanical room	1.5	1.24	0	0
Storage	0.8	0.62	0	0
Corridor	0.5	0.5	0	0
Stairs	0.6	0.57	0	0

HVAC Systems

PTACs and split air conditioners in the baseline buildings were replaced by a water-source heat pump (WSHP) system in the advanced building models. Each zone or space has one or more WSHP units, which are connected to a two-pipe water loop. Similar to the system setup in the baseline buildings, a dedicated make-up air system, conditioned by a WSHP unit, was assumed to supply required outside air to the guest rooms in the advanced model.

The recommendations for equipment cooling and heating efficiency were based on the Air-conditioning, Heating and Refrigeration Institute (AHRI)'s Certified Equipment Database and California Energy Commission (CEC) Appliances Database. The advanced models also used a condensing gas-fired boiler with a thermal efficiency of 95% in the WSHP loop, which is achievable for many ENERGY STAR labeled boilers. The improved motor efficiency for fans was based on the premium-efficiency motors initiative launched by the Consortium for Energy Efficiency.

Having a setback temperature for unoccupied periods during the heating season or setup temperature during the cooling season will help to save energy. The design package contains installing guest room occupancy-based energy management systems to manage the guest room air-conditioning system for occupied and unoccupied time periods. The guest room thermostat automatically reverts to unoccupied set points (usually 4°F from set point) when the passive infrared (PIR) sensor in conjunction with the door switch determines that the room is unoccupied. Setback and setup controls were also adopted for the meeting rooms, employee lounge and exercise room, which were usually unoccupied during night time.

Low static pressure ductwork is recommended to reduce the fan energy use. It was assumed in the advanced model as a maximum ductwork friction rate being no greater than 0.08 in. per 100 linear feet of duct run, in comparison with the baseline models that assumed a maximum ductwork friction rate being no greater than 0.1 in. per 100 linear feet of duct run.

The design package includes use of motorized dampers to prevent outdoor air from entering during unoccupied periods. When the guest rooms are not rented, outside air intake was turned off by the central energy management system. The systems serving the meeting room, exercise room and employee lounge, which are usually not in use during night time, were also assumed to be equipped with motorized dampers. Energy recovery ventilators (ERV) can provide an efficient means to deal with the latent and sensible outdoor air cooling and heating loads during peak summer and winter conditions. The design package also includes using exhaust air ERVs for the make-up air system and the systems serving the common areas. Following the recommendation in the AEDG-HL Guide, the design package also recommends lowering the capacity threshold for air economizers from 65,000 Btu/h to 54,000 Btu/h for climate zones 3 through 8.

Table 3. Energy Efficiency Measures Recommendations – HVAC and Service Water Heating

Item	Component	Climate Zones 1-8 (except economizer)
HVAC Efficiency	Water-source heat pumps, <17 kBtu/h	14.7 EER, 5.2 Htg COP.
	Water-source heat pumps, >17 kBtu/h and < 65 kBtu	17.6 EER, 5.9 Htg COP
	Water-source heat pumps, >65 kBtu and <135 kBtu	16.0 EER, 5.0 Htg COP
	Water-source heat pump heat source	Use condensing boiler for circulating loop heat source
	Pumping for water-source heat pumps	Variable-speed pumping
	Water-source heat pump heat rejection	Control cooling tower to maximize heat pump EER
	Water-source heat pump heat source	Condensing boiler with 95% E_t
Controls	System operation and thermostat control	Occupancy-based energy management system for guest rooms, thermostat reset for meeting room, employee lounge and exercise room
Economizer	Air conditioners and heat pumps – single package	Climate Zone 1and 2: no requirement Climate Zone 3 to 8: Cooling capacity >54 kBtu/h (15.8 kW)
Ventilation	Ventilation air supply	Motorized damper to control ventilation supply volume to match occupancy
	Heat recovery	Ventilation heat recovery with toilet exhaust
Ducts	Friction rate	0.08 in. w.c./100 ft (2.0 mm w.c./ 30.5 m)
Water Heater	Gas storage water heater efficiency	95% E_t
Water Usage	Hot water usage reduction	Use 1.75 gpm shower heads, 1.0 gpm faucets and 0.45 gal hot water/lb laundry water-conserving clothes washers. Utilize laundry and shower heat recovery.

