International Energy Agency

Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (Annex 61)

Project Summary Report

October 2017

EBC is a programme of the International Energy Agency (IEA)

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Published by New Buildings Institute (NBI)

ISBN 978-978-3-9819330-2-4

Participating countries in EBC:

Australia, Austria, Belgium, Canada, P.R. China, Czech Republic, Denmark, France, Germany, Ireland, Italy, Japan, Republic of Korea, the Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom and the United States of America.

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Preface

THE INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) was established in 1974 within the framework of the Organization for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international cooperation among the 29 IEA participating countries and to increase energy security through energy research, development, and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

THE IEA ENERGY IN BUILDINGS AND COMMUNITIES PROGRAMME

The IEA coordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes. The mission of the IEA Energy in Buildings and Communities (IEA EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities through innovation and research. (Until March 2013, the IEA EBC Programme was known as the IEA Energy in Buildings and Community Systems Programme, ECBCS.)

The R&D strategies of the IEA EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. These R&D strategies aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five areas of focus for R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use.

THE EXECUTIVE COMMITTEE

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)

Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy and CO2 Equivalent Emissions for Building Construction (*)
Annex 58: Reliable Building Energy Performance Characterization Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems
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Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings
Annex 73: Towards Net Zero Energy Public Communities
Annex 74: Energy Endeavour
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables
Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - HVAC Energy Calculation Methodologies for Non-residential Buildings

Acknowledgements

The “Deep Energy Retrofit – The Final Report” was developed within the IEA EBC Program Annex 61, “Business and technical Concepts for Deep Energy Retrofit of Public Buildings” as the result of a joint effort by researchers and practitioners from Austria, Canada, China, Denmark, Estonia, Germany, Latvia, UK, and the United States. The authors express their appreciation to the many international contributors and organizations whose volunteer efforts contributed to development of a series of Guides developed under this project. Special gratitude to the ASHRAE and its Technical Committees TC 7.6 “Building Energy Performance,” TC 5.2 “Duct Design,” and a Standing Standard Project Committee 90.1 for providing a platform for public discussion of the project progress, to Chartered Institution of Building Services Engineers (CIBSE) and the Federation of European HVAC associations (REHVA) for sharing its technical information and providing valuable input into these documents. The authors would like to personally thank the members of the EBC Program Executive Committee for their directions, guidance, and support to the project. Special appreciation to the following reviewers, who provided their valuable comments and suggested improvements to this Guide:

Paul Ruyssevelt (UCL, UK) and Conny Rolen (Formas, Sweden). The authors gratefully acknowledge William J. Wolfe, Writer-Editor, ERDC-CERL for his help in coordinating the preparation of this document. The authors would like to acknowledge the financial and other support from the following: the office of the Assistant Secretary of the US Army for Installations, Energy, and Environment; US Army Corps of Engineers; US Department of Energy (Federal Energy Management Program), The Austrian Ministry for Transport, Innovation and Technology, the EUDP-programme of the Danish Energy Agency and Bundesministerium für Wirtschaft und Energie, Germany.

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Project Summary

1. Background and Goals

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 new requirements. In typical retrofit projects, reduction of energy use varies between 10 and 20%, while experience from executed projects around the globe shows that energy use reduction can exceed 50%, and renovated buildings can cost-effectively achieve the passive house standard or even approach net zero-energy status.

Research conducted under the International Energy Agency’s Energy in Buildings and Communities Program (IEA-EBC) Annex 46 (2009) identified and analyzed more than 400 energy efficiency measures (EEMs) that can be used when buildings are retrofitted. Implementation of some individual measures (such as building envelope insulation, improved airtightness, and cogeneration) can significantly reduce building heating and cooling loads or minimize energy waste, but can require considerable investments with long and unattractive paybacks. As cost effectiveness is still the major decision-making criterion in the public building sector, IEA EBC Program Annex 61 has conducted research with a goal of providing a technical and business framework, selected tools, and guidelines to significantly —and cost effectively— reduce energy use (by more than 50%) in government and public buildings.

