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.

How to Achieve a Deep Energy Retrofit (DER) with Major Building Renovation?

Alexander Zhivov[1], Ph.D., Rüdiger Lohse[2]

[1] *U.S. Army Engineer Research and Development Center, 2902 Newmark Dr., Champaign, IL 61822, USA,* Alexander.M.Zhivov@usace.army.mi

[2]*Klimaschutz- und Energieagentur Baden- Württemberg (KEA), Kaiserstr. 94a, Karlsruhe, Germany,* ruediger.lohse@kea-bw.de

Abstract

Numerous pilot projects conducted all over the world have demonstrated that energy use in commercial and public buildings can be reduced by more than 50% after renovation. Research conducted under the International Energy Agency's Energy Conservation in Buildings and Community Systems (IEA ECBCS) Annex 46 has identified more than 400 energy efficiency measures that can be used when buildings are retrofitted. Implementation of some individual measures can significantly reduce building heating and cooling loads or minimize energy waste, but require significant investments with long paybacks. However, when a limited number of "core technologies" are implemented together ("bundled"), they can significantly reduce energy use for a smaller investment and thereby provide a faster payback.

The "core bundle of technologies" include building envelope insulation levels and window characteristics has been optimized by the Annex 61 modelling team from Austria, China, Denmark, Estonia, Germany, Latvia, Sweden, UK, and the United States by computational simulation of representative buildings for different climate zones of participating countries.

Modeling results described in this paper show that it is possible to achieve a deep energy retrofit (DER) combined with major renovation of buildings with low internal loads. This task is more difficult in hot climate zones with significant cooling needs, and may require that additional energy efficiency measures be applied (e.g., reduction of plug loads, water conservation measures, advanced heating, ventilating, and air-conditioning [HVAC] systems). DER is easier to achieve in heating-dominated climates and in cases when either by cultural or normative reasons, cooling is not desired and building users can tolerate temporarily increases in indoor air temperature (e.g., up to 77 °F [25 °C].

Key Words: Deep Energy Retrofit, Core Technologies, Building Energy Modelling.

INTRODUCTION

A list of core energy efficiency technologies (Table 1) were generated from the results of case studies of DERs conducted in Europe and North America [9], surveys and discussions conducted at the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Technical Committee (TC) 7.6 "Public Buildings" working group meetings in 2013 and 2014, and previous experience and research conducted by the Annex 61 team members (www.iea-annex61.org). These technologies, when applied together (as a bundle), will reduce the total building site energy use by about 50% (including plug loads). Technical characteristics of these building envelope related technologies combined into a "core technologies bundle" have been studied through modeling and life cycle cost (LCC) analysis for representative national climate conditions. Other characteristics of these technology bundles are based on the requirements of national standards (

) or on best international practices that have been collected and summarized and will be presented in the Annex 61 *Deep Energy Retrofit Guide*.

Table 1. Core Technologies Bundles for Deep Energy Retrofit.

Category	Name	Source for characteristics
Building Envelope	Roof insulation	Modeling Results
	Wall insulation	Modeling Results
	Windows	Modeling Results
	Doors	National Requirements
	Thermal bridges remediation	DER Guide based on best practices
	Airtightness	National the Most Stringent Requirements

Category	Name	Source for characteristics
	Vapor Barrier	DER Guide based on best practices
	Building Envelope Quality Assurance	DER Guide based on best practices
Lighting and Electrical Systems	Lighting design, technologies and controls	DER Guide based on best practices
HVAC	High performance motors, fans, furnaces, chillers, boilers, etc.	National the Most Stringent Requirements
	Dedicated Outdoor Air System (DOAS)	DER Guide based on best practices
	HR (dry and wet)	National the Most Stringent Requirements
	Duct insulation	National the Most Stringent Requirements
	Duct airtightness	National the Most Stringent Requirements
	Pipe insulation	National the Most Stringent Requirements

Table 2. Current National Standards for Renovation Projects.