Service Water Heating Systems

Service water heating constitutes a significant fraction of the total energy usage of lodging facilities in all climate zones. Great energy savings can be identified by examining each of the components that provide the heated water and control its use. The least expensive means of reducing service water heating energy consumption is by reducing service hot water consumption. Therefore, the design package includes using low flow shower heads and faucets that can yield an average of 20% reduction in hot water use compared with the baseline system. Water-conserving commercial washers are also recommended, which results in about 62.5% hot water use reduction compared with the conventional washers.

Potable water supply temperature to buildings in winter in cold climates can be extremely low, often below 50°F (10°C). Drain waste heat recovery units can raise the temperature of cold water supply by recovering waste heat, thus significantly reducing the energy needed to heat cold water. A commercially available device that utilizes this technology is the Gravity-Film-Heat Exchanger (GFX) device (DOE 2005). The design package includes applying the heat recovery units to shower and laundry water loops to preheat both the cold water supply to the washer/shower and the make-up water to the water heater. And the hot water energy use can be further reduced by using condensing water heaters that have a high thermal efficiency of 95%. Table 3 summarizes the EEM recommendations for HVAC and service and hot water systems for each of the climate zones.

Cost Effectiveness Analysis

The costs for the recommended EEMs were developed as incremental costs based on the difference between the costs for the baseline and the EEMs. The incremental costs are based on a per unit cost, such as costs per square foot of wall area, or a per building cost, such as the cost of a single air-conditioning unit that serves an entire building or section of a building. This approach requires that, for each measure, both the baseline cost and the EEM cost must be developed or data must be explicitly available on incremental costs. The highway lodging prototype building for the baseline cases and advanced cases was used as the basis to develop the cost data. Costs were developed for each of the EEMs used in the building, and then the measure costs were summed to get the overall cost premium for the building prototype.

The recommended energy efficiency measures have an average simple payback of 11.3 years and vary from 9.6 to 15.9 years as shown in Table 4. The variability in payback results is caused by differences in the location cost index for different climate locations as well as energy savings and climate zone specific differences in the EEMs such as insulation values. The simple payback for each climate zone is calculated for the energy savings measures in aggregate by dividing the total incremental cost of the measures by the energy savings in dollars. Energy savings in dollars is calculated by using the Energy Information Administration (EIA) national average natural gas rate of $1.16/therm and the national average electric rate of $0.0939/kWh. Actual project costs will vary, but the cost-effectiveness analysis does suggest that 50% energy savings can be achieved for new highway lodging buildings with a reasonable added cost for this level of energy cost savings.

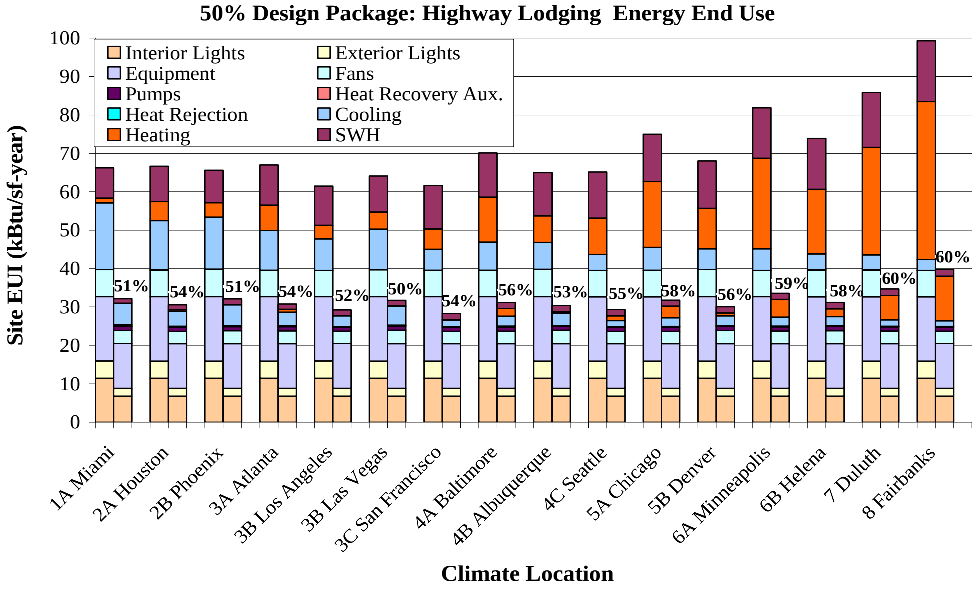
Table 4. Simple Payback Period for 50% Energy Saving Highway Lodging