2. Approach

Case Studies. The Annex 61 team studied and documented 26 examples of implemented retrofit projects from Europe (Austria, Denmark, Estonia, Germany, Ireland, Latvia, Montenegro, The Netherlands, United Kingdom) and the United States, in which site energy use has been reduced by 50% or better compared to the pre-renovation base line. After the projects data were collected, the case studies were analyzed with respect to energy use before and after renovation, reasons for undertaking the renovation, co-benefits achieved, resulting cost effectiveness, and the business models followed. Finally, the lessons learned were compiled and compared in the “Annex 61 DER Case Study Report.”

Bundle of Core Technologies. A list of core energy efficiency technologies was generated from the results of case studies, from surveys and discussions conducted at the ASHRAE Technical Committee (TC) 7.6 “Public Buildings” working group meetings in 2013 and 2014, and from previous experience and research conducted by the Annex 61 team members. These technologies, when applied together (as a bundle), will reduce the total building site energy use by 50% or more, including energy used by appliances. Technical characteristics of building envelope-related technologies included into a “core technologies bundle,” have been studied through modeling and life cycle cost (LCC) analysis for representative national climate conditions. Characteristics of other technologies included in the bundle of technologies are defined by requirements of national standards and on best international practices that have been collected and that are summarized and presented in the “Annex 61 DER Technical Guide.” This Guide contains recommendations that are based on studies conducted by national teams associated with Annex 61 (see Annex 61 publications). Results of these studies provided a base for setting minimum requirements to the building envelope-related technologies under the different framework conditions of the participating countries to make Deep Energy Retrofit feasible and, in many situations, cost effective. This Guide also provides best practice examples of how to apply these technologies in different construction situations.

Business and Financial Models. In addition to the limitation of available funding for public buildings refurbishment, the major obstacle hindering the implementation of DER projects is a lack understanding of how to increase the cost effectiveness of these projects. Therefore, this part of the Annex 61 project has been focused on collecting and analyzing the information related to project organization, reduction of investment costs, introduction of least cost planning approaches, and the monetization of a wide spectrum of operational and non-operational benefits resulting from DER projects. The work on the "DER Business Guide" consisted of a literature review, analysis of existing and emerging financial and policy mechanisms, interviews with industry stakeholders, and an evaluation of the value implications through financial modeling.

Pilot Projects. Seven pilot projects were conducted in the working phase of Annex 61 with a goal of achieving a reduction in energy consumption of 50% or more when compared with the baseline (energy consumption before the refurbishment):

- Dormitory in Manheim, Germany.
- IWU Office Building in Darmstadt, Germany.
- Almegårds Kaserne Military Barracks in Bornholm, Denmark.
- Presidio Military Barracks in Monterey, California, USA.
- Federal building and courthouse in St. Croix, U.S. Virgin Islands.
- Federal Buildings, Silver Spring, MD, USA.
- Kindergarten, Estonia (Estonia).

Some of Technical and Business concepts developed and described in the Annex 61 Guides and their combinations have been further studied and tested during these pilot projects. The "DER Pilot Projects" report documents the technical concepts implemented in these projects along with the cost information, cost effectiveness, and lessons learned.

3. What Is Deep Energy Retrofit?

Analysis conducted by the Annex 61 team (Annex 61 DER Technical Guideline) 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. According to the Global Building Performance Network prognosis,[1] deep retrofit that follows the most recent and proposed European Union (EU) and U.S. guidance should improve the buildings energy performance by at least 50% and up to 75%;

Based on experiences described above, the IEA-EBC Annex 61 team has proposed the following definition of the DER:

> "Deep Energy Retrofit (DER) is a major building renovation project in which site energy use intensity (including plug loads) has been reduced by at least 50% from the pre-renovation baseline with a corresponding improvement in indoor environmental quality and comfort."