Country	Building Energy	Building Envelope	HVAC	Lighting
Austria	OIB Directive Nr.6	OIB RL 6, 2011	EN 1507, EN 12237 ÖNORM H 5057, OIB RL 6, 2011	EN 12464-1 and -2 EN 15193
China	GB 50189-2015	GB 50189-2015, GB/T 7016-2008	GB 50736-2012 GB 50189-2015	GB 50034-2013 GB 50189-2015
Denmark	Danish Building Regulation 2010 DS Standard 418	Danish Building Regulation 2010	Standard 447 Standard 452	DS/EN ISO 12464-1
Estonia	Ordinance No. 63. RT I, 18.10.2012, 1, 2012; Ordinance No. 68. RT I, 05.09.2012, 4, 2012	EVS-EN ISO 10077, EVS-EN 1026 EVS-EN 12207 EVS-EN 12208	EVS-EN 13779, EN 12237 Ordinance No. 70. RT I, 09.11.2012, 12	Ordinance No. 70. RT I, 09.11.2012, 12
Germany	DIN 18599- 1; EnEV 2014	EnEV 2014, DIN 18361 DIN 18355, DIN V 18599/2 DIN 4102, DIN 4108 DIN EN 13162, DIN EN 13163 DIN EN 13164, DIN EN 13165 DIN EN 13167, DIN EN 13171	EnEV 2014, DIN V 18599 DIN 1946- 6, DIN EN 13779 DIN 24192 II/III/IV DIN 4108- 6, DIN 4701-10,	DIN 18599- 4, DIN 5035 T 1- 14
Latvia	Law On the Energy Performance of Buildings; Cabinet Regulation No. 348; Cabinet Regulation No. 383; Cabinet Regulation No. 382.	Latvian Construction Standard LBN 002-01	Latvian Construction Standard LBN 231-03 Latvian Construction Standard LBN 003-01	Cabinet Regulation No. 359-
Sweden	BBR BFS 2011:6; SFS 2006:985	BBR BFS 2011:6;	BBR BFS 2011:6; EVP BFS 2011:11; SS-EN 12237; AFS 2009:2	BBR BFS 2011:6; SS-EN 12464-1; AFS 2009:2

Country	Building Energy	Building Envelope	HVAC	Lighting
UK	BS EN 15603:2008	Building Regulations 2010-Conservation of Fuel and Power: Part L. Scottish Building Standards 2015-Technical Handbook 2015.	Non-Domestic Building Services Compliance Guide:2013 Non-Domestic Building Services Compliance Guide for Scotland: 2015 BS EN 15727:2010 BS 5422:2009	BS EN 12464-1:2011 Non-Domestic Building Services Compliance Guide:2013 Non-Domestic Building Services Compliance Guide for Scotland:201
USA	ASHRAE Std 90.1 2010 ASHRAE Std 100 2015	ASHRAE Std 90.1 2010	ASHRAE Std 90.1 2010	ASHRAE Std 90.1 +IESNA recommended practices, 10th edition 2010

When buildings are retrofitted, additional energy efficiency measures can be used to gain greater energy savings than can be achieved by using a “core technologies bundle” alone. The use of some of these measures may depend on the end-user, rather than on contractor (e.g., purchasing and installation more energy efficient appliances and other plug loads, separate power lines, and timers to turn-off some of electrical appliances). Other measures might include those that are specific to a particular building type (e.g., water saving shower heads and clothes washers, which can significantly reduce domestic hot water usage) or measures specific to the project (e.g., use of such low exergy heating and cooling systems as indirect evaporative cooling, or radiant heating and cooling systems; or by reusing heating and cooling return water energy and other waste streams).

OPTIMIZATION OF BUILDING ENVELOPE TECHNOLOGIES

The “core bundle of technologies” include building envelope insulation levels and window characteristics optimized by the Annex 61 modeling team by computational simulation of representative buildings for different climate zones of participating countries [4,5,6,7,8]. The parameters for individual technologies were selected to enable a reduction in building site energy use of about 50% (including plug loads) and to yield a bundle that is LCC effective. Modeling was conducted for 17 US climate zones (c.z.) and for representative climates in Austria, China, Denmark, Estonia, Germany, Sweden, and UK (Table 3).

Table 3. Representative US Department of Energy (DOE) Climate Zones in the Annex 61 Participating Countries.