Climate Zone	Climate City	Incremental First Cost	Energy Cost Savings: Electricity	Energy Cost Savings: Natural Gas	Energy Cost Savings: Total	Simple Payback (Years)
1A	Miami	$329,366	$27,930	$5,235	$33,165	9.9
2A	Houston	$327,513	$26,472	$6,815	$33,286	9.8
2B	Phoenix	$330,109	$25,952	$5,751	$31,703	10.4
3A	Atlanta	$330,852	$25,503	$7,299	$32,802	10.1
3B	Los Angeles	$397,243	$23,114	$6,352	$29,466	13.5
3B	Las Vegas	$387,706	$23,604	$6,185	$29,789	13.0
3C	San Francisco	$468,638	$22,227	$7,247	$29,474	15.9
4A	Baltimore	$348,246	$25,148	$8,818	$33,966	10.3
4B	Albuquerque	$335,902	$22,716	$7,703	$30,420	11.0
4C	Seattle	$388,644	$22,588	$8,368	$30,957	12.6
5A	Chicago	$433,435	$25,369	$10,834	$36,203	12.0
5B	Denver	$358,367	$23,168	$9,173	$32,340	11.1
6A	Minneapolis	$417,252	$25,171	$13,464	$38,635	10.8
6B	Helena	$341,630	$23,286	$11,494	$34,780	9.8
7	Duluth	$388,003	$25,501	$14,801	$40,302	9.6
8	Fairbanks	$456,192	$25,364	$19,005	$44,370	10.3

Energy Savings Results

Energy savings were calculated for 16 climate locations covering all 8 climate zones. The energy simulation results show that the 50% energy savings goal is achievable in all climate zones, and the national weighted average savings is 55%. To understand the impact of the various EEMs on different energy end-use sectors, the energy end-use intensities for the baseline and the advanced models are illustrated in Figure 3. The percentages of on-site energy savings of the advanced models in comparison with the ASHRAE Standard 90.1-2004 baseline are also shown in the figure.

Figure 3. Site Energy Savings by End-Use Category



The lighting EEMs save about 40% interior lighting energy and 55% exterior lighting energy compared with the baselines. The equipment and plug load energy savings average about 30% in all climate zones. The energy savings of lighting and plug loads are observed to be nearly the same across all 16 climate locations. The space cooling energy is reduced by a national weighted-average of 63% attributed to the set of EEMs including high efficiency water source heat pumps and the advanced HVAC system controls, the improved envelope insulation levels, high performance windows, reduced interior lighting energy use, and reduced plug loads. Cooling energy savings vary by climate zone with the highest savings of 70% in climate zone 2A and lowest savings of 44% in climate zone 6B. The space heating energy is reduced by about weighted-average of 88% as a result of the improved envelope insulation levels, high performance windows, the high efficiency water-source heat pump system and the advanced HVAC system controls. The space heating is reduced by more than 95% in several locations in climate zones 1-4, and the lowest energy savings is about 72% in climate zone 8. The service water heating energy use is reduced by an average of 86% with all climate zones.

Among all the EEMs in the design package, it is observed that the water heating EEMs and space cooling and heating EEMs have the greatest impact on the overall energy use reduction. The water heating EEMs contribute to 20~30% of total energy savings, the cooling related EEMs contribute to 25~35% of total energy savings in hot climates (zones 1-2) and the space heating related EEMs contribute to 20~50% of total energy savings in cool and cold climates (zones 4-8).

Summary and Discussions

This paper is intended to provide recommendations and design assistance to designers, developers, and owners of highway lodging properties that will encourage steady progress toward net-zero energy buildings. Prescriptive packages of recommendations presented in the design package by climate zone cover building envelope technologies, lighting technologies, HVAC and service water heating technologies, and miscellaneous appliance technologies. The energy analysis results indicated the developed design packages can achieve a national-weighted average energy savings of 55% over all buildings and climates in comparison with the Standard 90.1-2004 as baseline. The authors recognize that there are other ways of achieving the 50% energy savings, and offer the recommendations in this study as “a way, but not the only way” of meeting the energy savings target.

