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Business and Technical Concepts for Deep Energy Retrofit of Public Buildings

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Figure 1. Example of Deep Retrofit Projects: (a) Renovation of the medieval Franciscan monastery in Graz, Austria to Zero Energy building; Source [11]; (b) Renovation of a residential building in Kapfenberg (Austria) – renovated to 85% site energy use reduction; Source: [11]; (c) Renovation of VOLARM barracks at Fort Polk, Louisiana (USA) - one of 30 barracks renovated to 50% site energy use reduction; Renovation of kindergartens in Denmark [13]: (d) the primary energy consumption has been reduced from 224 kWh/m²/yr to 103 kWh/m²/yr, (e) The primary energy consumption has been reduced from 224 kWh/m²/yr to 103 kWh/m²/yr, (f) Renovation of a school campus in Aachen. The primary energy consumption has been reduced from 240 kWh/m²year to 78 kWh /m² year.
250x272mm (96 x 96 DPI)

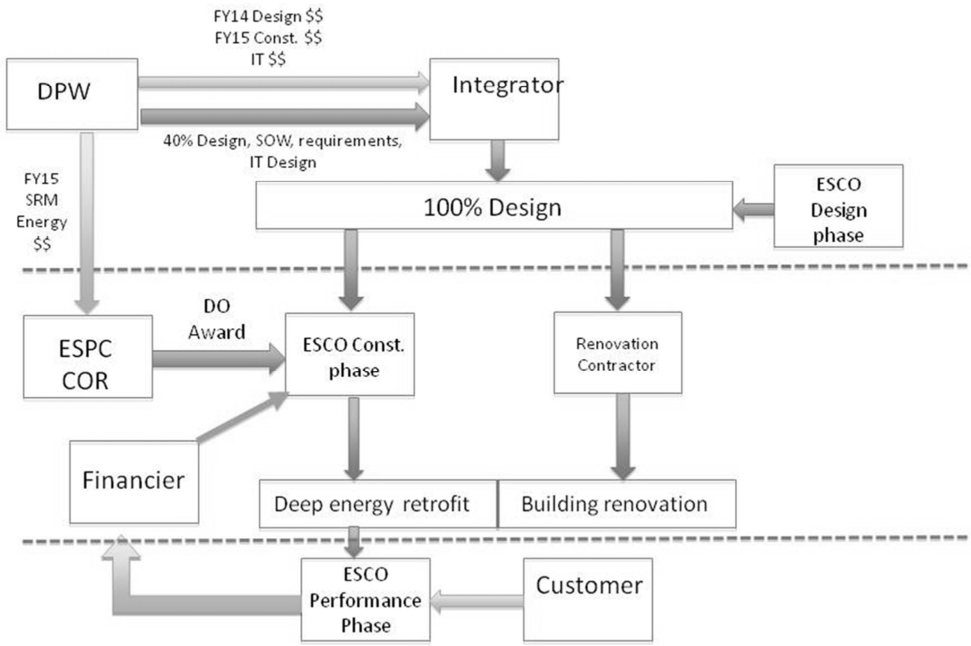

Figure 2. Example of the business model for the US Federal sector.
322x214mm (96 x 96 DPI)

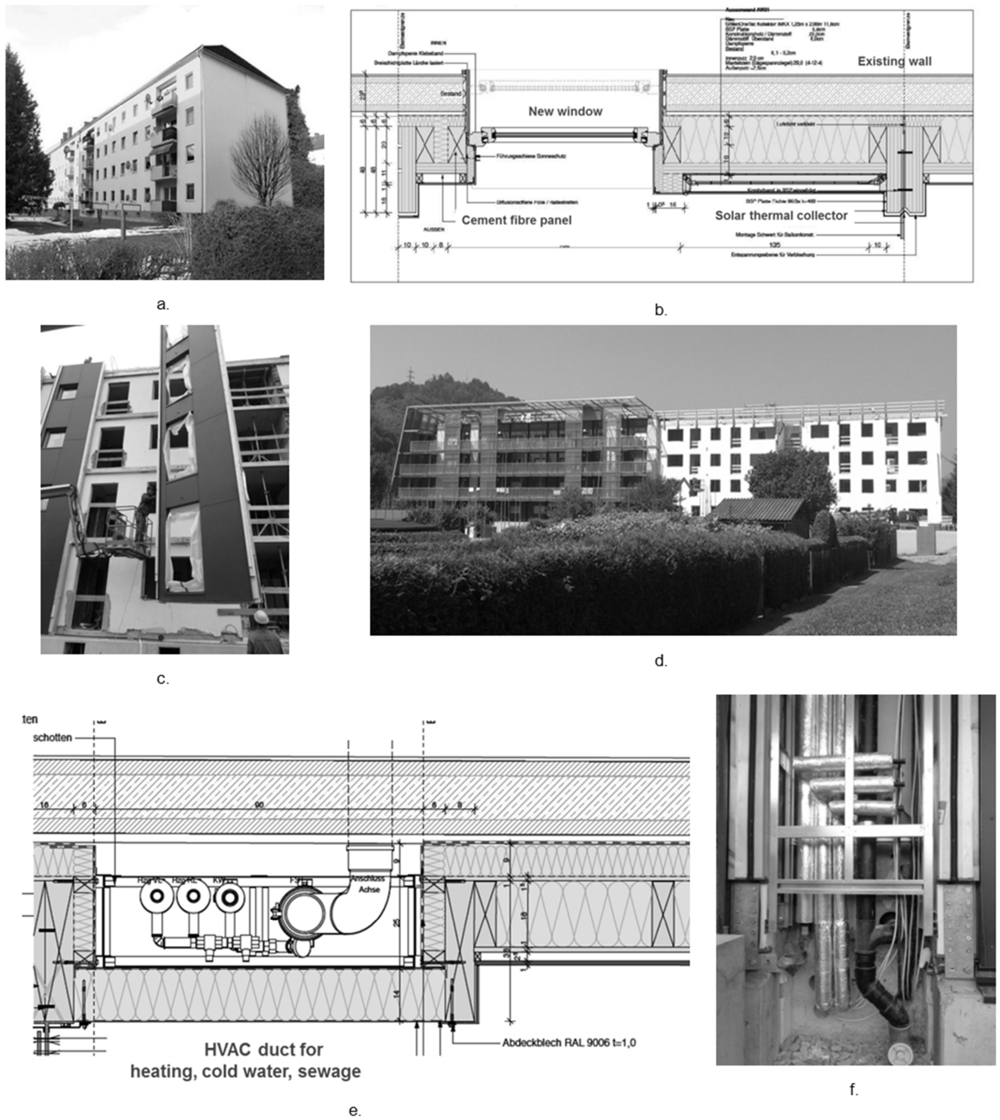

Figure 3. Renovation of a multi-story housing block in the city of Kapfenberg: (a) picture of the building prior to renovation; (b) schematic of the wall section with new window and solar thermal collector; (c) mounting of façade elements; (d) renovate façade; (e, d) schematic and picture of a new HVAC system elements installed within the external façade. Source: AEE INTEC, Nussmüller Architekten ZT GmbH
271x303mm (96 x 96 DPI)

