International Energy Agency

Methodology for Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation (Annex 56)

Energy in Buildings and Communities Programme

March 2017

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

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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: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)

Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings
Annex 53: Total Energy Use in Buildings: Analysis & 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
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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

Buildings are responsible for a major share of energy use and have been a special target in the global actions for climate change mitigation, with measures that aim at improving their energy efficiency, reduce carbon emissions and increase renewable energy use.

IEA-EBC project «Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation» intends to develop the basics for future standards, which aim at maximizing effects on reducing carbon emissions and primary energy use while taking into account the cost-effectiveness of related measures. The project pays special attention to cost effective energy related renovation of existing residential buildings and low-tech office buildings (without air conditioning systems).

Objectives and contents of the methodology report

The present report outlines the methodology and methodological guidelines for IEA EBC Annex 56. It develops a common methodology for

- a comprehensive evaluation and assessment of cost effective reductions of primary energy use and carbon emissions within energy related building renovation, comprising also life cycle impacts like embodied energy use;
- a clarification of the relationship between emissions and energy targets, the relation between energy efficiency improvement and renewable energy deployment and trade-off analyses between energy efficiency improvement and renewable energy deployment;
- an evaluation of cost effective combinations of energy efficiency measures and renewable energy use and
- highlighting relevant co-benefits, achieved in the process of energy related renovation.

This methodology report comprises the following parts:

- Scopes and perspectives for the assessment: Scope of energy use and carbon emissions investigated, private and societal perspective for the cost and impact assessment;
- Definition of system boundaries for the assessment of costs, energy use and renewable energy generation as well as for related carbon emissions taken into consideration;
- Definition of concepts, approaches, notions, units, metrics and conversion factors for energy and carbon emissions reductions within building renovation;
- Framework for the assessment of costs and the determination of cost optimal as well as cost effective energy efficiency measures and deployment of renewable within building renovation;

- Calculation procedures like calculation of. heating and cooling demand for residential and low-tech office buildings and for different climate zones;
- Life cycle assessment (LCA) methodology to take into account the life-cycle impacts of energy related building renovation, focusing primarily on embodied primary energy use;
- Identification of relevant co-benefits from energy related building renovation and methods to integrate co-benefits into the assessment process of the renovation measures.

Scope of the assessments and evaluations

The focus of Annex 56 is on residential and non-technical office buildings (with no air conditioning systems) which have not been significantly energetically renovated yet. Main issues are primary energy use and related carbon emissions of such buildings as well as the costs incurred by energy related renovation measures/packages.

Assessed energy use, carbon emissions and corresponding conversion factors

Energy use and related carbon emissions are determined on the level of primary energy use and related carbon emissions. Primary energy use is determined from delivered energy to cover the energy demand of the building with the help of national primary energy conversion factors and carbon emission factors. Primary energy conversion factors take into account upstream primary energy use for energy carriers delivered (from the source to the delivery). Carbon emission factors indicate equivalent CO_2 emissions per unit of energy carrier delivered, thereby expressing non-CO_2 greenhouse gas emissions as $CO_{2equivalent}$ emissions, applying the Kyoto CO_2-conversion factors to express the emissions of greenhouse gases as CO_2-equivalents.

Primary energy conversion factors of delivered electricity correspond to the average conversion factor of electricity consumed in the particular country. (Net) electricity exports from on-site renewable electricity generation to the grid apply either

- an appropriate conversion factor for grid electricity substituted by the surplus electricity generated on-site or
- embodied energy of on-site generation equipment.

Elements of operational energy use considered in the assessments:

a) Mandatory:
   - space heating and space cooling;
   - domestic hot water;
   - ventilation;
   - auxiliary electricity for building integrated technical systems (fans, pumps, electric valves, control devices, etc.);

- artificial lighting

b) Optional, if possible and appropriate:
   - built in common appliances (like lifts)

Operational energy demand for plug-in appliances is not considered since it is user dependant (except corresponding its influence on the calculations of the (heat) energy needs of a building where it might be taken into account by standard values).

Embodied energy of renovation measures is considered to be part of the comprehensive assessment. It is desirable to integrate it in the assessments and evaluations of energy related renovation measures. Embodied energy represents an increasing share of the remaining overall primary energy use of buildings albeit for building renovation it is not as important as in the case of new building construction.

Life cycle assessment (LCA)

The LCA methodology of Annex 56 only includes processes with a relevant contribution to the total environmental impacts of renovated buildings which can be put into practice with a reasonable effort. Main focus is the integration of embodied energy and related carbon emissions in the assessments of operational energy use.