The analysis approach and methodology adopted for this work more or less follow what were used for the previous AEDG work. The approach could be improved in future 50% (or beyond) design package work. The simple payback period method was adopted as the metric for cost-effectiveness study in this study. To assess the additional costs, savings and benefits of various EEMs over their life time, however, we suggest that the life cycle cost analysis method would be more appropriate. Furthermore, the analysis approach in this work decouples the energy savings evaluation from the cost effectiveness analysis. The latter follows after the former is complete. It would be superior, and more reflective of the realities, to use an integrated approach to identify cost-effective recommendations and to consider energy and cost saving potential simultaneously. This is particularly important because we see relatively long payback periods for the set of EEMs in this design package. In the future, it is also important to study the energy savings potential and cost-effectiveness of individual EEMs, which would be helpful to improve payback by pulling back on some EEMs that are individually not as cost effective and that provide modest incremental savings.

Acknowledgements

This work was funded by the U.S. Department of Energy’s (DOE) Office of Building Technologies. The authors would like to thank Dr. Dru Crawley, Commercial Building Team Lead under DOE’s Building Technology Program, for his dedicated support and his thoughtful guidance of this project. The authors would like to thank Erin McConahey of Arup, Floyd Barwig of New York State Office of Energy Efficiency and Environment, Glenn Hansen of Portland Energy Conservation Incorporated, Kent Peterson of P2S Engineering, Dr. Merle McBride of Owens Corning Science and Technology Center, Michael Lane of Seattle Lighting Design Lab and Oliver Baumann of Ebert & Bauman Consulting Engineers, Inc. for their tremendous volunteer efforts and insightful reviews of our work.

Last, but not least, the authors would like to specially recognize Andrew Nicholls, the program manager overseeing the Commercial Building Integration Program at PNNL, for his strong support of this particular project. The authors greatly appreciate the assistance from Todd Taylor, Dr. Weimin Wang and Dr. Jian Zhang at PNNL during the course of the project. The paper also benefited greatly from the insightful comments of the anonymous reviewers.

References

AHLA. 2008. *2008 Lodging Industry Profile*. http://www.ahla.com/uploadedFiles/AHLA/information_center/08LIP_web.pdf.. American Hotel & Lodging Association, Washington, D.C

ANSI/ASHRAE. 1999. *ASHRAE Standard 62-1999, Ventilation for Acceptable Indoor Air Quality*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

ANSI/ASHRAE. 2004. *ASHRAE Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

ANSI/ASHRAE/IESNA. 1999. *ANSI/ASHRAE/IESNA Standard 90.1-1999, Energy* Standard for Buildings Except Low-Rise Residential Buildings. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

ANSI/ASHRAE/IESNA. 2004. *ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

ANSI/ASHRAE/IESNA. 2007. *ANSI/ASHRAE/IESNA Standard 90.1-2007, Energy Standard for Buildings Except Low-Rise Residential Buildings.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

ASHRAE. 2004. *Advanced Energy Design Guide for Small Office Buildings*. American Society of Heating, Ventilating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

ASHRAE. 2005. *Handbook of Fundamentals*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

ASHRAE, 2006. *Advanced Energy Design Guide for Small Retail Buildings*. American Society of Heating, Ventilating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

ASHRAE. 2007. *HVAC Applications Handbook*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

ASHRAE. 2008a. *Advanced Energy Design Guide for Small Warehouses and Self-Storage Buildings*. American Society of Heating, Ventilating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

ASHRAE. 2008b. *Advanced Energy Design Guide for K-12 School Buildings*. American Society of Heating, Ventilating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

ASHRAE. 2009a. *Advanced Energy Design Guide for Highway Lodging Buildings*. American Society of Heating, Ventilating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

ASHRAE. 2009b. *Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities*. American Society of Heating, Ventilating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

Briggs R.L., R.G. Lucas, and Z.T. Taylor. 2003. "Climate Classification for Building Energy Codes and Standards: Part 1—Development Process". *ASHRAE Transactions* 2003 (1) Page 4610. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

CEC. 2005. *Case Study - Hotel Bathroom Lighting Control System*. Pub # CEC-500-2005-141-A26, California Energy Commission, Sacramento, California.

Continental. 2007. *E-Series High Performance Water Extractor Specifications*. http://worldwidelaundry.com/brochures/continental/CoinE_SeriesBrochure.pdf. Continental Girbau Inc., Oshkosh, Wisconsin

DOE. 2000. *Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment*. U.S. Department of Energy, Washington, D.C.