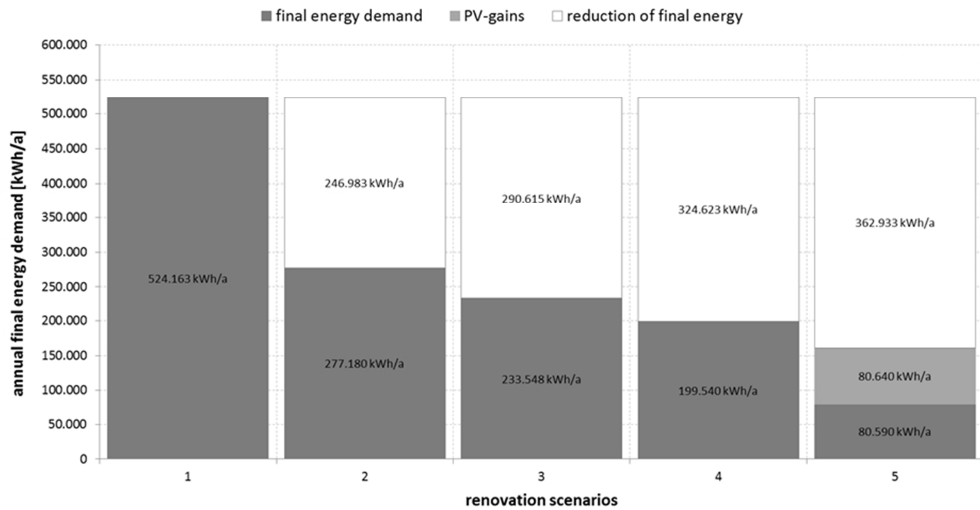

Figure 4. Calculated energy use in different renovation scenarios.
248x131mm (96 x 96 DPI)

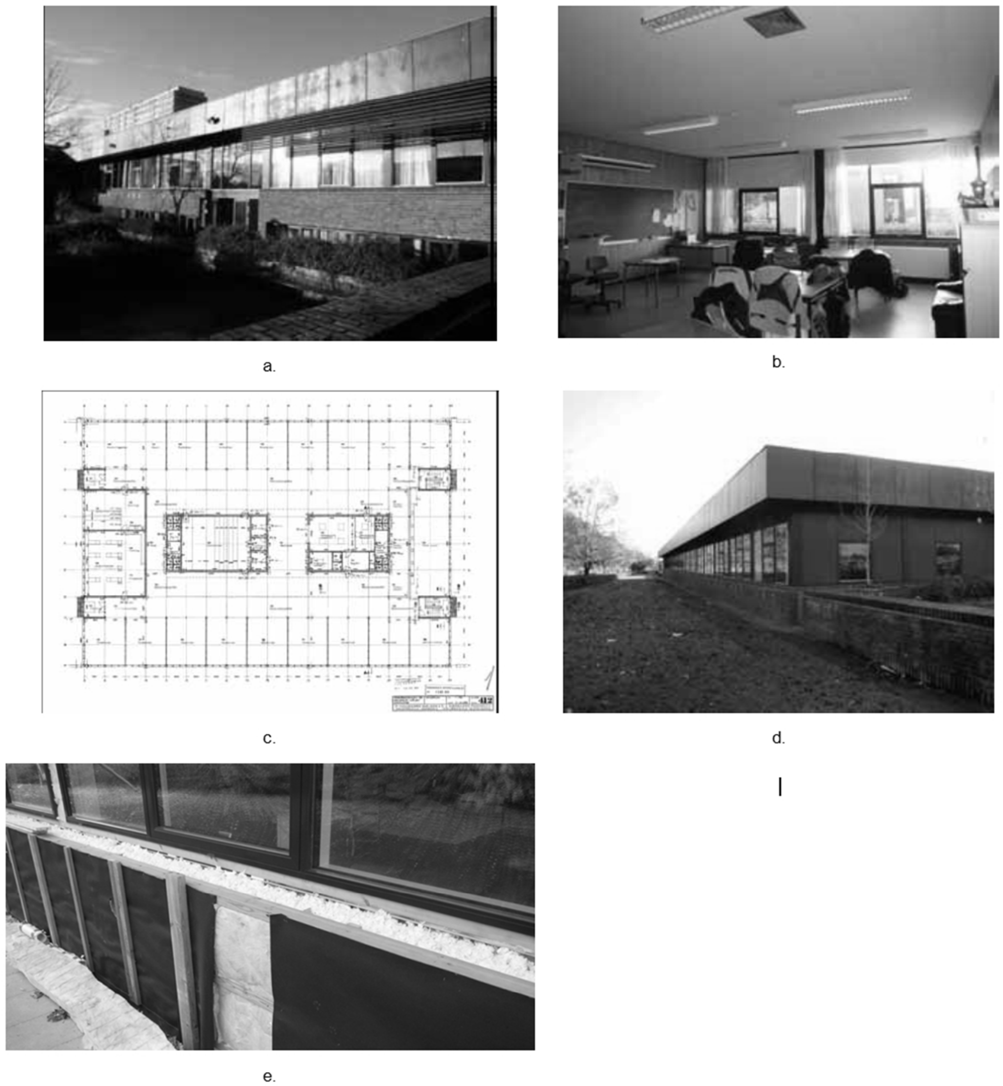

Figure 5. Hedegaards School building: (a) south façade, (b) class room; (c) floor plan, (d) picture from WNW, (e) external insulation with the U-value as low as 0.1 W/m²K
264x287mm (96 x 96 DPI)

