CLIMA 2016 - proceedings of the 12th REHVA World Congress

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 10. Aalborg: Aalborg University, Department of Civil Engineering.

A Parametric Study of Core Energy Efficiency Measures Used in Deep Energy Retrofits for Dining Facilities in U.S. Climate Zones

Michael Case, Ph.D., Alexander Zhivov, Ph.D., Richard Liesen, Ph.D.

U.S. Army Engineer Research and Development Center,
2902 Newmark Dr., Champaign, IL 61822 U.S.A.

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 from around the world[1]. 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.

Computational modeling analysis using the Net Zero Planner conducted by the U.S. Army Engineer Research and Development Center team[2] demonstrated that about 50% site energy use reduction is achievable using only the "core technologies" bundle for two types of buildings with low internal loads: Barracks and Office buildings in all 15 U.S. climates.

This paper addresses building with higher internal/process loads and high ventilation requirements, e.g., Army dining facilities (DiFac). Results of computational modeling analysis conducted for DiFac show that DER cannot be achieved using only core technologies bundle and that application of additional measures (e.g., process improvement, enhancement of local exhaust systems and ventilation systems control will allow significant energy use reduction (50% and better).

Key Words: Deep energy retrofit, Core technologies, Building Energy Modeling, Dining Facilities.

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" [3] that can be used in DER projects (Table 1). Characteristics of some of these "core technologies" i.e., building envelope-related technologies (insulation levels, windows, vapor and water barriers, requirements to building air tightness, 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[2] using two types of typical Army buildings with low internal loads: barracks and office buildings. In addition to these studies, it was decided to analyze how these parameters will affect energy use by buildings with higher internal loads and ventilation requirements, e.g., dining facility (DFAC), in 15 U.S. climate zones.

BUILDING DESCRIPTION

Dining Facilities. 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.

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

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. Modeled building use in this paper is based on parameters of the dining facility sized to serve between 801 and 1300 meals during a 1½ hour serving period. The rendered view of the energy simulation model is shown in Figure 1a with thermal zones shown in Figure 1b. More details regarding this building are presented in [4].

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: breakfast (0600–0800 hours), lunch (1100–1300 hours), and dinner (1600–1800 hours).

LOCATIONS

Fifteen locations were selected to represent 15 Department of Energy climate zones in the United States[5]. 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: 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, 7 - Duluth, MN and 8 - Fairbanks, AK.

SIMULATION SCENARIOS

Scenario 1: Baseline. Baseline energy performance is modeled using requirements of ASHRAE Standard 90.1 1980 [6]. 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. 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 [7])**.** Since neither designer nor contractor has control over the plug loads, they remain the same as in the baseline.

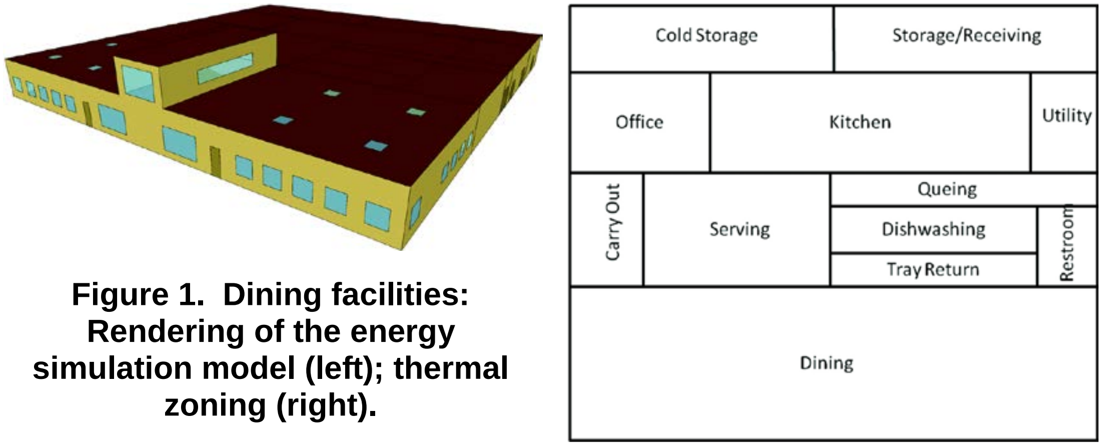

Figure 1. Dining facilities: Rendering of the energy simulation model (left); thermal zoning (right).