DOE. 2005. Heat *Recovery from Wastewater Using a Gravity-Film Heat Exchanger*. DOE/EE-0247 Revised, Washington, D.C.

Ducker Worldwide. 2001. *2000 U.S. Market for Residential and Specialty Air Conditioning: PTAC (Packaged Terminal Air Conditioning).* HVAC0002. Final Report, March 2001. Ducker Industrial Standards, 6905 Telegraph Road Suite 300, Bloomfield Hills, MI 48301.

EIA. 2005. *Commercial Buildings Energy Consumption Survey 2003*. http://www.eia.doe.gov/emeu/cbecs/contents.html. Energy Information Administration of U.S. Department of Energy, Washington, D.C.

EIA. 2006. *Annual Energy Review 2006*. Energy Information Administration of U.S. Department of Energy, Washington, D.C.

Eilert, P. 2000. *High Albedo (Cool) Roofs - Codes and Standards Enhancement (CASE) Study*. www.pge.com/includes/docs/pdfs/shared/saveenergymoney/rebates/remodeling/coolroof/coolroofdesignbrief.pdf. San Francisco, California: Pacific Gas and Electric Company.

Galasiu A.D., G.R. Newsham, C. Savagau, and D.M. Sander. 2007. "Energy Saving Lighting Control Systems for Open Plan Offices: A Field Study." *Leukos* 4 (1), pp. 7-29.

Jarnagin R.E., B. Liu, D.W. Winiarski, M.F. McBride, L. Suharli, and D. Walden. 2006. *Technical Support Document: Development of the Advanced Energy Design Guide for Small Office Buildings*. PNNL-16250, Pacific Northwest National Laboratory, Richland, Washington.

Jarnagin R.E. and GK Bandyopadhyay. 2010. *Weighting Factors for the Commercial Building Prototypes Used in the Development of ANSI/ASHRAE/IESNA Standard 90.1-2010*. PNNL-19116, Pacific Northwest National Laboratory, Richland, WA.

Jiang W, R.E. Jarnagin, K. Gowri, M.F. McBride, and B. Liu. 2008. *Technical Support Document: Development of the Advanced Energy Design Guide for Highway Lodging Buildings*. PNNL-17875, Pacific Northwest National Laboratory, Richland, Washington.

Jiang W, K. Gowri, M.D. Lane, B.A. Thornton, M.I. Rosenberg, and B. Liu. *Technical Support Document: 50% Energy Savings Design Packages for Highway Lodging Buildings*. PNNL-18773, Pacific Northwest National Laboratory, Richland, Washington.

Liu, B., R.E. Jarnagin, D.W. Winiarski, W. Jiang, M.F. McBride and G.C. Crall. 2006. *Technical Support Document: Development of the Advanced Energy Design Guide for Small Retail Buildings*. PNNL-16031, Pacific Northwest National Laboratory, Richland, Washington.

Liu, B., R.E. Jarnagin, W. Jiang, and K. Gowri. 2007. *Technical Support Document: Development of the Advanced Energy Design Guide for Small Warehouse and Self-storage Buildings*. PNNL-17056, Pacific Northwest National Laboratory, Richland, Washington.

LRC. 2004. *Reducing Barriers to Use of High Efficiency Lighting*. Final Report Year 3. Rensselare Polytechnic Institute, Troy, New York.

Pless, S., P. Torcellini and N. Long. 2007. *Technical Support Document: Development of the Advanced Energy Design Guide for K-12 Schools--30% Energy Savings*. NREL/TP-550-42114, National Renewable Energy Laboratory, Golden, Colorado.

Richman, E.E., E. Rauch, J. Knappek, J. Phillips, K. Petty and P. Lopez-Rangel. 2008. “National Commercial Construction Characteristics and Compliance with Building Energy Codes: 1999-2007.” *In Proceedings of the 2008 ACEEE Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Washington D.C.

Torcellini P., M. Deru, B. Griffith, K. Benne, M. Halverson, D. W. Winiarski, and D. Crawley. 2008. “DOE Commercial Building Benchmark Models.” *In Proceedings of the 2008 ACEEE Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Washington D.C.

VonNeida B., D. Maniccia, and T. Allan. 2000. *An Analysis of the Energy and Cost Savings Potential of Occupancy Sensors for Commercial Lighting Systems*. www.lrc.rpi.edu/resources/pdf/dorene1.pdf. Rensselaer Polytechnic Institute, Troy, New York.