LCA shall be integrated in the assessment and in the optimization of renovation measures. The Life Cyle (LC) impacts of renovation packages are determined by comparing them with the LC impacts of a corresponding renovation solution which occurs «anyway» and which aims at restoring full functionality of the building not improving energy efficiency yet. Hence only LC impacts of measures that affect energy performance of the building are considered (thermal envelope, building integrated technical systems (BITS), energy use for on-site production and delivered energy). Thereby the LCA methodology in Annex 56 only includes the operational and embodied energy use and related carbon emissions.

Temporal System boundary: The temporal system boundary for LCA comprises the different stages of the life cycle of building renovation measures (see Figure 1). At least the green stages from Figure 1 are supposed to be taken into account for life cycle assessments in Annex 56. Generally the time range for LCA (reference study period) should comprise at least the service life time of the building elements with the longest service life. In Annex 56 it is suggested to use a study period of 60 years and to report it if a different period is used.

Physical system boundary: The physical system boundary for LCA defines the materials and energy fluxes which must be taken into account for the LCA. The main impacts stem from construction elements and building integrated technical systems (BITS). The construction elements consist of one or more materials. The BITS consist of components (boilers, pumps, etc.) which are made of materials. In addition, these components use one or more energy vectors. The LC impacts are caused by envelope materials and/or BITS components which are added or replaced by energy related renovation measures as well as by operational energy use of BITS during building operation to deliver the expected energy services (heating, cooling, DHW production, etc.), without accounting for those elements which would be replaced anyway.

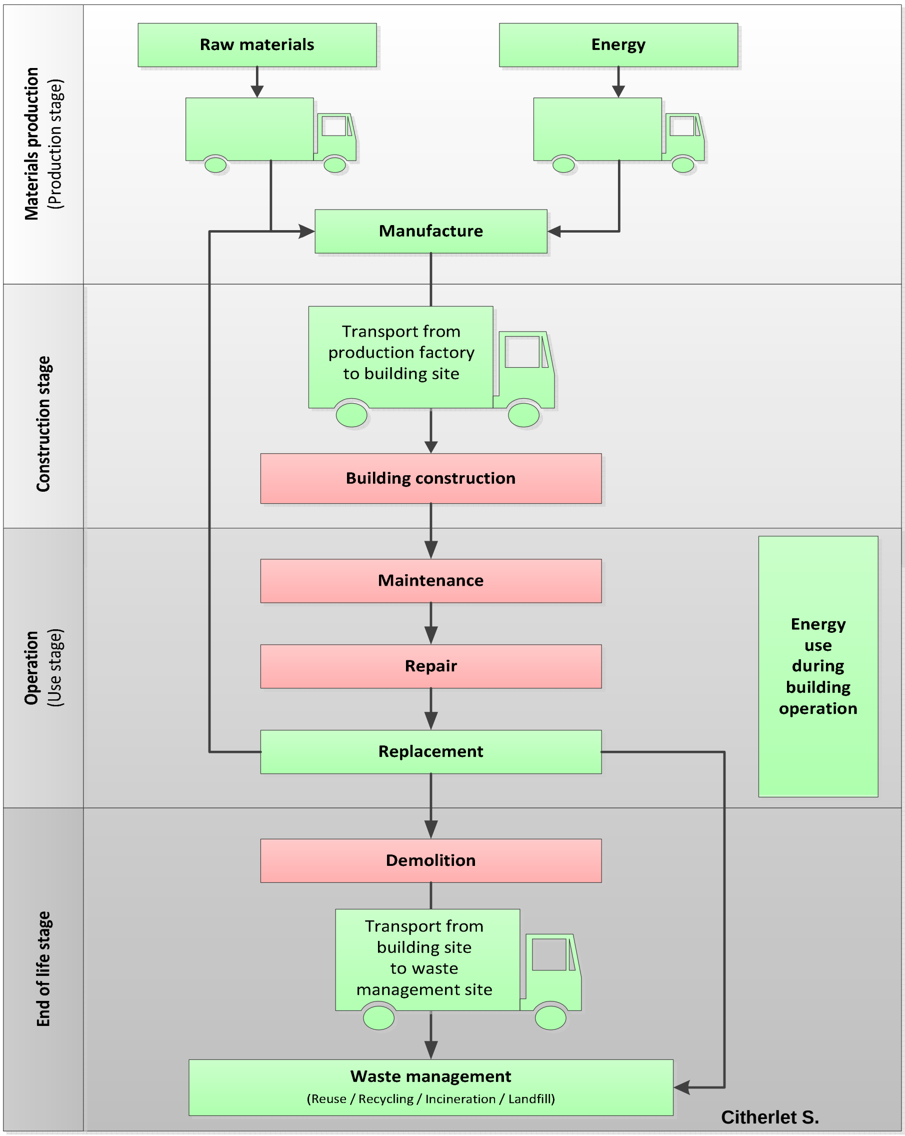

Figure 1 Schematic breakdown of a building's life cycle into elementary stages.