Country	Climate zone(s)	Representative City
Austria	4a and 7	Wien, Obertauren
China	2a, 3a, 3c, 4a, 7	Guangzhou , Shanghai, Kunming Beijing, Harbin
Denmark	5a	Copenhagen
Estonia	6a	Tartu
Germany	5a	Wurzburg
Latvia	6a	Riga
Sweden	6a, 7	Stockholm, Kiruna
UK	4a, 5a	London, Aberdeen
USA	1a-8b	Miami, Houston, Phoenix, Memphis, El Paso, San Francisco, Baltimore, Albuquerque, Seattle, Chicago, Colorado Springs, Burlington, Helena, Duluth, Fairbanks

The following scenarios were modeled:

- *Scenario 1*. This Baseline scenario uses a pre-1980 standard to describe the building envelope and systems. Building use, systems operation schedules, and appliances and their use (expressed in W/m^2), used in Scenario 1 were fixed for all scenarios even though in actual conditions it is likely that such scenario elements would be improved/reduced over time.

- *Scenario 2*. This "Business as Usual" (base case) scenario describes a major renovation with energy-related measures included in the scope of work that meet the minimum current standards (usually related to energy efficiency of fans, motors, chillers, furnaces, lighting fixtures, etc.) listed in
- . Building use schedules and plug-loads remain the same as in Scenario 1.
- *Scenario 3*. In this scenario, the characteristics of the core technology bundle listed in
- Table 1 are optimized to achieve about 50% of energy use reduction against the baseline or current national minimum building energy use requirement for existing buildings (whichever is more stringent).
- *Scenario 4*. This scenario optimizes the characteristics of the core technology bundle listed in
- Table 1 and uses additional energy efficiency measures (e.g., reduction in plug loads and domestic hot water use, etc.) to achieve the current "national dream" energy use intensity (EUI) levels in renovated buildings (e.g., the Passive House Standard), required in national regulations "if LCC effective."

Based on results of these studies [4,5,6,7,8], the levels of the building envelope insulation and window types required to achieve DER in different climate conditions (summarized in Tables 4-6) were identified. These values were selected based on the performance of technology bundles (not on the economics of individual measures) for different climate conditions and individual country energy prices, and on minimum national requirements for these technologies. These values are therefore equal to or more stringent than those listed in

. For example, insulation values of building envelope elements, and characteristics of windows and requirements to airtightness presented in Tables 4-6 for the United States are more stringent than those listed in ASHRAE Standard 90.1 (2013), ASHRAE Standard 189.1 (2013), or the ASHRAE Advanced Energy Design Guides; they are not, however, as aggressive as those based on the Passive House Institute Standard.

Table 4. Wall Insulation.

Country	U-value W/(m^2*K) (Btu/(hr*ft^2*°F)	R-value (m^2*K)/W (hr*ft^2*°F)/Btu
Austria (c.z. 5A)	0.135 (0.024)	7.4. (42)
c.z.7	0.24 (0.043)	4.17 (23)
China c.z. 7	0.31(0.054)	3.2(19)
c.z. 4A	0.48(0.084)	2.1(12)
c.z. 3A	0.60(0.106)	1.7(9)
c.z. 2A	0.96(0.169)	1.0(6)
c.z. 3C	0.96(0.169)	1.0(6)
Denmark (c.z. 5A)	0.15 (0.026)	6.7 (38)
Estonia (c.z. 6A)	0.17 (0.03)	5.9 (33)
Germany (c.z. 5A)	0.17-0.24 (0.03-0.04)	4.2-5.9 (24-33)
Latvia (c.z. 6A)	0.19 (0.033)	5.3 (30)
Sweden (c.z. 6A	0.18 (0.031)	5.6 (32)
c.z. 7	0.18 (0.031)	5.6 (32)
UK (c.z. 4A)	0.22(0.039)	4.5(26)
5A	0.22(0.039)	4.5(26)
USA c.z. 1	0.76 (0.133)	1.3 (8)
c.z. 2	0.38 (0.067)	2.6. (15)
c.z. 3	0.28 (0.050)	3.6 (20)
c.z. 4	0.23 (0.040)	4.3 (25)
c.z. 5	0.19 (0.033)	5.3. (30)
c.z. 6	0.14 (0.025)	7.1. (40)
c.z. 7	0.11 (0.020)	9.1 (50)
c.z. 8	0.11 (0.020)	9.1 (50)

Table 5. Roof Insulation.

