International Energy Agency

Co-benefits of energy related building renovation - Demonstration of their impact on the assessment of energy related building renovation (Annex 56)

Energy in Buildings and Communities Programme

March 2017

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

International Energy Agency

Co-benefits of energy related building renovation - Demonstration of their impact on the assessment of energy related building renovation (Annex 56)

Energy in Buildings and Communities Programme

March 2017

Authors

University of Minho – Civil Engineering Department, Guimarães, Portugal

Manuela de Almeida (Operating Agent Annex 56), malmeida@civil.uminho.pt

Marco Ferreira, marcoferreira@civil.uminho.pt

Ana Rodrigues, anarocha32846@yahoo.co.uk

Authors of Shining Examples

Karl Höfler, Julia Maydl, David Venus, Jiří Sedlák, Karel Struhala, Ove Christen Mørck, Iben Østergaard, Kirsten Engelund Thomsen, Jørgen Rose, Søren Østergaard Jensen, Federica Zagarella, Simone Ferrari, Tiziano dalla Mora, Piercarlo Romagnoni, Henk Kaan, Manuela Almeida, Marco Ferreira, Nelson Brito, Jon Terés Zubiaga, Åke Blomsterberg, Stéphane Citherlet, Blaise Périsset

Authors of Detailed Case Studies

David Venus, Karl Höfler, Julia Maydl, Ove Christen Mørck, Iben Østergaard, Kirsten Engelund Thomsen, Jørgen Rose, Søren Østergaard Jensen, Manuela Almeida, Marco Ferreira, Ana Sánchez-Ostiz, Silvia Domingo-Irigoyen, Åke Blomsterberg, Rikard Nilsson

Author of Parametric Calculations of Generic Buildings

Roman Bolliger

Published by University of Minho, Portugal

ISBN: 978-989-99799-2-5

Participating countries in EBC:

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

Additional copies of this report may be obtained from:
www.iea-ebc.org
essu@iea-ebc.org

Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 28 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 co-ordinates research and development in a number of areas related to energy. The mission of the Energy in Buildings and Communities (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 Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development 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. The research and development (R&D) strategies of IEA-EBC 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 focus areas 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: Inhabitant 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 Ventilating Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Environmental Performance of Buildings (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multizone Air Flow Modelling (*)
Annex 24: Heat, Air and Moisture Transport in Insulated Envelope Parts (*)
Annex 25: Real time HEVAC 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: Control Strategies for Hybrid Ventilation in New and Retorfitted Office Buildings (HybVent) (*)
Annex 36: Retrofitting in Educational Buildings - Energy Concept Adviser for Technical Retrofit Measures (*)
Annex 37: Low Exergy Systems for Heating and Cooling (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Thermal Insulation (*)
Annex 40: Commissioning of buildings HVAC Systems for Improved 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 (COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy-Efficient Future 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 (NZEBs)
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods (*)
Annex 54: Integration of Micro-Generation & Related Energy Technologies in Buildings
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost
Annex 56: Cost Effective Energy & CO2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy & CO2 Emissions for Building Construction
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements
Annex 59: High Temperature Cooling & Low Temperature Heating in Buildings
Annex 60: New Generation Computational Tools for Building & Community Energy Systems
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings
Annex 62: Ventilative Cooling
Annex 63: Implementation of Energy Strategies in Communities
Annex 64: Optimised Performance of Energy Supply Systems with Energy Principles
Annex 65: Long-Term Performance of Super-Insulation in Building Components & Systems
Annex 66: Definition and Simulation of Occupant Behaviour in Buildings
Annex 67: Energy Flexible Buildings
Annex 68: Design and Operational strategies for High IAQ in Low Energy Buildings
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements

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 - Survey on HVAC Energy Calculation Methodologies for Non-residential Buildings

Management summary

Introduction

The renovation of the existing building stock represents a huge potential in actions to mitigate climate change, not only by the improvement of the overall energy performance of the built environment, but also by the reduction of resource depletion and minimization of waste production related with new construction. Nevertheless, this potential hasn't been fully explored.

Contributing to this, the evaluation of building renovation measures normally considers only the energy savings and the costs, disregarding other relevant benefits and thus, significantly underestimating the full value of improvement and re-use of buildings at several levels of the economy. In Annex 56, the reduction of energy use, emissions and global costs are the direct benefits resulting from energy related renovation measures and the notion of co-benefits refers to all the other positive or negative effects resulting from those renovation measures.

These co-benefits can be felt at the building level (like increased user comfort, fewer problems with building physics, improved aesthetics, see Table 1), but also at the societal or macroeconomic level (like health benefits, job creation, energy security, impact on climate change, see Table 2).

Table 1 Typology of private co-benefits[1] of cost effective energy related renovation measures

Category	Co-benefit	Description
Building quality	Building physics	Less condensation, humidity and mould problems
	Ease of use and control by user	Ease of use and control of the renovated building by the users (automatic thermostat controls, easier filter changes, faster hot water delivery, etc.)
	Aesthetics and architectural integration	Aesthetic improvement of the renovated building (often depending on the building identity) as one of the main reasons for building renovation
	Useful building areas	Increase of the useful area (taking advantage of the balconies by glazing or enlarging the existing ones) or decrease of useful area (like the case of applying interior insulation or new BITS). This can also occur as a result of removal of cold surfaces, making it more comfortable to be nearer to e.g. windows.
	Safety (intrusion and accidents)	Replacement of building elements with new elements at the latest standards, providing fewer risks such as accidents, fire or intrusion.

1 As better explained later in this report, the notion of co-benefits in Annex 56 refers to all benefits and disadvantages (positive or negative co-benefits) resulting from renovation measures related to energy and carbon emissions optimized building renovation, besides or as a consequence of energy efficiency increment, carbon emissions reduction or costs reduction

Category	Co-benefit	Description
Economic	Reduced exposure to energy price fluctuations	Reduced exposure to energy price fluctuations gives the user a feeling of control and increased certainty to be able to maintain the desired level of comfort.[2]
User wellbeing	Thermal comfort	Higher thermal comfort due to better control of room temperatures, higher radiant temperature, lower temperature differences, air drafts and air humidity.
	Natural lighting and contact with the outside	More daylighting, involving visual contact with the outside living environment (improved mood, morale, lower fatigue, reduced eyestrain).
	Indoor Air quality	Better indoor air quality (less gases, particulates, microbial contaminants that can induce adverse health conditions) better health and higher comfort
	Internal and external noise	Insulation against outside noise but increased risk of higher level of annoyance due to internal noise after the reduction of external noise level
	Pride, prestige, reputation	Enhanced pride and prestige, an improved sense of environmental responsibility or enhanced peace of mind due to energy related measures
	Ease of installation and reduced annoyance	Ease of installation can be used as a parameter to find the package of measures that aggregates the maximum of benefits

Table 2 Typology of macroeconomic benefits of cost effective energy related renovation measures

Category	Subcategory	Description
Environmental	Reduction of air pollution	Outdoor air pollution is reduced through reduced fossil fuel burning and the minimization of the heat island effect in warm periods. Less air pollution has positive impacts on environment, health and building damages.
	Construction and demolition waste reduction	Building renovation leads to reduction, reuse and recycling of waste if compared to the replacement of existing buildings by new ones.
Economic	Lower energy costs	Decrease in energy costs due to reduced energy demand
	New business opportunities	New market niches for new companies (like ESCOs[3]) possibly resulting in higher GDP[4] growth when there is a net effect between the new companies and those that are pushed out of the market.
	Job creation	Reduced unemployment by labour intensive energy efficiency measures
	Rate subsidies avoided	Decrease of the amount of subsidized energy sold (in many countries energy for the population is heavily subsidized).[5]

2 Energy costs considered in a traditional cost-benefit analysis do not take into account the short term fluctuations of the energy prices, which are relevant in the psychologic effects here described.

3 An energy service company or energy savings company (ESCO or ESCo) is a commercial or non-profit business providing a broad range of energy solutions including designs and implementation of energy savings projects, retrofitting, energy conservation, energy infrastructure outsourcing, power generation and energy supply, and risk management.

4 Gross domestic product (GDP) is a measure of the size of an economy.

5 In the case of subsidized energy related renovation measures these has to be discounted.

Category	Subcategory	Description
	Improved productivity	GDP/income/profit generated as a consequence of new business opportunities and job creation
Social	Improved social welfare, less fuel poverty	Reduced expenditures on fuel and electricity; less affected persons by low energy service level, less exposure to energy price fluctuations
	Increased comfort	Normalizing humidity and temperature indicators; less air drafts, higher level of air purity; reduced heat stress through reduced heat islands.
	Reduced mortality and morbidity	Reduced mortality due to less indoor and outdoor air pollution and reduced thermal stress in buildings. Reduced morbidity due to better lighting and mould abatement.
	Reduced physiological effects	Learning and productivity benefits due to better concentration, savings/higher productivity due to avoided “sick building syndrome”[6].
	Energy security	Reduced dependence on imported energy.

The methodology to enable cost-effective building renovation towards the nearly-zero energy and emissions objective developed within the context of Annex 56 intends to highlight these co-benefits resulting from the renovation process and to evaluate how they can be taken into account in decision-making processes. This will assist owners and promoters in the definition and evaluation of the most appropriate renovation measures and help policy makers in the development of energy related policies and understanding how these policies may impact on other areas of the policy action (As an example, the promotion of energy efficiency measures in existing buildings impacts the job market, with an increase of jobs in a labour intensive area and reducing some jobs in the energy supply companies).

Objectives and contents of the Co-Benefits report

This report presents findings from IEA EBC Annex 56 concerning the identification of relevant co-benefits related to building renovation and the demonstration of how such co-benefits can be integrated into decision making in the case of building renovation. Direct benefits are explored on other reports produced within the project.

It is a main goal of this report to give guidance to building owners, investors and promoters to integrate qualitative information regarding co-benefits in their cost/benefit assessment and subsequent decision-making for energy related building renovation and to policy-makers to highlight the relevance of considering the broader impact of energy policies in several other areas of policy making.

6 The term "sick building syndrome" is used to describe situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified.

The report is supported by a literature review and by the analysis of case studies by several countries participating in IEA EBC Annex 56, comprising the following main parts:

- Definition of the concept and its relevance to the overall added value by energy related building renovation;
- Distinction between co-benefits at the building level and co-benefits at the societal or macroeconomic level;
- Definition of a matrix identifying the relationship between co-benefits and specific renovation measures in order to increase owners and promoters awareness regarding this topic and promote their use during the decision-making process;
- Highlight of the relationship between energy policy actions and other policy actions in order to increase perception of the energy related renovation co-benefits;
- Promotion of an interdisciplinary approach that is needed to fully understand the extent of the impact of these energy related renovation measures on several areas of the society;
- Literature review and summary of the most common methods to determine and quantify co-benefits within energy related building renovation;
- Assessment of co-benefits in IEA EBC Annex 56 case studies (Generic buildings, Shining Examples and Detailed Case Studies), particularly focusing on the comparison of cost optimal and cost effective renovation packages of renovation measures with packages that might be able to provide additional co-benefits;
- Recommendations for the main target groups of IEA EBC Annex 56, namely the policy makers and professional owners of residential buildings for the integration of co-benefits in their decision making processes.

Recommendations

The main objective of Annex 56 is to provide guidance to support decision makers, which includes technicians, owners, investors, promoters and policy makers, in the evaluation of the efficiency, cost-effectiveness and acceptance of the renovation measures towards both the nearly-zero emissions and the nearly-zero energy objectives.

Policy makers must be aware of how energy efficiency policies not only lead to energy savings but also create impacts on a broad range of areas of the political action, from environmental aspects, such as those related to pollution or climate change, to economic aspects, as employment or economic growth, and social aspects, as health or fuel poverty.

Actions to gather data, quantify benefits and apply study results to address policy challenges are needed and several methodologies and tools already exist and can be used to implement such an approach within a national policy process (see Chapter 5). Policy makers should create interdisciplinary teams to deal with the mechanisms by which the broader range of benefits can be measured and monetised, and propose how they can be integrated into policy development and evaluation, to support their efforts on the optimisation of the potential value of energy efficiency.

Regarding the analysed Annex 56 case studies, some important aspects related with the co-benefits associated with renovation measures at building level, should be considered by the policy makers as the following:

- Energy efficiency measures, when compared with measures associated with the use of renewable energy sources, are the main source of co-benefits at building level;
- To maximize the co-benefits associated with energy related building renovation, it is more effective to improve the performance of all the elements of the building envelope than to significantly improve the performance of just one element;
- Depending on the original condition of the building, improving the performance of all the elements of the building envelope usually means going beyond cost optimality, but it is still cost-effective when compared to the “anyway renovation”, i.e. a renovation scenario where energy performance is not improved;

For private owners, investors and promoters, the value of a building depends on the willingness to pay by the customer whether in a sale process or in a rental one. In the case of energy related building renovation, this willingness to pay depends on the expectation of future reduced costs on energy bills and building operation, but also on other benefits not related with energy costs that result from energy related building renovation measures.

The analysis presented in this report allows drawing some recommendations targeted to the maximization of the added value associated to energy related renovation measures such as the following ones:

- There is a close relation between specific building renovation measures and co-benefits. These relationships are explored and explained throughout this report and can be used as additional information in the cost/benefit assessment and subsequent decision making;
- Independent of the renovation measures, a wrong design or a bad execution can compromise the achieved added value of the building renovation, potentially eliminating the co-benefits associated with the related renovation measures;
- Cost optimal packages of renovation measures only considering investment and operational costs are often not sufficiently ambitious regarding the building energy performance. Many times, this is due to the fact that the intervention on some of the elements of the building envelope is not cost-effective when considering only energy related costs and benefits. Nevertheless, the investment on those elements presents other benefits beyond energy and costs, increasing the added value from energy related renovation measures. This often leads to the need of improving all main elements of the building envelope to a minimum energy

performance in order to maximize the added value from the renovation. Often cost effective renovation measures can pay for some renovation measures, which are not cost effective, still resulting in a cost effective renovation package.

Table of contents

Abbreviations

Abbreviations	Meaning
AT	Austria
BAU	Business as usual
BITS	Building integrated technical systems
CH	Switzerland
DHW	Domestic Hot Water
DK	Denmark
EN	European Norm
EPBD	Energy Performance of Buildings Directive
ES	Spain
HP	Heat pump
IEA EBC	Energy in Buildings and Communities Programme of the International Energy Agency
IO	Input-Output (tables)
kWh	Kilowatt-hour: 1 kWh = 3.6 MJ
λ	Lambda-Value (value for the insulating capacity of a material)
LCI	Life cycle impact
LCIA	Life cycle impact analysis
MFB	Multi-family building
MJ	Mega joule; 1 kWh = 3.6 MJ
MVHR	Mechanical ventilation with heat recovery
NO	Norway
NZEB	Nearly-zero energy building or nearly-zero emissions building
PT	Portugal
PV	Photovoltaics
Ref	Reference
RES	Renewable energy sources
RW	Mineral wool insulation
SE	Sweden
SFB	Single family building
STA	Annex 56 Subtask A (Methodology, parametric calculations, LCIA, co-benefits)
STB	Annex 56 Subtask B (Tools)
STC	Annex 56 Subtask C (Case Studies)
STD	Annex 56 Subtask D (User Acceptance and Dissemination)
U-value	Thermal transmittance of a building element
WP	Work Package
XPS	Extruded polystyrene insulation

1. Introduction

The renovation of the existing building stock is a relevant part of the actions to deal with climate change mitigation (European Commission, 2006) and to move towards a sustainable relation with our planet (European Commission, 2011). This happens not only because of the reduction of carbon emissions that can be achieved by promoting the improvement of the overall energy performance of the built environment, but also by the reduction of resources depletion and minimization of waste production for which new construction is contributing significantly.

Although existing buildings represent a huge potential in these areas (BPIE, 2011), it has been found difficult to fully exploit this potential, mainly because of social and economic barriers that hamper owners and promoters in the decision-making process and mislead policy makers in the development of subsidy programs and in the design of building directives. One of the common problems associated with the evaluation of building renovation measures is that only the energy savings and the costs are considered, disregarding other relevant benefits and thus, significantly underestimating the full value of improvement and re-use of buildings at several levels of the economy (Ürge-Vorsatz et al., 2009). In Annex 56, the reduction of energy use, emissions and global costs are the direct benefits resulting from energy related renovation measures and the notion of co-benefits refers to all the other positive or negative effects resulting from those renovation measures. Direct benefits are the focus of the report “Investigation based on parametric calculations with generic buildings and case studies” (Bolliger, R. and Ott, W.) while present report explores the co-benefits.

In fact, renovation works improving the energy performance of the existing buildings trigger substantial co-benefits that can be felt not only at a financial level, but also at the environmental and social levels (IEA, 2012a). These co-benefits can be felt at the building level (Wyon, 1994) by the building owner or user (like increased user comfort, fewer problems with building physics, improved aesthetics), but also at the society level (OECD, 2003) (like health benefits, job creation, energy security, impact on climate change).

The methodology to enable cost-effective building renovation towards the nearly-zero energy and emissions objective developed within the context of Annex 56, intends to highlight these benefits resulting from the renovation process and to evaluate how they can be taken into account in decision-making processes. These processes intend to assist owners and promoters in the definition and evaluation of the most appropriate renovation measures and help policy makers in the development of energy related policies.

For policy makers, a societal perspective is assumed to emphasize the effects in areas such as public health, economy and employment, energy security or climate change mitigation, and the importance of their consideration in the development of resource and polluter tax schemes, subsidy programs, the design of building directives and the evaluation of specific programs or directives on growth, import/export balances, employment, environmental impacts of air pollution.

For the owners and promoters, a private perspective is considered, limited in the co-benefits to consider to the level of the building (building owner and building user) such as increased user comfort, fewer problems with building physics or improved aesthetics.

2. Definition

According to the International Valuation Standards, the market value of a property is the ''estimated amount for which a property should exchange on the date of valuation between a willing buyer and a willing seller in an arm's length transaction after a proper marketing where parties had each acted knowledgeably, prudently, and without compulsion'' (International Valuation Standards Committee, 2007). Considering this definition, the added value due to higher energy performance depends on the willingness to pay more for having an energy efficient building. This willingness to pay depends on the expectation of future reduced costs on energy bills and building operation, but also on other benefits not related with energy that result from energy efficiency measures.

In this context, the added value of energy efficiency measures for a certain building refers to the difference in the market value of this building before and after the improvement of its energy performance and results from the valuation from the market of the future energy related costs and of the resulting co-benefits.

In the reviewed literature, several notions are used to refer to the benefits that arise from building renovation with energy efficiency and carbon emissions reduction concerns. In Annex 56, the main focus is on energy, carbon emissions and costs and consequently, the reduction of energy use, carbon emissions and costs are direct benefits. All the benefits that arise from a renovation project besides these direct benefits are included in the notion of co-benefits. Only co-benefits deriving from energy and carbon emissions related renovation measures are to be considered (e.g. the change of the interior floor of a dwelling from carpet to a wooden floor might be a measure that improves the indoor air quality but has no impact on the operational energy or carbon emissions).

The co-benefits that arise from energy and carbon emissions related building renovation can be independent from energy, carbon emissions and costs (e.g. less outside noise), or can be a consequence of these (e.g. less risk exposure to future energy price increases), and the benefits can impact at private level (e.g. increased user comfort) or/and at society level (e.g. impact on climate change or air pollution).

In this context, the notion of co-benefits in Annex 56 refers to all benefits (positive or negative) resulting from renovation measures related to energy and carbon emissions optimized building renovation, besides or as a consequence of energy efficiency increment, carbon emissions reduction or costs reduction. This notion is graphically represented in Figure 1.

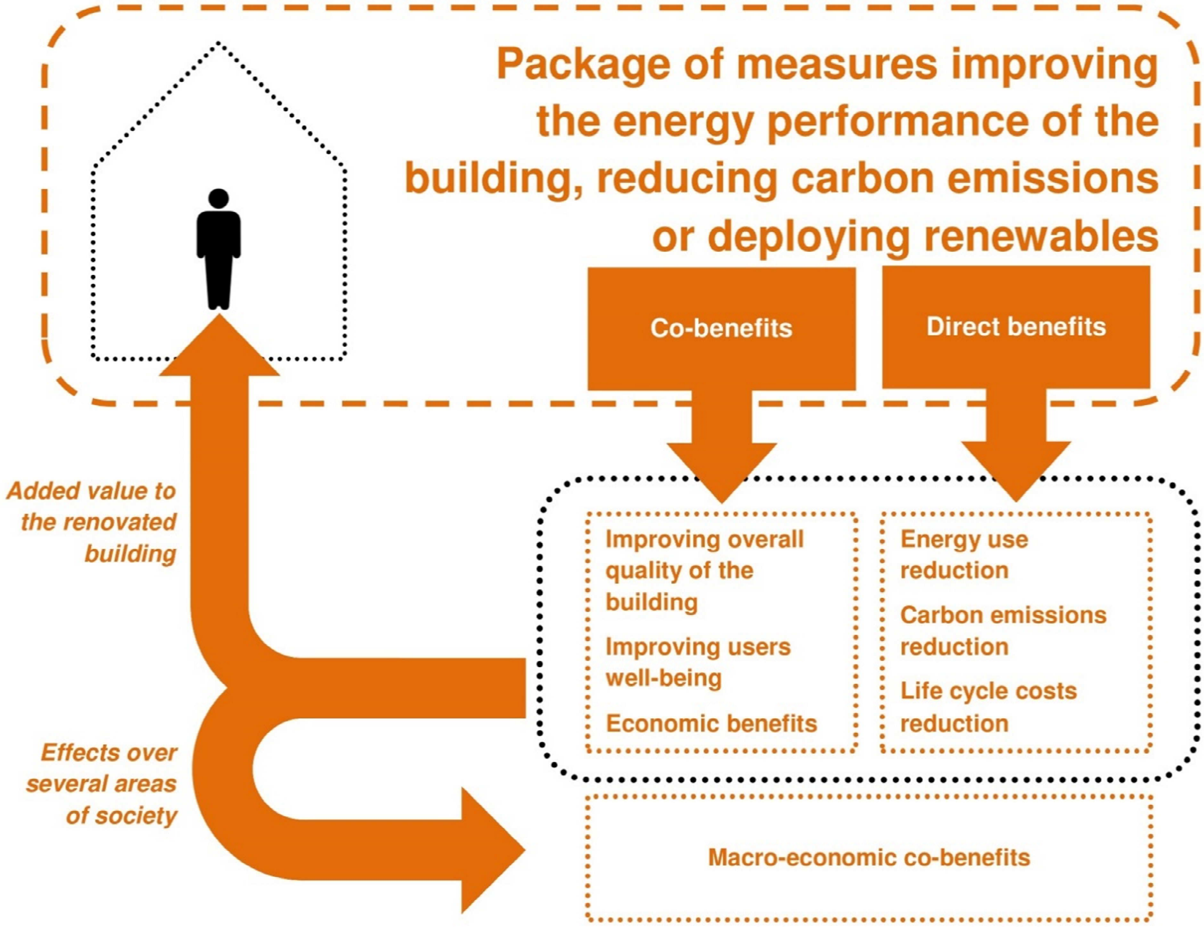

Figure 1 Direct benefits and co-benefits from cost effective energy and carbon emissions related building renovation

The co-benefits resulting from renovation measures related to energy and carbon emissions, besides or as a consequence of energy efficiency increment, carbon emissions reduction or costs reduction is a quite embracing concept, including numerous effects at different levels of economy and society. Therefore, it is useful to identify and classify these co-benefits according to underlying principles helping to better understand their nature.

The first distinction that needs to be made regards the different perspectives of the different Annex 56 target groups. For the policy makers, a societal or macroeconomic perspective is required in order to show how policies that are implemented for the reduction of energy and emissions in the building sector may be used to reach other objectives such as economic and social development, sustainability and equity. From the perspective of building owners and promoters, the economic value of a building and the value added by energy related renovation measures, are the most relevant indicators and, therefore, the co-benefits that can potentially increase the willingness to pay for the building, present a private perspective.