[1] http://www.gbpn.org/more-and-deeper-renovation/definition-dr

Deep Energy Retrofit requires a whole-building analysis approach along with an integrative design process. A "whole-building analysis" means that the building is considered as an integrated system rather than as a collection of single standalone systems. The technologies include the building envelope, HVAC systems, renewable energy supply system, all of which must be combined with recommissioning, monitoring, maintenance, and building operations. The whole-building approach requires the identification and applications of synergistic relationships between the component systems. For example, improving the building envelope and improving lighting systems will substantially reduce a building's heating and cooling energy demand. This would in turn reduce the size of boilers, chillers and duct systems, which would consequently require smaller air handling units. Also, replacing an aging air-handling unit with an air supply controlling system and a high-efficiency heat recovery system will improve indoor air quality and reduce energy demand. Cascading benefits are only achievable if the buildings were analyzed as an integrated whole in a DER process.

After the identification of a DER bundle of energy conservation and supply technologies, the key to the implementation of a DER project is the use of an integrated interdisciplinary design process, starting with an initial charrette-based study of the problem as a whole, based on collaboration and shared information. This contrasts with the more traditional process, which is based on a linear flow of information passing from one discipline to another.

4. How To Make DER Cost-Effective?

The scope of deep energy retrofit project and its attractiveness to investors depends on the project's cost effectiveness. Calculation of the project cost effectiveness is defined by National and International Standards on Life Cycle Cost Analysis.

An important consideration in LCCA is the selection of the Base Case Scenario, against which cost effectiveness of DER will be evaluated. The base case scenario should not be confused with the Baseline, which is used for benchmarking energy use in the building before renovation. Most of major renovation projects include a scope of work that is non-energy related and one that is energy related.

A non-energy-related scope of work may include such elements as different construction jobs related to changing floor layouts (e.g., moving/removing internal partitions), adding bathrooms, removing asbestos, adding sprinkler system, etc.

An energy-related scope of work for a major renovation project typically includes replacement of existing mechanical, lighting and electrical systems, replacement of some or all windows, and replacement of exiting ductwork and plumbing systems. Major renovation with some energy-related scope of work that will meet current minimum standard requirements will be considered to be a Base Case for the LCCA. While a non-energy-related scope of work will remain the same in both the Base Case and DER scenarios, the energy-related scope of work with a DER can include the same items, but will use higher efficiency equipment and systems, as well as additional items that are not often a part of typical major renovation projects (i.e., building envelope insulation, improvement of building air tightness, heat recovery, etc.). Some improvements, such as additional insulation and high-performance windows increase the cost of renovation; other improvements (e.g., smaller heating and cooling systems, boilers, and chillers) allow for a reduction in cost compared to similar budgeted items. Therefore, the overall budget for a DER project is typically higher than the budget required for a major renovation that simply follows minimum energy requirements.

The main drivers for improving cost effectiveness of DER projects include the optimization of investment costs, and an accounting of all operational costs savings and of additional non-energy-related life cycle cost benefits

4.1. Investment Cost Reduction

4.1.1. Timing

Timing a DER to coincide with a major renovation is best since at that time, the building is typically evacuated and gutted; scaffolding is installed; single pane and damaged windows are scheduled for replacement; building envelope insulation is replaced and/or upgraded; and most of mechanical, electrical lighting, and energy conversion systems (e.g., boiler and chillers) along with connecting ducts, pipes, and wires will be replaced. At that time, the significant sum of money covering the cost of energy-related scope of the renovation designed to meet minimum energy code has already been budgeted anyway.

4.1.2. DER Planning Costs

DER planning costs are a part of the investment costs and may account to 15-30% of the overall first costs. The "DER Technical Guide" provides valuable information on limited bundle of technologies which, when applied will reduce energy consumption by 50% or more. Technical characteristics of these technologies (e.g., building envelope insulation values, window characteristics, level of air tightness, etc.) listed in the Guide can be used as a starting point for further project optimization.

4.1.3. Quality Assurance

A DER project must be properly implemented through all its phases to accomplish the goals and required performance levels that the Owner requires. Like all construction projects, there are many steps, decisions, and operations that require an orderly QA process to avoid significant cost increases in the construction and the operation phases. A properly implemented DER will increase a building's value, improve its indoor climate and thermal comfort, and meet the owner's energy and sustainability goals. When established and well understood, the QA process requires minimum or no additional cost.