Business and Technical Concepts for Deep Energy Retrofit of Public Buildings

ABSTRACT

Many governments worldwide are setting more stringent targets for reductions in energy use in government/public buildings. Buildings constructed more than 10 years ago account for a major share of energy used by the building stock. However, the funding and "know-how" (applied knowledge) available for owner-directed energy retrofit projects has not kept pace with the new requirements. With typical retrofit projects reduction of energy use varies between 10 and 20%, while experiences from executed projects around the globe show that energy use reduction can exceed 50% and renovated building can cost effectively achieve the passive house standard or even apprach net zero energy status [1,2,3] Previous research conducted under IEA EBC Annex 46 identified and analyzed more than 400 energy efficiency measures that can be used when buildings are retrofitted. Measures include those related to the building envelope, mechanical and lighting systems, energy generation and distribution, internal processes, etc. Implementation of some individual measures (such as building envelope insulation, improved air-tightness, co-generation, etc.) can significantly reduce building heating and cooling loads or minimization of 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, thereby providing a faster payback.

In some countries, the Energy Savings Performance Contract (ESPC) has, in recent years, proven to be a very effective tool for implementing energy retrofit projects. Nevertheless, in many countries the number of projects funded by ESPCs still do not form a significant part of the total investment budgeted by public institutions for energy retrofits. This paper presents the concept and several case studies that illustrate mechanisms that will increase the acceptance of Deep Energy Retrofit (DER) and broaden acceptance of its implementation using ESPCs for a comprehensive refurbishment of existing buildings.

TECHNOLOGY BUNDLES

What is Deep Energy Retrofit?

Though Deep Energy Retrofit (DER) concept is currently widely used all over the world, there is no established global definition of this term. Since the energy crisis of the 1970s, energy requirements pertaining to new construction and building renovation worldwide have significantly improved. Tables 1 and 2 list standards and requirements used to design and construct buildings pre-1980s and today. Since the 1980s, building energy-use requirements in the United States (Table 1) have improved by more than 50%. However, buildings and building systems degrade over time. They develop cracks in the building envelope, and dirty and leaky ducts; HVAC systems are not regularly commissioned, etc. This results in a reduction of their energy performance of at least 10%. Therefore, it is technically feasible to reduce building energy use by more than 50% using technologies readily available on the market by simply adapting current minimum requirements for new buildings to refurbishment of building stock.

Table 1. Historical improvement of the ASHRAE Standard 90.1 [4].

ASHRAE Standard 90.1 Version	Energy Use Index
1975	100
1980	100
1989	86
1999	81.5
2001	82
2004	69.7
2007	65.2
2010	46.7
2013	43.4

Table 2. Historical improvement in European National Energy Requirements for buildings [4, 5, 6]

Country	National Standard/Code	EUI, kWh/m^2	
		Pre-1980	Current
Denmark	BR10 [5]	Dwellings: 167.1 kWh/m²y	Dwellings: 52.5kWh/m²y +1650kWh/GFA Office: 71.3kWh/m²y +1650kWh/GFA
Germany	Pre- 1980: WSVO 1977[6] Current: Energy Ordinance (EnEV 2012 for new buildings Refurbishment: EnEV 2009 + <30%	Dwellings 150-250 kWh/m²y [7] Schools: 210 kWh/m²y[8]	Dwellings (new) 50-60 kWh/m²y Schools new/refurbished: 155-125 kWh/m²y
Austria	OIB RL 6 [9]	Maximum U-values	Heating energy demand: residential buildings: max. 87.5 kWh/m^{2}y Non residential buildings: max. 30 kWh/m3y

The recently (2010) rewritten Energy Performance Building Directive (EPBD) [10], which requires buildings to “be refurbished to a nearly zero-energy condition,” states that “member states shall not be required to set minimum energy performance requirements that are not cost-effective over a building’s estimated economic lifecycle.” By the EPBD definition, a nearly zero-energy building (NZEB) is “a building that has a very high energy performance.” In the United States, the “Massachusetts Save Energy Retrofit Builder Guide” refers to DER as the “the retrofit of the building enclosure and other building systems in a way that results in a high performance building.” Not many national and international bodies take their definition beyond this level of specificity except for Austria, Germany and the Czech Republic, which decided that a high performance or “nearly zero-energy” building is a building meeting approximately the Passive House Institute standard. Denmark has decided to use a new standard defined in the Danish Building regulations 2010 referred to as the “2020 definition of NZEB.” The authors’ joint experience shows that a significant number of commercial and public buildings have reduced their energy consumption by more than 50% after renovation, and that some have met the Passive House Institute energy efficiency standard or even Net Zero energy state (see examples in Figure 1). Table 3 shows some examples of US commercial buildings [2] in which energy use has been reduced by more than 50% from the pre-renovation baseline.

Figure 1. Example of Deep Retrofit Projects: (a) Renovation of the medieval Franciscan monastery in Graz, Austria to Zero Energy building; Source [11]; (b) Renovation of a residential building in Kapfenberg (Austria) – renovated to 85% site energy use reduction; Source: [11]; (c) Renovation of VOLARM barracks at Fort Polk, Louisiana (USA) - one of 30 barracks renovated to 50% site energy use reduction; Renovation of kindergartens in Denmark [13]: (d) the primary energy consumption has been reduced from 224 kWh/m^2/yr to 103 kWh/m^2/yr, (e) The primary energy consumption has been reduced from 224 kWh/m^2/yr to 103 kWh/m^2/yr, (f) Renovation of a school campus in Aachen. The primary energy consumption has been reduced from 240 kWh/m^2year to 78 kWh /m^2 year.

According to the Global Building Performance Network prognosis [3], deep retrofit that follows the most recent and proposed EU guidance can improve the buildings energy performance by at least 80%.

Based on experiences described above, the working team of the IEA EBC Annex 61 [14] project has decided, that for the purpose of this project, the building will be considered to achieve DER status when the site energy has been reduced by more than 50% against the pre-renovation baseline with a corresponding improvement in indoor environmental quality and comfort.