3. Co-benefits from a private perspective

The private perspective of co-benefits takes into account the concerns of owners, investors, promoters and users and mainly focuses on the financial aspects relevant for these stakeholders, namely the reduction of the global cost7 of the renovation works and the increase of maximum value of the building as well as on the individually perceived benefits of the stakeholders.

The reduction of the global cost of the renovation works to the possible minimum corresponds to the cost optimal level. Theoretically, this tends to be the market based solutions if co-benefits are not taken into account. It is relevant that decision makers are fully aware of expected co-benefits of each possible renovation measure during the decision-making process which might lead to decisions beyond the cost optimal level.

3.1. List of co-benefits

From the perspective of building owners or promoters, the economic value of a building and the value added by energy related renovation measures, are the most comprehensive indicators. The value of the building reflects the willingness to pay for using the building, which comprises an implicit monetary valuation of the building quality and the overall benefits of a building which goes far beyond the cost, energy and carbon emissions assessment of the building renovation and includes parameters such as useful area, thermal comfort, indoor air quality, natural lighting comfort, operational comfort, aesthetics and building reputation.

Table 3 presents an overview of co-benefits at building level associated to renovation measures improving the energy performance of the building, and their grouping in three categories.

Table 3 Typology of private co-benefits of cost effective energy and carbon emissions optimization in building renovation

7 Global costs considering a life cycle cost approach and including initial investment cost (planning and construction costs, professional fees, taxes, etc.), replacement cost during the (remaining) lifetime of the building (periodic investments for replacement of building elements at the end of their lifetime) and running costs: Energy costs (including existing energy- and CO2-taxes), maintenance costs (repair, cleaning, inspection, etc.), operational costs (taxes insurance, regulatory costs, etc.).

Category	Co-benefit	Description
Building quality	Building physics	Building renovation should be performed in ways that reduce possible problems related to building physics such as humidity and mould, with measures to normalise humidity and to prevent condensation. The use of air renewal systems and the control of adequate ventilation rates are renovation measures that reduce the humidity levels and prevent condensation. Prevention of condensation can also be done by increasing temperature of cold surfaces, reducing cold surfaces, eliminating thermal bridges and increasing indoor air temperature which can be achieved with the use of vapour barriers and the correct insulation of external walls, roof, ground floor or basement ceiling, correction of reveal's and balconies' thermal bridges and the use of efficient heating systems.
	Ease of use and control by user	Ease of use and control by the users of the renovated building is related with parameters such as the existence of automatic thermostat controls, easier filter changes, faster hot water delivery, less dusting and vacuuming or automatic fuel feeding.
	Aesthetics and architectural integration	The aesthetic improvement of the renovated building is very often mentioned as one of the main reasons for building renovation and a largely cited co-benefit of energy efficiency measures. The impact of building renovation measures on aesthetics and architectural integration strongly depends on the building identity (related to architectural, cultural and historical values of the building and to the building context). The question of "how" measures are implemented is decisive and the quality of the design process is crucial.
	Useful building areas	The increase of useful areas of the buildings is normally related with the glazing of balconies or enlarging the existing ones, but it also can occur with the replacement of building equipment by other with smaller dimensions. Also as a result of increased comfort with less draught making it more comfortable (possible) to sit closer to windows and other surfaces that may have been cold prior to renovation A decrease in useful area is a common negative effect from renovation measures such as interior insulation of the outer walls and the introduction of new equipment related to controlled ventilation or equipment for the building systems replacing smaller ones.
	Safety (intrusion and accidents)	The substitution of elements in the building envelope to improve its energy performance is usually done with new elements that accomplish the latest standards leading to improvements in dealing with risks such as accidents, fire or intrusion.
Economic	Reduced exposure to energy price fluctuations	The reduction of the exposure to energy price fluctuations gives the user a feeling of control over the energy bill and therefore an increased certainty on the future ability of providing the needed level of comfort to the household.
User wellbeing	Thermal comfort	Thermal comfort depends on the room temperature, but also on the radiant temperature, temperature differences, air drafts and air humidity. Measures such as envelope insulation, the introduction of glazed balconies and external shading, have an impact on these parameters and are able to change the feeling of thermal comfort (positively and negatively), even for the same levels of room temperature and humidity. In the case of ventilation with heat recovery, due to the loss of air humidity the air is uncomfortably dry in the winter time resulting in a disadvantage.
	Natural lighting and contact with the outside environment	Daylighting, particularly involving the visual contact with the outside living environment, has been associated with improved mood, enhanced morale, lower fatigue, and reduced eyestrain. The enlargement of window areas and the introduction of roof- lights or sun pipes are renovation measures with positive effects regarding this co-benefit, while the use of glazed balconies can reduce significantly the

Category	Co-benefit	Description
		natural lighting and views from the liveable areas and therefore produce a negative co-benefit.
	Indoor Air quality	Indoor air quality (IAQ) refers to the air quality within buildings especially as it relates to the health and comfort of building occupants. IAQ can be affected by gases, particulates and microbial contaminants that can induce adverse health conditions. Source control, filtration and the use of ventilation to dilute contaminants are the primary methods for improving indoor air quality in most buildings.
	Internal and external noise	The noise reduction benefits arising from a building renovation should be evaluated for two distinct effects, namely the reduction of the exterior noise, and the annoyance from internal noise. Renewal of building envelope presents opportunities to reduce the transmission of external noise into the interior of buildings. Although, if exterior noise is reduced, noise from within the dwelling and from adjacent dwellings becomes more noticeable (negative co-benefit). Reducing the causes of overheating in summertime by measures as shading, minimizes the use of air conditioning, providing reduced indoor noise from the operation of the equipment.
	Pride, prestige, reputation	People who have performed relevant energy related improvements in their dwellings, currently report feelings such as enhanced pride and prestige, an improved sense of environmental responsibility, or an enhanced peace of mind related with the responsibility for the family well-being.
	Ease of installation and reduced annoyance	People who have performed energy related improvements of their buildings currently justify the selection of certain renovation measure based on the ease of implementing it. When comparing different building renovation measures, the ease of installation can be used as a parameter to find the package of measures that aggregates the most benefits

3.2. Matrix of co-benefits and related renovation measures

Based on the list of co-benefits presented in Table 3 and the corresponding literature review, on the evaluation of the Annex 56 Shining Examples and Detailed Case Studies and also on the contributions of Annex 56 participants, a matrix of relationships between co-benefits and specific renovation measures has been developed and is presented in Table 4. This matrix is intended to be used by owners and promoters during the decision-making process, so that they can be fully aware of the co-benefits of each possible renovation measure.

In the table, signal (+) indicates a positive co-benefit and signal (–) indicates a negative co-benefit. The quantity of these signals indicates their relevance, e.g. 3 signals “+ + +” or 2 signals “– –“ for more or less relevance of the co-benefit. Above these signals, the numbers and letters indicate the source supporting the link between the co-benefit and the renovation measures. These sources are described below the table.

Table 4 Relationship between co-benefits in a private perspective and specific renovation measures

CO-BENEFIT	Thermal comfort	Natural lighting	Air quality	Building physics	Internal noise	External noise	Ease of use	Reduced exposure to energy price fluctuations	Aesthetics / Architectural integration	Useful living area	Safety (intrusion and accidents)	Pride/prestige	Ease of installation
Facade insulation (external)	1, 2, 6, 7, CS + + +	EX -	CS +	EX, CS + +	EX -	6, CS + +		5, CS + +	6 - - +	CS +		7, CS + +	
Facade insulation (internal)	1,2,6,7 - + +	EX -		EX -	EX -	6 + +		5 + +		3 - -		7 +	
Roof insulation	1, 2, 6, 7, CS + + +		CS +	CS +	EX -	6, CS + +		5, CS + +		CS +		7, CS + +	
Ground floor insulation	1, 2, 6, 7, CS + + +							5, CS + +				7, CS +	
Cellar ceiling insulation	1, 2, 6, 7, CS + + +							5 + +				7 +	
Windows replacement	1, 2, 6, 7, CS + + +			CS +	EX -	1, 6, 7 + + +		5, 7, CS +	7 +		7 + +	7, CS +	
Insulation of entire building envelope	EX + + +	EX -		EX, CS + +	EX -	EX + +		EX + +	EX - +			EX + +	
Larger window areas	EX -	6, CS + + +											
Roof light or Sun pipes		3 + +						5 +					
External shading	5 + +					5 +		5 +					
Balconies and loggias	6 - + +	6 - -		6 + +		EX +			6 + +	6, CS + +			
Heat Pump for heating								5,7 +					7, EX + + -
Biomass heating system								5 +					
Efficient DHW system								5,CS + +				CS +	
Automatic control systems							CS +						
Air renewal systems	EX, CS + +		1,4,5, CS + + +	1, CS + +	EX -		EX -	5 +					
MVHR systems	EX, CS + +		CS + -	CS +	3 - -			5 +				CS +	
Solar Thermal systems								7,CS + +				7,CS + +	7 + +

EX Annex 56 participants experience

CS Identified in Annex 56 Case Studies

1 Jakob, M., "Marginal costs and co-benefits of energy efficiency investments. The case of the Swiss residential sector". Energy Policy, 34, pp 172-187, 2006

2 Jochem, E., Madlener, R. "The Forgotten Benefits of Climate Change Mitigation:_Innovation, Tecnological Leapfrogging, Employment, and Sustainable Development". OECD Workshop on the benefits of climate policy: Improving information for policy makers, 2003

3 Institute for Sustainability, "Post occupancy interview report. Key findings from a selection of Retrofit for the Future projects", 2013

4 Ürge-Vorsatz D, Novikova A, Sharmina M., “Counting good: quantifying the co-benefits of improved efficiency in buildings”, 2009

5 European Environmental Bureau, “Harmonised Cost Optimal Methodologies for the Energy Performance in Buildings Directive”, 2010

6 Kalc, I., “Energy Retrofits of Residential Buildings. Impact on architectural quality and occupants comfort”, 2012

7 ISCTE IUL Business School, “Comunicar Eficiência Energética. O Caso Português”, 2011

3.3. Relevance of co-benefits

The matrix of relationship between co-benefits and specific renovation measures has been developed based on the literature review, on the analysis of the case studies and on the Annex 56 participants’ experience and perception. The relevance of the identified relationship is described with a plus (+) signal for positive impact and a minus (-) for negative impacts and +, ++, +++ or -, - -, - - -- to indicate their relevance as positive or negative co-benefits.

It is important to notice that the indicated relevance is intended to describe the average and most common situation. Nevertheless, the relevance of the co-benefits may be conditioned by several factors leading to significant divergences in relation to the values from the matrix. In the process of decision making, the guidance from the matrix should take into consideration the existence of those factors which may determine the relevance of co-benefits. In the next lines, some of these factors are highlighted.

- The ***physical or technical condition of building prior to the renovation*** affects the relevance of the improvements obtained from the implementation of renovation measures and the perception of these benefits by the residents. In fact, the degradation of the building or any of its elements (roof, facade, windows, heating system, etc.) and its original energy performance are decisive for the definition of the benefits from the improvement of its energy performance. As an example, the introduction of 10 cm of insulation on a facade originally not insulated or in a facade which originally had already 5 cm of insulation may lead to significantly different proportion of benefits for the residents in thermal comfort. As well as the cost-effectiveness of energy efficiency measures decreases when the energy performance of the original building element is higher, the relevance of the related co-benefits also decreases becoming marginal or imperceptible. This fact is also true for the analysis of several levels of energy performance of the renovation measures, with significant co-benefits from the initial improvement of a building element but marginal co-benefits from the further improvement of the same building element;
- The ***climate conditions of the building site*** are also decisive for the impact of the renovation measures. The introduction of the same 10 cm of insulation on the facade as described in the previous point, for buildings with similar original thermal performance, will not be as relevant in a location in the south of Portugal, Spain or Italy as it is in central European locations to the improvement of thermal comfort;

- Also the ***urban context of the building*** may be relevant for the co-benefits identification. As an example, the replacement of old single glazed windows by new double or triple glazed windows in a renovation measure is normally related with the co-benefit of reducing external noise. In one of the analysed case studies, the residents clearly stated that this was not a real benefit since external noise has never been a problem. In fact, the building is located in a very quiet area, so, since external noise was not an issue before the renovation, the change of the windows was not felt to have any impact on the reduction of external noise;
- The ***information and knowledge*** of the residents about the implemented renovation measures and the reasons for their implementation plays an important role in their capacity to link the co-benefits to the renovation measures. The added value for a building resulting from the co-benefits associated to energy related renovation measures depends on the perception and identification of those benefits by the residents and from their knowledge on the origin of the benefits;
- The co-benefits included in the user wellbeing category such as thermal comfort, natural lighting, air quality and noise have a strong relation with the physical condition of the resident. Factors such as the ***age, gender and health*** of the residents should be taken into account since these may impact on the relevance of the co-benefits. Older people and small children tend to be more sensitive to thermal comfort and people with respiratory problems tend to be more sensitive to air quality;
- The ***financial condition*** of the residents is likely to play a role on the relevance of some of the co-benefits. Residents unable to heat their dwellings adequately due to the high energy bill are more likely to identify and highly appreciate the improvement of thermal comfort from energy related renovation measures than those who had the financial capacity to keep the dwelling warm despite a low thermal performance of the building before the renovation;
- The ***occupation profile*** of the dwellings affects the perception of the renovation measures by the residents. Those who use the dwelling nearly 24 hours per day are likely to be much more sensitive to the potential co-benefits and highly valuate measures with impact on their wellbeing compared to residents who spend most of the time away from the dwelling;
- ***Cultural habits*** such as the accommodation to low comfort levels or the constant use of natural ventilation, even during winter, affect the full exploitation of the benefits associated to certain renovation measures and even the acceptance of others. Just as an example, the introduction of non-operable windows with controlled air rate admission devices in dwellings where residents are used to open windows to ventilate (typical in Southern countries), makes the occupants feel that the air quality has decreased and even feel claustrophobic;
- ***Wrong design and execution*** have a strong negative impact on the renovation measures overlapping the benefits;
- ***Aesthetics:*** Impact of energy related renovation measures on building aesthetics is depending on the quality of the (envelope) measures and might even lead to negative co-benefits.

The described factors are only some examples that intend to highlight that the relevance of the co-benefits has to be evaluated during the process of decision making, considering the objective conditions of the building to be renovated and the characteristics of the residents who will evaluate the building renovation.

3.4. Co-benefits in the evaluation of renovation packages beyond cost optimal

Co-benefits and reduced costs from improved energy performance represent integral parts of the overall market value of the building. However, when it comes to market value, the two aspects can be distinguished only theoretically – as in the case of building and land values which both make up the overall market value and cannot be separated precisely. In fact, the costs for upgrading existing conventional buildings to energy-efficient buildings do not necessarily lead to a proportional added value. An improvement of the energy performance of a building with identical life-cycle costs and identical energy performance may have different added values in different locations, just because the willingness to pay revealed by consumers in different markets may vary substantially. Therefore, one needs to keep in mind that evidence from other markets concerning price variations for energy performance and related co-benefits may not be relevant.

Considering the constraints, these benefits are often very difficult to quantify making it much more difficult to add their contribution to a traditional cost-benefit analysis. Nevertheless, a growing interest in this theme has been leading to several studies aiming to reach this goal and it is an objective of Annex 56 to evaluate possible forms of integrating co-benefits in the methodology for cost effective energy and carbon emissions optimization.

Evaluating different packages of renovation measures with different global costs, energy use and carbon emissions, it is possible to identify the packages of measures with greater potential of delivering co-benefits. Figure 2, which is included here only as an example, presents annualised global costs and carbon emissions resulting from the application of 9 different packages of renovation measures on a typical Swiss single-family building. The measures start with the application of 12 cm insulation on the walls and evolve to consecutive improvements of the energy performance of the building envelope. The global costs decrease with every renovation package until the 6th package of renovation measures (not counting the reference). This is the cost optimal package. Global costs increase for the following packages (7th, 8th and 9th packages) coinciding with the introduction of windows with increasingly better energy performance. Comparing the cost optimal package of measures (wall 30 cm + roof 36 cm + cellar 16 cm), with the package of measures with the best energy performance among the tested packages (wall 30 cm + roof 36 cm + cellar 16 cm + window-U-value 0.8 W/m^{2}K), there´s a reduction of carbon emissions, a reduction of primary energy consumption but an increase of global costs. This means that the change of windows (in the 7th, 8th and 9th package) when added to the previous renovation measures, induces an increase of global costs, meaning that these packages of measures are beyond the cost optimum. The cost gap between the two renovation packages is, as shown in Figure 2, around 5 € per year and m^2 or 1000 € per year (building has 210m^2 of heated GFA).

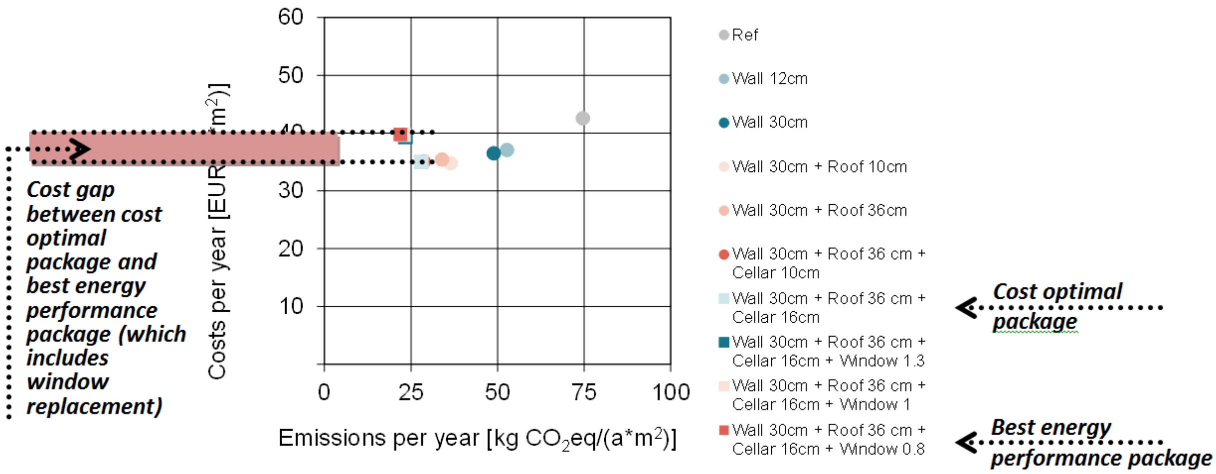

Figure 2 Comparison of cost effectiveness of energy efficiency renovation measures with oil heating system and related impacts on carbon emissions in Switzerland, for a single family building

From the matrix of co-benefits, window replacement is a renovation measure that produces several co-benefits, some of which resulting also from the previous steps of renovation measures. While for the cost optimal package, the insulation of walls, roof and cellar ceiling will improve the thermal comfort, mitigate problems with mould and humidity, reduce the exposure to energy price fluctuations and increase the sense of pride and prestige of the residents towards their home, the package with the best energy performance, with the replacement of windows, also improves protection against external noise and safety against intrusion and reduce relevant mould-risks from thermal bridges in the connection between window and wall .

The decision on the package of measures to implement depends on the valuation for those additional co-benefits from the decision-maker. If the cost gap between the cost optimal and the best energy performance packages is lower than its willingness to pay for having improved protection against external noise and safety against intrusion, the rational option would be going for the best energy performance package.
In Chapter 6, Annex 56 case studies are analysed with this method.

4. Co-benefits from a macroeconomic perspective

The co-benefits resulting from renovation measures related to energy and carbon emissions, besides or as a consequence of energy efficiency increment, carbon emissions reduction or costs reduction is a quite embracing concept, including numerous effects at different levels of economy and society.

The societal or macroeconomic perspective allows analysing how policies that are implemented for the reduction of energy and emissions in the building sector may be used to reach other objectives such as economic and social development, sustainability and equity.

4.1. List of co-benefits

Cost effective energy and carbon emissions optimization in building renovation can deliver a broad range of benefits to the economy and society (IEA, 2012b). However, energy related renovation programmes and policies evaluation is commonly based mainly on energy savings, leading to the underestimation of their full impact and misleading policies. Additionally, increased consumption and expenditures often undermine and counterbalance the benefits from these programmes and policies, the so-called rebound effect, creating uncertainty for government energy officials and politicians regarding energy efficiency as an effective strategy to really achieve energy and carbon emissions reduction goals (IEA, 2011).

In fact, investigations on the range of benefits beyond energy savings that energy efficiency improvements may deliver, suggest that these investments can act as a driver for achieving many other policy goals (IEA, 2012b; Goodacre, 2001). However, while energy efficiency specialists tend to focus solely on energy-related effects such as primary energy consumption and costs, professionals from other fields (such as health professionals or economists) are unlikely to consider the impact of energy efficiency improvements relevant to achieving goals in their areas (IEA, 2012b). This means that illuminating information to increase perception of co-benefits as well as interdisciplinary cooperation is needed to fully understand the extent of the non-energy saving benefits and to let them influence investment and operational decisions.

Besides the fact of the benefits being felt in different areas, many of these benefits, such as user comfort, health improvements and development goals, are associated with the spending of cost savings (or part of it) due to energy efficiency measures. These spending can occur in increased energy consumption or for consumption of different goods or services, which induces the rebound effect. The rebound effect occurs when energy efficiency improvements do not reduce energy consumption by the amount predicted by simple engineering models based on physical principles. If such improvements make energy services cheaper, consumption of those services increases (direct rebound effect) and cost savings will be spent for other services, which also use energy (indirect rebound effect; UK ERC, 2007). However, from an economic growth perspective, these rebound effects can be seen as a positive overall outcome of energy efficiency improvements being the basis and one of the prerequisites for economic growth.

Several studies (see sub-chapter 4.2) have analysed co-benefits of energy efficiency investments in the built environment, showing that they can act as a supporting instrument to reach policy goals in several areas. Based on suggested classification of co-benefits from several studies, three categories are proposed for the building sector as described in Table 5.

Table 5 Typology of macroeconomic benefits of cost effective energy and carbon emissions optimization in building renovation (adapted from Ürge-Vorsatz et al., 2009)

Category	Subcategory	Description
Environmental	Reduction of air pollution	Outdoor air pollution is reduced through reduced fossil fuel burning and the minimization of the heat island effect in warm periods through reduced local energy consumption. Besides air pollution impacts on environment, also health impacts and damage to building construction are reported.
	Construction and demolition waste reduction	Considering the goal of improving the overall energy performance of the built environment, building renovation, depending on how renovation is performed, but particularly when considering LCIA in the evaluation of renovation measures, might lead to reduction, reusing and recycling of waste (especially if compared to the replacement of existing buildings by new ones).
Economic	Lower energy costs	Decrease in energy costs due to reduced energy demand driven by energy efficient measures implemented (thereby inducing rebound effects).
	New business opportunities	New market niches for new companies such as energy service companies (ESCOs) resulting in higher GDP growth depending on the extent existing business is pushed out of the market (growth only if there is a net effect).
	Employment creation	Reduced unemployment through labour intensive energy efficiency measures and new companies hiring workers.
	Rate subsidies avoided	Decrease in the number of subsidized units of energy sold (in many countries energy for the population in heavily subsidized). In the case of subsidized energy related renovation measures these has to be discounted.
	Improved productivity	GDP/income/profit generated as a consequence of new business opportunities and employment creation
Social	Improved social welfare and fuel poverty alleviation	Reduced expenditures on fuel and electricity; reduced fuel/electricity debt; changed number of inadequate energy service level related damages such as excess winter deaths.
	Increased comfort	Normalizing humidity and temperature indicators; less air drafts, more air purity; reduced heat stress through reduced heat islands.
	Reduced mortality and morbidity	Mortality is reduced through improved indoor and outdoor air pollution and through reduced thermal stress in buildings. Reduced morbidity results from the same effects and also from better lighting and mould abatement. This results in avoided hospital admissions, medicines prescribed, restricted activity days, productivity losses.
	Reduced physiological effects	Learning and productivity benefits due to better concentration, savings/higher productivity due to avoided "sick building syndrome".
	Improved energy security	Reduced dependence on imported energy.