Scenario 3: In other Annex 61 modeling studies [e.g., 2, 8, 9,10], Scenario 3 for buildings with low internal loads represented Deep Energy Retrofit (DER) - 50% Energy Use Reduction Compared to the Baseline**.** In this study, an attempt was made in Scenario 3 to achieve site energy use reduction to extend maximally possible using only the bundle of core technologies: building envelope insulation, increased air tightness, heat recovery, improved lighting design and technologies, and increased efficiency of heating, ventilating, and air-conditioning (HVAC) and electrical systems.

Scenario 4: High Performance Buildings. The final scenario is intended to push the envelope further that in Scenario 3 by using additional energy efficiency technologies such as high efficiency process equipment (lower plug loads), improved kitchen hoods, 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[11]. Within NZP, building energy simulation is performed by a combination of EnergyPlus version 8[12] 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[11] 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 the user can change 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 (1980). The building is also modeled using parameters for the base case (ASHRAE 90.1, 2010). 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. For Scenario 3, the bundle of core technologies that brought the energy reduction the closest to 50% that could be achieved was selected. Finally, the high performance building (Scenario 4) was created by selecting the highest performing set of technology bundles in the tool. This included the use of high efficiency kitchen, equipment, high performance kitchen hoods, etc.

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 Standards 90.1 (2010) and 189.1 - 2009 [12], 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) standard. A well-insulated, airtight building envelope is important for building energy use 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 [14], 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, climate, and other factors. Table lists insulation requirements (R-values) for walls, roofs, and floors in different climate conditions resulted from this study.

In addition to energy conservation, improved building insulation and air tightness 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.

Table 2. Recommended Wall, Roof, and Floor Insulation Values.

Item	c.z. 1 W/(m²*K)	c.z. 2 W/(m²*K)	c.z. 3 W/(m²*K)	c.z. 4 W/(m²*K)	c.z. 5 W/(m²*K)	c.z. 6 W/(m²*K)	c.z. 7 W/(m²*K)	c.z. 8 W/(m²*K)
Roof, U-value	0.164	0.14	0.126	0.126	0.11	0.095	0.307	0.0755
Wall, U-value	0.38	0.38	0.284	0.227	0.187	0.165	0.142	0.114
Wall below grade, U-value	1.14	0.57	0.57	0.38	0.38	0.284	0.22	0.159
Floors over unconditioned space U-Value	0.57	0.236	0.236	0.187	0.187	0.142	0.125	0.114
Windows (assembly) thermal transmittance, U-Value	<1.98	<1.98	<1.7	<1.7	<1.53	<1.36	<1.25	1.02
Windows, SHGC	<0.25	<0.25	0.25	<0.3	<0.4	NR	NR	NR

Air Tightness. According to USACE ECB 2014-16 [15], the air leakage rate of a building envelope shall not exceed 0.25 CFM/sq ft (1.27 L/s/**m²**) 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 air tightness of 0.10 cfm/sq ft [0.51 L/s/m2] or better was not uncommon) at no or minimal additional cost [16]. Based on this experience and on industry consensus, the new level for air tightness in high performance buildings was proposed to be lowered to 0.15 CFM/sq ft (0.76 L/s/**m²**) 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. 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 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 air tightness levels was accounted for in the outdoor ventilation rates for the baseline and energy efficient models.

Table 3. Infiltration Leakage Rate Modeling Assumptions.

Parameter	0.25 cfm/sq ft	0.15 cfm/sq ft
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. (cfm@5 Pa)	5832	3499
Excess ventilation flow at 5 Pa (L/s)	2752	1651

HVAC SYSTEMS

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 m3/s) and the peak exhaust flow for the baseline building design is over 31,000 cfm (14.63 m3/s). Some of the 10,000 cfm (4.72 m3/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 ft from the hood, if possible, to provide the best capture of cooking effluent.

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. More details on kitchen equipment and ventilation systems improvements refer to [4].

Heating and Cooling. 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 assuming a flow reduction based on the effects of adding side and back panels to the exhaust hoods. 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.

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.

LIGHTING

The lighting improvements for all building types were based on recommendations from the Lighting Design Guide [17] developed in collaboration with Atelier Ten. The focus was on efficient lighting design, and not just on improving the efficiency of existing fixtures. 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 current ASHRAE 90.1 2010 standards so there will not be a difference between the baseline and base case lighting densities.