4.1.4. Selection and Optimization of the DER Scenario

The energy-related scope of work and specific characteristics of technologies to be used can be selected using energy modeling. The scenarios to be considered may include: DER (50% of energy use reduction compared to the Baseline); renovation to the new building standard; a "ideal scenario," which could be passive house, near zero energy (NZE), etc. For each scenario, investment costs and operating cost savings are estimated and then compared to the Base Case scenario. From the cost-benefit analysis provided for each scenario, the decision maker than selects the one to be further fine-tuned using the least cost planning approach (see the DER Business Guide). A review of completed refurbishment projects shows that the application of a LCP can improve the cost effectiveness of DER projects by 5 to 28%.

4.2. Operating Costs

Operating costs typically include the energy use cost and the cost of operation and maintenance. Compared to the Base Case, DER may or may not result in the following operating cost savings:

- Energy use and cost reduction due to improved efficiency of the building and its systems.
- Energy cost reduction due to shifting energy peaks, switching to different fuels (e.g., using cogeneration or tri-generation) or replacing fossil fuel based thermal or electrical systems to systems from renewable energy sources.
- Maintenance cost reduction with replacement of worn-out equipment at the end of its life cycle.
- Maintenance cost reduction due to downsizing of mechanical systems with reduced heating and cooling loads.
- Operation cost reduction using advanced building automation systems.

4.3. Other Bankable Cost Benefits

Studies and pilot projects executed around the world by frontrunners indicate that, in addition to the traditional areas of operating cost reduction listed above, other bankable cost reduction and income-generating opportunities related to DER should be investigated in an LCCA:

- Improved building durability due to better temperature and humidity control (e.g., reduced cost of building envelope repair and mold mitigation).
- Grants, rebates, and other financial subsidies for energy efficient and sustainable design (one-time payment).
- Reduced costs and time related to employee turnover in flexible and sustainable work spaces (single or multiple time cost reduction) .
- Increased usable space due to downsized and consolidated mechanical equipment (additional cost reduction or income generating cash flows).
- Increased usable space due to improved thermal comfort in areas close to external walls (additional cost reduction or income generating cash flows).
- Increased usable space due thermal insulation and ventilation of the attic space (additional cost reduction or income generating cash flows).
- Reduced short term absenteeism due to improved indoor air quality and comfort (additional cost reduction).
- Improved workers ‘productivity resulting from improved indoor air quality and comfort (additional income generating cash flows).
- Recruiting and retention cost savings through employees’ satisfaction (additional cost reduction that can be spread over time).
- Additional revenues from the enhanced demand for deep retrofit properties from potential tenants (additional income-generating cash flow).
- Reduced insurance premiums with building components replacement and improved protection against losses (additional cost reduction).

The potential positive benefits that can be achieved in best- practice cases through direct and indirect cost savings beyond energy cost savings due to DER as summarized by the Rocky Mountains Institute (2015) are presented in the Table below.

Direct and indirect cost savings beyond energy cost savings due to DER (RMI 2015).

Maintenance Costs (Fowler et al 2008; Leonardo Academy, 2008, Aberdeen Group (2010)	↓ 9 -14%
Occupational satisfaction GSA (2011)	↑ 27-76%
Rental premium Eicholtz, Kok & Quigley (2010), Wiley et al. (2011), Fuerst & McAlister (2011) Eicholtz, Kok et al. (2011), Kok et al (2011), Newel, Kok et al. (2011), Miller, Kok et al. (2011), Pogue et al. (2011), McGraw Hill/Siemens (2012)	↑ 2 -17%
Occupancy premium Wiley et al. (2011), Pogue et al. (2011), McGraw Hill/Siemens (2012)	↑ 3-18%
Property sale price premium Eicholtz, Kok & Quigley (2010), Fuerst & McAlister (2011), Eicholtz, Kok et al. (2011), Newel, Kok et al. (2011)	↑ 11-26%
Employee productivity Lawrence Berkeley National Laboratory	↑ 1-10%
Reduced employee sick days Miller, Poque, Gough & Davis (2009), Cushman, Wakefield et al. (2009), Dunckley (2007), City of Seattle (2005), Romm & Browning (1995)	↑ 0-40%