4.2. Relation between energy policy actions and other policy actions

Some of the analysed studies in literature review were considered particularly representative of the research in this field and highlight the relation between energy policy actions and other policy actions. These will be briefly presented with the goal of increasing the understanding of co-benefits as well as interdisciplinary cooperation that is needed to fully understand the extent of the impact that energy related building renovation can have in several areas of the society.

This limited literature review aims only to highlight examples of developed studies and corresponding estimates. Results shown should not be used for direct comparison.

In October 2012, Copenhagen Economics published the report ***Multiple benefits of investing in energy efficient renovation of buildings***, where the authors have attempted to appraise benefits beyond energy savings such as improved health through reduced air pollution and improved indoor climate, reduced outlay on government subsidies, and macroeconomic benefits from increased economic activity through higher revenue from taxes and reduced unemployment benefits, in order to quantify the aggregate benefits from investing in energy efficient renovation of buildings in the European Union (Copenhagen Economics, 2012).

Energy savings through reduced energy consumption in publicly owned buildings, after discounting the initial investment cost to achieve the operational cost savings, will benefit the public entities and therefore improve public budgets. In addition, these reductions of energy consumption both in publicly as in privately owned buildings will have the benefit of the avoided capital cost of building additional power plants, as these capital costs are included in the price of electricity. In the case of district heating systems or gas distribution systems, their capacities are saved allowing, in some case, for the supply of further end users with an existing system.

Although energy efficient renovation of buildings will reduce energy consumption which represents a negative effect on public budgets through reduced tax revenue from energy consumption taxes, this reduction allows European Member States to reduce subsidies both on fossil fuel consumption and deployment of renewable energy technologies with positive effect on public finances.

Several energy efficiency measures improve the indoor temperature and the indoor climate, from which health benefits can be obtained through less disease, reduced mortality, improved worker productivity, and improved overall quality of life. Besides the general benefits to the society, public budgets may also be improved through reduced hospital expenses and fewer sick days. Also other health benefits from reduced energy consumption can be obtained from the reduction of air pollution from power and heat production from power plants, combined heat and power plants and local heating, which give rise to air pollution such as NO_x, SO_2, small particulate matters and CO_2.

The methodology for the calculations used two scenarios for the level of energy efficiency investments (Low Energy Efficiency scenario and High Energy Efficiency scenario) which depend on the level of policy commitment.

The first scenario includes investment in energy efficiency measures which are cost-effective for the end-user. It also assumes a high level of political ambition in terms of removing barriers to energy efficiency investments. The more barriers are removed, the higher the potential will be.

The second scenario includes all investments in energy efficiency measures that are economically possible to put into practice. This scenario only includes technologies that are technically viable and not extremely expensive. The investment may not be cost-effective from a purely energy savings perspective, but they bring additional benefits through improved health, reduced subsidies to RE technologies, etc.

To calculate the amount of air pollution from the different input sources, emission factors were used and it was assumed that the reduction in energy production will reduce the input use proportionally to the expected input-mix in 2020.

Studies that state both the costs of the renovation and the value of the health improvements were used. Based on primarily available studies the cost-benefit ratios were calculated by comparing the cost of implementing the programmes with the estimated health benefits the improvements give rise to. Based on these estimates and the cost of the specific energy efficient projects, a cost-benefit ratio for each individual health benefit can be calculated. When the different studies have given different results, an interval from the lowest estimate to the highest estimate was constructed. The result comes from reduced mortality rate due to low indoor temperature. By applying these cost-benefit ratios to the investments needed to realize the energy saving potentials in the EU, it has been possible to arrive at estimates of the health benefits associated with these investments. The authors underline that these estimates are highly uncertain at the EU level, since the uncertainty related to the estimate of each study is accentuated by applying it to the EU as a whole. Moreover, lower public health spending is highly dependent on the specific health system in each country.

The public finance effects are primarily related to the reduced public health spending. Note that the lower estimate on public health spending is derived from the UK health system, and the higher estimate from the New Zealand health system. It is difficult to apply these figures directly to an aggregate European level, as they are very dependent on the level of publicly paid healthcare.

To calculate the effect of increased investments in energy efficient renovation of buildings on gross domestic product (GDP) and the public finances, it is necessary to know how many jobs are “created” per € invested. For the effects on GDP the gross value added (GVA) per employed in sectors was used, once it is believed to be associated with energy efficiency investments in buildings. The natural starting point is the GVA per employed in the construction sector. Based on these statistics, a low, an average, and a high estimate for GVA per employee from energy efficiency measures in buildings were created. In these cases, it seems that only the higher investments in energy efficiency have been considered, neglecting withdrawal effects created by the removal of resources and finances from other sectors of the economy which lead to an overestimation of effects.

In order to assess the size of the effects on the public finances the so-called fiscal multipliers were used indicating how much public budget is improved/deteriorated when GDP is increased/decreased. The main drivers are the increase in tax revenue and avoided unemployment benefits.

It was also considered that building renovation will make it cheaper to heat, cool, ventilate etc., which will increase energy consumption. Based on the survey of the economic literature on rebound effect it was applied a percentage of 10 to 30% to represent this effect.

In order to analyse the impact of these co-benefits, the authors divided the effect of the energy renovation in two: the direct and the indirect ones. The direct effects include private and/or public energy savings, reduced energy tax income and reduced outlay on subsidies which have impact on public finances. The health effects are considered to be indirect and affect the private and public finances.

Main findings from the calculations suggests a monetised permanent annual benefit to society of €104-175 billion in 2020 depending on the level of investments made from 2012 to 2020. These values result from lower energy bills (€52-75 billion), from the co-benefits of reduced outlay on subsidies and reduced air pollution from energy production (€9-12 billion) and from health benefits from improved indoor climate (€42-88 billion). These health benefits, although evident, are considered by the authors as very uncertain to estimate, and should be interpreted accordingly. If investments are continued after 2020, these annual benefits are considered to be able to double by 2030.

The annual permanent net revenue gains to public finances could reach €30 – 40 billion in 2020 if health-related benefits from energy efficient renovations are included such as less hospitalisation. This gain is made up from reduced outlay on government subsidies, reduced energy bills, and less hospitalisation need. In these estimates the loss of government tax revenue from energy taxation was taken into account.

The results also suggest that by harvesting the investment opportunities provided by energy efficiency renovations in the existing building stock, the EU Member States can stimulate economic activity, which can give rise to jobs for 760,000 – 1,480,000 people and bring benefits to GDP of €153 - 291 billion depending on the level of investments. These benefits are associated with more activity and more employment, and come from increased revenue from income taxation, corporate taxation, and VAT, and from reduced outlay on unemployment benefits. These benefits are not permanent, but instead a "one-off" benefit from stimulating activity in a period of economic underperformance.

In another study from 2010, the Center for Climate Change and Sustainable Energy Policy of Central European University, Budapest, on behalf of the European Climate Foundation, analysed the ***Employment Impacts of a Large-Scale Deep Building Energy Retrofit Programme in Hungary*** (Ürge-Vorsatz, D., 2010)

The authors, from the several methodological approaches available to analyse the impact of climate change related interventions on the labour market (direct estimates based on scaling up case studies, Input-Output analysis, computable general equilibrium model (CGEM) analysis and transfer of results from previous studies), considered Input-Output analysis the most widely used methodology for forecasting the direct, indirect and induced employment impacts of changes in the economy, including energy efficiency interventions. Input-Output tables allow the analysis of changes in the economic activity of all sectors generated by an intervention. Provided the labour intensity of each sector, estimates of the net employment effects (the balance of jobs created and destroyed) can be derived.

This study used a mixed approach to calculate the employment impact of energy efficient retrofits. In order to estimate the direct effects in the construction sector, data from a number of case studies has been collected and up-scaled; for indirect and induced effects, the Input-Output method has been used. This mixed approach was chosen because Input-Output analysis, after a first detailed run at applying it, was deemed too crude to estimate direct effects, thus a bottom-up approach was believed to hold more precise estimates. The results of the IO research have been used to benchmark the bottom-up method. On the other hand, indirect and induced impacts can be better estimated by applying the Input-Output method.

The programme used for the study was assumed to start in 2011; impacts have been evaluated as a function of time, with special focus on analysis for the year 2020, a key year for the completion of several EU strategies (particularly in climate and employment).

For the direct negative effects in the energy sector, as well as the positive indirect and induced effects generated by the renovation programme, the total renovation investment costs and energy savings were calculated. These represent the increase of demand in the construction sector and the decrease in energy demand. Those values have then been entered into the Input-Output tables, returning as a result the indirect and induced (by additional disposable income from new jobs) changes in output for every sector of the economy. By multiplying these changes in output by the labour intensity in each sector (i.e. the number of Full-Time Equivalent, or FTE, workers employed per unit of output in each industry), the employment effects for all sectors have been determined.

The calculations have demonstrated that up to 85% of Hungarian heating energy use, and the corresponding CO_2 emissions, can be avoided by a consistent and wide-spread economically viable deep retrofit programme in the country. This, in turn, can substantially improve the country's energy security, reaching by 2030, in a deep renovation scenario, savings of up to 39% of annual natural gas imports, and up to 59% of natural gas import needs in the most critical month from the perspective of energy security.

At the same time, the research has also highlighted the important risk related to less ambitious renovation programs. If renovations aim at keeping BAU retrofit depth such as the one implemented by existing programmes (i.e. reducing around 40% of present energy use in existing buildings on average), this results in a significant lock-in effect. This sub-optimal renovation scenario saves only approximately 40% of final heating energy use, locking in approximately 45% of 2010 building heating-related emissions at the end of the programme, around 22% of 2010 total national emissions. This means that reaching ambitious mid-term climate targets, such as the often quoted 75 – 85% reductions that are needed by 2050, will become extremely difficult, and expensive, to achieve.

The study has demonstrated that a large-scale, deep renovation programme in Hungary could create by 2020 up to 130,000 net new jobs, as opposed to 43,000 in the suboptimal scenario. Though job losses in the order of the 3,200 to 1,300 FTE per year have been estimated for the energy sector, the results also indicate that for every FTE unit lost in the energy sector in that year, almost 30 jobs would be created in construction for the deep renovation scenarios.

The research has also found that redirecting the current energy subsidies and making a wise use of available EU funds would make available around 1 billion euros per year, an amount that by itself practically covers during the first years of the programme the full annual costs of renovating Hungarian buildings at a rate of 100,000 units per year.

In addition, from a total cost perspective a more gradual implementation of a deep renovation program is much more attractive. Due to the relative inexperience with deep renovation know-how and technologies, initially these will be more expensive than after a learning period when experience accumulates and more mature markets and competitive supply chains are established. As a result, a more aggressive renovation programme (i.e., 250,000 renovated per year instead of 150,000 or 100,000) results in higher overall costs of renovating the Hungarian building stock.

On the qualitative aspects of the new jobs created, it is believed that the length of the programme ensures that the employments created are long-term, and the fact that the whole building stock is considered for renovation implies that the new jobs are likely to be distributed throughout the country as renovations are usually carried out by local small and medium enterprises spread throughout the country. The availability of labour to satisfy the additional workers demand generated by the programme seems to be guaranteed by the existing unemployed.

It is important to highlight that up to 38% of the employment gains are due to the indirect effects on other sectors that supply the construction industry and the induced effects from the increased spending power of higher employment levels.

In conclusion, the results clearly indicate that adopting a high efficiency retrofitting standard close to passive house (reducing on an 85% of the energy consumption for heating) would result in a substantially higher number of employments, larger energy savings and carbon reductions than the business-as-usual and sub-optimal renovation alternatives.

In the United States, Lisa Skumatz pioneered the work in quantifying and monetizing the environmental, business and household benefits of energy efficiency which has been used extensively in regulatory proceedings, program planning and evaluation. In ***Lessons Learned and Next Steps in Energy Efficiency – Measurement and Attribution: Energy Saving, Net to Gross, Non-Energy Benefits, and Persistence of Energy Efficient Behaviour*** evaluation, measurement, and attribution of direct and indirect effects of energy efficiency and behavioural programs are examined based on the relevant experience of the author (Skumatz, L., 2009).

Relevant highlights from this report, which mainly refers to results from energy efficiency programs, are summarized:

- Non-energy benefits (NEB) are indirect and hard to measure. Consequently, they may also tend to be related to higher levels of uncertainty than some other measurements associated with energy efficiency programs. The level of efforts spent on estimating these effects should be somewhat proportionate with their potential impact in helping avoid wrong decisions about programs or energy efficiency interventions;
- Best practices for measurement should be used to assure that the NEB estimates represent measurable impacts, which involves an assessment of “what would have happened absent the program intervention.”;
- Participant NEBs are large – commonly equalling or exceeding the value of the energy savings emanating from the program. This is especially true for whole house/whole building programs, new construction and similar programs in both the residential and non-residential sectors;
- Not measuring the effects means that decisions about programs are likely to be suboptimal. Running scenario analysis around ranges or order of magnitude values would be preferable to excluding the impacts altogether. Thus, approximate estimates provide value; the improving sophistication of measurement methods implies that these approximations are getting better and better.

In the end of 2014, the International Energy Agency published a report on ***Capturing the Multiple Benefits of Energy Efficiency***. The report is presented as a first step to assist policy makers in evaluating the impacts of both proposed and implemented energy efficiency measures in a range of ways that suit their own unique circumstances and objectives in order to provide feedback to refine ongoing programmes and help design and prioritise future energy efficiency actions. It results of an extensive review and synthesis of the state of the art of quantifying the multiple benefits of energy efficiency, in a process involving more than 300 people from 27 countries and 60 organisations (IEA, 2014).

Five benefit areas are analysed due to the existence of enough evidence about their potential impacts and because they tend to be policy priorities in IEA member countries, namely: macroeconomic development; public budgets; health and well-being; industrial productivity; and energy delivery.

For each of the areas the range of impacts is described with sample results, methodological approaches for the assessment are explained and policy-making considerations are presented. In the end, a method for the use and optimisation of the multiple benefits approach by policy makers is proposed and methodologies to be used within the multiple benefits approach are described.

The proposed approach on multiple benefits of energy efficiency presents a key strength of encouraging a cross-sectoral approach to policy making and enhancing the capacity of governments to tackle more complex issues through interdisciplinary co-operation.

The approach has to be different in every country due to national circumstances, economic and social priorities. Policy makers need to assess the type and scope of possible multiple benefits that could realistically be achieved in their own countries, taking into account factors such as geographic situation, level of economic development, energy resource availability and demographics. As an example, countries in which efficiency in buildings is already high, may not expect a major improvement in health through building energy efficiency measures, but may instead focus on the potential to support employment through investment in energy efficiency.

The early identification of the desired outcome objectives will enable policy makers to quickly draw on best-practice examples and supplement these with local knowledge to design energy efficiency policy that maximises the targeted benefits. As governments become more aware of energy efficiency´s capacity to deliver outcomes across a range of policy areas, it seems tenable the creation of teams that bring together the skills and experience of experts from diverse fields so decision makers have full and accurate information on which to base their decisions.

The report finishes underlining that, although the evidence gathered so far clearly demonstrates the value of the multiple benefits approach, the investigation of these benefits is still in its early stages and that much more work needs to be done to fully understand the interactions that occur across the economy and society through investments in energy efficiency.

5. Methods to determine and quantify co-benefits within energy related building renovation

The value of the co-benefits from energy related building renovation depends on the "beneficiary" or the "perspective". From a macro-economic perspective, co-benefits represent indirect benefits from investments in the improvement of energy performance of buildings accruing to society at large. From a private perspective, co-benefits represent the overall increment of the building value resulting from the renovation measures, not explained by direct benefits.

Private co-benefits report a value that depends on the beneficiary and on the context as previously explained. Therefore, methods to determine and quantify these co-benefits rely on self-reporting surveys whose main purpose is to develop monetized estimates of the indirect impacts that can be assigned to the renovation measures (Skumatz, L., 2009):

- Simple Contingent Valuation (CV) and Willingness to Pay (WTP) / Willingness to Accept (WTA) surveys: The contingent valuation method for co-benefit valuation entails in its most basic form simply asking respondents to estimate the value of the benefits that they experienced in monetized terms (willingness to pay (WTP)/ willingness to accept (WTA) are common approaches). An advantage of WTP surveys is that they provide specific monetized values for the overall benefits that can be compared with each other. Disadvantages are the difficulties that many respondents have in answering the questions (artificial situation), often lacking budget constraint, the volatility of the responses, and significant variations in responses due to socioeconomic, demographic and attitudinal variables;
- Relative scaling methods: In this approach, respondents are asked to state how much more valuable (specific or total) co-benefits are relative to a base. That base may be a monetary amount, or another factor known to the respondents;
- Ranking based survey approaches: These surveys ask respondents to rank co-benefits or measures with alternative sets of co-benefits on a two-way comparison basis or more numerous options in rank order;

For macro-economic co-benefits, the value of the co-benefits does not depend on the valuation of the beneficiary and, theoretically, could be accounted and not estimated by following and measuring the path of the effects of the energy related measures. Although this might be acceptable in theory, the crossed impacts in different areas of the society make it impracticable to fully understand the scope of the effects in society. Nevertheless, a growing number of attempts have been emerging in some areas where the impacts seem to be more relevant for the development of public policies:

- Climate change: Strategies to reduce the use of fossil fuels can provide environmental benefits to the region and to society, particularly due to their role as a pollution abatement strategy.

Studies evaluating the benefits in terms of helping to reduce acid rain, and a variety of other environmental benefits and their associated health effects have been widely used (Skumatz, L., 2009);

- Health: Health benefits have been currently reported by several studies as the most important benefit of energy efficiency improvements in residential buildings, especially in cold regions and among low income households. The benefits are analysed comparing health costs before and after renovation (ex.: prescriptions, hospitalisations and benefits of reduced mortality; Grimes, A. et al., 2011);
- Economic development: Job creation and economic development benefits accrue as secondary benefits from energy efficiency programs. These benefits include increased (net-) employment, (net-) earnings, and additionally generated tax revenues; increased economic output; and decreased unemployment payments. Work in this field relies largely on input-output models. The estimation work requires running a “business as usual” (BAU) and “scenario” case, specifying the industries in which money will be spent incorporating the energy related renovation investment, and comparing the results to the BAU case (Skumatz, L., 2009).

6. Results from assessment of co-benefits within Annex 56

Within Annex 56, the gathering of case studies is one of the activities undertaken to reach the overall project objectives because it is a recognized fact that the process of decision-making has to be strongly supported by success stories from real life and experiences and lessons learned from practice. These case studies are divided in Shining Examples and Detailed Case Studies, and both are to be evaluated from the perspective of the co-benefits obtained from the renovation process. Besides these, also a group of buildings that are representative of the residential building stock (generic buildings) of each country have been studied and are also analysed.

6.1. Co-benefits in Shining Examples

The Shining Examples are renovation projects that have already been implemented and that have been gathered among the participating countries mainly for motivation and stimulation purposes, highlighting the advantages of the energy and emissions cost optimized renovation. The focus is to show advantages of these interventions and demonstrate innovative solutions and strategies.

In Table 6, the different case studies from the Shining Examples are listed together with the corresponding benefits derived from energy related measures, as identified by the authors of the analysis of these case studies, not considering the co-benefits matrix from Table 4. All renovation projects have been initiated mainly because of other reasons than the reduction of the energy demand. The energy renovation was most often an addition to an anyway renovation of the buildings.

Table 6 Co-benefits from energy related measures within IEA EBC Shining Examples

Country	Designation	Co-benefits from energy related measures
Austria	**Kapfenberg**	Improved thermal quality by reduction of thermal bridges; Better indoor climate by mechanical ventilation system with heat recovery; Improved operational comfort by a new centralized and automatically controlled system from the renewal of old heating and DHW systems; Improved reputation of the building from the global intervention
Austria	**Bruck an der Mur**	High thermal comfort in summer and winter; Acoustic comfort; High ratio of daylight; Possibility of natural ventilation
Czech Republic	**Kaminsky, Brno**	Improved user comfort for students and staff once the new equipment is easier to use and maintain

Country	Designation	Co-benefits from energy related measures
Czech Republic	**Koniklecova, Brno**	Significantly reduced energy consumption, which lead to reduction of costs. Comfort of tenants and usable space improved thanks to the renovation of envelope and new enclosed loggias instead of original open balconies. Aesthetic perception of the building and its surroundings. Improved user comfort for the tenants once the new equipment, windows, doors, etc. are easier to use and maintain
Denmark	**Skodsborgvej, Virum**	Increased useable space due to the insulation of the first floor; Elimination of mould and draught; Sense of control over the energy costs
Denmark	**Traneparken, Hvalsø**	Better indoor climate due to the new ventilation system
Denmark	**Sems Have, Roskilde**	Improved architecture; Improved indoor climate; New lighting in the staircases
Italy	**Ca' S. Orsola, Treviso**	Increased prestige of a historic building leading to significant added value; Increased living conditions and qualified living spaces; First class acoustic according to national standard
Italy	**Via Trento, Ranica**	Increased thermal comfort from improved mean radiant temperature due to the radiant floor and the highly insulated envelope; Improved acoustic features; Improved internal air quality due to the mechanical ventilation system; Improved control of light and of comfort mitigation in summer due to the new shading devices
The Netherlands	**Wijk van Morgen, Kerkrade**	Reduced exposure to energy price fluctuation; The overall status of the area has improved.
Portugal	**Pontes Country House, Melgaço**	The renovation measures recovered the building living conditions, with levels of thermal and acoustic comfort and air quality consistent with current requirements; The focus on energy consumption minimization and usage of low embodied environmental impact materials is to be used for marketing purposes, as a sign of pride, prestige and reputation.
Portugal	**Bairro Rainha Dona Leonor, Porto**	Improved thermal comfort conditions with users now able to heat indoor spaces and keep the interior environment within healthy and comfortable temperatures; Improved natural lighting with larger glazing areas in living room.
Portugal	**Montarroio, Coimbra**	Increased value of the building and increased potential rent value from seismic safety, energy performance and increased living area
Spain	**Dwellings Corazón de Maria, Bilbao**	Reduction of the risk of energy poverty and cold homes once the renovation makes easier to deliver affordable warmth to the poor households
Sweden	**Backa rod AB, Gothenburg**	Improved thermal comfort; Improved indoor air quality
Sweden	**Brogården, Alingsås**	Improved thermal comfort Improved indoor air quality
Sweden	**Maratonvägen, Halmstad**	Improved thermal comfort;

Country	Designation	Co-benefits from energy related measures
		Reduced noise from outside; Towels dry faster in bathrooms; Additional useful area from glazing of balconies
Switzerland	**Les Charpentiers, Morges**	Better comfort (noise, thermal) ; Increased living area from the new thermal envelope that wraps balconies to avoid thermal bridges.

Although in some shining examples the described co-benefits are presented as a result from the global intervention, in many cases it has been possible to identify relations between energy related measures and co-benefits. In Table 7 the matrix of relations between measures and co-benefits is used to identify each shining example where that relation has been identified.

The correspondence between the abbreviations in the matrix and each shining example is described below the table. The abbreviations between brackets means that the identified co-benefit was also present in the case of an “anyway renovation” so, it must not be accounted as a co-benefit deriving from the energy related renovation.