Service life and replacement: The service life is defined as the time during which a building component (construction element, BITS component (boiler, etc.)) fulfils its function. At the end of its service life, the component must be replaced. Not all layers (materials) of a building element are replaced at the same time, some are never replaced (e.g., the bearing structure).

- Some heavy layers are part of the element structure but might still be replaced during the life cycle of the building.

- A material placed between two layers of the envelope structure will have the same service life as the layer with the shorter service life.
- If a construction element is designed to make it easy to replace some internal parts, only the replaced material is taken into account for the assessment.

Hence, the service life of materials depends on the type of construction element (wall, floor, roof, etc…), the situation of the construction element (against ground, exterior and interior) and the position of the material layer within the construction element.

Cost Assessment

Integrating the cost perspective is one of the goals of Annex 56. It is crucial for finding cost effective or cost optimal solutions for far reaching reductions of energy use and carbon emissions by energy efficiency improvements and increased renewable energy use and on-site energy generation. The methodology developed is based on a life cycle cost approach. Usually a private cost/benefit perspective is assumed, comprising

- 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)
- running costs: Energy costs (including existing energy- and CO_2-taxes), maintenance costs (repair, cleaning, inspection, etc.), operational costs (taxes insurance, regulatory costs, etc.).

Subsidies for energy related measures are excluded from the assessment of costs and benefits to have an assessment which is undistorted by currently prevailing subsidy programs (owners or investors assessing a specific renovation project will take possible subsidies for energy related measures into account).

The private cost perspective is relevant for owners and investors but also for policy makers, to consider the impacts of possible policy measures on the private sector.

Social costs, including external costs and benefits and excluding taxes and subsidies are relevant for policy makers for the sake of target setting and for the design of energy and emissions related policy programs. But it may be also relevant for investors and users who assume a societal and long run perspective.

Cost assessment has to be performed dynamically, discounting future costs and benefits (applying the global cost method or the annuity method for the parametric calculations).

Energy related impacts by comparing energy related renovation with «anyway» renovation

To correctly allocate the impacts of energy and carbon emissions related renovation measures, system boundaries have to be clearly defined. Impacts on cost, primary energy and carbon emissions are assessed by comparing energy related renovation solutions with a reference situation which corresponds to an «anyway» renovation, implemented «anyway» because of functional necessity (end of lifetime, defect, outmoded, outworn). Such «anyway» renovations may be needed to restore the previous functionality and the quality of the building, but do not aim at improving the energy performance of the building nor at deploying renewable energy sources (even if they might sometimes improve energy efficiency since the replaced elements are anyway more efficient because of technological progress).

Assessment of cost effective energy related renovation measures

These assessments reveal the trade-offs between (lifecycle) costs, energy efficiency improvements and renewable energy use to reduce primary energy use and carbon emissions and to explore the range of cost optimal and cost effective renovation measures (see Figure 2).