Table 3. US Buildings with Energy Use Reduced by More than 50% from Pre-Renovation Baseline [2].

Name	Location	Building Type	Size (sq ft)	% Over Baseline	Baseline	Measured or Estimated	Project Completion
1. Home on the Range	Billings, MT	Office	8,300	79%	ASHRAE 90.1-1999	Measured	2006
2. Pringle Creek Painter's Hall	Salem, OR	Office, Assembly	3,600	68%	Other	Measured	2009
3. Jefferson Place	Boise, ID	Office, Retail	75,000	60%	Pre-data	Estimated	Still in design
4. King Street Station	Seattle, WA	Transportation	60,000	56%	ASHRAE 90.1-2007	Estimated	2010
5. St. Als RMC South Tower	Boise, ID	Health Care	412,000	56%	CBECS	Estimated	Still in design
6. Johnson Braund Design Group	Seattle, WA	Office	8,000	51%	Other	Measured	Ongoing

Major Renovation and DER

The US Department of Energy (USDOE) [15] and EPBD [10] define a major building renovation as any renovation with the cost that exceeds 25% of the replacement value of the building. EPBD also defines building renovation as a major renovation if more than 25% of the surface of building envelope undergoes renovation.

Buildings usually undergo major renovation for reasons other than energy use reduction. The most common reasons include:

- Extension of the useful building life requiring overhaul of its structure, internals partitions and systems;
- Repurposing of the building, e.g., renovation of old warehouses into luxury apartments (Soho area in New York, NY, or into boutique shops in Montreal, QC), or renovation of old Army barracks into offices);
- Bringing the building into compliance with to new or updated codes;
- Remediation of environmental problems (mold and mildew) and improvement of the visual and thermal comfort and indoor air quality, Adding the value to increase investment (increasing useful space and/or space attractiveness/quality) resulting in a higher sell or lease price.

It is best to time a deep energy retrofit to coincide with the major renovation since, during renovation, the building is typically evacuated and becomes gutted; scaffolding is installed; single-pane and damaged windows are often scheduled for replacement; building envelope insulation is considered; and most of mechanical, electrical lighting, and energy conversion systems (e.g., boiler and chillers), and connecting ducts, pipes, and wires will be replaced anyway.

In a major building renovation, a significant sum of money must be budgeted (programmed) to cover the cost of the construction and of the energy-related scope of the renovation, which should be designed to meet minimum energy code requirements. These funds may be applied to implement advanced energy retrofit design. The shortage of public appropriated funds for major renovation projects, which can slow the number and pace and their implementation as DER, can be resolved by using PPP models.

Additional funding can become available either from the government or from the private funding sources (using ESPC or UESC models). However, in some countries such as the United States, the ESPC requires that measures linked to DER be clearly distinguished from the major renovations, which *not* considered as linked to reduction of energy consumption.

Technologies Used for DER and theirCost Effectiveness

Several pilot projects have been funded in various European countries to develop best practice examples for deep energy retrofit. Typical measures applied in these projects usually included those used for Passive Houses (Table 4).

Table 4. Deep Energy Retrofit Measures – European Experience

Measure	Germany	Austria	Denmark
Wall insulation	12-24 cm (0.20-0.10 w/m^{2}K)	16 -20 cm (0.20 - 0.10) W/m^{2}K	15-30 cm
Roof insulation	20 – 40 cm (0.20- 0.10 w/m^{2}K)	20 – 40 cm (0.20- 0.10 w/m^{2}K)	20-40cm
New Windows	0.8-1.1 W/m^2 K	triple glazing (0.70 – 0.90 W/m^{2}K)	U-value down to 0.5-1.2 W/m^2 K
Unheated basement ceiling insulation	5-20 cm (0.25- 0.10 W/m^{2}K)	10 – 20 cm (0.20 – 0.10 W/m^{2}K)	10-20cm
Reduction of thermal bridges	Reduction as good as reasonable possible		Foundation: down to: 0.15W/mK Windows: down to: 0.8-0.5 W/mK
Improved building envelope air tightness	n50 value = 1.0 1/h - 0.6 1/h (Low-energy buildings + (Passive houses)	n50 value = 1.0 1/h - 0.6 1/h (Low-energy buildings + Passive houses)	q(50pa): from 4l/s/m² to 1.5l/s/m²
Ventilation system heat recovery	Heat recovery rate: 65 – 80%	Heat recovery rate 65 – 80%	SEL: down to:1.5-1.2kJ/m³

Measure	Germany	Austria	Denmark
Solar Thermal Collectors for DHW	Dwellings: 3- 5 m² /+500- 800 l storage per residential unit, NRB with 2- 3 m² per shower unit + 300- 400 l/ storage per unit	In some provinces (e.g. Styria) residential buildings are obliged to have solar thermal collector	Dwellings: 3-5m²?
Advanced lighting system design with day-lighting controls	Dwellings: 10- 12 m² high efficient solar evacuated tube collector + > 1,000 l storage/ unit s		Yes with daylight and dimming control.

Research and analysis conducted by US Army Corps of Engineers ERDC [16] has developed major parameters for building envelop new construction and major renovation (Table 5).

Result drawn from an Annex 61 survey, combined with discussions conducted the ASHRAE TC 7.6 Public Buildings working group meeting and with previous experience of the team were used to generate a list of energy efficiency technologies (Table 6). This "core bundle of technologies" will be used in further technical and economical analyses by simulating representative buildings in different climate zones of participating countries. Modeling will be conducted for all 17 US climate zone (c.z) and for representative climates in Austria (DOE c.z. 5A, 6A and 7), Canada (c.z. 4C, 5A,B,C, 6A, 7 and 8), Denmark (c.z. 5A) Estonia (c.z. 6A, Finland (c.z. 6A and 7), Germany (c.z. 5A0, Poland (c.z. 5A and 6A) and Sweden (c.z. 5A, 6A, 7, 8). The analysis assumes that energy prices in different countries range from: gas (2.7 to 9.7 c/kWh); electricity (8 to 35 c/kWh).

In addition to the core bundle of technologies listed in Table 4, different building-type and climate specific technologies (e.g., listed in [19, 20]) can be used in the renovation project.

Table 5. Major Parameters for Building Envelope New Construction and Renovation.