Table 7 Identification of shining examples where relations between energy related renovation measures and co-benefits have been identified

CO-BENEFIT	Thermal comfort	Natural lighting	Air quality	Building physics	Internal noise	External noise	Ease of use	Reduced exposure to energy price fluctuations	Aesthetics / Architectural integration	Useful living area	Safety (intrusion and accidents)	Pride/prestige	Ease of installation
Insulation	AT.1; AT,2; CH.1; CZ.1; CZ.2; DK.3; ES.1; IT.2; PT.1; PT.2; SE.1; SE.2; SE.3;			AT.1; CH.1; DK.1; PT.1; SE.1				DK.1; ES.1; NL.1				[PT.1]	
Windows (and/or door) glazing	IT.2; PT.1; ES.1; SE.2; SE.2; SE.3; CH.1	AT.2; [PT.2]	PT.1			AT.1; AT.2; CH1.; IT.1; IT.2; PT.1	CZ.2; [IT.2]			[SE.3]	[SE.3]		
Mechanical Ventilation	CH.1; DK.2; DK.3; SE.2; SE.3		AT.1;AT.2; DK.2; IT.2; SE.2;				CZ.2						

CO-BENEFIT	Thermal comfort	Natural lighting	Air quality	Building physics	Internal noise	External noise	Ease of use	Reduced exposure to energy price fluctuations	Aesthetics / Architectural integration	Useful living area	Safety (intrusion and accidents)	Pride/prestige	Ease of installation
Solar thermal								NL.1; PT.1; PT.2; PT.3					
Efficient lighting							CZ.2						[DK.3]
New/improved heat distribution system or DHW system	IT.2; PT.2; SE.1						AT.1; [DK.3]	PT.3					[DK.3]; IT.1
New heat supply	IT.2; PT.1; PT.2; SE.1						AT.1;CZ.1; CZ.2; DK.3	AT.1; CZ.1; CZ.2; ES.1; PT.1					

AT.1 Austria, Kapfenberg
AT.2 Austria, Bruck na der Mur
CH.1 Switzerland, Les Charpentier
CZ.1 Check Republic, Koniklecová 4
CZ.2 Check Republic, Kaminkly 5
DK.1 Denmark, Skodsborgvej
DK.2 Denmark, Traneparken
DK.3 Denmark, Sems have
ES.1 Spain, Viviendas Corazón de Maria
IT.1 Italy, Casa S' Orsola
IT.2 Italy, Ranica
NL.1 Netherlands, Wijk van Morgen
PT.1 Portugal, Rainha Dona Leonor
PT.2 Portugal, Pontes Country house
PT.3 Portugal, Montarroios
SE.1 Sweden, Bäcka Röd
SE.2 Sweden, Brogarden
SE.3 Sweden, Maratonägen

From the matrix, it is clear that many measures have a positive impact on thermal comfort, but insulation of the building envelope is clearly the most important. Measures improving the building envelope, such as insulation and window replacement, besides thermal comfort, also have an impact on natural lighting, building physics and external noise. Measures changing the heating system and promoting the use of renewable energy sources are easy to use and reduce the exposure to energy price fluctuations.

Additionally, the results have been analyzed according to the climate region where the building is located in order to find some specific relations based on the climate conditions. The shining examples have been divided between Southern Europe (A), The Alps and Central Europe (B) and Northern Europe (C), with the number of buildings where the correlation has been identified in brackets.

Table 8 Identification of shining examples by climate region where relations between energy related renovation measures and co-benefits have been identified

CO-BENEFIT	Thermal comfort	Natural lighting	Air quality	Building physics	Internal noise	External noise	Ease of use	Reduced exposure to energy price fluctuations	Aesthetics / Architectural integration	Useful living area	Safety (intrusion and accidents)	Pride/prestige	Ease of installation
Insulation	A(4); B(5); C(4)			A(1); B(2); C(2)				A(1); B(1); C(1)				A(1)	
Windows (and/or door) glazing	A(3); B(1); C(2)	A(1); B(1)	A(1)			A(3); B(3)	A(1); B(1)			C(1)	C(1)		
Mechanical Ventilation	B(1); C(4)		A(1); B(2); C(2)				B(1)						
Solar thermal								A(3); B(1)					
Efficient lighting							B(1)						C(1)
New/improved heat distribution system or DHW system	A(2); C(1)						B(1); C(1)	A(1)					A(1); C(1)
New heat supply	A(3); C(1)						B(3); C(1)	A(2); B(3)					

Results indicate that there is no significant correlation between the climate region and the identified relation between energy related measures and co-benefits.

6.2. Co-Benefits in Case Studies

In the following pages, the findings from the investigated detailed case studies are presented and analysed together with the corresponding benefits derived from energy related measures. The analysis is based on the parametric calculations following the methodology developed in the project (IEA EBC, 2014) and also, for some of the case studies, on interviews performed among the residents of the renovated buildings.

The presentation of the results from parametric calculations only represents the primary energy use and not the emissions due to the higher correlation between the energy efficiency measures and primary energy. In fact, when using renewable energy sources the impact of energy efficiency measures is reduced, making the graphs less clear to analyse the co-benefits. Nevertheless, the results of the analysis of the co-benefits would lead to similar results.

6.2.1. Multi-family building in Kapfenberg (Austria)

This case study is a multi-family building with residents renting the dwellings. Some interviews were done with the residents considering the building renovation rather or very important due to the several problems and difficulties felt before the renovation, namely the moist, cold, low fresh air, too small areas and discomfort. All the residents of the building had to leave their dwelling for nearly one year because the building renovation was performed in 2 construction phases and also the dwellings inside the building were renovated and modified. That means people living in a dwelling of the 1st construction phase moved to a dwelling in the 2nd construction phase and after finishing the 1st construction phase they moved back.

After the renovation the residents consider the dwelling convenient, large, dry and warm. Less consistent opinions were collected regarding the noise, natural light and air quality. 1/3 of the respondents considered that the dwelling became noisy. Regarding the natural light, 31% of the respondents considered it dark and regarding the air quality 62% of the respondents considered not having enough fresh air in the dwelling.

Although 85% of the respondents have declared that the expectations with the building renovation have been rather or totally satisfied, about 1/3 have identified some relevant problems, namely disturbance through construction works, less daylight and too low indoor temperature.
Considering the results from the parametric calculations in the analysis of this building, nine different renovation packages to improve the buildings envelope were analysed in order to realise which one had the best balance between costs and energy during the buildings life cycle. Figure 3 shows the results considering the use of oil heating system.

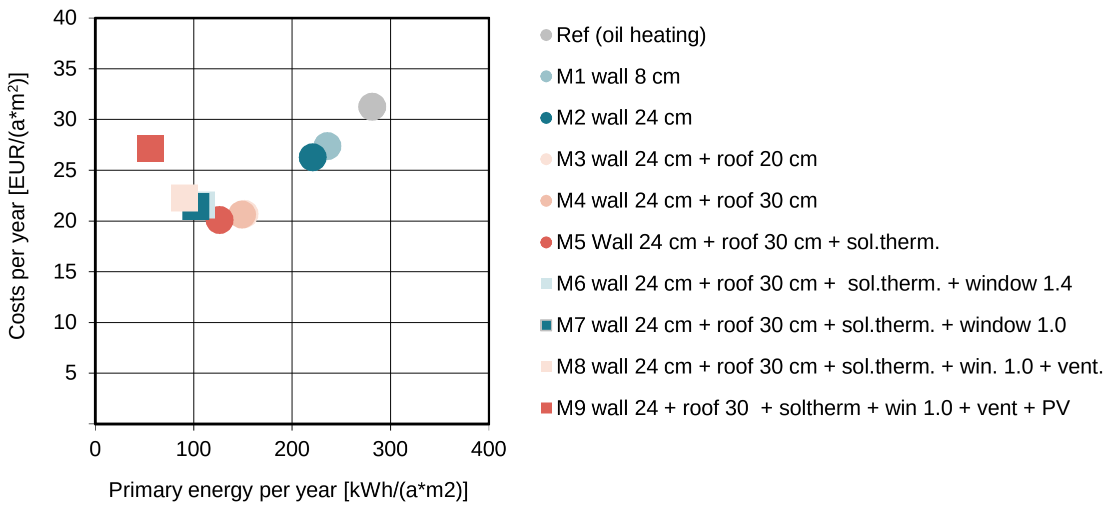

Figure 3 Evaluation of life cycle costs and primary energy use for nine renovation scenarios using oil heating system in Kapfenberg

Observing Figure 3 it is clear that all the renovation packages are cost effective once their costs are below the costs of the reference case. For this system, the cost optimal solution is M5. Close to M5 there are M6 and M7 which include the changing of the windows and also M8 which additionally include the introduction of a new ventilation system, all these with a small increase in the global costs. With the least primary energy use we have package M9 which also includes a PV system, leading the global costs to increase to a level similar of M2, where only the insulation of the walls has been improved. These nine renovation packages were combined with different heating systems, with the results illustrated in Figure 4.

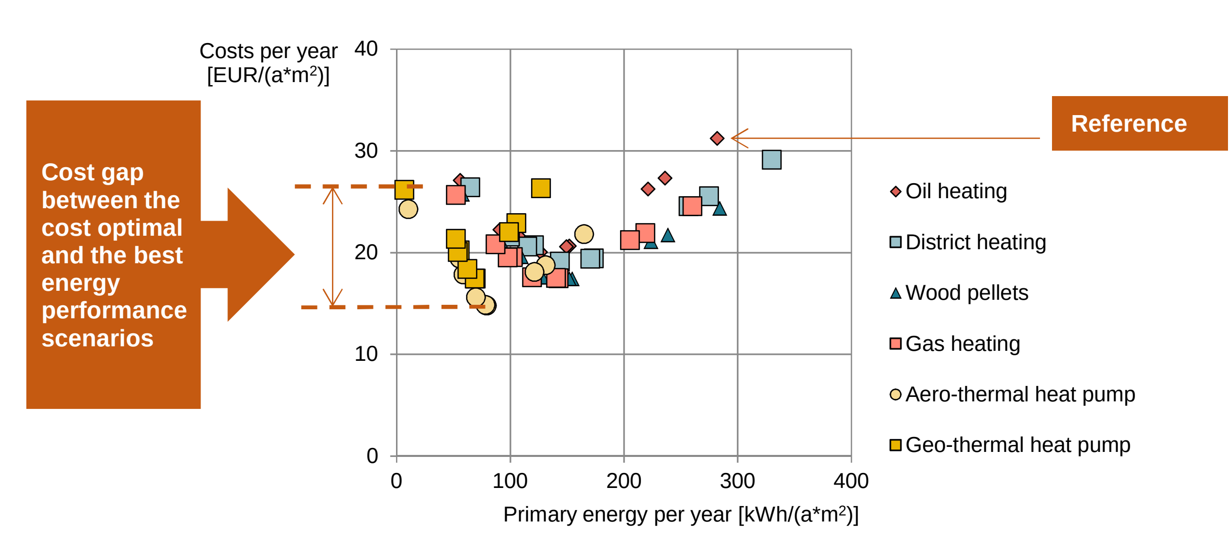

Figure 4 Evaluation of life cycle costs and primary energy use for nine renovation scenarios combined with six different heating systems in Kapfenberg

Table 9 Identification of co-benefits in several renovation packages in Kapfenberg

Building elements	Reference	M3 + Air-HP	M3 + Geo. HP	M9 + Geo HP
Facade	Maintenance	24cm of insulation	24cm of insulation	24 cm insulation
Roof	Maintenance	20 cm of insulation	20 cm of insulation	30cm insulation
Floor	Maintenance	Maintenance	Maintenance	Maintenance
Windows	Maintenance	Maintenance	Maintenance	Windows (U=1)
Ventilation	Natural	Natural	Natural	Mech + heat recov.
Heating system	Oil heating	Air Heat pump	Geo Heat pump	Geo Heat pump
DHW system	Oil heating	Air Heat pump	Geo Heat pump	Geo Heat pump
RES	None	None	None	Solar thermal + PV
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲	▲	▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲▲	▲▲	▲▲▲
Ease of installation		▲▲	▲▼	▲▼
Air Quality		▲	▲	▲▲▲
External noise				▲▲▲
Safety				▲▲
Additional costs [€/m².y]	16	Cost optimal	2	11

In the table, green triangle indicates a positive co-benefits and red triangle indicates a negative co-benefits. The quantity of these signals indicates their relevance, e.g. 3 signals "▲▲▲" or 2 signals "▲▲ " for more or less relevance of the co-benefit.

Considering different BITS, the cost optimal solution is achieved with the air-thermal heat pump for heating and DHW and the combination of renovation measures M3. The best energy performance is achieved with M9 combined with the geothermal heat pump. The primary energy use is very close to zero, but it represents a considerable increase in the global costs comparing with the cost optimal scenario.

However, when analysing the packages of measures beyond the cost optimal, it is possible to understand that some of these packages present co-benefits that may justify the extra costs that result from the cost benefit calculations that only considers energy related costs. Table 9 presents the co-benefits for some of the renovation packages, namely: the reference case, the cost optimal scenario (M3 + air heat pump), the best energy performance scenario which is very close to zero (M9 + geothermal heat pump) and the least cost scenario using the geothermal heat pump (M3 + Geothermal heat pump).

Based on Table 9, M9 + Geo HP present more co-benefits than the other renovation packages. The mechanical ventilation with heat recovery improves the air quality and the change of windows allows reducing the disturbance from external noise and the security against intrusions. The geothermal heat pump, due to its high efficiency leads to reduced exposure to energy price fluctuations, but on the other hand its installation is not an easy task. In all of the scenarios, the intervention on the facades affects positively the aesthetics, but this benefit is also present in the reference scenario, so it is not a co-benefit that derives from energy related renovation measures.

The use of renewable energy system such as the solar thermal panels and the photovoltaic system as well as the mechanical ventilation with heat recovery, allows reducing significantly the exposure to energy price fluctuation and also increase the notion of pride and prestige related with the building.

Comparing the cost optimal scenario (M3 + air heat pump) with the scenario with the best energy performance (M9 + geothermal heat pump) yearly costs per m^2 increase €11. On the other hand, the air quality is improved, the building becomes more protected from external noise and against intrusions, residents are less exposed to energy price fluctuations and experience an increased sense of pride and prestige related to their renovated building.

6.2.2. Multi-family building in Traneparken (Denmark)

Traneparken consists of 3 multi-story blocks of flats. Each block has 3 storeys with in all 66 flats. The buildings are typical of the 1960s and made of prefabricated reinforced sandwich concrete elements with approx. 50 mm insulation material. The floor above basement has approximately 45 mm insulation material, the roof is insulated with approximately 190 mm and windows are double-glazed with a U-value of 1.8 W/m^{2}K. The buildings are heated by district heating delivered through the basement of one of the blocks to a 200 kW plate heat exchanger. In each block there are pre-insulated domestic hot water (DHW) tanks with 300l. Originally, the flats were ventilated by a mechanical exhaust system which extracted air from bathroom, toilets and kitchens.

Before renovation, the buildings seemed rather grey and boring and had problems with facades, windows and roofs. The indoor climate was unacceptable and the energy consumption was very high.

In the Danish case study, seven different renovation packages for the building envelope were analysed. The results considering the primary energy consumption and the global costs for these seven renovation packages, combined with district heating for heating and DHW are presented Figure 5.

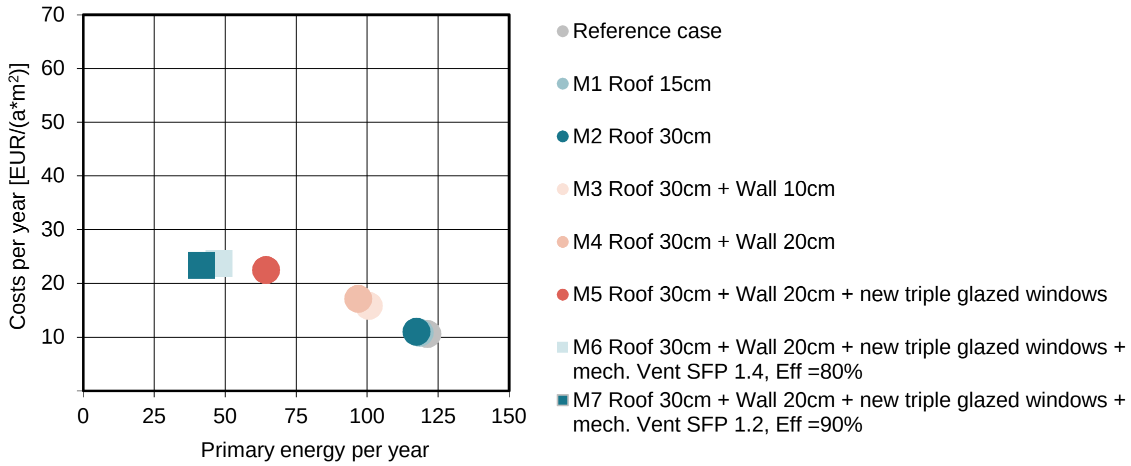

Figure 5 Evaluation of life cycle costs and primary energy use for nine renovation scenarios using district heating system in Traneparken

In the Danish case study, none of the analysed renovation packages is cost effective, once their costs are all above the reference case. This is probably due to the fact that the original building already presents a good level of insulation in some of its elements which decreases the cost-effectiveness of the introduced measures (50mm on facades, 45mm on floor above basement, 190mm on the roof and double-glazed windows with a U-value of 1.8 W/m^{2}K).

Also the change of the energy source doesn't allow to reduce global costs.

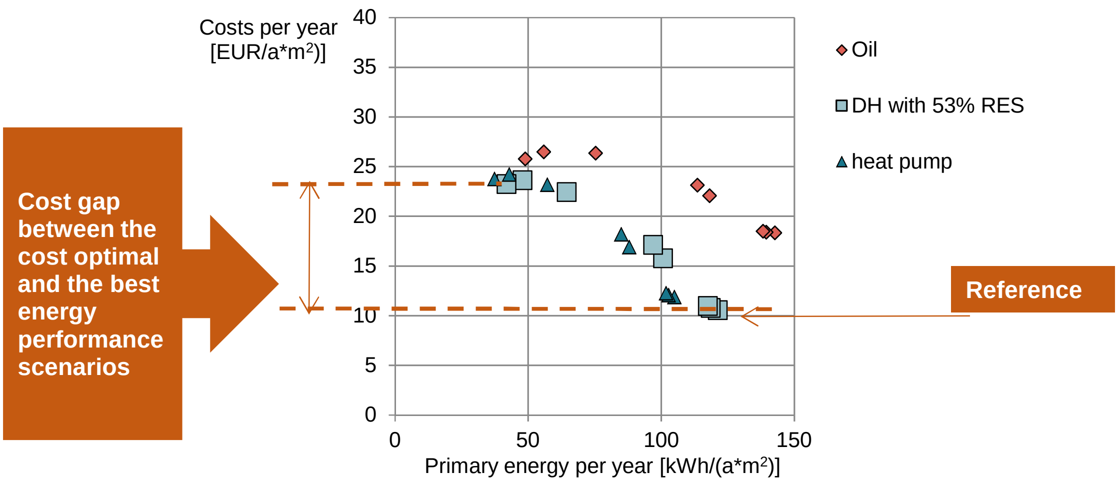

Figure 6 Evaluation of life cycle costs and primary energy use for seven renovation scenarios combined with three different heating systems in Traneparken

Figure 6 presents the results for the seven renovation packages with different systems for heating and DHW. Observing the figure it is possible to conclude that the cost optimal scenario is the reference case combined with the district heating with 53% RES (which is the real case scenario). Nevertheless, a scenario improving the buildings energy performance has been implemented.

Table 10 Identification of co-benefits in several renovation packages in Traneparken

Building elements	Reference	Reference + HP	M4 + DH	M7 + HP
Facade	Maintenance	Maintenance	20 cm insulation	20 cm insulation
Roof	Maintenance	Maintenance	30cm insulation	30cm insulation
Floor	Maintenance	Maintenance	Maintenance	Maintenance
Windows	Maintenance	Maintenance	Maintenance	Triple Glazed
Ventilation	Maintenance	Maintenance	Maintenance	Mech + heat recov
Heating system	District heating	Heat pump	District heating	Heat pump
DHW system	District heating	Heat pump	District heating	Heat pump
RES	53% RES	None	None	None
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort			▲▲▲	▲▲▲
Building physics			▲▲	▲▲
Internal noise			▼	▼
Price fluctuation		▲	▲	▲▲▲
Air Quality			▲	▲
External noise				▲▲
Safety				▲
Additional costs [€/m².y]	Cost optimal	1	7	13

Table 10 shows the co-benefits of four renovation packages: the cost optimal solution, a renovation package using a heat pump instead of district heating, renovation package M4 which improves the energy performance of the facade and the roof, and the scenario that leads to the best energy performance (M7 + Heat Pump).

Looking at the table, the last two renovation packages which improve the buildings envelope, present some advantages that can play an important role in the final decision. From an economical perspective the difference in the global cost to the cost optimal solution is small and the improvements in the thermal comfort and reduction in the problems related to the building physics are interesting additional benefits. There is a negative co-benefit related to the increase of the insulation on the buildings envelope which is the internal noise from adjacent dwellings that becomes noticeable when the external noise is reduced.

The exposure to the energy price fluctuation decreases significantly in the last renovation package, which also presents the co-benefits of further reducing the external noise and improve safety against intrusions, related with the replacement of windows.

6.2.3. Multi-family building in Lourdes neighbourhood, Tudela (Spain)

This residential building was built in 1970 and is a part of a big social neighbourhood with low quality construction. It is a five storey building with 4 dwellings per floor of approximately 70m^2 of net area. The building lacks of any insulation, with the existing facade made of a single hollow brick with 25 cm of width. The floor of the first floor (in contact with unheated spaces) is made of a concrete beam slab with ceramic hollow fillers. The old pitched roof has an unheated space under it and is covered by ceramic tiles. The original wooden windows were nearly all replaced by owners at different times during the last years so their thermal performance is variable. The building was connected to an inefficient district heating grid with gas boilers (originally oil boilers with the burner changed to use gas). Individual electrical boilers for domestic hot water have been installed in different times by occupants. There are only a few individual air conditioning units and no energy saving system for lighting or common appliances.

In the Spanish case study, the energy related building renovation measures are analysed in order to identify the related co-benefits. Using the LCC analysis results, each of the renovation scenarios was analysed to verify their cost effectiveness and the co-benefits from energy related measures that may justify going beyond cost optimal.

The results for the 10 packages of measures improving the building envelope are presented Figure 7. These results are related to the use of an oil boiler system for heating and DHW.

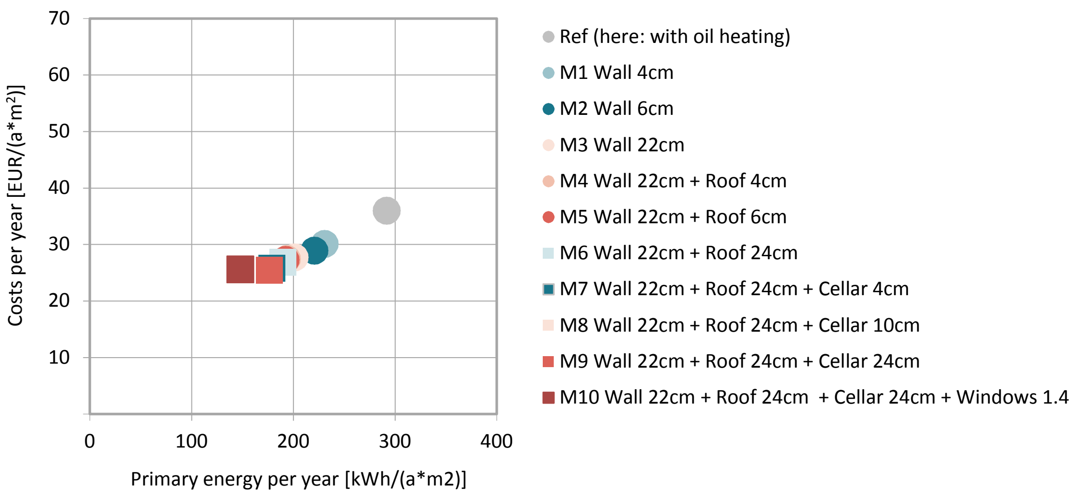

Figure 7 Evaluation of life cycle costs and primary energy use for ten renovation scenarios combined with oil boiler system for heating and DHW in Lourdes neighbouhood

For this system the cost optimal solution is M9, which corresponds to the point with lower costs. M10 is slightly better in the energy performance, with a small difference in terms of global costs, including the replacement of the windows that can be an important issue in some buildings especially in busy areas and for safety reasons. The weight of the addition of this measure, even with an increase of the costs is a positive co-benefit.

If different systems are considered, the cost optimal results may vary. Therefore, different systems were combined with the 10 renovation packages for the buildings envelope. The results are presented in Figure 8.