RESULTS

Table 4 lists the results of the computational analysis of simulated DiFac building. The data in Table 4 show the energy use intensity (EUI) as a percentage of the baseline EUI prior to renovation. Site energy represents the EUIs 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 the Tables reveals two interesting points. First, upgrading DiFac building from a 1980 standard to a 2010 version of ASHRAE Standard 90.1 only results in a decreased of modeled energy usage by 2 to 24% in different climate zones. This is partly because the dominating contribution to the energy balance from kitchen equipment and energy required for local exhaust and make-up air systems. Also, lighting upgrades were already factored into the older buildings. Second, application of the bundle of core technologies results in total site energy usage reduction only by 15 to 39% and heating-only energy use reduction by 29 to 64% in the modeled building, which is much smaller that is expected from DER project. The only additional measures in Scenario 4 were related to the use of higher efficiency kitchen equipment, significant improvement in kitchen hood designs, and system controls, which bring energy use reduction for most climates to the levels of 50% and better. Site energy use reduction remains still below 50% level in climate zones 1A and 2A with significant cooling requirements, and in locations with marine climate (c.z. 3C).

A look at the energy resource breakdowns from the tool is instructive. Figure 2 shows the breakdown of energy use for Climate Zones 3A and 7 in dining facility for Scenarios 1, 3, and 4. As improvements to the building envelope, lighting, and higher efficiency of HVAC equipment reduce the EUI, internal loads and lighting systems increasingly dominate energy usage; improvements in kitchen equipment are therefore becoming critical in achieving DER.

Table 4. Energy Use Reduction in Dining Facilities (EUIh – Heating Energy Use Intensity; EUIt – Total Energy Use Intensity).

Climate Zone	Baseline			Base Case		DER			HPB	
	Site EUIh (100%) kWh/m^2 yr	Site EUIt (100%) kWh/m^2 yr	Source EUIt (100%) kWh/m2 yr	Site energy %	Source energy %	Site energy %	Site heating energy %	Source energy %	Site energy %	Source energy %
1A	29	604	1616	2%	3%	15%	29%	16%	22%	25%
2A	147	706	1687	11%	9%	22%	45%	20%	40%	36%
2B	111	744	1897	10%	9%	22%	43%	22%	42%	41%
3A	307	840	1765	16%	12%	17%	43%	23%	51%	40%
3B	201	749	1704	16%	12%	26%	52%	23%	44%	37%
3C	196	646	1371	8%	7%	26%	29%	14%	38%	25%
4A	459	964	1832	20%	15%	30%	47%	25%	57%	43%
4B	333	854	1753	22%	16%	30%	53%	25%	52%	40%
4C	434	897	1665	19%	14%	27%	43%	22%	55%	38%
5A	572	1071	872	19%	17%	31%	45%	42%	62%	60%
5B	470	972	1833	24%	18%	33%	52%	23%	58%	43%
6A	733	1215	2041	21%	17%	33%	45%	28%	67%	49%
6B	681	1177	2035	24%	19%	35%	50%	29%	65%	49%
7	938	1420	2257	22%	19%	36%	47%	31%	72%	54%
8	1376	1863	2732	18%	17%	39%	64%	34%	79%	63%