Item	Component	C.Z. 1		C.Z. 2		C.Z. 3		C.Z. 4		C.Z. 5		C.Z. 6		C.Z. 7		C.Z. 8	
		Assembly Max	Min R-Value	Assembly Max	Min R-Value	Assembly Max (2)	Min R-Value (2)	Assembly Max (2)	Min R-Value (2)	Assembly Max (2)	Min R-Value (2)	Assembly Max (2)	Min R-Value (2)	Assembly Max (2)	Min R-Value (2)	Assembly Max (2)	Min R-Value (2)
Roof	Insulation Entirely Above Deck	U-0.029	R-35ci	U-0.025	R-40ci	U-0.0222	R-45ci	U-0.0222	R-45ci	U-0.020	R-50ci	U-0.0167	R-60ci	U-0.0154	R-65ci	U-0.0133	R-75ci
	Metal Building		R-11 + R-30 LS		R-25 + R-11 + R-11 LS		R-13 + R-13 + R-28ci		R-13 + R-13 + R-28ci		R-13 + R-13 + R-34ci		R-13 + R-13 + R-38ci		R-13 + R-13 + R-43ci		R-13 + R-13 + R-53ci
	Vented Attic and Other		R-38		R-49		R-60		R-60		R-60		R-71		R-82		R-93
Walls	Mass	U-0.067	R-15ci	U-0.067	R-15ci	U-0.050	R-20ci	U-0.040	R-25ci	U-0.033	R-30ci	U-0.029	R-35ci	U-0.025	R-40ci	U-0.020	R-50ci
	Metal Building		R-13 + R-6ci		R-13 + R-6ci		R-13 + R-11ci		R-13 + R-17ci		R-19 + R-17ci		R-19 + R-23ci		R-19 + R-28ci		R-19 + R-38ci
	Steel Framed		R-13 + R-7ci		R-13 + R-7ci		R-19 + R-11ci		R-19 + R-15ci		R-19 + R-20ci		R-19 + R-25ci		R-19 + R-30ci		R-19 + R-40ci
	Wood Framed and Other		R-13 + R-4ci		R-13 + R-4ci		R-13 + R-8ci		R-19 + R-9ci		R-19 + R-14ci		R-19 + R-20ci		R-19 + R-25ci		R-19 + R-35ci
	Below Grade/Basement	U-0.2	R-5ci	U-0.10	R-10ci	U-0.10	R-10ci	U-0.067	R-15ci	U-0.067	R-15ci	U-0.050	R-20ci	U-0.040	R-25ci	U-0.028	R-35ci
Floors Over Unconditioned Space	Mass	U-0.1	R-8 spray foam	U-0.0416	R-16 Spray Foam + R-6ci.	U-0.0416	R-16 Spray Foam + R-6ci.	U-0.033	R-16 Spray Foam + R-11ci.	U-0.033	R-16 Spray Foam + R-11ci.	U-0.025	R-16 Spray Foam + R-25ci.	U-0.022	R-16 Spray Foam + R-30ci.	U-0.020	R-16 Spray Foam + R-30ci.
	Steel Joist		R-8 spray foam		R-16 Spray Foam + R-8ci.		R-16 Spray Foam + R-8ci.		R-16 Spray Foam + R-13ci.		R-16 Spray Foam + R-13ci.		R-16 Spray Foam + R-25ci.		R-16 Spray Foam + R-30ci.		R-16 Spray Foam + R-35ci.
	Wood Framed and Other		R-11		R-19 + R-5ci.		R-19 + R-5ci.		R-19 + R-10ci.		R-19 + R-10ci.		R-19 + R-20ci.		R-19 + R-25ci.		R-19 + R-30ci.
Slab-on-Grade	Unheated	F-0.73	NR	F-0.73	NR	F-0.73	NR	F-0.54	R-10 for 24 in.	F-0.54	R-10 for 24 in.	F-0.52	R-15 for 24 in.	F-0.30	R-15 for 24 in.	F-0.30	R-15 for 24 in.
	Heated	F-0.64	R-7.5 for 12 in. + R-5ci below	F-0.64	R-7.5 for 12 in. + R-5ci below	F-0.64	R-7.5 for 12 in. + R-5ci below	F-0.55	R-10 for 24 in. + R-5ci below	F-0.44	R-15 for 36 in. + R-5ci below	F-0.44	R-15 for 36 in. + R-5ci below	F-0.44	R-20 for 36 in. + R-5ci below	F-0.373	R-20 for 36 in. + R-5ci below
Doors	Swinging	U-0.60	Insulated	U-0.60	Insulated	U-0.60	Insulated	U-0.60	Insulated	U-0.60	Insulated	U-0.40	Insulated	U-0.40	Insulated	U-0.40	Insulated
	Non-Swinging	U-0.50	Insulated	U-0.50	Insulated	U-0.50	Insulated	U-0.40	Insulated	U-0.40	Insulated	U-0.40	Insulated	U-0.40	Insulated	U-0.40	Insulated
Vertical Glazing	Window to Wall Ratio (WWR)	≤ 20%		≤ 20%		≤ 20%		≤ 20%		≤ 20%		≤ 20%		≤ 20%		≤ 20%	

	Thermal Transmittance (U-value)	≤ 0.45	≤ 0.35	≤ 0.30	≤ 0.30	≤ 0.27	≤ 0.24	≤ 0.24	≤ 0.22
	Solar Heat Gain Coefficient (SHGC)	≤ 0.25	≤ 0.25	≤ 0.25	≤ 0.35	≤ 0.40	NR	NR	NR

Table 6. Proposed Core Technology bundles for Deep Energy Retrofit

Category	Name	Specification
Building Envelope	Roof insulation	Level to be defined through modeling
	Wall insulation	Level to be defined through modeling
	Slab Insulation	Level to be defined through modeling
	Windows	Parameters to be defined through modeling
	Doors	Parameters to be defined through modeling
	Thermal bridges remediation	See the BE Guide
	Air tightness	0.15 cfm/ft2at 75Pa [17],0.6- 1.0/h at 50 Pa
	Vapor Barrier	See the BE Guide
	BE QA	See the BE Guide
Lighting and Electrical Systems	Lighting design , technologies and controls	See the Lighting Guide [18]
	Advanced plug loads, smart power strips and process equipment	TopTen (Europe, USA), Top Tier EnergyStar, FEMP Designated,???, etc
HVAC	High performance motors, fans, furnaces, chillers, boilers, etc	ASHRAE Std 90.1 2013 and EPBD (Table will be provided in the Guide), efficiency classification EU for motors
	DOAS	See the Guide
	HR (dry and wet)	>80% efficient, see the Guide
	Duct insulation	Based on EPBD requirements
	Duct airtightness	Based on EPBD requirements- DIN- EN 18955
	Pipe insulation	Based on EPBD requirements DIN- EN 18955