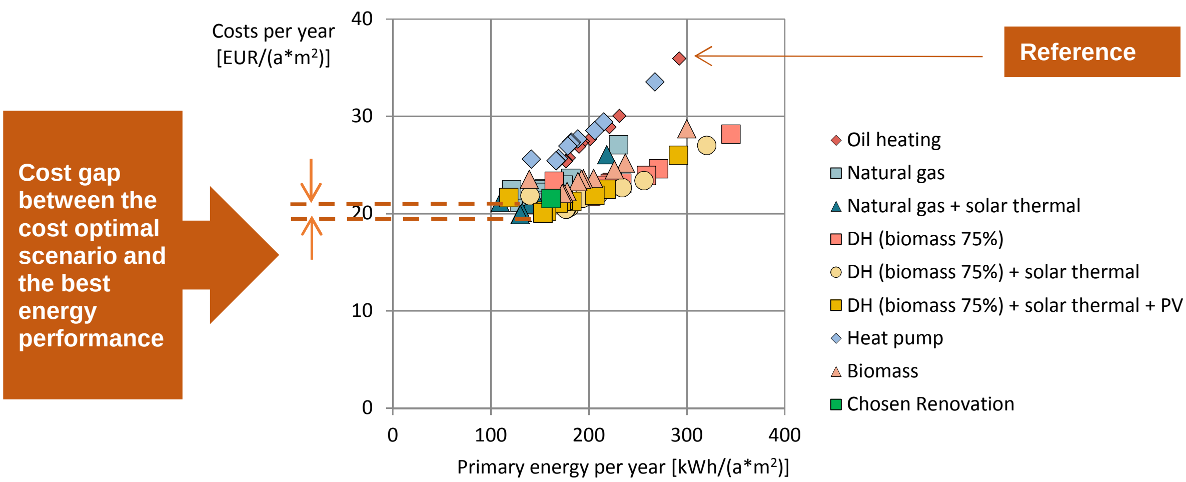

Figure 8 Evaluation of life cycle costs and primary energy use for ten renovation scenarios combined with eight different heating systems in Lourdes neighbourhood

The cost optimal solution for the building envelope is still M9, however, the system that leads to the cost optimal level consists in a gas boiler backed by solar thermal panels. The renovation package with the best energy performance is achieved with the same system for heating and DHW, but further improving the insulation in the building envelope. The difference in the costs is not relevant, so the co-benefits may justify going a little further in the renovation process. Considering the costs, the chosen renovation is very close to the solution with best energy performance, but it uses more primary energy than this one and also than the cost optimal solution.

Taking this into consideration, Table 11 presents the co-benefits for some of the renovation packages, namely the reference case, the cost optimal solution (M9 with gas boiler backed by solar thermal), the solution with the best energy performance (M10 with gas boiler backed by solar thermal) and the chosen renovation package.

Despite presenting higher global costs and worse energy performance than the other two packages improving the energy performance, the chosen renovation package presents more positive co-benefits than the cost optimal and similar benefits to the scenario with the best energy performance. This evaluation derives from the fact that the cost optimal scenario doesn't include the change of the windows while the chosen renovation and the scenario with the best energy performance include improvements in all the building envelope elements.

Table 11 Identification of co-benefits in several renovation packages in Lourdes neighbourhood

Building elements	Reference	Chosen Renov.	M9 + GB + ST	M10 + GB + ST
Facade	Maintenance	6 cm of XPS	22 cm of XPS	22 cm of XPS
Roof	Maintenance	6 cm of XPS	24 cm of XPS	24 cm of XPS
Floor	Maintenance	10 cm of RW	24 cm of RW	24 cm of RW
Windows	Maintenance	New windows U 1.8	Maintenance	New windows U 1.4
Heating system	Collec. Oil boiler	DH biomass + gas	Gas boiler	Gas boiler
DHW system	Collec. Oil boiler	Gas boiler	Gas boiler	Gas boiler
Renewables	None	None	Solar thermal	Solar thermal
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲▲	▲▲	▲▲
Air Quality		▲	▲	▲
External noise		▲▲		▲▲
Safety		▲▲		▲▲
Additional costs [€/m².y]	16	1.4	Cost optimal	1.2

6.2.4. Multi-family building in Rainha Dona Leonor neighbourhood, Porto (Portugal)

The building is part of a social housing neighbourhood built in 1953 with several two floor buildings with variations in the area and the number of bedrooms. The neighborhood consisted of 150 dwellings, but after the complete renovation they will be only 90 due to the aggregation of very small apartments. None of the buildings had thermal insulation or installed heating or cooling systems and the windows were the original wooden framed with single glazing. The domestic hot water was provided by an electric heater with a storage tank.

In the Portuguese case study, the energy related building renovation measures included in the renovation package that has been implemented are analysed in order to identify the related co-benefits. Then, the co-benefits from this renovation package are compared with the cost optimal renovation package, with those from the renovation package with the best energy performance and also with the reference scenario.

The renovation package with the best energy performance presents a relevant increase in the global costs when compared with the cost optimal but it is very close to zero primary energy use and clearly cost effective when compared with the reference case and achieves similar costs than the implemented scenario.

Figure 9 shows the LCC results for each of the analysed envelope renovation measures combined with electric heating and an electric heater with a storage tank for DHW.

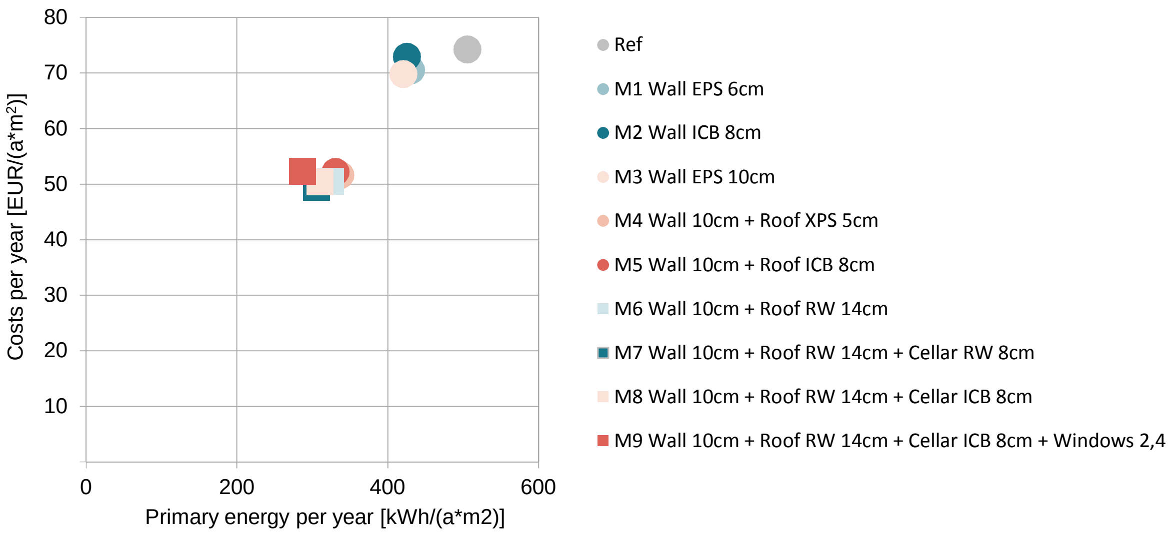

Figure 9 Evaluation of life cycle costs and primary energy use for nine renovation scenarios combined with electric heaters for heating and DHW in Rainha Dona Leonor neighbouhood

Analysing Figure 9 it can be concluded that for this system, all renovation packages are cost effective and the cost optimal solution is M7. However, there are at least four packages that are very close to the cost optimal, namely M6, M8 and M9. The package M9 is the renovation package that leads to the best energy performance. Compared to the cost optimal solution the difference in the global costs between this and the best energy performance package is very small, so there may be some advantages in investing a little bit more. The best energy performance scenario includes window replacement which can bring co-benefits such as reduction of the external noise and increase safety. Nevertheless, is important to realise the relevance of these two co-benefits to the real context of the building.

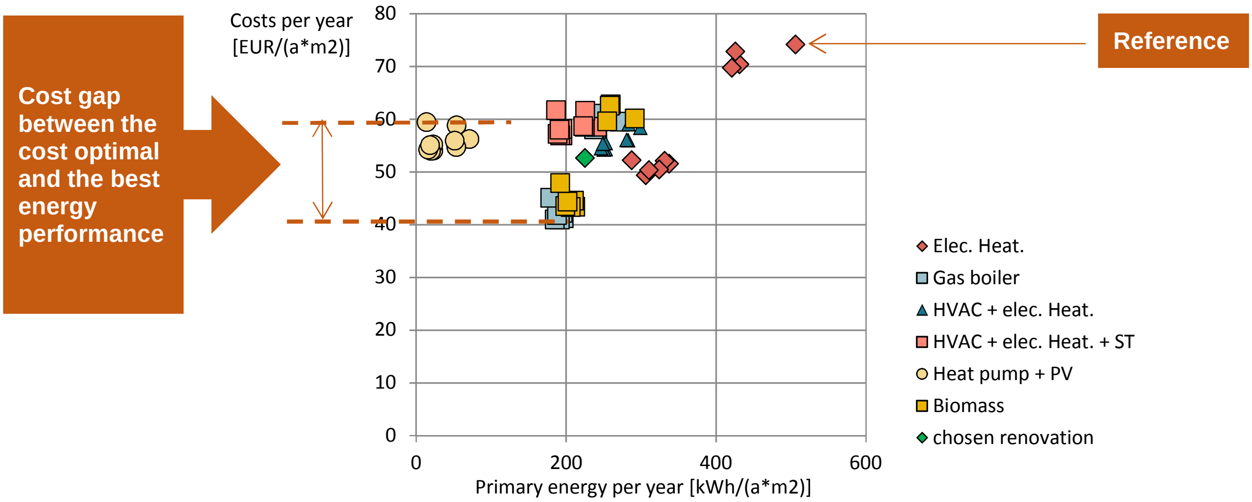

Figure 10 Evaluation of life cycle costs and primary energy use for nine renovation scenarios combined with seven different heating systems in Rainha Dona Leonor neighbourhood

Analysing one system is not enough, because different systems can affect the costs and lead to different co-benefits. Therefore, besides the 9 envelope solutions, the LCC analysis also included different heating systems. The results are presented in Figure 10.

Using different heating systems, the cost optimal solution is achieved with a gas boiler for heating and DHW, but the renovation package for the buildings envelope with the lowest cost is still M7. Using the same renovation package for the buildings envelope is possible to achieve values of energy that are very close to zero, by changing the BITS and using renewable energy.

Considering the chosen renovation solution, it is noticeable that it presents worse energy performance than the cost optimal solution, but unlike the first case it includes replacement of the windows. To synthetize the co-benefits analysis, 3 different renovation packages were compared to the cost optimal solution, namely the reference case, the chosen renovation and the best energy performance solution (M9 wit heat pump and photovoltaic panels). The results are presented in Table 12.

Regarding the aesthetics/architectural integration, the positive co-benefit is also present in the reference case, so it cannot be accounted as a co-benefit deriving from energy related measures. In fact, in the best energy performance package, the existence of photovoltaic panels may be a problem due to the required dimensions and the characteristics of the buildings.

Table 12 Identification of co-benefits in several renovation packages in Rainha Dona Leonor neighbourhood

Building elements	Reference	Chosen R.	M7 + GB	M9 + HP + PV
Facade	Maintenance	6 cm of RW	10 cm of EPS	10 cm of EPS
Roof	Maintenance	8 cm of RW	14 cm of RW	14 cm of RW
Floor	Maintenance	5 cm of RW	Maintenance	8cm ICB
Windows	Maintenance	New windows U 2.4	Maintenance	New windows U 2.4
Heating system	Electric heater	Electric heater	Gas boiler	Heat pump + PV
DHW system	Gas boiler	Electric heater + ST	Gas boiler	Heat pump + PV
Co benefits				
Aesthetics	▲	▲	▲	▲ ▼
Pride/prestige	▲ ▲	▲ ▲	▲ ▲	▲ ▲
Thermal comfort		▲ ▲ ▲	▲ ▲ ▲	▲ ▲ ▲
Building physics		▲ ▲	▲ ▲	▲ ▲
Internal noise		▼	▼	▼
Price fluctuation		▲ ▲	▲ ▲	▲ ▲ ▲
Air Quality		▲	▲	▲
External noise		▲		▲
Safety		▲		▲
Additional costs [€/m².y]	33	12	Cost optimal	13

In the implemented renovation package, the introduction of new frames with double glazing present the co-benefit of safety and also of reduced external noise. However, in the interviews performed among the residents, these positive co-benefits have never been mentioned. In fact, once the neighbourhood is located in a very quiet area, nor noise or safety were an issue before the renovation. So the potential co-benefits from the improved window were not felt. Therefore, the relevance of these co-benefits is reduced when compared with the same measure in other detailed case studies.

In the reduction of the exposure to the energy price fluctuation, the best energy performance package is the most independent one, due to the renewable energy production.

The analysis of the interviews to the respondents have also made visible that wrong design might have a huge influence in residents perception. In this case, internal shading and larger windows had negative impact in thermal comfort, natural lighting, building physics, and in the case of internal shading also creating problems with functionality and useful living areas.

6.2.5. Multi-family building in Backa röd Katjas gata, Gothenburg (Sweden)

The pilot project Katjas gata is located in Gothenburg in the district of Backa röd, consisting of 1574 apartments in high-rise buildings, low-rise buildings and low tower blocks built in the sixties during the 'million homes' program. The apartments have good floor plans, with generous and easily furnished rooms. However, the buildings needed to be renovated due to maintenance needs.

The buildings are typical for the 1970's with a prefabricated concrete structure with sandwich facades panels, a triple layer wall. The facades were damaged by carbonation and were in need of renovation. The building was leaky, through the facade and between the apartments. Draught occurred from the infill walls at the balcony and cold floors were caused by thermal bridges from the balconies. The buildings are heated by district heating and in each apartment there were radiators under the windows, which are the most common solutions for Swedish multi-family buildings. One of the low tower blocks with 16 apartments was renovated in a pilot project, which is described here.

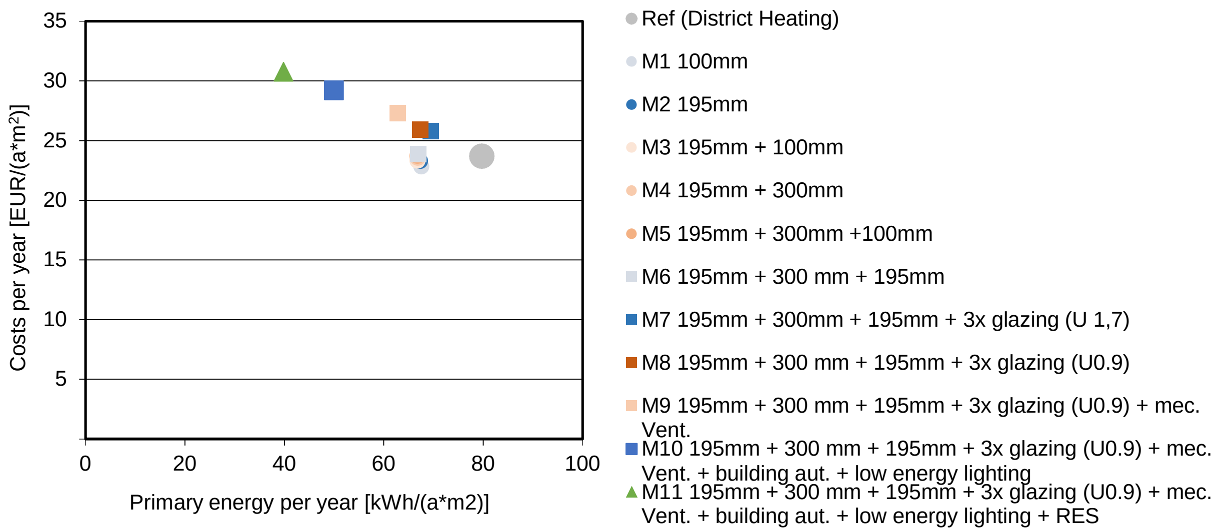

Figure 11 Evaluation of life cycle costs and primary energy use for eleven renovation scenarios combined with district heating in Backa röd

Observing Figure 11 it is observed that, for this system, renovation packages M1 to M4 are cost effective once their costs are below the cost of the reference package. In this case, the cost optimal solution is M1. Combining the renovation package M10 with RES (PV for fans, pumps, common lighting etc.), on the renovation package M11 it is possible to achieve a primary energy use lower than the reference package in more than 50%, but with a relevant increase on the global costs compared to the cost optimal solution and also with the reference package. The introduction of the triple glazing on M7 leads to an increase on the global costs beyond the limit of cost-effectiveness and also to an increase on the primary energy use comparing with packages M1 to M6, which is due to the embodied energy from triple glazing and to the fact that these do not introduce a relevant reduction in energy use when compared with the existing ones. The mechanical ventilation system with heat recovery on M9 leads to a more significant increase of the global costs, but in this case also primary energy use reduces.

The eleven renovation packages were combined with different BITS and the results are presented in Figure 12.

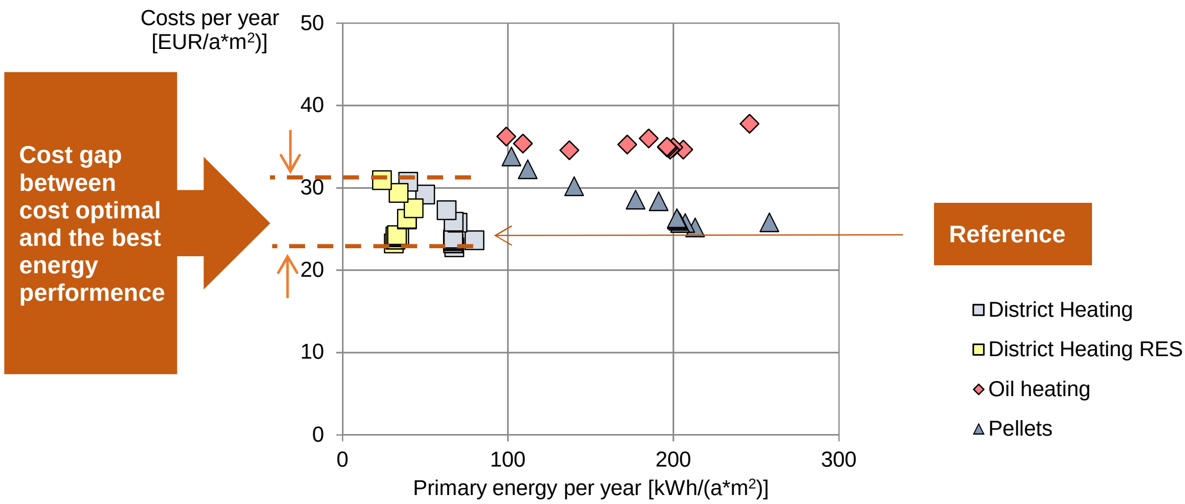

Figure 12 Evaluation of life cycle costs and primary energy use for eleven renovation scenarios combined with four different heating systems in Backa röd

Among all the analysed renovation packages the one that leads to the cost optimal level is still M1 combined with the existing district heating. The oil heating is the system with higher global costs.

Table 13 Identification of co-benefits in several renovation packages in Backa röd

Building elements	Reference	M1 + DH	M11 + WP + PV	M11 + resDH + PV
Facade	Maintenance	19.5 cm of RW	19.5 cm of RW	19.5 cm of RW
Roof	Maintenance	Maintenance	50 cm of RW	50 cm of RW
Floor	Maintenance	Maintenance	19.5 cm of RW	19.5 cm of RW
Windows	Maintenance	Maintenance	3x glazing U=0.9	3x glazing U=0.9
Ventilation	Natural	Natural	Mech. + heat recov	Mech. + heat recov
Heating system	District heating	District Heating	Wood pellets	RES District heating
DHW system	District heating	District Heating	Wood pellets	RES District heating
RES	None	None	PV	PV
Co benefits				
Aesthetics	▲	▲	▲ ▼	▲ ▼
Pride/prestige	▲	▲	▲ ▲	▲ ▲
Thermal comfort		▲ ▲	▲ ▲ ▲	▲ ▲ ▲
Building physics		▲	▲ ▲	▲ ▲
Internal noise			▼	▼
Price fluctuation		▲	▼	▲ ▲
Air Quality			▲	▲
External noise			▲ ▲	▲ ▲
Safety			▲ ▲	▲ ▲
Additional costs [€/m².y]	1	Cost optimal	11	8

A significant difference is observed, both in primary energy use as on costs, between the use of district heating and decentralized systems, mainly on the packages of measures with worst energy performance. In the case of the RES based district heating, the packages of measures improving the energy performance have very low impact on the reduction of the primary energy use and when the triple glazing is introduced, the impact from their embodied energy is higher than the energy savings during the building use.

In a case such as this one, where for most of the BITS the cost optimal package of renovation measures means a very small intervention on the building envelope, and where most of the packages of renovation measures are not cost-effective, the analysis of the co-benefits is even more relevant. In fact, co-benefits may be the main reason to perform the renovation. The co-benefits analysis was performed comparing the cost optimal solution to the solution that leads to best energy performance with RES District Heating and also with wood pellets.

Analysing Table 13 it is noticeable that the packages of measures improving significantly the building envelope present several co-benefits related with the building quality such as improved thermal comfort, reduced problems related to building physics, reduced external noise and improved safety against intrusion., with increased global cost comparing with the cost optimal package of 8 to 11€/m^2.y. On the other hand, the use of district heating, particularly if mainly based on renewables, is the main origin of financial benefits and economic co-benefits, namely the reduction of the exposure to energy price fluctuations.

6.2.6. Elementary school Kamínnky 5 (Czech Republic)

Kamínky 5 is an elementary school that was built in 1987 with approximately 9,900m^2 that went through a renovation between 2009 and 2010. The school currently has approx. 340 pupils and 40 permanent staff, mostly female (only headmaster, janitor and 4 teachers are males).

In this case study 10 people were interviewed: headmaster, janitor, administration worker, head cook, 4 teachers, 2 9th grade pupils. Out of these 6 were in school during renovation and 4 came to school after the renovation. There are significant differences in answers, caused by the position of the interviewed. Teachers had only minimum knowledge about BITS and mostly didn't care about sources of heat, etc. Administrative worker (female) didn't show interest in the interview at all and her interview is considered by the interviewer has "guess estimate". Both pupils (male and female) and 2 younger teachers (both female) shown interest in the interview, but admitted that they do not have much knowledge about technical equipment installed in the school.

It is interesting that almost everyone agreed that improving the energy consumption of the school leads to reduced exposure to fluctuation of costs, but almost nobody wrote that it has an influence on the independence on energy sources.

Comparing the relationship between the renovation measures and the co-benefits identified in these interviews and those from the matrix, a significant co-relation is present, but two different relations have been identified. The façade and roof insulation has been identified as the source of bad air quality and windows replacement has led to better natural lighting.

Regarding the parametric calculations, the Czech case study has been tested with two renovation packages for the building envelope, besides the reference scenario and the executed renovation (V3), and three energy sources, including or not the contribution from the photovoltaic system. The calculation results are shown in the next figure. With the exception of renovation package v1 with heating and DHW production based on electricity which achieves higher Life Cycle Costs than the reference case, all the tested renovation packages are cost-effective.

The lowest carbon emissions are achieved by renovation package v2, with heating and DHW production based on natural gas, including also the photovoltaic installation owned by the school.