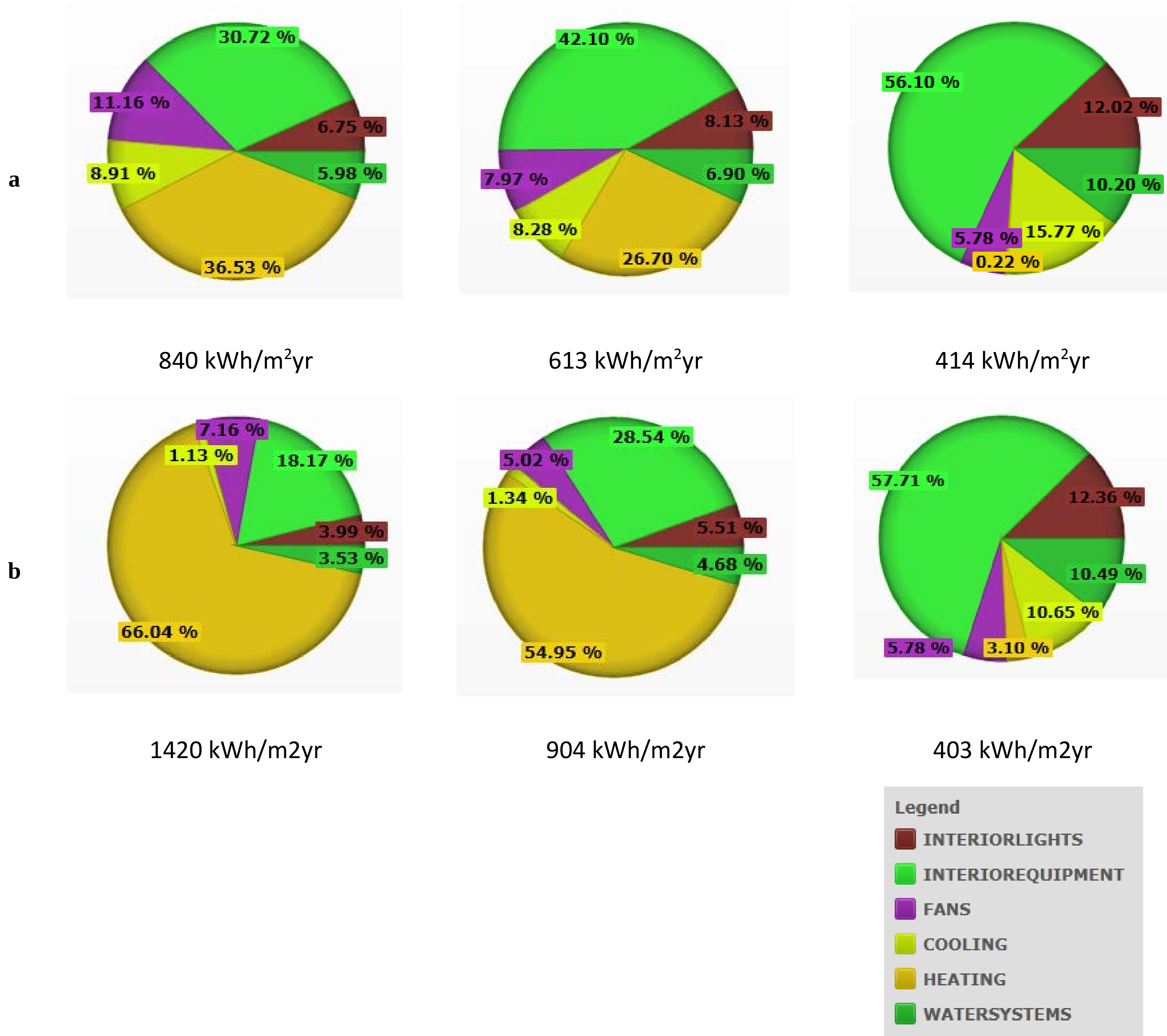

Figure 2. Energy end use in Dining Facility as percentage of total EUI: (a) Climate Zone 3A; (b) Climate Zone 7.

CONCLUSIONS

The base case scenario, which describes major renovation to minimum requirements of ASHRAE Standard 90.1 2010 reduces site energy use in Dining Facilities in Climate Zones 1-8 by 2-24% compared to the Baseline. Application of core technologies bundle more than doubles energy savings (15-39%), but does not come close to requirements of Deep Energy Retrofit. These technologies allow a significant reduction in energy required for building heating and cooling (Table 5), but the level of reduction is not as dramatic as in buildings with low internal loads and ventilation requirements (e.g., barracks and office buildings) described in [2].

Table 5. 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, %		
		CZ 3A	CZ 5A	CZ 7	CZ 3A	CZ 5A	CZ 7
Dining Facility	Base Case	35%	30%	29%	9%	6%	4%
	Scenario 3	47%	45%	47%	32%	29%	25%
Barracks	Base Case	42%	41%	39%	31%	27%	21%
	DER	87%	87%	90%	60%	58%	67%
Office	Base Case	57%	61%	64%	48%	45%	39%
	DER	63%	87%	87%	54%	58%	51%

Additional energy savings can result from reduced interior equipment load including those associated with kitchen equipment, use of water conservation technologies (e.g., low flow shower heads), advanced dish washers, improved design of exhaust hoods and demand controlled ventilation systems, grey water heat recovery from dishwashers, etc.[4] This can result in an additional site energy use reduction in all climate zones reaching DER levels in most climate zones. Additional energy savings can be achieved by introducing building-based or building cluster-wide energy power and thermal energy generation from renewable sources.

ACKNOWLDGEMENTS

The paper presents information produced as a part of the international collaborative effort under the International Energy Agency's "Energy in Buildings and Communities Programme Annex 61 Business and Technical Concepts for Deep Energy Retrofit of Public Buildings" and the U.S. Army Net Zero Planner Installation Energy, Water, and Waste Simulation and Modeling Program.