Some of the listed energy efficiency measures (e.g., wall and slab insulation, window replacement) listed in Tables 2, 3, and 4 are costly and have a long payback period when used individually. To become cost effective, DER must exploit the effects of synergy between different demand- and supply-side measures, and it must implement an innovative and integrative design approach. To increase a building's value and improve its indoor climate, DER must include quality assurance (QA) and quality control (QC) processes that specify the areas of major concern to be addressed and checked during the design, construction, and post-occupancy phases, and it must clearly delineate the responsibilities and qualifications of stakeholders in this process. This process addresses parameters and qualities of materials; components and building systems to be used; installation methods; testing; and commissioning. Special attention needs to be paid to architectural details to be used for the building envelope renovation, continuity of thermal and air barriers, windows and their installation techniques, control systems, etc. Once established, QA and QC processes, which will have a significant effect on the building performance, may be implemented at minimal cost.

Specification of a high-performance building envelope in the retrofit project can significantly reduce the size and the cost of heating, cooling loads. The separation of ventilation and heating/cooling systems using a dedicated outside air system (DOAS) can significantly reduce the size and space used by the duct system (and its cost) and allow the HVAC system to be better controlled.

Specification of an advanced lighting design using a combination of electrical- and day-lighting, ambient and task lighting, and efficient luminaries and control strategies can significantly reduce electrical consumption by lighting and reduce the cooling load on HVAC system.

The measures described above result in efficient, simpler, smaller HVAC systems with smart control strategies designed to meet a significantly reduced heating and cooling loads. The reduced cost of mechanical and electrical systems will compensate for a significant part of increased construction costs resulted from the building envelope related measures.

The differential cost to achieve deep energy renovation compared to a standard (code based) renovation is equal to the cost of the DER less the programmed (budgeted) cost of building renovation to meet the minimum building code discussed above. Rough cost comparisons of different levels of building energy retrofit made by Pike Research Company [21] are presented in Table 7.

Table 6. ***Energy Savings and Payback from Energy Retrofits of Various Types***

Energy Retrofit Type	% Energy Savings	Simple Payback from Energy Cost Savings	Cost $/SF
Retro-commissioning (mostly HVAC- measures)	10 to 20	4 months to 2.4 years	0.30
ESCO (HVAC- measures)	20 to 40	3 to 12 years **	$2.50
DER with Integrated design* (HVAC and thermal envelope)	30 to 60	7 to 12 years	$2.50

*Includes all renovation costs including those to meet energy targets
Sources: Pike Research and LBNL

BUSINESS MODELS FOR DEEP ENERGY RETROFIT: CURRENT SITUATION IN EUROPE AND THE UNITED STATES

In the US federal sector, the majority of ESCO projects (including those offered by the US Department of Energy, and by the US Army Corps of Engineers) are implemented using indefinite delivery, indefinite quantity (IDIQ) contracts. These contracts allow agencies of the federal government to quickly select an ESCO from a list of pre-qualified companies. The contracts permit ESCOs to install energy conservation measures only. Since the deep retrofit model combines building renovation with building energy efficiency measures, two separate contracts are required: a conventional appropriations-funded contract with a renovation contractor, and a privately funded performance contract with an ESCO to implement the energy-related measures. This requires close coordination between the two contractors during the design and construction phases. In general, this approach also requires a separate entity to act as "Integrator" and manager of the two contracts and contractors. Figure 2 shows the process.

Figure 2. Example of the business model for the US Federal sector.

Note that, in some recent projects, the US General Services Agency (GSA) has achieved energy savings in excess of 60% through the use of ESPC alone. GSA's approach begins with a "design charrette" that emphasizes the desire for deeper energy savings and the use of advanced/underused technologies. While deep energy savings have not been achieved in all cases, nevertheless in the recent National Deep Energy Retrofit project, this approach has allowed GSA to achieve, in the aggregate, almost twice the energy savings usually achieved in ESPC projects.

On the US state and local level, a variety of regulations exist, and not all restrict the use of ESPC to energy conservation measures alone. In some cases, it may be possible for the ESCO to implement both the renovation and the energy retrofit project to achieve deep energy savings.

In Europe, there is no agreed framework for ESCO and general contractor collaboration. In fact, a single company can offer the solutions for both major renovation and deep energy retrofits. In return, as markets are relatively small in many smaller EU Member States, the construction sector does not necessarily have many companies that would specialize in DER, which is seen as a by-product for major construction companies, a perception that results in less competence in direct involvement into DER projects and solutions.

The fact that there is no single European business model or regulatory framework for ESPC's makes it difficult to do a comparative analysis of US and European markets. The European model offers more flexibility in that it does not require a separation of the general contractor and ESPC contractor roles. This can make the DER easier, but its total costs more difficult to define. Specifically, it becomes difficult to measure actual energy savings resulting from measures directly aiming at energy consumption reduction in isolation from other renovation measures.

Also, DER's have not become a trend in a current renovation process in European markets. The number of DER's needed to meet 2020 energy saving targets is far above the current number of DER projects. This will make it difficult to meet those targets, given that construction of new building stock has dramatically declined during the economic downturn period.

An even more worrisome aspect of the European scene is that, apart from a handful of companies that are managing the ESCO business (some of which operate in the US market as well), the market does not seem to be developing. The market for DER financing is still in its infantry stages in Europe. There needs to be a significant expansion, perhaps through more elaborated Public-Private Partnership (PPP) in funding arrangements. There is a need to rapidly explore new funding sources as well as to speed up the rate of DER's to gain higher energy savings.