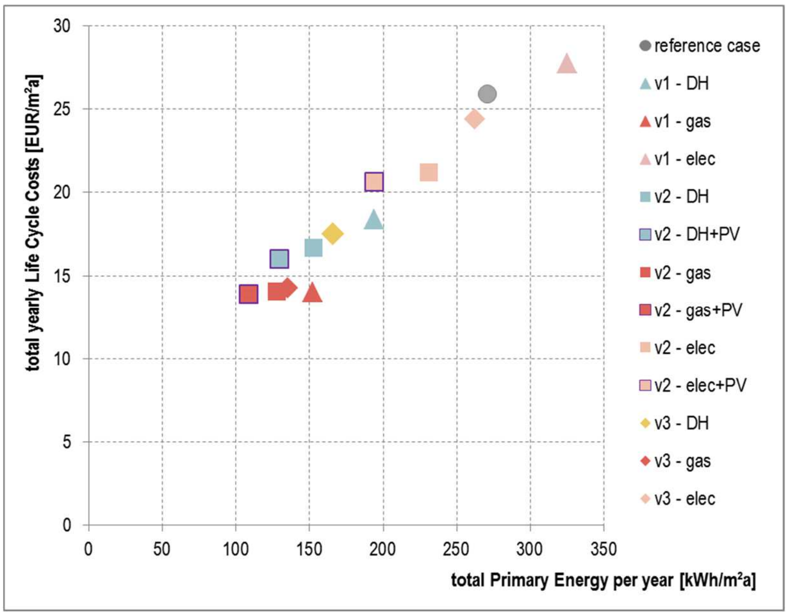

Figure 13 Life Cycle Costs in comparison with total Primary Energy of the Case Study “Kamínky 5”, Czech Republic

Analysing

Table 14 it is noticeable that the packages of measures improving significantly the building envelope present several co-benefits related with the building quality such as improved thermal comfort, reduced problems related to building physics, reduced external noise and improved safety against intrusion. The renovation package with the best energy performance is also the cost optimal package. On the side of the energy sources, the use of natural gas and also PV are the main origin of financial benefits and economic co-benefits, namely the reduction of the global costs and the reduced exposure to energy price fluctuations.

Table 14 Identification of co-benefits in several renovation packages in Kamínky 5

Building elements	Reference	V1 + gas	V2 + gas + PV	V3 + DH
Facade	Maintenance	6 to 9 cm of insul.	6 to 29 cm of insul.	6 to 16 cm of insul.
Roof	Maintenance	9 cm of EPS	30 cm of EPS	18 cm of EPS
Floor	Maintenance	13 cm of insul.	38 cm of insul.	24 cm of insul.
Windows	2x and 3x glazing	2x and 3x glazing	3x glazing	2x and 3x glazing
Ventilation	Mech. + heat recov	Mech. + heat recov	Mech. + heat recov	Mech. + heat recov
Heating system	District heating	Natural gas	Natural gas	District heating
DHW system	District heating	Natural gas	Natural gas	District heating
RES	None	None	PV	None
Co benefits				
Aesthetics	▲	▲	▲▼	▲
Pride/prestige	▲	▲	▲▲	▲
Thermal comfort	▲	▲▲	▲▲▲	▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲	▲▲	▲
Air Quality		▼	▼	▼
External noise	▲	▲▲	▲▲	▲▲
Safety	▲	▲▲	▲▲	▲▲
Additional costs [€/m².y]	12	-	Cost optimal	3,5

6.3. Co-Benefits in Generic Buildings

Within Annex 56, calculations with single-family or/and multi-family residential reference buildings from Austria, Denmark, Norway, Portugal, Spain, Sweden and Switzerland have been developed. For each investigated country, one or more reference buildings, typical for existing and not yet renovated residential buildings for the specific country, have been defined, and their properties regarding dimensions and energy performance levels of the building elements are determined.

Costs of «anyway measures» regarding the heating system and the building envelope are determined and the costs of energy related renovation packages are compared with this reference case. In the following pages, the different generic buildings from the several countries are presented and analysed from the perspective of co-benefits that packages going beyond cost optimal might present.

6.3.1. Single family building in Austria

In the Austrian single-family generic case study, the energy related building renovation packages are analysed in order to identify the related co-benefits. Then, the co-benefits from the cost optimal renovation packages are compared with other interesting renovation packages in terms of energy and costs. Figure 14 shows the cost effectiveness of packages of energy efficiency renovation measures for different heating systems and related impacts on primary energy use.

The cost optimal scenario was obtained with the geothermal heat pump. However, there other packages close to this one that may have some benefits that can justify a different option for the renovation process.

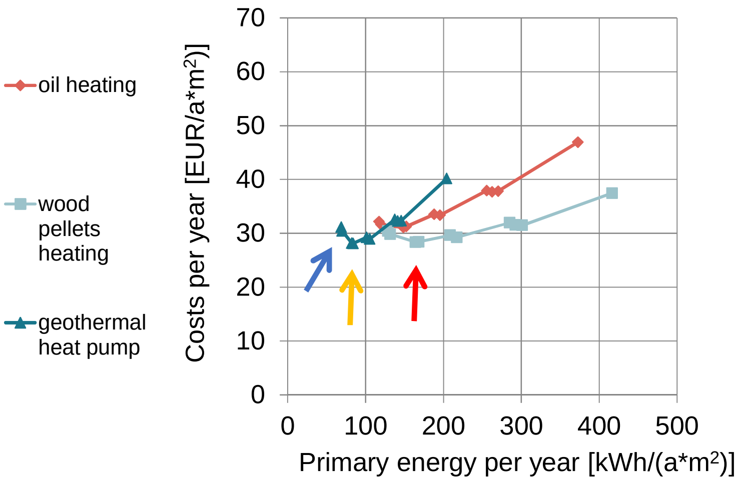

Figure 14 Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on primary energy use in Austria, for a single-family building

Table 15 Identification of co-benefits in selected renovation packages in Austrian single-family generic building

Building elements	Reference	M7 + Geo HP	M9 + Geo HP	M7 + Biomass
Facade	Maintenance	40 cm of RW	40 cm of RW	40 cm of RW
Roof	Maintenance	30 cm of RW	30 cm of RW	30 cm of RW
Floor	Maintenance	12 cm of RW	12 cm of RW	12 cm of RW
Windows	Maintenance	Maintenance	New wood U=0.7	Maintenance
Heating system	Geothermal HP	Geothermal HP	Geothermal HP	Biomass
DHW system	Geothermal HP	Geothermal HP	Geothermal HP	Biomass
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲	▲	▲▲
Air Quality		▲	▲	▲
External noise			▲▲	
Ease of installation		▼▼▼	▼▼▼	▲
Safety			▲▲	

Concerning the co-benefit analysis, three renovation solutions were chosen, namely the cost optimal (M7 + Geothermal heat pump), the solution that leads to the best energy performance (M9 + Geo HP) and the least cost package for the buildings envelope combined with a renewable system such as the biomass boiler (M7 + Biomass).

These solutions may be slightly more expensive than the cost optimal, but present other benefits that can be relevant within the buildings context and for the decision making process. Table 15 presents the co-benefits for the selected renovation packages.

The renovation package with the best energy performance presents a small increase in the global costs when compared with the cost optimal, but allows, with the introduction of new windows, to reduce the exposure to external noise and to increase the safety of the building against intrusions. On the other hand, the difficulties related with the installation of the geothermal heat pump could be avoided with the use of a wood pellets boiler, with a small increase in global costs but clearly with a worse energy performance. The heat pump is usually seen as having positive co-benefits in the ease of installation. However, the geothermal heat pump may present additional difficulties in this particular aspect.

6.3.2 Multi-family building in Austria

For the multi-family building, the analysed combinations of renovation measures were very similar to the ones from the single family building. Figure 15 shows the cost effectiveness of packages of energy efficiency renovation measures for different heating systems and related impacts on primary energy use for the multi-family building.

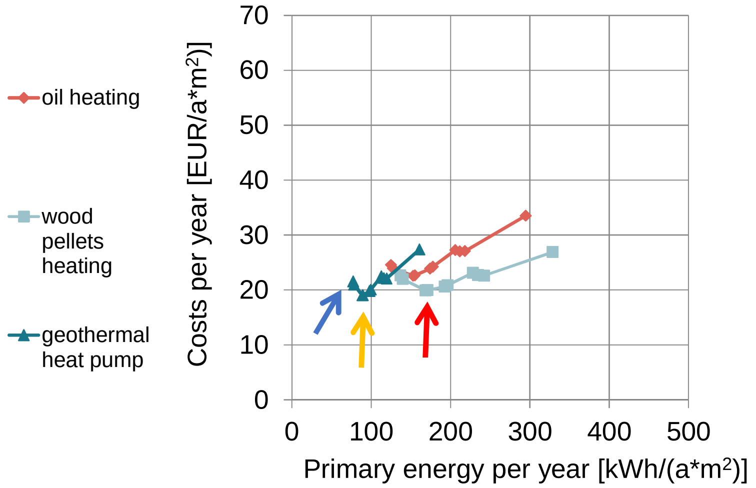

Figure 15 Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on primary energy use in Austria, for a multi-family building

The cost optimal scenario was also achieved with the use of a geothermal heat pump.

In order to compare the co-benefits, the same criterion of the single family building was applied. As so, the cost optimal scenario (M7 + Geothermal heat pump) was compared with the scenario with the best energy performance (M9 + Geothermal heat pump) and also to the least cost renovation scenario using the biomass boiler (M7 + Biomass).

Table 16 Identification of co-benefits in selected renovation packages in Austrian multi-family generic building

Building elements	Reference	M7 + Geo HP	M9 + Geo HP	M7 + Biomass
Facade	Maintenance	40 cm of RW	40 cm of RW	40 cm of RW
Roof	Maintenance	30 cm of RW	30 cm of RW	30 cm of RW
Floor	Maintenance	12 cm of RW	12 cm of RW	12 cm of RW
Windows	Maintenance	Maintenance	New wood U=0.7	Maintenance
Heating system	Geothermal HP	Geothermal HP	Geothermal HP	Biomass
DHW system	Geothermal HP	Geothermal HP	Geothermal HP	Biomass
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲	▲	▲▲
Air Quality		▲	▲	▲
External noise			▲▲	
Ease of installation		▼▼▼	▼▼▼	▲
Safety			▲▲	

In the Austrian multi-family generic case study, the energy related building renovation measures are the same as for the single-family building and results are also identical. Although the similarities, the difference in the energy performance of the two BITS is significantly higher in the case of the multi-family building than in the single-family building.

The renovation package with the best energy performance also presents a small increase in the global costs when compared with the cost optimal, allowing, with the introduction of new windows, to reduce the exposure to external noise and to increase the safety of the building against intrusions.

6.3.3. Single family building in Switzerland

Figure 16 presents the cost effectiveness of packages of energy efficiency renovation measures for three different heating systems and related impacts on primary energy use in the Swiss single-family generic case study.

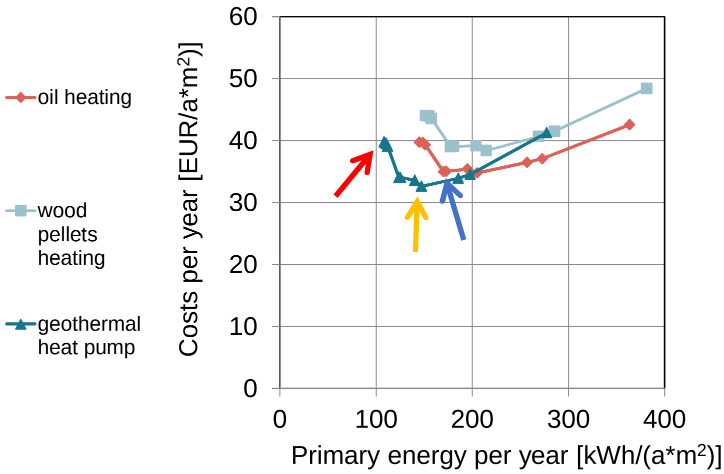

Figure 16 Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on primary energy use in Switzerland, for a single family building

Observing the figure it can be seen that the cost optimal scenario and the scenario that leads to the best energy performance are achieved with the geothermal heat pump.

Table 17 Identification of co-benefits in selected renovation packages in single family generic building in Switzerland

Building elements	Reference	M3 + Geo HP	M3 + Oil heating	M9 + Geo HP
Facade	Maintenance	30 cm of RW	30 cm of RW	30 cm of RW
Roof	Maintenance	12 cm of RW	12 cm of RW	36 cm of RW
Floor	Maintenance	Maintenance	Maintenance	16 cm of RW
Windows	Maintenance	Maintenance	Maintenance	New window U0.8
Heating system	Geothermal HP	Geothermal HP	Oil heating	Geothermal HP
DHW system	Geothermal HP	Geothermal HP	Oil heating	Geothermal HP
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲▲	▲▲	▲▲
Air Quality		▲	▲	▲
External noise				▲▲
Ease of installation		▼▼▼	▲	▼▼▼
Safety				▲▲

Closer to the cost optimal solution there are some interesting packages that can have co-benefits that are important within the building context, for a small difference in the global costs. In this context the cost optimal scenario (M3 + Geothermal heat pump) was compared to the scenario that leads to the best energy performance (M9 + Geothermal heat pump) and to the least cost scenario of those using oil heating (M3 + Oil heating). Table 17 summarizes this comparison.

The renovation package with the best energy performance presents a small increase in the global costs when compared with the cost optimal, allowing to reduce the exposure to external noise and to increase the safety of the building against intrusions. On the other hand, the difficulties related with the installation of the geothermal heat pump could be avoided with the use of oil heating. This alternative implies a small increase on global costs, but worse energy performance.

6.3.4. Multi-family building in Switzerland

Figure 17 presents the cost effectiveness of packages of energy efficiency renovation measures for three different heating systems and related impacts on primary energy use in the Swiss multi-family generic case study.

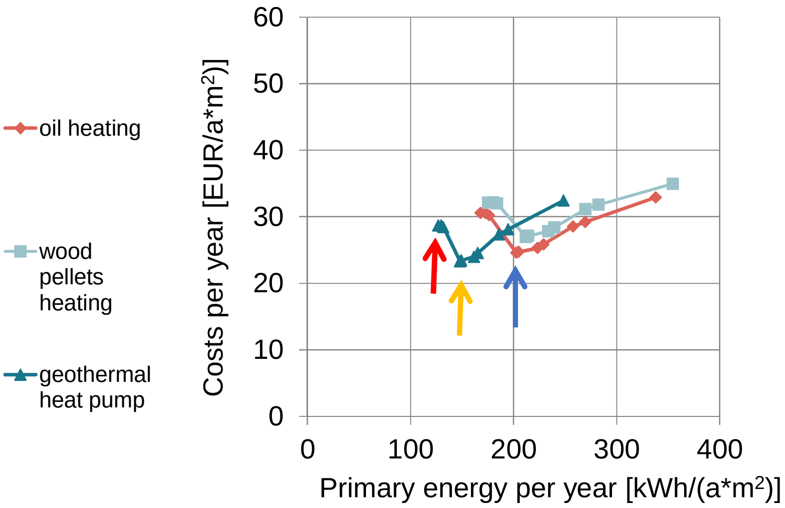

Figure 17 Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on primary energy use in Switzerland, for a multi-family building

The results concerning the BITS are very similar to the single family building. However, the packages of measures for the buildings envelope include higher levels of insulation. The co-benefits comparison followed the criteria used for the single family building. Thus, the cost optimal scenario (M6 + Geothermal heat pump) was compared to the scenario with the best energy performance (M9 + Geothermal heat pump) and also with the least cost scenario using oil heating.

The co-benefit analysis presents the same results as in the single family building, where the disadvantage of the geothermal heat pump installation is a significant negative co-benefit and the new windows allow improving the insulation to external noises and safety to intrusion on the building.

Table 18 Identification of co-benefits in selected renovation packages in multi-family generic building in Switzerland

Building elements	Reference	M6 + Geo HP	M6 + Oil heating	M9 + Geo HP
Facade	Maintenance	30 cm of RW	30 cm of RW	40 cm of RW
Roof	Maintenance	36 cm of RW	36 cm of RW	30 cm of RW
Floor	Maintenance	16 cm of RW	16 cm of RW	16 cm of RW
Windows	Maintenance	Maintenance	Maintenance	New window U0.8
Heating system	Geothermal HP	Geothermal HP	Oil heating	Geothermal HP
DHW system	Geothermal HP	Geothermal HP	Oil heating	Geothermal HP
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲▲	▲▲	▲▲
Air Quality		▲	▲	▲
External noise				▲▲
Ease of installation		▼▼▼	▲	▼▼▼
Safety				▲▲

The gap between the costs of the selected renovation measures is higher on the single family building, than in the multi-family building.

6.3.5. Single family building in Denmark

Figure 18 presents the cost effectiveness of packages of energy efficiency renovation measures for three different heating systems and related impacts on primary energy use in the Danish single family generic case study.

The cost optimal scenario was achieved using wood pellets for heating. The other analysed BITS have higher costs, but may present co-benefits that can play an important role in the decision making process.

Table 19 shows the co-benefit analysis for some of the renovation packages, namely the cost optimal scenario (M4 + Wood pellets), the least cost scenario with geothermal heat pump (M4 + Geothermal heat pump) and the package that leads to the best energy performance (M9 + Geothermal heat pump).

The renovation package with the best energy performance presents a significant increase in the global costs when compared with the cost optimal, but allows to reduce the exposure to external noise and to increase the safety of the building against intrusions. On the other hand, the difficulties related with the installation of the geothermal heat pump could be avoided with the use of a wood pellets boiler, but with worse energy performance.

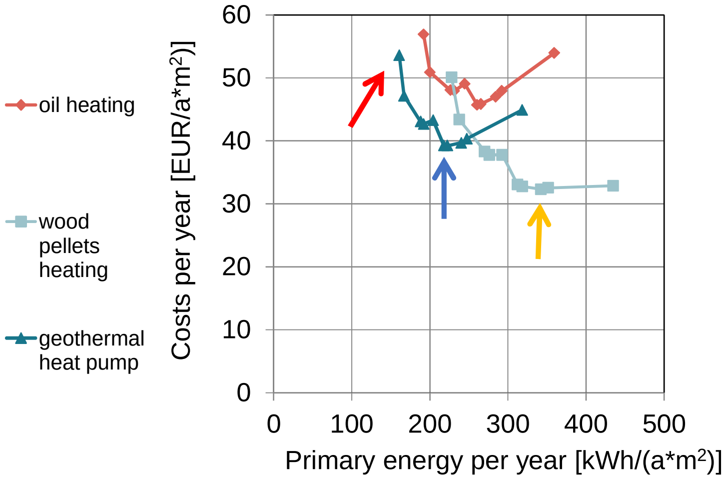

Figure 18 Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on primary energy use in Denmark, for a single family building

Table 19 Identification of co-benefits in selected renovation packages in single family generic building from Denmark

Building elements	Reference	M4 + Wood pellets	M4 + Geo HP	M9 + Geo HP
Facade	Maintenance	Maintenance	Maintenance	30 cm of RW
Roof	Maintenance	30 cm of RW	30 cm of RW	30 cm of RW
Floor	Maintenance	12 cm of RW	12 cm of RW	12 cm of RW
Windows	Maintenance	Maintenance	Maintenance	New window U 0.7
Heating system	Geothermal HP	Biomass	Geothermal HP	Geothermal HP
DHW system	Geothermal HP	Biomass	Geothermal HP	Geothermal HP
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲▲	▲▲	▲▲
Air Quality		▲	▲	▲
External noise				▲▲
Ease of installation		▲	▼▼▼	▼▼▼
Safety				▲▲

6.3.6. Multi-family building in Denmark

In the Danish multi-family generic case study, the energy related building renovation measures are the same as for the single-family building. Figure 19 presents the cost effectiveness of packages of energy efficiency renovation measures for three different heating systems and related impacts on primary energy use in the Danish multi-family generic case study.

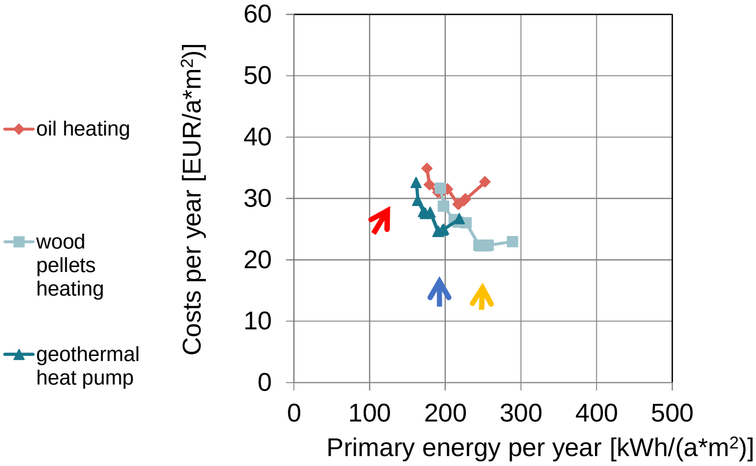

Figure 19 Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on primary energy use in Denmark, for a multi-family building

Table 20 Identification of co-benefits in selected renovation packages in multi-family generic building from Denmark

Building elements	Reference	M4 + Wood pellets	M4 + Geo HP	M9 + Geo HP
Facade	Maintenance	Maintenance	Maintenance	30 cm of RW
Roof	Maintenance	30 cm of RW	30 cm of RW	30 cm of RW
Floor	Maintenance	12 cm of RW	12 cm of RW	12 cm of RW
Windows	Maintenance	Maintenance	Maintenance	New window U 0.7
Heating system	Geothermal HP	Biomass	Geothermal HP	Geothermal HP
DHW system	Geothermal HP	Biomass	Geothermal HP	Geothermal HP
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲▲	▲▲	▲▲
Air Quality		▲	▲	▲
External noise				▲▲
Ease of installation		▲	▼▼▼	▼▼▼
Safety				▲▲

Following the same criteria as in the single family building, three renovation packages were analyzed. Once again the cost optimal (M4 + Wood pellets) was compared to the renovation package that leads to the best energy performance (M9 + Geothermal heat pump) and also with the least cost scenario with the use of the geothermal heat pump (M4 + Geothermal heat pump). Results of this comparison are presented in Table 20.

Similarly to what happens in the single family building, the renovation package with the best energy performance presents an increase, although smaller, in the global costs when compared with the cost optimal solution, but allows to reduce the exposure to external noise and to increase the safety of the building against intrusions. On the other hand, the difficulties related with the installation of the geothermal heat pump could be avoided with the use of a biomass boiler, although with worse energy performance.

6.3.7. Multi-family building in Spain

Figure 20 presents the cost effectiveness of packages of energy efficiency renovation measures for three different heating systems and related impacts on primary energy use in the Spanish multi-family generic case study.

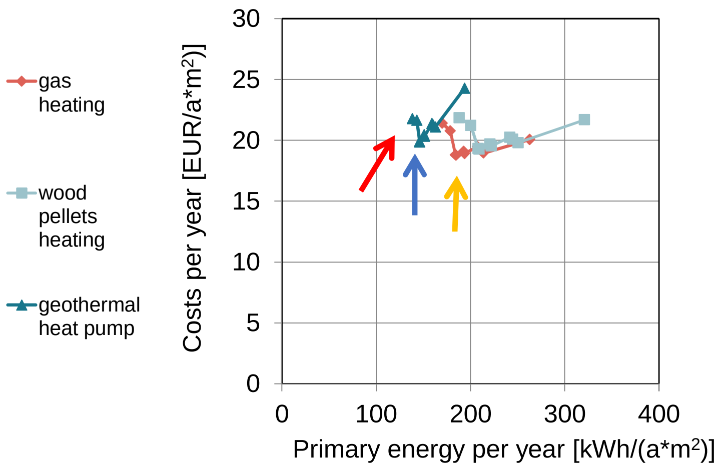

Figure 20 Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on primary energy use in Spain, for a multi-family building

The BITS that leads to the cost optimal scenario includes gas heating while the best energy performance is achieved with the geothermal heat pump. The wood pellets heating present the worse energy performance among the analysed BITS.

To compare the packages of renovation measures concerning the co-benefits, three different renovation packages were selected, namely the cost optimal renovation scenario (M7 + Gas boiler), the scenario that leads to the best energy performance (M9 + Geothermal heat pump) and the least cost package of measures for the building envelope combined with the geothermal heat pump (M7 + Geothermal heat pump), once it allows better energy performances than the cost optimal renovation package. The selected renovation scenarios are presented in Table 21.

The renovation package with the best energy performance presents a significant increase in the global costs when compared with the cost optimal, but the introduction of new windows allows reducing the exposure to external noise and to increase the safety of the building against intrusions.