REFERENCES

1. Moerck, O, A. Zhivov, R. Lohse. 2016. Deep Energy Retrofit – Case Studies. International Energy Agency EBC Programme Annex 61.
2. Case, M., A. Zhivov, R. Liesen, M. Zhivov. 2016. A Parametric Study of Energy Efficiency Measures Used in Deep Energy Retrofits for Two Building Types and U.S. Climate Zones. ASHRAE Transactions Vol. 122, Part 1. American Society of Heating Refrigeration and Air-conditioning Engineers, Inc., Atlanta, GA.
3. Zhivov, A., R. Liesen, R. Lohse, O. Moerck. 2016. Core Bundles of Technologies to Achieve Deep Energy Retrofit with Major Building Renovation Projects in Europe and North America. ASHRAE Transactions. Vol 122, Part 1. Atlanta, GA: American Society of Heating Refrigerating, and Air-Conditioning Engineers.
4. Deru, M., R. Langner, A. Zhivov, R. Liesen, D. Herron and V. Smith. 2012. Extremely Low Energy Design for Army Buildings: Dining Facilities. ASHRAE Transactions. Vol 118, Part 1. Atlanta, GA: American Society of Heating Refrigerating, and Air-Conditioning Engineers
5. Briggs, R.S., Lucas, R.G., and Taylor, T. (2003). Climate Classification for Building Energy Codes and Standards: Part 2 - Zone Definitions, Maps and Comparisons, Technical and Symposium Papers, ASHRAE Winter Meeting, Chicago, IL, January, 2003. Atlanta, GA: American Society of Heating Refrigerating, and Air-Conditioning Engineers.
6. ASHRAE Standard 90.1 – 1980. Energy Standard for Buildings except Low-Rise Residential Buildings, American Society of Heating Refrigeration and Air-conditioning Engineers, Inc., Atlanta, GA.

7. ASHRAE Standard 90.1 – 2010. Energy Standard for Buildings except Low-Rise Residential Buildings, American Society of Heating Refrigeration and Air-conditioning Engineers, Inc., Atlanta, GA.

8. Rose, J., K.E. Thomsen, O. C. Mørck, Kalle Kuusk, Targo Kalamees, Tõnu Mauring. 2016. Economic challenges of deep energy renovation - differences, similarities and possible solutions for northern Europe - Estonia and Denmark. ASHRAE Transactions. Vol. 122, Part 1. Atlanta, GA: American Society of Heating Refrigerating, and Air-Conditioning Engineers.

9. Riel, J.M., R. Lohse, H. Staller. 2016. Building envelope parameters optimization for deep energy retrofit of public buildings in Germany and Austria. ASHRAE Transactions. Vol 122, Part 1. Atlanta, GA: American Society of Heating Refrigerating, and Air-Conditioning Engineers

10. Yao, R., X. Li, B. Li, M. Shahrestani, S. Han. 2016. Building envelope parameters optimization for deep energy retrofit of public buildings for different climate zones in UK and China. ASHRAE Transactions. Vol 122, Part 1. Atlanta, GA: American Society of Heating Refrigerating, and Air-Conditioning Engineers

11. Case, M., R.J. Liesen, A. Zhivov, M. Swanson, B. Barnes and J. Stinson. 2014. A Computational framework for low energy community analysis and optimization. ASHRAE Transactions Vol. 118 (1). American Society of Heating Refrigeration and Air-conditioning Engineers, Inc., Atlanta, GA.

12. DOE (2008). EnergyPlus, Building Energy Simulation Software web site. Washington, DC: U.S. Department of Energy. www.EnergyPlus.gov.

13 ASHRAE Standard 189.1 – 2009. Standard for the Design of High-Performance Buildings except Low-Rise Residential Buildings. American Society of Heating Refrigeration and Air-conditioning Engineers, Inc., Atlanta, GA.

14. Liesen, R., P. Ellis, A. Zhivov, D. Herron. 2012. Extremely Low Energy Design for Army Buildings: Barracks. ASHRAE Transactions Vol. 118, Part 1. American Society of Heating Refrigeration and Air-conditioning Engineers, Inc., Atlanta, GA.

15. USACE. 2014. Engineering Construction Bulletin. ECB 2014-16. Building Air Tightness Requirements.

16. Zhivov, A., Dale Herron, J. Lee Durston, Matthew Heron, and George Lea. 2014. Airtightness in New and Retrofitted U.S. Army Buildings. The International Journal of Ventilation Volume 12 No 4 March 2014.

17. USACE. 2013. Lighting Design Guide for low energy buildings – new and retrofits. ERDC.