Country	Climate zone	U-value W/(m^2*K) (Btu/(hr*ft^2*°F)	R-value (m^2*K)/W (hr*ft^2*°F)/Btu
Austria	4a	0.159 (0.028)	6.3 (36)
	7	0.23 (0.041)	4.4 (25)
China	2a	0.53 (0.093)	1.9(11)
	3a	0.53 (0.093)	1.9(11)
	3c	0.53 (0.093)	1.9(11)
	4a	0.38(0.067)	2.6(15)
	7	0.30 (0.053)	3.3(19)
Denmark	5a	0.10 (0.018)	1 (57)
Estonia	6a	0.11 (0.02)	9.1 (52)
Germany	5a	0.14-0.2 (0.025-0.035)	5.0-7.1 (29-40)
Latvia	6a	0.16 (0.029)	6.3 (35)
Sweden	c.z. 6A	0.13 (0.023)	7.7 (44)
	c.z. 7	0.13 (0.023)	7.7 (44)
UK	4a	0.13(0.023)	7.7 (44)
	5a	0.13(0.023)	7.7 (44)
USA	1	0.16 (0.029)	6.3 (35)
	2	0.14 (0.025)	7.1 (40)
	3	0.12 (0.022)	8.3 (45)
	4	0.12 (0.022)	8.3 (45)
	5	0.11 (0.020)	9.1 (50)
	6	0.09 (0.0167)	11.1 (60)
	7	0.09 (0.0154)	11.1 (65)
	8	0.08 (0.0133)	12.5 (75)

Windows allow daylight into the building and give occupants visual contact with their surroundings. They protect against the outdoor climate and transmit solar energy that can reduce energy consumption in winter. However, windows are also the least insulated part of the building thermal envelope. Older windows commonly have single-pane glass; frames that are rotten or damaged, or that have thermal bridges; cracked glass; nonfunctioning locks; and/or leaky, poorly fitting sashes. Replacing such windows can not only substantially improve visual and thermal comfort, but can represent an important opportunity for energy savings that, in turn, can help reduce the size of heating and cooling loads imposed on HVAC equipment.

Determining the window options considered to be "energy efficient" depends on climate. In cold climates, a window's ability to retain heat inside the building is most important; in warm climates, a window's capacity to block heat gain from the sun and infiltration is a priority. The main energy parameters of a window are its insulation value, transparency to solar radiation, and airtightness. The most significant factors to consider in selecting window systems are U-Factor, Solar Heat Gain Coefficient (SHGC), and Visible Transmittance (VT) of light. In addition, Air-Leakage (AL) of a window assembly is a critical measure of the airtightness of the installed window system. Airtightness is usually measured in cubic meters (cubic feet) per minute of air leakage for a given framed area of the window at a specific pressure difference. Air leakage is usually expressed as m^3/min/m^2 (ft^3/min/ft^2). Table 6 lists window characteristic determined in modeling studies that are based on the climate-specific considerations, i.e., a low SHGC for warm climates and a low U-Factor for cold climates.

Table 6. Window Characteristics.

Country	U-value W/(m^2*K) (Btu/(hr*ft^2*°F)	R-value (m^2*K)/W (hr*ft^2*°F)/Btu	SHGC
Austria (c.z. 5A)	1.09 (0.19)	0.92 (5.3)	0.60
c.z.7	1.09 (0.19)	0.92 (5.3)	0.60

Country	U-value W/(m^2*K) (Btu/(hr*ft^2*°F)	R-value (m^2*K)/W (hr*ft^2*°F)/Btu	SHGC
China			
c.z. 2A	2.55(0.45)	0.39 (2.2)	0.48
c.z. 3a	2.55(0.45)	0.39 (2.2)	0.48
c.z. 3C	2.70(0.48)	0.37 (2.1)	0.48
c.z. 4A	1.79(0.32)	0.56 (3.1)	0.68
c.z. 7	1.79(0.32)	0.56 (3.1)	0.68
Denmark (c.z. 5A)	1.2 (0.21)	0.83 (4.8)	0.63
Estonia (c.z. 6A)	1.1 (0.19)	0.91 (5.3)	0.56
Germany (c.z. 5A)	1.0 -1.3 (0.18-0.23)	0.77-1.0 (4.3-5.7)	0.55
Latvia (c.z. 6A)	1.2 (0.21)	0.83 (4.8)	0.43
Sweden c.z. 6A	1.2 (0.208)	0.8 (5)	0.55
c.z. 7	1.2 (0.208)	0.8 (5)	0.55
UK (c.z. 4A)	1.32 (0.23)	0.76 (4.3)	0.48
c.z. 5A	1.79 (0.32)	0.56 (3.1)	0.68
USA c.z. 1&2	1.98 (< 0.35)	> 0.51 (2.9)	< 0.25
c.z. 3&4	1.70 (< 0.30)	> 0.59 (3.3)	0.30- 0.35
c.z. 5	1.53 (< 0.27)	> 0.65 (3.7)	0.35- 0.40
c.z. 6	1.36 (< 0.24)	> 0.74 (4.2)	>50
c.z. 7	1.25 (< 0.22)	> 0.80 (4.5)	>50
c.z. 8	1.02 (< 0.18)	> 0.98 (5.6)	>50