CASE STUDIES

Case Study 1 - Germany

The German case study is a renovation of a school campus in the municipality of Linkenheim, which was constructed in several stages between the 1960s and 1980s. The total heated gross floor area is about 16,500 m²:

- Primary school: 6,276 m² (1960s), which contains a 60 m² indoor swimming pool
- Secondary school: 5,073 m² (1970s)
- Special school for disabled persons: 1,750 m²
- Gym 1: 2,140 m² (1970s)
- Gym 2: 1,223m² (1980s).

The reason for the DER was the school's age. One of the three heating plants, a large part of the lighting systems, and the building control system were more than 40 years old. The external wall surface of the gymnasiums required refurbishment. The targets of the DER were:

- Reduction of the heating consumption of more than 50%, from which at least 70% should be provided by biomass.
- Reduction of the electricity consumption of more than 30%
- Refurbish the thermal envelope of the gymnasiums and parts of the primary school by application of thermal insulation composite systems (extruded polystyrene) > 15 cm in average.

According to German building code, the benchmarks before the DER were 180 kWh/m² y for heating and 30 kWh/m²y for the electricity consumption.

The energy for heating was supplied by Oil (70%) and Gas (30%). Energy costs were:

- Electricity: 0.1352 €/kWh
- Gas: 0.0481 €/kWh
- Oil: 0.0720 €/kWh
- Wood chips: ~0.0195 €/kWh

The first 2 years of project monitoring and verification indicate that:

- Heating consumption was reduced by 51%
- Electricity consumption was reduced by 25%

The following measures were carried out:

- Insulation of two gymnasiums and parts of the primary school: 16 cm wall insulation, 24 cm roof top insulation and triple glazing with U value w = 1.3.
- Installation of 250 kW peak PV panels and integration in the campus grid
- Installation of a 500 kW biomass plant with a 400 m³ wood chip storage in the former oil storage basement, a 50 kWth/100 kWth CHP and two peak load oil boilers with capacity of 1,100 kW
- Installation of a two-pipe heating micro-grid with submetering and heating stations to service all five buildings
- Installation of a building automation system

- Replacement of approximately 800 lighting systems (T8 with 39W or 66 W per unit, T5 with 28W or 46W, and high efficient reflectors, partly with daylight control system) with 5-7 W/m² in class rooms, 4 W/m² in floor halls, and 12 W/m² in Gymnasiums
- Installation of ceiling heating panels with integrated lighting systems in Gymnasium 1
- Refurbishment of the ventilation systems in the swimming pool, the locker and shower rooms including high efficient desiccant heat recovery based on heat pump (80%).

Cost and Business Model

The municipality was able to fund all measures from appropriate funding without any bank loans but decided to engage an ESCO within an ESPC project to carry out all measures except the building envelope measures. The economic decision-making criteria used in the public tendering process were the guaranteed saving of the ESCO, the cost to install the ECM, and the internal municipal return of investment. To separate the impacts of the ESCO measures from those of the thermal envelope, the ESCO measures were installed within 10 months, after which one heating period was monitored, and then the thermal envelope improvements were put in place.

Total costs for insulation were 2.4M€ (approximately. 290 €/m²) with an average payback rate of 56 years.

Total costs for the ESCO measures were 2.2M€ with a guaranteed payback rate of 14 years.

Case study 2 - Austria

The Austrian case study is a renovation of a multi-story housing block in the city of Kapfenberg that was built in 1960 – 1961 with four floors and 24 apartments with a size of 20 – 65 m^2. The total heated gross floor area is 2845 m^2. The housing company was forced to do a major renovation to improve the energy, technical, and architectural quality of the building. (The apartments were too small and the equipment outdated.) The Austrian “Building of Tomorrow” research program has supported such renovation activities to break new ground for ambitious concepts.

The final energy demand (based on the calculation required for the Austrian energy certificate) of the existing building is 524,163 kWh/yr, respectively 184 kWh/m^2 gross floor area and year.

Main targets for the renovation were:

- 80% energy efficiency (80% reduction of the energy demand of the existing building)
- 80% ratio of renewable energy sources (80% of the total energy consumption of the renovated building should be provided by renewable energy sources)
- 80% reduction of CO2 emissions (80% reduction of the CO2 emissions of the existing building)
- Plus energy standard through energy production on site (PV modules and solar thermal collectors).

To demonstrate alternative (ecological optimized) solutions to conventional thermal insulation composite systems (like extruded polystyrene) the renovation was done using standardized, pre-fabricated wooden façade elements in Passive House standard with integrated HVAC systems (PV, solar thermal collectors, disposal systems). Figure 3 shows construction details of the pre-fabricated elements.

Figure 3. Renovation of a multi-story housing block in the city of Kapfenberg: (a) picture of the building prior to renovation; (b) schematic of the wall section with new window and solar thermal collector; (c) mounting of façade elements; (d) renovate façade; (e, d) schematic and picture of a new HVAC system elements installed within the external façade. Source: AEE INTEC, Nussmüller Architekten ZT GmbH

Energy calculations were done for five different scenarios. Figure 4 shows the results.

Figure 4. Calculated energy use in different renovation scenarios.

Energy reductions were:

1.	Existing building	baseline
2.	Minimum requirements Austrian building code	reduction of 47%
3.	Scenario e80^3 (improvement of u-values)	reduction of 55%
4.	Scenario 3 + mechanical ventilation with heat recovery	reduction of 62%
5.	Scenario 4 with PV modules and solar collectors	reduction of 85% (realized)

The final energy demand (based on the calculation required for the Austrian energy certificate) of the renovated building is 80,590 kWh/yr, or 28 kWh/m^2/yr. The total reduction is achieved by energy efficiency measures (-323,433 kWh/yr), generation of electricity with PV-panels (-80,640 kWh/yr), and generation of solar heat (-39,500 kWh/yr).

Reduction of heat energy demand is 322,222 kWh/yr, which leads to a financial reduction of 25,734€ per year (based on the price for district heating of the city of Kapfenberg). Reduction of electricity demand is 83,504 kWh/yr, which leads to a reduction of 7858€ per year (based on the electricity price of the energy company of the city of Kapfenberg).

Total renovation costs are ~4.8M€ (energy related costs and other costs). Additional innovative, energy related costs compared to a renovation following the minimum requirements of the Austrian building code are ~2M€.