An analysis conducted under Annex 61 showed that, compared to energy cost savings:

- Replacement of equipment that is at the end of its life cycle and requires significant maintenance and replacement costs can contribute another 20-30%.
- Reduced investment costs by sizing all equipment and the execution of DER project in one phase rather than in several consecutive steps can contribute an additional 5-10%.
- With a typical labor cost of 20€-50€ per m², improved thermal comfort and IAQ resulting in higher staff productivity and reduced absenteeism may result in savings comparable to 100-200% of the energy cost savings.
- Increase in usable floor space (close to insulated external walls and advanced windows, attributable to reduced leakage through the building envelope) by ~10% produces a value comparable to additional 20-50% from energy cost savings.
- The combination of DER with installation of renewable energy technologies eligible for subsidies or rebates can improve overall project cost effectiveness by adding another 30-50% to energy cost savings.

5. DER Financing

5.1. Appropriated Funds

Most major renovation projects are funded using appropriated funds available to public/government building owners or funded by the commercial building owner.

5.2. Financial Instruments

The conventional financial instruments that have been used for building energy improvement projects since the oil crises of the 1970s include: grants, subsidies, and tax incentives to reduce the capital costs. This “business as usual” financing is procured either by equity provided by the building owner, or by requiring a certain internal return rate (IRR). If equity is not sufficiently available, the major financing instrument in use is a dedicated investment loan that requires a payoff in a certain period at a specified interest rate. Moreover, bank financing is also provided by national and international institutional funds associated with life insurance companies, pension funds, or private equity or mezzanine funds. “Green bonds” or “green funds” provide an additional format that may provide private investors with incentives to co-invest in DER projects. The “European Bank for Reconstruction and Development” (EBRD) and European Investment Bank (EIB) provide large grant programs on the supranational level that distribute large scale funding into regional or national grant based loan programs such as BEEF in Latvia. In Germany, the KfW is the major financier of energy efficiency grant and loan programs. The formats used are mostly dedicated loans and grants, increasingly distributed by commercial banking institutions.

5.3. Private Public Partnerships

In comparison with normal bank loans or funds procured through combined business and financing models such as public private partnerships, energy performance contracting (EPC) or leasing provides certain funded liabilities. The liability of a public building owner in an EPC project is covered by the cost-saving guarantee provided by the ESCo, which has no impact on the debt threshold. However, from the perspective on an ESCo, the creditworthiness of DER projects is currently in doubt. Data are only available for a few projects; the market for DER and the number of DER projects is still low; the overhead costs for risk and creditworthiness assessment is still high; and no well proven contracts are available for a DER EPC. Also, ESCos are often at a disadvantage when they attempt to access public grant programs.

5.4. Combined Public and Third-Party Financing

Combining a general refurbishment of a building with a DER increases the project’s cost effectiveness and drastically reduces the demand for third party financing. Since the investment costs for the general refurbishment already have to be provided to start the process, the remaining investment costs are typically small by comparison. Several DER pilot case studies in Annex 61 have demonstrated that (as a best practice), the incremental demand for funding to start a DER may be estimated between 10-30% of the budget of the general refurbishment project.

6. Business Models

A business model describes a product’s value proposition, infrastructure, customers, and finances. In the case addressed by the Annex 61, the product is the Deep Energy Retrofit in the public building sector. The Annex 61 “DER Business Guide” describes the following main business models that are available for energy efficiency retrofit projects to public and commercial sectors.

6.1. Owner Directed Model

In this model, the building owner takes responsibility for the project design, management, and financing of an energy efficiency retrofit to the property. The owner takes full responsibility (and assumes full liability) for the quality of the project and the economic returns on their investments. The project can be executed using “bid-build” or “design-bid-build” models. This implementation method is limited by the financial, organizational, and technological capacities of the public building agencies.