Modern window technologies are mature and ready for use. Assuming a 10-year payback threshold, it is generally justifiable in all climate zones to undertake energy conservation projects to replace existing windows with currently available advanced windows. For major building renovation projects or projects initiated to replace failed or failing windows, the cost of base case replacement windows and the labor to install them can be considered as a budgeted “regular maintenance” cost. In such cases, premium quality replacement windows options are available for each climate zone that satisfy the 10-year payback criteria [12]. It is not only important to select windows with climate appropriate characteristics, but also to install them without creating thermal bridges with a surrounding wall [11].

IMPROVED BUILDING AIRTIGHTNESS

Uncontrolled air transfer (including convection) through enclosures markedly increases the energy required to heat, cool, control humidity, and regulate indoor climate conditions in buildings. Investigations into building enclosure problems indicate that air leakage is a leading cause of moisture problems [13,14]. These problems include mold, moisture penetration, and durability problems, especially in intersections between exterior walls, roofs and windows, excessive rain penetration into wall cavities, unstable indoor temperature, and humidity profiles. To achieve required comfort levels, additional investments and life-cycle costs for heating and air-conditioning are necessary. In many cases, buildings with insufficient airtightness may suffer from moisture-related construction failures and losses of equity values. In colder climates, air leakage problems can cause such problems as icicles on exterior facades, spalling of masonry, premature corrosion of metal parts in exterior walls, high wood moisture content, and rot. In hot humid climates, infiltrating air in combination with insufficient construction thermal bridges causes mold due to condensation on cold air-conditioned surfaces. Sealing penetrations and reducing the chimney effect of interior ventilation can address these concerns. Application of air barrier theory in a building design requires the selection of a component or layer in an assembly to serve as the airtight layer. It is important to clearly identify all air barrier components of each envelope assembly on construction documents and detail the joints, interconnections, and penetrations of the air barrier components.

Table 7. Airtightness Best Practice Requirements

Country	Source	Requirement	cfm/ft^2 @ 75Pa*
Estonia	Ordinance No. 58. RT I, 09.06.2015, 21, 2015	≤6 $m^3/(h\cdot m^2)$ @ 50Pa for renovation ≤3 $m^3/(h\cdot m^2)$ @ 50Pa for new construction	0.42 0.21
Austria	OIB RL 6, 2011 for buildings with mechanical ventilation	1.5 1/h at 50 Pa	0.28
Denmark	Danish Building Regulations BR10	1.5 1/h at 50 Pa	0.28
Germany	DIN 4108-2	1.5 1/h at 50 Pa	0.28
USA	USACE ECB for all buildings [21], ASHRAE Standard 189.1-2011, 2013 Supplement, ASHRAE Standard 189.1.–2013 Supplement, ASHRAE Standard 90.1 - 2013		0.25
	USACE HP Buildings and DER proposed requirement		0.15
Latvia	Latvian Construction Standard LBN 002-01 for buildings with mechanical ventilation	2 $m^3/(m^2h)$ at 50 Pa	0.14
UK	ATTMA-TSL2	2 $m^3/h/m^2$ at 50 Pa	0.14
CAN	R-2000	1 sq. in. EqLA @10 Pa /100 sq. ft.	0.13
Germany	Passive House Std	0.6 1/h at 50 Pa	0.11
Sweden	FEBY 12 Std	1.08 $m^3/h/m^2$ at 50 Pa	0.08
*Based on example for four-story building, 120 x 110 ft., n=0.65. [13]			

The air barrier material, which must be structurally supported to withstand the maximum positive and negative air pressures to which it will be exposed, may have only a limited air permeance. Existing buildings undergoing major renovations, especially those located in cold or hot and humid climates, should be sealed to the same standard as new construction if construction details allow for this. The quality assurance of that process will require a “blower-door” test.