Table 21 Identification of co-benefits in selected renovation packages in multi-family generic building in Spain

Building elements	Reference	M7 + Gas boiler	M7 + Geo HP	M9 + Geo HP
Facade	Maintenance	30 cm of GW	30 cm of RW	30 cm of RW
Roof	Maintenance	14 cm of RW	14 cm of RW	14 cm of RW
Floor	Maintenance	12 cm of RW	12cm of RW	12cm of RW
Windows	Maintenance	Maintenance	Maintenance	New window U 1.0
Heating system	Gas heating	Gas heating	Geothermal HP	Geothermal HP
DHW system	Gas heating	Gas heating	Geothermal HP	Geothermal HP
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲▲	▲▲	▲▲
Air Quality		▲	▲	▲
External noise				▲▲
Ease of installation		▲	▼▼▼	▼▼▼
Safety				▲▲

On the other hand, the difficulties related with the installation of the geothermal heat pump could make it less attractive. The renovation package with best energy performance (M9) combined with the gas heating, could be an alternative, in order to avoid the difficulties with the installation of the geothermal heat pump, although it presents a worse energy performance.

6.3.8. Single family building in Norway

Figure 21 presents the cost effectiveness of packages of energy efficiency renovation measures for three different heating systems and related impacts on primary energy use in the single family generic case study from Norway.

The cost optimal scenario was achieved using electric heating. The air/water heat pump is very close to it concerning the costs leading to a significant decrease in primary energy use.

For the co-benefits analysis, tree different renovation packages were selected, namely, the cost optimal (M6 + Electrical heating), the renovation package that leads to the best energy performance (M9 + Air/Water heat pump) and the lowest cost package considering the air/water heat pump. The results of the co-benefits comparison are presented in Table 22.

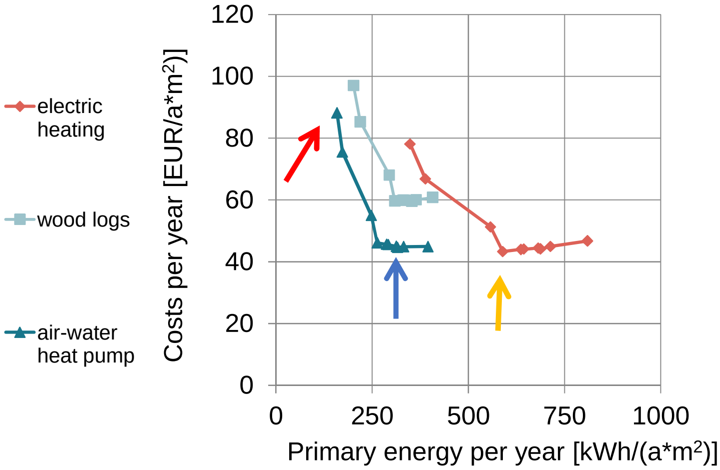

Figure 21 Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on primary energy use in Norway, for a single family building

Table 22 Identification of co-benefits in selected renovation packages in multi-family generic building in Spain

Building elements	Reference	M6 + Elec. heating	M2 + Air/Water HP	M9 + Air/Water HP
Facade	Maintenance	Maintenance	Maintenance	40 cm of RW
Roof	Maintenance	Maintenance	Maintenance	44 cm of RW
Floor	Maintenance	Maintenance	Maintenance	12 cm of RW
Windows	Maintenance	New window U 0.8	New window U 0.8	New window U 0.7
Heating system	Geothermal HP	Elect. heating	Heat pump	Heat pump
DHW system	Geothermal HP	Elect. heating	Heat pump	Heat pump
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲	▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲	▲▲	▲▲
Air Quality				▲
External noise		▲▲	▲▲	▲▲
Ease of installation			▼	▼
Safety		▲▲	▲▲	▲▲

The renovation package with the best energy performance presents a significant increase in the global costs when compared with the cost optimal, but allows a great reduction of the primary energy use and also to improve the thermal comfort and air quality, as well as reducing the problems with building physics. The renovation packages that account with the heat pump present the ease of installation has negative co-benefit, once it is compared with the electrical heating.

The reduction of the risk of exposure to energy price fluctuations is more effective on the heat pump than with the electric heating.

6.3.9. Single family building in Portugal

Figure 22 presents the cost effectiveness of packages of energy efficiency renovation measures for three different heating systems and related impacts on primary energy use in the single family generic case study from Portugal.

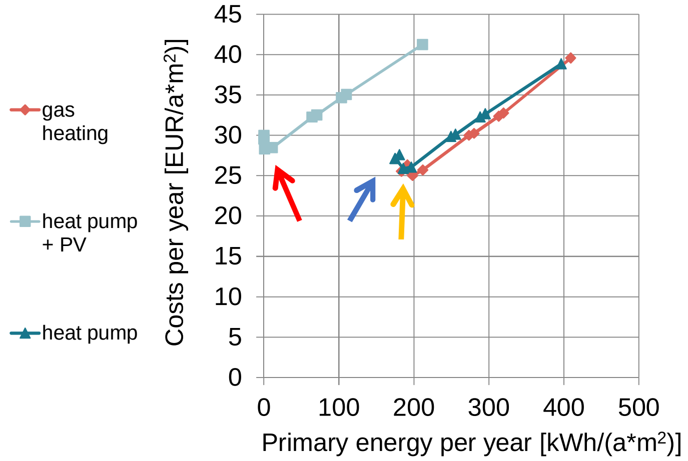

Figure 22 Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on primary energy use in Portugal, for a single family building

The cost optimal scenario includes the use of a gas boiler for heating and the best energy performance was achieved with the heat pump combined to photovoltaic panels. This last combination of BITS achieves nearly-zero values of primary energy use. The nZEB may be a good argument in favour of these BITS, but it presents higher costs.

In order to understand the differences between some of the interesting renovations packages, Table 23 summarises the comparison between the cost optimal scenario (M6 + Gas boiler), the least cost package using the heat pump and the photovoltaic panels (M6 + Heat pump and PV) and the scenario with the best energy performance using the heat pump.

The renovation package using the heat pump and PV presents a small increase in the global costs when compared with the cost optimal scenario. This package presents additional value concerning the reduction of the exposure to price fluctuation due the photovoltaic panels.

Table 23 Identification of co-benefits in selected renovation packages in single family generic building in Portugal

Building elements	Reference	M6 + Gas boiler	M9 + Air/Water HP	M6 + Air/Water HP + PV
Facade	Maintenance	6 cm of RW	Maintenance	4 cm of RW
Roof	Maintenance	8 cm of RW	8 cm of RW	3 cm of RW
Floor	Maintenance	5 cm of RW	5 cm of RW	12 cm of RW
Windows	Maintenance	Maintenance	New window U 2.3	Maintenance
Heating system	Gas boiler	Gas boiler	Heat pump	Heat pump + PV
DHW system	Gas boiler	Gas boiler	Heat pump	Heat pump + PV
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲	▲	▲▲
Air Quality		▲	▲	▲
External noise			▲▲	
Ease of installation		▲▲	▲▲	▲▲
Safety			▲▲	

However, it does not include the window replacement, not accounting with this action co-benefits, such as improve safety to intrusion and improvement of the insulation to external noises. Package M9 with the heat pump, including the change of windows presents these two co-benefits with a very small increase of global costs when compared with the cost optimal scenario.

6.3.10. Multi-family building in Portugal

In the Portuguese multi-family generic case study, the energy related building renovation measures are the same as for the single-family building. Figure 23 presents the cost effectiveness of packages of energy efficiency renovation measures for three different heating systems and related impacts on primary energy use in the Danish multi-family generic case study.

Observing the figure it is possible to conclude that for this building the cost optimal scenario is achieved using a heat pump. Once the combination of the heat pump with the photovoltaic leads to better energy performances, the cost optimal solution was compared with two different scenarios for the buildings envelope combined with this BITS, namely M6 and M9. The results of the co-benefits comparison are presented in Table 24.

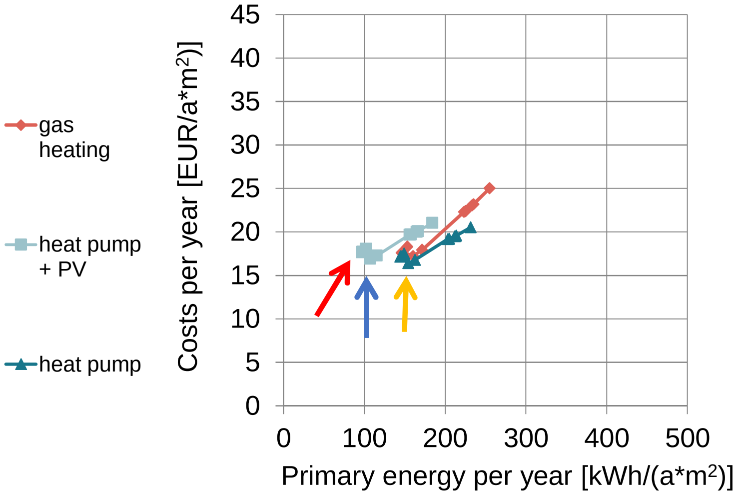

Figure 23 Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on primary energy use in Portugal, for a multi-family building

Table 24 Identification of co-benefits in selected renovation packages in multi-family generic building in Portugal

Building elements	Reference	M6 + Air/Wat. HP	M6 + A/W. HP + PV	M9 + Air/Water HP + PV
Facade	Maintenance	10 cm of RW	10 cm of RW	10 cm of RW
Roof	Maintenance	14 cm of RW	14 cm of RW	14 cm of RW
Floor	Maintenance	8 cm of RW	8 cm of RW	8 cm of RW
Windows	Maintenance	Maintenance	Maintenance	New window U 2.3
Heating system	Gas boiler	Heat pump	Heat pump + PV	Heat pump + PV
DHW system	Gas boiler	Heat pump	Heat pump + PV	Heat pump + PV
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲	▲	▲▲
Air Quality		▲	▲	▲
External noise			▲▲	
Ease of installation		▲▲	▲▲	▲▲
Safety			▲▲	

The renovation package with the best energy performance presents a small increase in the global costs when compared with the cost optimal, but allows to reduce the exposure to external noise and to increase the safety of the building against intrusions as well as reducing the risk related to energy price fluctuations. On the other hand, there are some difficulties related with the installation of the photovoltaic panels on multi-family buildings due to limited space in the roof.

6.3.11. Single family building in Sweden

Figure 24 presents the cost effectiveness of packages of energy efficiency renovation measures for three different heating systems and related impacts on primary energy use in the single family generic case study from Sweden.

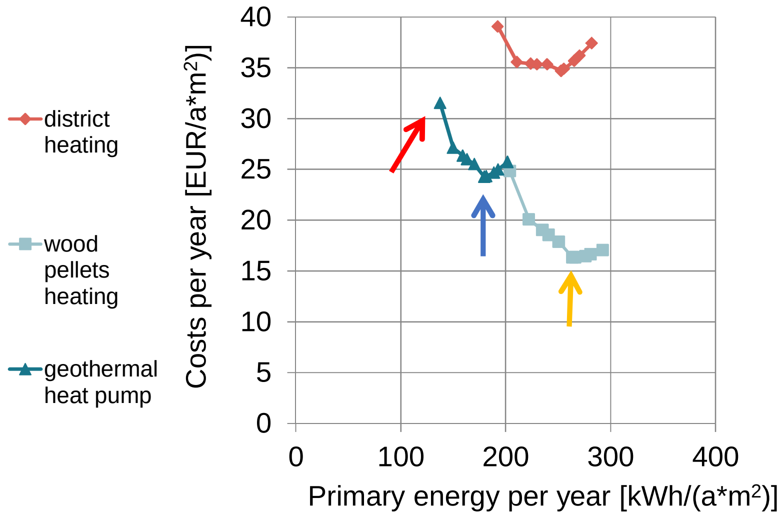

Figure 24 Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on primary energy use in Sweden, for a single family building

Table 25 Identification of co-benefits in selected renovation packages in single family generic building from Sweden

Building elements	Reference	M4 + Wood pellets	M4 + Geo HP	M9 + Geo HP
Facade	Maintenance	30 cm of RW	30 cm of RW	40 cm of RW
Roof	Maintenance	14 cm of RW	14 cm of RW	30 cm of RW
Floor	Maintenance	Maintenance	Maintenance	12 cm of RW
Windows	Maintenance	Maintenance	Maintenance	New window U 1.0
Heating system	Geothermal HP	Biomass	Geothermal HP	Geothermal HP
DHW system	Geothermal HP	Biomass	Geothermal HP	Geothermal HP
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲▲	▲▲	▲▲
Air Quality		▲	▲	▲
External noise				▲▲
Ease of installation		▲	▼▼▼	▼▼▼
Safety				▲▲

The BITS that leads to the cost optimal scenario includes wood pellets heating and the best energy performance is achieved with the geothermal heat pump.

To compare the solutions concerning the co-benefits, in Table 25, three different renovation packages are presented, namely the cost optimal renovation package (M4 + Wood pellets), the scenario that leads to best energy performance (M9 + Geothermal heat pump) and the least cost scenario for the building envelope combined with the geothermal heat pump (M4 + Geothermal heat pump), once it allows better energy performances than the cost optimal renovation package.

The renovation package with the best energy performance presents a significant increase in the global costs when compared with the cost optimal, but with the introduction of new windows, it allows to reduce the exposure to external noise and to increase the safety of the building against intrusions. On the other hand, the difficulties related with the installation of the geothermal heat pump could make it less attractive.

6.3.12. Multi-family building in Sweden

In the Swedish multi-family generic case study, the energy related building renovation measures are the same as for the single-family building, but the cost optimal results present some variations, as shown in Figure 25.

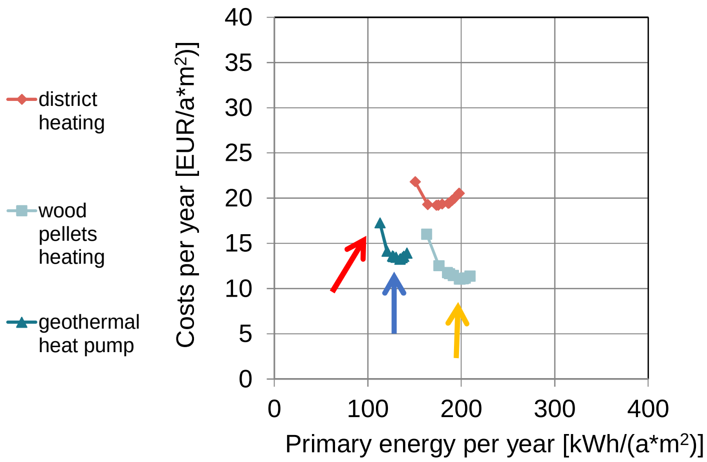

Figure 25 Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on primary energy use in Sweden, for a multi-family building

The cost optimal solution was once again obtained with the use of wood pellets heating. Following the same strategy of the single family building, Table 26 presents the co-benefits for this generic building.

The renovation package with the best energy performance, although presenting an increase in the global costs when compared with the cost optimal, with the introduction of new windows it allows reducing the exposure to external noise and to increase the safety of the building against intrusions. On the other hand, the difficulties related with the installation of the geothermal heat pump could be avoided with the use of a wood pellets boiler, with a decrease of the global costs but with worse energy performance.

Table 26 Identification of co-benefits in selected renovation packages in multi-family generic building from Sweden

Building elements	Reference	M4 + Wood pellets	M4 + Geo HP	M9 + Geo HP
Facade	Maintenance	40 cm of RW	40 cm of RW	30 cm of RW
Roof	Maintenance	30 cm of RW	30 cm of RW	30 cm of RW
Floor	Maintenance	Maintenance	Maintenance	12 cm of RW
Windows	Maintenance	Maintenance	Maintenance	New window U 1.0
Heating system	Geothermal HP	Biomass	Geothermal HP	Geothermal HP
DHW system	Geothermal HP	Biomass	Geothermal HP	Geothermal HP
Co benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲▲	▲▲	▲▲
Air Quality		▲	▲	▲
External noise				▲▲
Ease of installation		▲	▼▼▼	▼▼▼
Safety				▲▲

For the Swedish buildings, the difference in the global costs between the cost optimal solution and the best energy performance is more significant in the single-family building, than in the multi-family building.

7. Recommendations

The main objective of Annex 56 is to provide guidance to support decision makers, including technicians, owners, investors, promoters and policy makers, in the evaluation of the efficiency, cost-effectiveness and acceptance of the renovation measures towards both the nearly-zero emissions and the nearly-zero energy objectives. Thereby it is an objective to identify the optimal range of “minimization of demand” and “generation of renewable energy” measures in a cost/benefit perspective. One of the key challenges is to understand how far it is possible to go with energy conservation and efficiency measures (initially often less expensive measures) and from which point the carbon emissions reduction measures become more cost effective.

The project goes beyond the cost effective reduction of carbon emissions and energy consumption, focusing also on the overall added value achieved in a renovation process, which means also identifying global quality improvement, economic impact of the intervention, operating cost reductions and some co-benefits like comfort improvement (thermal, natural lighting, indoor air quality, acoustics, etc.), increased value of the building and fewer problems related to building physics. In fact, the added value of a building due to the improvement of its energy performance and the deployment of renewable energy refers to the difference in the market value before and after the improvement of the energy performance and results from the valuation from the market of the future energy related costs and also of the resulting co-benefits.

The evaluation of the co-benefits resulting from energy related building renovation that has been presented in the previous chapters of this report allows presenting some conclusions and recommendations for the main target groups of Annex 56, namely the policy makers and the professional owners of residential buildings.

7.1. Recommendations for policy makers

The reduction of energy demand or energy conservation has been the main driver for energy efficiency policies in many countries, with this goal being pursued primarily by improving the efficiency both on the demand side and the supply side. The policy actions to deal with this goal include policies targeting the demand side, such as, in the building sector, establishing building energy codes and setting minimum energy performance requirements for equipment. Other energy efficiency measures focus on improving efficiency in energy supply, such as reducing technical losses in generation, transmission and distribution.

Additionally, the increase of renewable energy in many countries energy portfolio has been used more and more as the way of generating energy that produces no greenhouse gas emissions from fossil fuels and reduces some types of air pollution and to diversify energy supply and reduce dependence on imported fuels. Investments in renewable energy sources are significant, being justified by some governments as having the additional benefit of creating economic development and jobs in manufacturing, installation and technological development.

This report explains and highlights how policies promoting energy efficiency and renewable energy sources do not only lead to energy savings but at the same time create impacts in a broader range of areas of the political action. From environmental aspects such as those related to pollution or climate change, economic aspects as employment or economic growth, and social aspects as health or fuel poverty, energy related policies are connected with a quite broad scope of the range of the political actions.

From a global perspective, policy makers would benefit from gaining a deeper understanding of the dynamics at play in any investment in energy efficiency and renewable energy sources, and subsequently policy design and implementation can be adjusted to minimise undesirable impacts and maximise prioritised impacts. It is the task of policy makers to consider any trade-offs between implementation and other costs of a particular policy related to energy efficiency and renewable energy sources and the related socio-economic gains in welfare.

To effectively be able to take informed policy decisions, policy makers must have available a robust evidence base over the several impacts from their decisions, which implies a rigorous approach to gathering data, quantifying the benefits and applying study results to address policy challenges. Several methodologies and tools exist and can be used to implement such an approach within a national policy process.

Policy makers should create interdisciplinary teams to deal with the mechanisms by which the broader range of benefits can be measured and monetised, and propose how they can be integrated into policy development and evaluation, to support their efforts in optimising the potential value of energy efficiency and the use of renewable energy sources.

Regarding the analysed case studies, some important aspects related with co-benefits from renovation measures at building level should be considered by the policy makers:

- At the building level, in the renovation of existing buildings, energy efficiency measures, when compared to measures for the use of renewable energy sources, are the main source of co-benefits, particularly those improving the building quality (reduction of problems with building physics, increase of useful building areas and improved safety against intrusion) and the resident physical wellbeing (increased thermal and acoustic comfort, increased use of daylighting and better indoor air quality);
- To maximize the co-benefits from energy related building renovation, it is more relevant to improve more elements of the building envelope in combination than to significantly improve single elements. As an example, the improvement of a facade with additional 20 cm of insulation instead of improving it with 10 cm of insulation will be much less relevant (from the perspective of co-benefits) than to supplement the improvement of the facade with 10 cm of insulation with the replacement of windows;
- Depending on the original condition of the building, improving all the elements of the building envelope usually means going beyond cost optimality (once the improvement of certain elements may not be cost effective in a comprehensive package of measures). Although, the difference in

global costs is usually not relevant and packages of measures remain cost-effective when compared to “anyway renovation”. Furthermore, improving all the elements of the building envelope is usually the way to achieve the maximization of the added value from the co-benefits;

- At the building level, measures for the use of renewable energy sources usually have the co-benefits of reducing the exposure to energy price fluctuations. Residents with systems based on renewables (with the exception of systems based on wood pellets) are more comfortable regarding future variations on the energy prices once they are less dependent on energy from the market. Regarding their implementation, many renewable energy systems present a challenge for their integration on existing buildings. Some of these systems (e.g. photovoltaic or solar thermal) often present a challenge for their integration in the architectural characteristics of the existing buildings, while others (e.g. geothermal heat pump) present technical and often also financial challenges to be implemented. On the other hand, other systems (e.g. air/air or air/water heat pumps or wood pellets boilers) are much easier to implement than most of the high efficiency measures and may allow reducing the depth of the interventions on the building envelope.

These conclusions from the analysis of the case studies within the project allows drawing some recommendations for policy makers to be considered when designing standards, regulations and specific programs targeted for the renovation of the existing building stock:

- The economic value of the existing building stock is an important asset that should be potentiated in an optimized way. Energy related building renovation represents an opportunity for this optimized intervention, but renovation measures based on cost benefit analysis only considering energy related costs and benefits usually lead to missed opportunities to increase to the most the building value. Life cycle costs and co-benefits both contribute to improve the building value and cost optimal renovation scenarios are usually not enough to optimize the added value to the building;

- Regarding energy efficiency measures, all the elements of the building envelope should be improved to, at least, a minimum efficiency level designed according to the local climate (in some conditions, the energy performance of some elements prior to renovation, may already achieve that minimum level) in order to maximize the co-benefits from the intervention and consequently the added value to the building. Beyond that minimum level, cost effectiveness of the further improvement of each element can be freely used in the optimization process;

- Whenever the building integrated technical systems are changed, on-site use of renewable energy sources should be prioritized, taking the following issues into consideration:

    - The use of on-site renewables, besides being often the most cost-effective way of reaching significant reductions of emissions, gives the residents a significant comfort regarding energy price fluctuations. Additionally, when these measures are visible (e.g. photovoltaic or solar thermal), they offer the owners enhanced pride and prestige and an improved sense of environmental responsibility. These are co-benefits from measures promoting the use of renewables that contribute to increase the added value;

– The use of renewable energy systems in existing buildings can present a constraint that has to be considered to avoid that they become negative co-benefits contributing to reduce the building value, i.e. the aesthetics and architectural integration (e.g. photovoltaic or solar thermal). Their use has to be regulated in order to avoid negative contributions to the built environment;

– Very often, the cost optimal technical systems are not the ones based on renewable energy, and the related co-benefits are not enough to convince the owners and promoters, due to their increased initial investment. This increased initial investment of the shift to renewables has to be taken into account by policy-makers when preparing standards and incentives.

7.2. Recommendations for professional owners

The value of a building depends on the customers' willingness to pay, whether in a sale process or in a rental one. In the case of energy related building renovation this willingness to pay depends on the expectation of future reduced costs of energy bills and building operation, but also on other benefits not related with energy that result from energy efficiency measures and from the use of renewable energy sources.