Case Study 3 -Denmark

Hedegaards School is located in a relatively open urban area with mainly low-rise buildings in Ballerup, Denmark. Ballerup is a town/municipality of approximately 50,000 inhabitants, 15 west of Copenhagen, in an area often referred to as "greater Copenhagen." The climate in Denmark is cold-temperate. Annual mean temperature has increased from 8 °C in 1980 to 8.7 °C today. The number of heating degree days is 2900.The number of hours with bright sunshine is about 1700 – has also increased over the last 30 years from about 1500.

Hedegaards School is one of 10 schools in Ballerup. The school was built in 1972 and a mayor renovation of Part F is needed. The energy renovation of Hedegaards school was undertaken in relation to the EU – Project "School of the Future" [12].

Figure 5. Hedegaards School building: (a) south façade, (b) class room; (c) floor plan, (d) picture from WNW, (e) external insulation with the U-value as low as 0.1 W/m²K

This case study deals with the F – part of the school. These buildings are characterized by:

- Number of pupils: 15 classes of 24 pupils - 360
- Number of adults (teachers, administration workers, etc.): 18-20

- Gross area: 3850 m²
- Gross volume: 8,000 m³
- The surface areas of the facades are: ~900 m², of which 65% is glazed.

Most of the area is located at the ground floor – and about one fourth in a high basement to the east of the building.

The floor plan shows that class rooms are placed along the perimeter of the mostly one-story building. The building interior includes corridors, an auditorium, toilets, and a few more rooms. The high basement contains a cafeteria, which is no longer in service. It future use has not yet been decided.

Before renovation, heating and electricity energy consumption and costs were:

Heating: 187 kWh/m²-year – 0.08 €/kWh = 57500 €/yr
Electricity: 41 kWh/m²-year – 0.26 €/kWh = 41000 €/yr

In general, the building needed renovation. The roof was not weathertight, the windows were leaky, and the insulation levels were generally low.

The exterior walls are of double brick walls construction. Between the two layers of bricks is a layer of insulation – 70 mm thick. However, in several places the wall is solid (uninsulated) and thus has thick thermal bridges.

The windows are double-pane placed in a band almost all around the building (Figure 5). Many of the windows leak and the frames are in need of paint.

The school is heated by a hydronic system with two radiators in each classroom. The radiators preheat the fresh air, which enters through the radiators. The radiators were installed in a previous renovation project. Heating was originally provided through the ventilation system, supplemented by electrical resistance heaters in each classroom. Heat is provided from the local district heating network as high temperature water in pressurized pipes.

The electrical lighting in the classrooms is provided by fluorescent tubes (T8) controlled by occupancy sensors. The system is relatively efficient and it would be difficult to justify replacement based on simple return of investment calculated derived from the cost of installing a new lighting system, offset by energy savings. However, in the corridors in the central part of the building, the system is not controlled optimally and lighting levels are quite uneven. This area is used as additional teaching space and needs an upgrade in the lighting quality and level. Maintenance (changing of tubes) can be reduced considerably and the lighting levels and uniformity may be improved by installing a LED-based system.

ENERGY RENOVATION MEASURES

The Building Envelope

The energy renovation will greatly reduce the thermal losses of the building envelope. An average 25 cm of insulation has been added on the roof so the average thickness now is 45 cm. All the exterior walls and the all the windows have been replaced. The new walls are insulated with 33 cm of mineral wool with a lambda value of 0.034 W/mK. The new three-pane windows have frames with very low thermal transmittance.

Electrical Lighting System in the Corridors

The corridors needed improved electrical lighting. It was decided to upgrade the corridor lighting to classroom levels using LED down lights placed for uniform light distribution to allow the corridors to serve as extended teaching areas.

Renewable Energy System

A PV system has been installed on the south facing sloping roof of one of the roof light systems of the school building. The area is 152 m² and the total installed power is 22.5 kWp. The expected yearly production will be 22.5 MWh, corresponding to 5.8 kWh/m²/yr.

Summary of Predicted Energy Savings

The heating and electrical energy saved by implementing the measures described above was calculated by the energy calculations program ASCOT. The energy consumption before energy retrofit was also established by a calculation made by the ASCOT program. The energy consumption has also been established over several years in the energy management programme of the municipality. The correspondence with the calculated values was found to be reasonable. Table 7 lists the before and after energy performance, which indicate estimated primary energy savings of 73%.

Table 7. Actual and predicted energy consumptions after renovation

Energy use	Performance before energy retrofit, [kW/m^2]	After renovation performance, [kW/m^2]
Heating consumption	187	44.7
Electrical consumption	22.1	8.2
Primary energy	242.25	65.2
Primary energy, %	100	26.9

CONCLUSIONS

Energy consumption of new buildings has been considerably reduced over the recent 40 years by more than 50% in both the United States and Europe. Now it is a time to improve the existing building stock and extensively reduce energy used in buildings by DER. This will help reduce fossil fuel use, help meet CO_2 targets, slow global climate change, and increase energy security and energy independence in energy-importing countries.

The examples and case studies presented in this paper show that DER is indeed possible and cost effective when it is combined with a major building renovation. “Core” technologies, which may not be cost effective when implemented individually, become economically attractive when implemented in technology “bundles.” Although the core “bundled” technologies required for deep energy retrofit remain the same, some characteristics of these technologies differ and depend on climate conditions and energy prices. The overall project cost and associated risks are further reduced by implementing an innovative and integrating building renovation design process. Also, the effectiveness and risks associated with DER significantly depend on establishing quality assurance and quality control processes that specify areas of major concern to be addressed and checked during the design, construction, and post-occupancy phases, and that define the responsibilities and qualifications of stakeholders in these processes. Implementation of major renovation projects using PPP (e.g., ESPC) can play a crucial role by increasing the number and pace of DER projects. Besides providing access to additional funding sources, PPP can contribute industry expertise during the design phase, installation, and operation and maintenance of technologies required for DER.

Despite their enormous market potential, the concepts, strategies, and business models described in this paper have not yet been fully developed and streamlined. This will be addressed during the next few years by the IEA EBC Annex 61 team. Major areas of future research include the technical and economical analysis of core bundles of technologies for three public building categories (offices, barracks/dormitories, and educational buildings) in a large number of climates, the development and demonstration of de- risking strategies, and the advancement of existing funding mechanisms.

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