For typical buildings, increasing building airtightness can easily account for 10 to 40% of the total energy saving, depending on climate. Table **7** lists requirements for building airtightness, which differ in different countries [12], and which are used in core technology bundles.

MODELING RESULTS

The summary of the modeling results conducted under the Annex 61 [4,5,6,7,8] (Table 8) shows that, by using only described above “core technology bundles” in major renovation projects, it is possible to reduce building site energy by about 50% compared to pre-renovation baseline.

Energy reduction (~40%) in hot and warm climates (c.z. 1-3) will be less dramatic due to the need for humidity control and significant cooling via plug loads. In cold and moderate climates, achieving 50% or better site energy use reduction does not present a problem. DER using only core technology bundles also results in significant source energy use reduction (35% and better). Modeling results have demonstrated that further site energy use reduction (up to 80% in moderate climates, i.e., achievement of the “national dream”) is technically possible with the use of some additional energy efficiency technologies and plug load control. Source energy is significantly reduced (60-70%) as well. Use of building dedicated renewable energy sources (e.g., photovoltaic [PV] and solar water heating) or heat pumps will further reduce both building site and source energy.

Table 8. Potential for Site and Source Energy Use Reduction (compared to the baseline) for DER Projects using Core Bundles of Technologies and Beyond.

	Baseline			Base Case		DER			HPB	
Climate Zone	Total site EUI (100%) kWh/m2yr (kBtu/ft2 yr)	Site EUI for heating (100%) kWh/m2 yr (kBtu/ft2 yr)	Source EUIt, (100%) kWh/m2 yr (kBtu/ft2 yr)	Site energy use reduction,%	Source energy reduction,%	Site energy use reduction,%	Site heating energy use reduction, %	Source energy use reduction, %	Site energy use reduction,%	Source energy reduction,%
Public Housing, Austria										

Climate Zone	Baseline			Base Case		DER			HPB	
	Total site EUI (100%) kWh/m2yr (kBtu/ft2 yr)	Site EUI for heating (100%) kWh/m2 yr (kBtu/ft2 yr)	Source EUIt, (100%) kWh/m2 yr (kBtu/ft2 yr)	Site energy use reduction,%	Source energy reduction,%	Site energy use reduction,%	Site heating energy use reduction, %	Source energy use reduction, %	Site energy use reduction,%	Source energy reduction,%
5A	218 (69)	152 (48)	210 (67)	38	31	50	73	64	55	68
7	253 (80)	184 (58)	235 (75)	47	36	50	68	62	55	68
Office Building, China										
2A	3(1)	105(33)	331(105)	37	37	47	56	47	54	54
3A	25(8)	119(38)	378(120)	38	38	51	62	51	65	65
3C	8(3)	77(24)	243(77)	36	36	47	64	47	69	69
4A	117(37)	201(64)	393(125)	42	42	53	71	41	62	55
7	239(76)	306(97)	472(150)	32	33	50	62	38	67	59
School Building, Denmark										
6A	252 (80)	210 (67)	314 (99)	19	16	56	67	45	82	63
Dormitory, Estonia										
6A	153 (49)	213 (68)	225 (71)	29	22	47	69	37	70	58
Office Building, Germany										
5A	256 (81)	220 (70)	307 (97)	40	27	55	58	53	81	76
School, Sweden										
6A	137 (43)	109 (34)	144 (45)	26	17	56	71	37	68	38
7	177 (56)	149 (47)	172 (54)	28	20	62	73	44	73	45
Office Building, UK										
4A	89(28)	155(49)	291(92)	20	16	51	84	32	58	42
5A	135(43)	201(64)	341(108)	23	20	60	83	42	67	52
Barracks, USA										
1A	1 (0)	398 (126)	1154 (366)	17	19	39	59	42	59	59
2A	33 (10)	380 (121)	1025 (325)	17	18	41	84	42	60	59
2B	17(5)	365 (116)	1008 (320)	17	18	40	80	42	61	61
3A	65 (21)	394 (125)	965 (306)	19	18	45	84	42	63	59
3B	37 (12)	326 (103)	812 (258)	15	14	39	82	37	60	57
3C	35 (11)	273 (87)	634 (201)	12	9	33	70	31	46	37
4A	103 (33)	397 (126)	869 (276)	20	16	48	85	25	65	59
4B	86 (27)	333 (106)	745 (236)	16	12	42	88	35	62	56
4C	111 (35)	330 (105)	678 (215)	18	12	44	86	35	62	55
5A	160 (51)	422 (134)	872 (277)	21	17	51	87	42	67	60
5B	133 (42)	362 (115)	733 (233)	18	13	52	88	37	65	57
6A	212 (67)	448 (142)	839 (266)	22	16	55	88	44	70	61
6B	192 (61)	414 (131)	773 (245)	21	14	53	89	41	69	60
7	283 (90)	508 (161)	878 (279)	24	18	59	88	47	73	63
8	417 (132)	630 (200)	978 (310)	24	18	64	92	52	77	67
Office Building, USA										
1A	24(7)	261 (83)	815 (259)	30	27	48	91	45	66	64
2A	60 (19)	285 (90)	814 (258)	32	28	46	63	43	70	65
2B	81 (26)	314 (100)	862 (273)	36	29	49	87	41	73	91
3A	82 (26)	288 (91)	771 (245)	34	28	47	63	43	71	64
3B	68 (22)	251 (80)	680 (216)	30	23	51	92	41	66	58
3C	45 (14)	183 (58)	507 (161)	26	16	41	96	30	59	51
4A	96 (30)	271 (86)	685 (217)	35	26	50	89	38	69	60
4B	71 (22)	227 (72)	593 (188)	31	21	50	95	37	63	54
4C	76 (24)	206 (65)	513 (163)	31	18	48	96	33	63	52
5A	107 (34)	270 (86)	656 (208)	35	25	50	87	37	69	58