6.2. Energy Performance Contracting and Advanced Energy Performance Contracting

Energy saving performance contracting (ESPC) is the model in which an energy efficiency retrofit provider designs and finances a retrofit, and is repaid exclusively through the energy savings, therefore assuming the responsibility for the economic success and quality of the retrofit. Performance contracting is typically delivered via energy saving performance contracts (ESPCs) or utility energy service companies (UESCs). ESPCs and UESCs can be effective financing instruments. ESPC business models provide bankable benefits that can exceed the liabilities.

Research done under IEA Annex 61 has improved EPC business models with regard to their technical scope, to their longer payback periods, and to the mitigation of risks. Annex 61 has applied EPC business models in four pilot projects with payback periods ranging from 16 to 25 years.

7. Lessons Learned from DER Pilot Projects

Annex 61 has had a relatively short duration (3 years). Pilot projects had different starting points and differing objectives, which as a result, has yielded different depths and breadths of information. The objectives varied from testing whether DER can be achieved with recommended Energy Conservation Measure (ECM) bundles; evaluating the cost effectiveness of DER compared to building a new facility; evaluating the application of ECMs in combination with renewable energy (RE) sources to achieve net zero energy building in a cost-effective way; and demonstrating EPC as a means to finance a DER project. Still, important lessons and conclusions can be drawn from a cross evaluation of these different projects.

The major lessons learned from these projects are:

- **DER Measure Bundles.** DER can be achieved with a limited bundle of core technologies that are readily available on the market. Characteristics of some of these core technology measures depend on the technologies available on an individual nation's market, on the minimum requirements of national standards, and on economics (as determined by a life cycle cost [LCC] analysis). Also, requirements to building envelope-related technologies (e.g., insulation levels, windows, vapor and water barriers, and requirements for building airtightness) depend on specific climate conditions. When a limited number of core technologies are implemented together (i.e. "bundled") in a DER planning process, synergetic effects will be unlocked that will significantly reduce energy use for a smaller investment and thereby provide a faster payback than the more commonly used energy saving approach based on the implementation of individual technologies and measures. The bundle of core technologies described in the "DER Technical Guide" allows site (end) energy use reduction of 50% or more in most climate conditions, and results in significant reduction of carbon footprint. This task requires specific solutions in hot climate conditions with significant cooling needs and may require reduction of electricity consumption including plug loads, advanced heating, ventilating, and air-conditioning (HVAC) systems with heat recovery. In heating-dominated climates and in buildings with low internal loads, DER will typically require significant energetic improvement of the thermal envelope. With increased air-tightness of buildings, DER will also require the installation of mechanical ventilation system to secure the indoor air quality. In some buildings undergoing major renovation, mechanical ventilation and cooling are not included in the original design (spaces were cooled and ventilated using operable windows.) New standards for indoor climate in renovated buildings may require advanced HVAC systems. Therefore, to compensate for the increase in energy demand resulted from enhancement of HVAC systems, additional energy efficiency measures may be needed. Also, special attention to energy efficiency of appliances and other plug loads/process equipment along with efficient local exhausts is essential to achieve Deep Energy Retrofit in buildings with significant ventilation requirements and high internal loads such as dining facilities, hospitals, or data centers.