The analysis presented in this report allows drawing some recommendations for those involved in the process of deciding among several possible packages of renovation measures, in order to maximize the added value from those renovation measures:

- There is a close relation between specific building renovation measures and co-benefits. This report includes a matrix of these relationships which can be used to support the process of decision-making;

- The matrix mentioned above includes an indication of the relevance of each co-benefit when related to a specific renovation measure. This indication may deliver guidance, but the relevance of the co-benefits should be assessed in depth in each renovation project, as it may vary according to several aspects: - physical or technical conditions of the building prior to the renovation; -climate conditions of the building site; - urban context of the building site; - information and knowledge about the renovation measures by the residents; - age, gender and health condition of the residents; - financial condition of the residents; - occupation profile of the residents; - cultural habits of the residents related with the use of the dwelling and comfort patterns; - market situation for buildings or apartments;

- Independent of the renovation measures, wrong design or bad execution are decisive for the added value of the building and the materialization of possible co-benefits, with a potential of losing the expected co-benefits from the related renovation measures;

- Depending on the original condition of the building and its context, cost optimal packages of renovation measures only considering investment and operational costs are often not very ambitious regarding energy performance, mainly due to certain specific measures which are not cost-effective (many times the replacement of windows, but also floor insulation, facade insulation or ventilation with heat recovery). To maximize the co-benefits from energy related renovation measures, all main elements of the building envelope should be improved to a minimum energy performance dimensioned according to the local climate. In most cases this improvement, represents just a small increase in global costs compared to the cost optimal solution, and is remaining cost effective when compared with “anyway renovation”. Often, cost effective renovation measures can pay for some renovation measures, which are not cost effective, still resulting in a cost effective renovation package;
- Energy efficiency measures, when compared to measures involving renewable energy sources, are the main source of co-benefits at building level. In the analysed case studies, some of the measures related to renewable energy sources were the origin of negative co-benefits, mainly related with the difficulties in their installation. Pride and prestige related with the use of renewable energy sources may be a relevant benefit encouraging their use, but their visibility is important for this particular co-benefit;
- Appendix 1 of this report describes in some detail the relations between co-benefits and several energy related renovation measures. Their use during the process of decision making is encouraged.

References

Amann, J., “Valuation of Non-Energy Benefits to Determine Cost-Effectiveness of Whole-House Retrofits Programs: A Literature Review”. American Council for an Energy-Efficient Economy, 2006

BPIE, “Europe´s Buildings Under the Microscope - A country-by-country review of the energy performance of buildings”, 2011

Copenhagen Economics, “Multiple benefits of investing in energy efficient renovation of buildings – Impact on Public Finances”, 2012

Edwards, L. and Torcellini, P., “A Literature Review of the effects of Natural Light on Building Occupants”, NREL, 2002

EUROPEAN COMISSION, “The European Climate Change Programme”. European Communities, 2006

EUROPEAN COMISSION, “Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A Roadmap for moving to a competitive low carbon economy in 2050”, 2011

European Environmental Bureau, “Harmonised Cost Optimal Methodologies for the Energy Performance in Buildings Directive”, 2010

Grimes A., Denne T., Howden-Chapman P., Arnold R., Telfar-Barnard L., Preval N., Young C., “Cost Benefit Analysis of the Warm Up New Zealand: Heat Smart Programme”, 2011

Goodacre, C., Sharples, S. & Smith, P., “Integrating energy efficiency with the social agenda in sustainability”, UK. Elsevier, 2001

IEA, “Evaluating the co-benefits of low-income energy-efficiency programmes”. Results of the Dublin Workshop 27-28 January 2011. France. OCDE/IEA, 2011

IEA, “Evaluating the Multiple Benefits of Energy Efficiency”, Workshop Report, Paris, 2012a

IEA, ”Spreading the net - The Multiple Benefits of Energy Efficiency Improvements”, France. OECD/IEA, 2012b

IEA, “Summary Workshop Report Roundtable on Health and Well-being Impacts - Capturing the Multiple Benefits of Energy Efficiency”, 18th and 19th April, Copenhagen, Denmark, 2013

IEA “Capturing the Multiple Benefits of Energy Efficiency: A Guide to Quantifying the Value Added”, IEA, Paris, 2014

IEA EBC, Methodology for Cost-Effective Energy and Carbon Emissions Optimization in building Renovation (Annex 56), Energy and Buildings Communities Programme, 2014

Institute for Sustainability, “Post occupancy interview report. Key findings from a selection of Retrofit for the Future projects”, 2013

ISCTE IUL Business School, “Comunicar Eficiência Energética. O Caso Português”, 2011

International Valuation Standards Committee, “8th Edition of the international valuation standards – IVS”. London, 2007

Jakob, M., “Marginal costs and co-benefits of energy efficiency investments. The case of the Swiss residential sector”. Energy Policy, 34, pp 172-187, 2006

Jochem, E., Madlener, R. “The Forgotten Benefits of Climate Change Mitigation:_Innovation, Tecnological Leapfrogging, Employment, and Sustainable Development”. OECD Workshop on the benefits of climate policy: Improving information for policy makers, 2003

Kalc, I., “Energy Retrofits of Residential Buildings. Impact on architectural quality and occupants comfort”, 2012

Max Wei et al, “Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?”, 2009

OECD “The forgotten Benefits of Climate Change Mitigation: Innovation, Technological Leapfrogging, Employment, and Sustainable Development”, 2003

SHC International Energy Agency Task 41, “Solar energy & Architecture,– Solar Heating and Cooling Programme: Solar energy systems in architecture. Integration criteria and guidelines”, 2012

Skumatz, L., “Lessons Learned and Next Steps in Energy Efficiency Measurement and Attribution: Energy Savings, Net to Gross, Non-Energy Benefits, and Persistence of Energy Efficiency Behavior”, Report prepared for CIEE Behavior and Energy Program, California Institute for Energy and Environment, 2009

Ürge-Vorsatz D, Novikova A, Sharmina M., “Counting good: quantifying the co-benefits of improved efficiency in buildings”, 2009

Ürge-Vorsatz, D., “Employment Impacts of a Large-Scale Deep Building Energy Retrofit Programme in Hungary”, Hungary, European Climate Foundation, 2010

UK ERC (Energy Research Center, “The Rebound Effect: An assessment of the evidence for economy-wide energy savings from improved energy efficiency”, 2007

Wyon, D., “The economic benefits of a healthy indoor environment”. La Riforma Medica, 109 (N2, Suppl. 1), pp 405-416, 1994

Appendix 1

Building quality category

Building physics

Building renovation should be performed in ways that reduce the problems related with building physics such as humidity and mould. These problems should be treated with measures to normalise humidity and measures to prevent condensation.

Reduction of the humidity can be done by reducing the production of water vapour and through ventilation. Therefore, the use of air renewal systems and the control of adequate ventilation rates are renovation measures that have the co-benefit of reducing the humidity levels inside the building.

Prevention of condensation can be done by reducing cold surfaces, eliminating thermal bridges and increasing air temperature. In this case, renovation measures such as correct insulation of external walls, roof, ground floor or basement ceiling, correction of balconies' thermal bridges and the use of efficient heating systems, present the co-benefit of reducing the risk of condensation.

On the other hand, wrongly done insulation, without the necessary emphasis on vapour tightness, may increase the risk of condensation. For instance, internal insulation will reduce the temperature in the outer part of the wall, and condensation may occur. Additionally, there is always a risk for negative co-benefits from internal insulation and attic insulation. If they are not properly executed warm moist indoor air can condensate behind the internal insulation and in the attic on the inside of the roof construction. In both cases airtightness is crucial to avoid these problems.

This co-benefit might raise some doubts in order to avoid double counting with "improved air quality" and also "aesthetics". In fact, the reduction of humidity and mould in buildings also has the effect of (further) improving the building appearance, (further) improve air quality and even (further) improve thermal comfort. Nevertheless, in this case the benefit does not relate to the impact of these problems on users or on the building appearance but rather to the physical durability and integrity of the building. It does not overlap neither with maintenance costs once the latter refer to regular maintenance to keep the building elements performing normally nor to works derived from building damages related to defects in the building design.

Ease of use and control by user

The operational comfort means the ease of use of the renovated building and is related with parameters such as the existence of automatic thermostat controls, easier filter changes, faster hot water delivery, less dusting and vacuuming or automatic fuel feeding (Amann, J. 2006).

Operational comfort is not directly correlated with energy consumption, carbon emissions or the costs of renovation measures, so the evaluation of the operational comfort provided by each package of renovation measures is a necessary condition to rank them. Some energy related measures might also have negative co-benefits regarding operational comfort as for example the need of regular filter changing or cleaning of ventilation with heat recovery, as well as heating systems with manual feeding such as wood pellets boilers.

Aesthetics and architectural integration

The aesthetic improvement of the renovated building is very often mentioned as one of the main reasons for building renovation and a largely cited co-benefit of energy efficiency measures (Skumatz, L. 2009). Although, the evaluation of the aesthetic value of the building isn't consensual and depends most on "how" the measures are implemented on the building than on the measure itself. Furthermore, and for the purpose of being considered a co-benefit of an energy related renovation measure, a distinction between aesthetic improvement of anyway renovation and aesthetic improvement by energy related renovation measures must exist.

It can be argued that in most cases, measures to improve the energy performance of the building envelope are an opportunity to improve the aesthetic value of the building, while measures to use on-site energy requires an integration effort. Nevertheless, the aesthetic value of the renovated building will always depend on the characteristics of the building and "how" the renovation measure is implemented, besides the subjective opinion of the evaluator.

When considering the impact of different renovation measures on the aesthetical value of the building, whenever the identity of the building is a value that is worth keeping, only renovation measures that are possible to implement without compromising the identity of the building should be accepted, eliminating all the others. On other words, if a renovation measure presents a negative co-benefit that is unacceptable regarding the impact on the building identity, that measure should not be an option. Then, for the acceptable measures, the technical and aesthetic qualities of the intervention should be weighed.

The danger of losing identity is a negative effect of several renovation measures within certain contexts. As an example, the generalized use of external composite systems causes the disappearance of the original diversity of the cladding, finishes and facade ornaments from the urban landscape (Kalc, I. 2012).

The weighing between technical and aesthetic qualities of the interventions is not an easy task once many interventions have impact on both aspects at the same time but their measurement and comparison uses different evaluation approaches and many times aesthetic and technical aspects may not go in the same direction, and actually could prove to be quite contrasting demands. An example of this is adding insulation at window reveals. Aesthetically, this affects the facade's window-to-wall area in a way that windows appear smaller. However, if windows were not insulated at the reveals, although the introduction of new windows could be perceived as an aesthetical improvement (ISCTE IUL Business School 2011), the result would almost certainly be mould at windows inside the kitchen, or in any other room with high relative humidity inside (Kalc,

l. 2012). In any case, the insulation at the window reveals had in this case a negative co-benefit rather from the aesthetic loss or from problems with building physics.

Another relevant aspect concerning the renovated building aesthetics is the architectural integration of the renewable systems, mainly solar thermal and photovoltaic panels. A controlled and coherent integration of the solar collectors must be achieved simultaneously from all points of view, functional, constructive, and aesthetic. When the solar system is integrated in the building envelope (as roof covering, facade cladding, sun shading, balcony fence…), it must properly take over the functions and associated constraints of the envelope elements it is replacing, while preserving the global design quality of the building (SHC IEA Task 41 2012). By norm, the use of these systems in renovated buildings will present a negative co-benefit, nevertheless, each building will be a single case and the architectural integration will have to be analysed accordingly.

In sum, the impact of building renovation measures in aesthetics and architectural integration strongly depends on the building identity (related to architectural, cultural and historical values of the building and of the building context) and the resulting co-benefits are described in figure 1. Measures that strongly compromise the identity values of a building present a negative co-benefit that should be considered unacceptable. Measures that compromise the identity values of a building in a way that may be acceptable represent a negative co-benefit that should be weighed against the remaining benefits (cost, energy and carbon emissions reductions). Finally, measures that can contribute to improve the identity values of a building represent a co-benefit that should be added to the remaining benefits of energy and carbon related measures. In all these cases, the question of "how" measures are implemented is decisive and the quality of the design process is crucial.

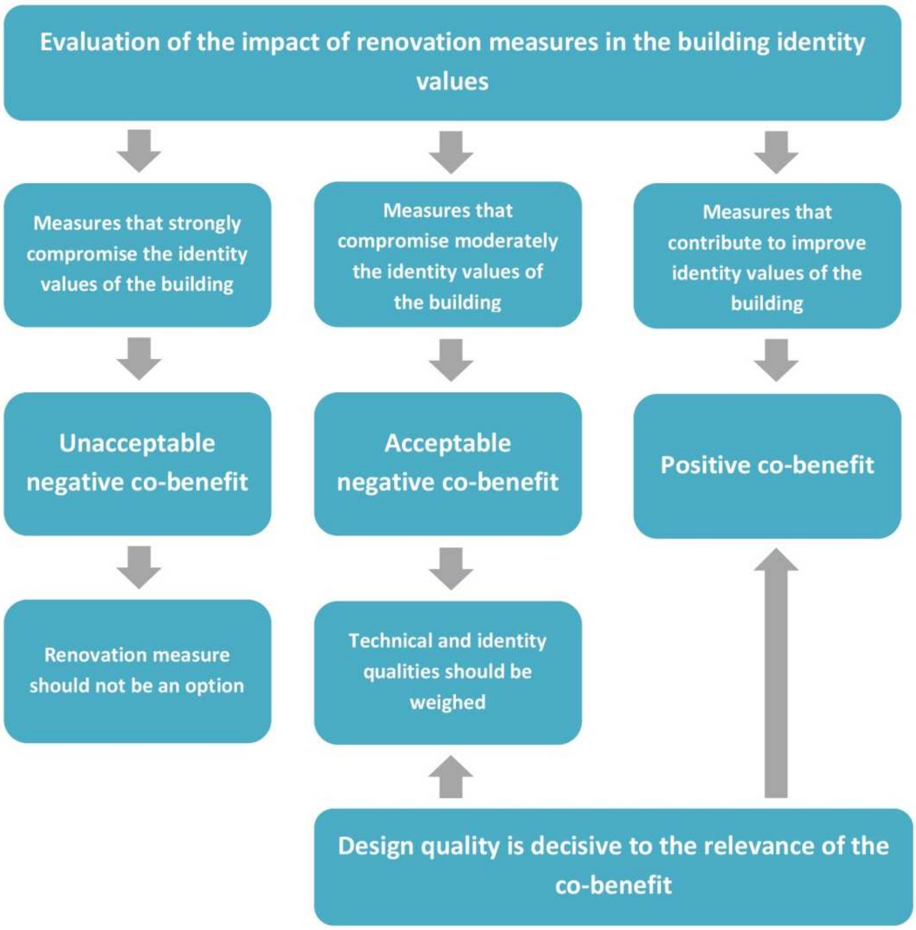

Figure 26 - Aesthetics and architectural co-benefits of building renovation measures

Useful building areas

Changes in useful areas of the buildings occur sometimes because of energy related renovation measures. The increase of this area is normally related with the glazing of balconies or just the replacement of the balconies for others with bigger areas (Kalc, I. 2012), but it also can occur with the replacement of building equipment by other with smaller dimensions. Any increase in useful areas within the dwelling is currently a co-benefit very well received by users (unless the rent has to be drastically increased).

A decrease in areas is a common negative effect from renovation measures such as interior insulation of the outer walls and the introduction of new equipment related to controlled ventilation or equipment for the building systems replacing smaller ones (Institute for Sustainability, 2013).

Safety (intrusion and accidents)

The substitution of elements in the building envelope to improve its energy performance is usually done with new elements that accomplish the latest standards leading to improvements in dealing with risks such as accidents, fire or intrusion.

As an example, the change of windows or doors is normally done using new elements built according to latest standards that enhance safety improvements (ISCTE IUL Business School, 2011) by the use of safety glazing or opening restrictors. These changes reduce the risk of accidents and the risk of intrusion, as well as improve the behaviour in case of fire whether blocking the fire progression or creating a well dimensioned escape exit.

Also in building systems, especially if gas is used, the replacement of the old systems and equipment allows to fulfil latest safety standards and therefore reduce the accidents risk.

Economic category

Reduced exposure to energy price fluctuations

The reduction of the exposure to energy price fluctuation is directly linked with the reduction of the annual energy bill and the regular maintenance costs. Although the full cost evaluation considers all the costs during the life cycle of the renovated building, it uses a scenario for the energy prices evolution. Even if the chosen scenario proves in the future to be correct in the long run, it doesn't consider the short term fluctuations that can raise the energy bill significantly in certain periods since energy demand is not elastic in the short term which causes high price reactions if there is temporary scarcity.

The reduction of the exposure to energy price fluctuations represents to the user a feeling of control over the energy bill and therefore an increased certainty on the future ability of providing to the household the needed level of comfort (Skumatz, L. 2009, Amann, J. 2006, European Environmental Bureau 2010, ISCTE IUL Business School 2011).

A correlation between energy efficiency improvements to buildings and improved mental health and well-being for occupants has also been noticed as a consequence from the control over the energy bill. Investigation of stress pathways and feedback loops can capture the link between energy efficiency upgrades and mental health and well-being improvements. A study of evidence from the UK's Warm Front home energy efficiency scheme suggests that achieving a reduction of financial stress (through energy savings) is an even more significant outcome for recipients than improvement in thermal comfort. Mental health improvements can in turn lead to physical health improvements, and there are both vicious and virtuous circles (IEA 2013).

User wellbeing category

Thermal comfort

Energy needs are usually calculated as the energy needed to keep the internal air temperature of the building within a certain range. However, thermal comfort is not only depending on the room temperature, but also on the radiant temperature, temperature differences, and on air drafts and air humidity.

For instance, high insulation increases the indoor temperature of the outer walls. A reduction of the difference between the outer wall temperature and the average indoor temperature by 5 °C, under certain circumstances, allows a reduction of the indoor temperature by 1 °C or the reduction of approximately 5 % of heat supply at a constant level of comfort. This reduction of the necessary heat supply and the improved comfort at lower temperatures, represents a co-benefit of a specific renovation measure, which can be felt not only from insulating the outer wall, but also with insulation on the other external surfaces (ceiling and floor) and with the replacement of windows improving its thermal transmittance (Amann, 2006). Also better comfort at lower temperatures is an additional co-benefit since there are less air drafts because of lower indoor temperature differences between rooms and indoor walls.

On the other hand, and particularly if this insulation is placed in the internal side of the outer wall, this high insulation level can potentially cause overheating in the summer months as it prevents the wall from absorbing heat from the interior (Kalc, 2012). The insulation in the interior of the outer walls delivers in this scenario a negative co-benefit. Another negative co-benefit of indoor insulation is the risk of humidity and mould damages if the indoor insulation is not done very properly (which is a challenge).

A current way to collect solar heat passively is the use of glazed balconies that can be seen on many retrofitted residential buildings. At the same time they reduce the losses from thermal bridges and collect heat by making use of the greenhouse effect, they increase the radiant temperature of the surfaces that encloses the acclimatized compartments affecting the thermal comfort, with the positive and potentially negative effects already described. In addition, external shading can provide significant control of radiant temperature, especially in windows, with the benefit of allowing a differentiated behaviour according to the year season (allowing radiance in winter and blocking it in summer). Furthermore, the usable living space might be extended for at least part of the year.

In dwellings with very low comfort levels prior to the renovation, the investment in energy efficiency measures is normally stated as not delivering the expected energy savings. This is because users take advantage of the improved performance of the building to improve their comfort conditions instead of reducing their energy bill. This rebound effect should be considered when predicting energy savings from energy renovation measures.

Natural lighting and contact with the outside environment

Humans are affected both psychologically and physiologically by the different spectrums provided by the various types of light. These effects are the less quantifiable and easily overlooked benefits of daylighting. Daylighting has been associated with improved mood, enhanced morale, lower fatigue, and reduced eyestrain. One of the important psychological aspects from daylighting is meeting a need for contact with the outside lying environment (Edwards, L. and Torcellini, P., 2002).

The body uses light as a nutrient for metabolic processes similar to water or food, stimulating essential biological functions in the brain. On a cloudy day or under poor lighting conditions, the inability to perceive the colours from light can affect our mood and energy level. Because natural views tend to produce positive responses, they may be more effective in reducing stress, decreasing anxiety, holding attention, and improving mood. Several studies in 1979, 1981, and 1986 by Ulrich as cited by (Edwards, L. and Torcellini, P., 2002) support the effectiveness of natural views. Viewing vegetation and water through slides or movies is more effective in creating psycho-physiological recovery from stress than built scenes without water or vegetation. In addition, individuals recovered faster and more completely from a stressful event when exposed to films of natural settings as opposed to urban scenes. Nature group subjects also had lower muscle tension, lower skin conductance, and higher pulse transit along with possibly lower blood pressure from these health differences. Furthermore, the same studies reported more positive emotional states and wakeful relaxation states for people exposed to natural scenes (Edwards, L. and Torcellini, P., 2002).

When choosing renovation measures, the enlargement of window areas and the introduction of roof lights or sun pipes are usually related with the reduction of energy use for lighting, but as this studies suggest, the benefits can go far beyond this energy related saving.

On the other hand, the use of glazed balconies can reduce significantly the natural lighting and views from the liveable areas and therefore produce a negative co-benefit in the renovation package. Also the introduction of insulation in the reveal and lintel of windows might reduce the window openings reducing the natural lighting that reaches the inside of the building.

Air quality

Indoor air quality (IAQ) is a term that refers to the air quality within buildings especially as it relates to the health and comfort of building occupants. IAQ can be affected by gases, particulates and microbial contaminants that can induce adverse health conditions. Source control, filtration and the use of ventilation to dilute contaminants are the primary methods for improving indoor air quality in most buildings.

The use of ventilation systems is a renovation measure that has a large influence on the indoor air quality. In buildings with a too-low air exchange rate related to highly airtight building envelopes, some problems in assuring a good interior air quality can be observed. This is due to excessive interior humidity (e.g. due to plants, cooking, showering while not ventilating enough) or due to relatively high pollutant and CO_2 concentration caused by the inhabitants (excessive smoking, used air) or even by the interior furnishing (e.g. synthetic carpets, furniture with pollutant emissions). A controlled minimum air exchange rate provided by the use of these systems can eliminate these problems.

On the other hand, in buildings located in areas with externally polluted air, better air quality is reached by a reduced air exchange rate due to the replacement of windows and doors or by filtering the outside air through ventilation systems and/or by drawing in air from the part of the building turned away from the road.

Improved indoor air quality is therefore a co-benefit of energy saving ventilation systems, particularly where smokers, humid indoor climates or high concentrations of chemicals (emitted from synthetic materials such as carpets or furniture) are present, as well as for buildings located within polluted areas.

Reduced air quality due to the use of mechanical ventilation with heat recovery is a common negative co-benefit due to the risk of dryer air in winter time.

Internal and external noise

The noise reduction benefits arising from a building renovation should be evaluated for two distinct effects, namely the reduction of the exterior noise intrusion, and the annoyance from the operation of HVAC and other equipment.

Introduction of closed balconies and loggias, the replacement of old double-glazed windows, the installation of double or triple-glazing with asymmetrical glass construction, the renewal of roller blind casings as well as heavy insulation material made from mineral substances, all help to reduce the transmission of external noise into the interior of residential buildings (Kalc, I., 2012; ISCTE IUL Business School, 2011). In addition, insulation measures using mineral materials in roofs are of relevant significance particularly against air-traffic noise or traffic noise (Kalc, I. 2012).

Reducing the causes of overheating in summertime by measures as shading, minimizes the use of air conditioning, and besides improves energy efficiency, provides the reduction of indoor noise from the operation of the equipment (European Environmental Bureau, 2010; Institute for Sustainability 2013).

In the case of the reduction of exterior noise, another factor to consider carefully, mainly in the case of the existence of adjacent dwellings, is the fact that when the exterior background noise is reduced, noises from within the dwelling and from adjacent dwellings become more noticeable. These can be considered by the users as uncomfortable or more than the previous background exterior noise and cause social problems between occupants, leading to the need of introducing noise insulation also between dwellings.

Pride, prestige, reputation

Interviews with respondents who have performed relevant energy related improvements in their dwellings, currently report feelings such as enhanced pride and prestige, an improved sense of environmental responsibility, or an enhanced peace of mind related with the responsibility for the family well-being (Amann, J. 2006; ISCTE IUL Business School 2011; Skumatz, L. 2009).

Ease of installation and reduced annoyance

Literature about generic benefits of energy related building renovation is usually focused on the effects occurring during the use of the building after the renovation works, but it is current people who have performed energy related improvements of their buildings to refer the ease or difficulty of performing a certain measure to justify their choice. When comparing different building renovation measures the ease of installation can be evaluated and be used as a parameter to find the package of measures that aggregates the most benefits (ISCTE IUL Business School 2011).

EBC

Energy in Buildings and Communities Programme

www.iea-ebc.org

iea Energy Technology Network

EBC is a programme of the International Energy