	Baseline			Base Case		DER			HPB	
Climate Zone	Total site EUI (100%) kWh/m2yr (kBtu/ft2 yr)	Site EUI for heating (100%) kWh/m2 yr (kBtu/ft2 yr)	Source EUIt, (100%) kWh/m2 yr (kBtu/ft2 yr)	Site energy use reduction,%	Source energy reduction,%	Site energy use reduction,%	Site heating energy use reduction, %	Source energy use reduction, %	Site energy use reduction,%	Source energy reduction,%
5B	83 (26)	223 (71)	552 (175)	31	20	50	95	35	64	53
6A	121 (39)	265 (84)	606 (192)	36	23	52	88	36	69	55
6B	118 (38)	254 (81)	575 (182)	34	22	51	88	34	68	55
7	145 (46)	278 (88)	594 (189)	39	24	54	87	36	71	55
8	218 (69)	340 (108)	634 (201)	42	27	59	83	39	76	58

CONCLUSIONS

The core technology bundles described in this paper make it possible to achieve DER with major renovation of buildings with low internal loads (e.g., office buildings, dormitories, barracks, and educational buildings). This task is more difficult in hot climate zones (DOE c.z. 1-3) with significant cooling needs, and may require the application of additional energy efficiency measures (e.g., reduction of plug loads, water conservation measures, advanced HVAC systems). DER is easier to achieve in heating-dominated climates and in cases when either by cultural or normative reasons, cooling is not desired and building users can tolerate temporarily increases in indoor air temperature (e.g., up to 77 °F [25 °C]).

In building simulations conducted for locations in China, the pre-renovation baseline (based on pre-1980s design) was developed for a naturally ventilated office building with inferior insulation levels and poorer building airtightness, as compared to European countries and the United States. This resulted in lower insulation levels of the building envelope and window characteristics required for the deep energy retrofit scenario (50% energy use reduction compared to the baseline) presented in Tables 4 through 6. If parameters similar to those adopted by western countries in similar climate conditions were used for DER in China, this will result in a greater energy use reduction in all climates.

High levels of energy use reduction using core technology bundles along with improvements in indoor climate and thermal comfort can be only achieved when a DER adopts a quality assurance that, in addition to design, construction, commissioning, and post-occupancy phases, includes formulation of clear and concise documentation of the owner’s goals, expectations, and requirements for the renovated building during development of the statement of work. Another important component of the QA process is a procurement phase, during which bidders’ qualifications, their understanding of the statement of work (SOW) and its requirements, and of their previous experience are analyzed.