- **DER Organizational Success Factors.** A major renovation project with DER involves significant investment costs. Experience shows that an improvement in: the building durability, significant energy use, other operating costs reductions, indoor air quality, and thermal comfort can be only achieved when a DER adopts and enforces a strict quality assurance process. In addition to design, construction, commissioning, and post-occupancy phases of the quality assurance process, the "DER Technical Guide" emphasizes the importance of clearly and concisely formulating and documenting the owner's goals, expectations, and requirements for the renovated building testing in the statement of work (SOW). Another important component of the quality assurance (QA) process is the procurement phase, during which bidders' qualifications; understanding of the SOW, its requirements, and the technical concept proposed; and previous experience in comparable processes are become key decision-making criteria.
- **Improving the Cost Effectiveness of DER.** The benefits of DER projects used to determine cost effectiveness may include not only reduced energy costs, but also reduced or avoided maintenance costs by as much as 15%.
- **Qualitative Criteria for DER Projects.** Besides cost-effectiveness, other qualitative improvements resulting from the DER (that may be difficult to monetize) such as the improved reliability of the renovated systems can be a consideration, e.g., an avoided shutdown-costs of a facility due to failures of HVAC, lighting, heating, or other energy-related systems.
- **DER and NZE.** DER is a challenging target in warm climates with high cooling loads and electricity demands. The pilot case studies in Monterrey and St Croix have shown that NZE concepts could support the DER approach and vice versa. By reducing a facility's need for energy, a DER project reduces the amount of fossil and renewable energy (e.g., photovoltaics) needed to make the building NZE in energy with respect to off-site energy sources. Here, a DER concept has to consider the improvement of cooling efficiency by using exhaust air energy recovery, by variable use of outdoor air depending on temperature and indoor air quality, and by using appropriate heat pump technology. The inclusion of renewables can have a positive impact on energy security and the system reliability. However, none of the concepts aimed at a full independence from grid. Projects done in colder climates, e.g., the pilot project in Mannheim, have shown that the integration of renewables into the DER scheme may reduce high-priced energy purchase from the grid by 33% and thus increase the cost effectiveness of the DER concept (dynamic payback period) by 30%.
- **Use of Different Business Models for DER Projects.** In the United States, the following business models have been used for DER pilot projects: (1) EPC combining public funding with private sector financing, with repayment coming from avoided energy and maintenance costs; and (2) implementing advanced ECMs when undertaking major

prenovation with the use of appropriated government funds. The public sector in the United States, which considers EPC as the primary way to finance DER projects, has been able to use this model to extend the scope of available public funding. GSA's strategy (for numerous projects) has been successful in developing cost-effective DER projects with ESPC financing. GSA sets an ambitious energy-saving goal (i.e. a DER project) and requires the ESCOs to develop a cost-effective design. This facilitates innovation, and helps GSA to enforce performance because GSA does not have to specify, and thus guarantee or stipulate performance of the advanced ECMs. EPC is far more widespread in the United States than in other countries participating in the Annex 61. In Europe, one pilot project (Mannheim) was implemented using an advanced DER EPC business model. The reason for this decision was that in some recent DER projects that were carried out using the "business as usual" business model, the performance of a couple of DER refurbished buildings failed the energy-saving targets by 80%. The EPC project in Mannheim combined public funds and private financing, with 15% of the total investment costs provided by public grant programs and the remaining 85% financed by the ESCO. The financing model was based on the saving guarantees provided by the ESCO; the building owner has only to pay the measured and verified savings in energy costs (i.e., "pay as you save"), reduced maintenance costs, and savings from fuel switching.

- **Engagement of Users.** When implementing an energy-saving project with advanced and/or complex HVAC systems, it is essential that: (1) building occupants receive sufficient training on how to operate the system and when to call for repairs/service, and (2) the occupants must be able to easily adjust indoor temperature and ventilation rates. Advanced ECMs and ECM bundles must have controls that are simple and easy to understand, and occupants of a building must be fully informed about the correct use of the refurbished building's systems to achieve the performance targets and maintain comfort.

Project Participants

Country	Organization
Belgium	Energinvest
Denmark	CENERGIA
	Danish Building Research Institute, SBi
Estonia	Tallinn University of Technology
	University of Tartu
Germany	KEA
	Passive House Institute
	IWU, Darmstadt
Ireland	MosArt
Latvia	Riga Technical University
Netherlands	KAW
UK	University of Reading
USA	USACE ERDC
	USACE HQ
	DOE FEMP
	ORNL
	GSA
	New Buildings Institute
	Rocky Mountains Institute

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EBC is a programme of the International Energy Agency (IEA)