The key to making a DER cost effective is to time the retrofit as part of a major building renovation that already has allocated funds, including those required to meet minimum energy requirements. Since there is an overlap between the funds allocated for the retrofit and those required for the DER, achieving the DER requires only an incremental cost because the DER is evaluated based on a bundle of core technologies, not on individual energy efficiency measures. Some “core” technologies (e.g., those related to building envelope insulation, replacement of windows, etc.), which may not be cost effective when implemented individually, become economically attractive when implemented in a technology bundle. Implementation of these technologies can significantly reduce building heating and cooling loads and consequently reduce the size and cost of HVAC mechanical equipment, which subsequently results in reduced annual maintenance and insurance costs of these systems.

A DER that results in improved building energy efficiency (reduced energy bills), better indoor air quality, and superior thermal comfort provides significant added value in terms of improved “leasability” and immediate financial return, i.e., higher rent. Also, many DER projects actually increase a building’s rentable/usable space, e.g., by reducing the size of mechanical rooms, adding thermally controlled areas (mansards, basements, repurposing storage spaces, etc.), which can be accounted for in the estimation of the rentable space revenues. For more objective understanding of DER economics, these factors need to be accounted for in the project LCC analysis.

ACKNOWLEDGEMENTS

The paper has presented 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." Modeling results cited in Tables 4, 5, 6, and 8 are based on research presented in papers [4,5,6,7,8].

REFERENCES

1. A. Zhivov, R. Lohse, J. Shonder, C. Nasseri, H. Staller, O. Moerck, and M. Nokkala. 2015. Business and Technical Concepts for Deep Energy Retrofit of Public Buildings. ASHRAE Transactions. Vol. 121, Part 1.
2. Annex 46. 2009. Energy and Process Assessment Protocol. International Energy Agency (IEA), Energy Conservation in Buildings and Community Systems (ECBCS). Published by ASHRAE.
3. ASHRAE. Energy Efficiency in Existing Buildings. 2015. ASHRAE Standard 100-2015.
4. M. Case (ERDC, USA), A. Zhivov (ERDC, USA), R. Liesen, (ERDC, USA) and M. Zhivov (UIUC, USA). 2016. Building envelope optimization with US Army barracks and office building renovation in 15 DOE climate zones for deep energy retrofit. ASHRAE Transactions. Vol. 122, Part 1.
5. J. Rose (DBRI-AAU, Denmark), K.E. Thomsen (DBRI-AAU, Denmark), O. C. Mørck (Cenergia, Denmark), Kalle Kuusk (TUT, Estonia), Targo Kalamees (TUT, Estonia), Tõnu Mauring (University of Tartu, Estonia). 2016. Economic challenges of deep energy renovation – differences, similarities and possible solutions for northern Europe – Estonia and Denmark. ASHRAE Transactions. Vol. 122, Part 1.
6. J.M. Riel and R. Lohse (KEA, Germany), H. Staller (AEE, Austria). 2016. Building envelope parameters optimization for deep energy retrofit of public buildings in Germany and Austria. ASHRAE Transactions. Vol 122, Part 1.
7. R. Yao (University of Reading, UK), X. Li(Chongqing University, China), B. Li (Chongqing University, China), M. Shahrestani (University of Reading, UK), S. Han(University of Reading, UK). 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.
8. Nägeli C., Ostermeyer Y. (2016). "Less than the sum of its parts – Economic and Environmental Challenges in designing Deep Energy Retrofit Concepts, the Case of Sweden". CLIMA 2016, Aalborg.
9. Annex 61. 2015. Deep Energy Retrofit – Case studies. Energy in Buildings and Communities Programme. Subtask B Report. (In print).
10. Annex 46. 2014. Energy Efficient Technologies and Measures for Building Renovation: Sourcebook. IEA ECBCS Programme Annex 46.
12. W. Anis. 2001. "The Impact of Airtightness on System Design." ASHRAE Journal, 43:12. Atlanta, GA: ASHRAE.
13. A. Zhivov., D. Herron, J. L. Durston, M. Heron, and G. Lea. 2014. Air Tightness in New and Retrofitted US Army Buildings. The International Journal of Ventilation. Vol. 12, No. 4. ISSN 1473 – 3315.
14. US Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes, Version 3, February 21, 2012" (http://www.wbdg.org/references/pa_dod_energy).