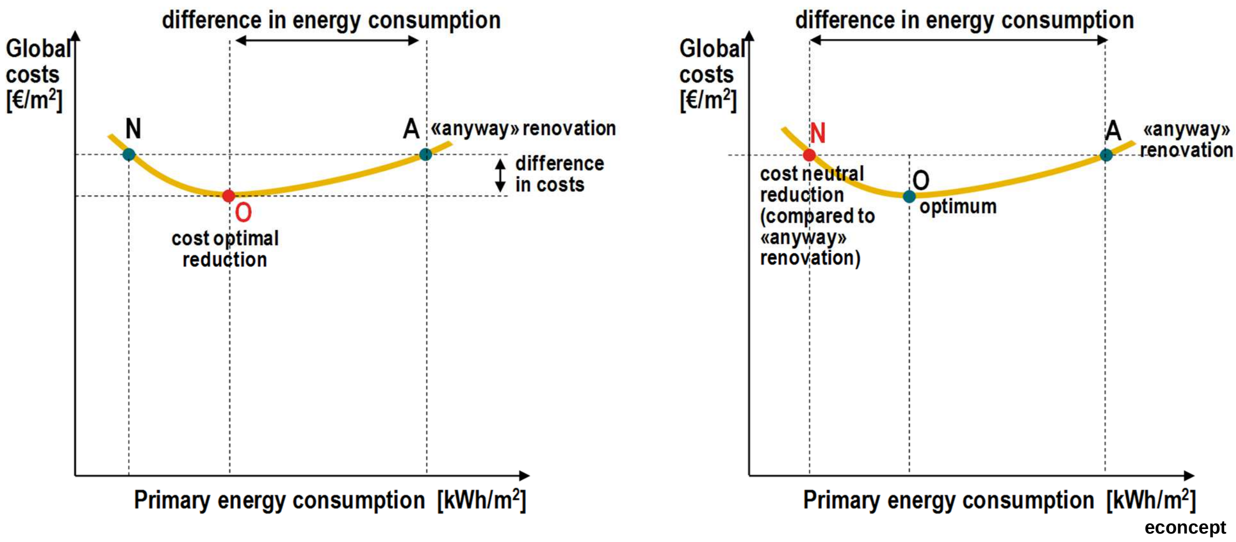

Figure 2 Global cost curve after renovation (yearly costs for interest, energy, operation and maintenance), starting from the reference situation **A** («anyway renovation») towards renovation options yielding less primary energy use than in the case of the anyway renovation. **O** represents the cost optimal renovation option. **N** represents the cost neutral renovation option with the highest reduction of primary energy (BPIE 2010, p. 15, supplemented by econcept).

Co-benefits

Co-benefits in Annex 56 refer to all benefits (as well as to possible negative co-effects of energy related measures) resulting from energy efficiency related renovation measures and deployment of renewable energy besides the direct benefits like less energy use, reduced carbon emissions and energy cost reductions (see Figure 3). Often, co-benefits are relevant or even decisive for overall value added by energy related building renovation (difference in the market value of the building before and after improvement of its energy performance) but are not integrated adequately in the decision processes for the particular renovation project. Co-benefits of energy related renovation accrue on the building level for the building owner or user (like increased user comfort, fewer problems with building physics, improved aesthetics, see Table 1) as well as on the society or macroeconomic level (like health benefits, job creation, energy security, impact on climate change, see Table 2)

Some of the subsequent co-benefits have to be attributed to anyway renovations too and accrue for packages of energy related renovation measures as well as for a package of anyway renovation measures (e.g. aesthetic improvement and enhanced pride or prestige because of a higher aesthetic value of building because of façades newly painted in the anyway case as well as in the case of a façade renewal with new additional insulation). Co-benefits which might also emanate from anyway renovations are marked in Table 1 with ***)**.

Table 1 Typology of private benefits of cost effective energy related renovation measures
***)** These co-benefits might also accrue (at least partly) in the case of an anyway renovation

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, easy filter change, faster hot water delivery, etc.)
	Aesthetics and architectural integration ***)**	Aesthetic improvement of renovated buildings (often depending on the building identity) as one of the main reasons for building renovation
	Useful building areas ***)**	Increase of the useful area (glazing of or replacement by larger balconies) but decrease of useful area in case of interior insulation or new BITS)
	Safety (intrusion and accidents) ***)**	Replacement of building elements with new elements at the latest standards, providing fewer risks such as accidents, fire or intrusion.
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 keep the needed level of comfort.
User wellbeing	Thermal comfort	Higher thermal comfort due to better room temperatures, higher radiant temperature, less temperature differences, air drafts and air humidity.
	Natural lighting and contact with outside	More day lighting, involving visual contact with the outside living environment (improved mood, morale, lower fatigue, reduced eyestrain).
	Air quality	Better indoor air quality (less gases, particulates, microbial contaminants that can induce adverse health conditions) better health and more comfort
	Internal and external noise	Reduced transmission of external noise into the interior but risk of more annoyance from internal noise after 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.

Category	Co-benefit	Description
	Ease of installation, reduced annoyance	Ease of installation can be used as a parameter to find the package of measures that aggregates the most benefits

Table 2 Typology of macroeconomic benefits of cost effective energy related renovation measures ***)** These co-benefits might also accrue (at least partly) in the case of an anyway renovation

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 impacts and building damages.
	Construction/demolition waste reduction	Building renovation leads to reduction, reuse and recycling of waste compared to the replacement of existing buildings by new ones.
Economic Social	Lower energy prices	Decrease in energy prices due to reduced energy demand
	New business opportunities	New market niches for new companies (like ESCOs) resulting in higher GDP growth.
	Employment 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 in heavily subsidized).
Social	Improved social wel-fare, less fuel poverty	Reduced expenditures on fuel and electricity; less affected persons by low energy service level, less exposure to energy price fluctuations
	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”.
	Energy security	Reduced dependence on imported energy.

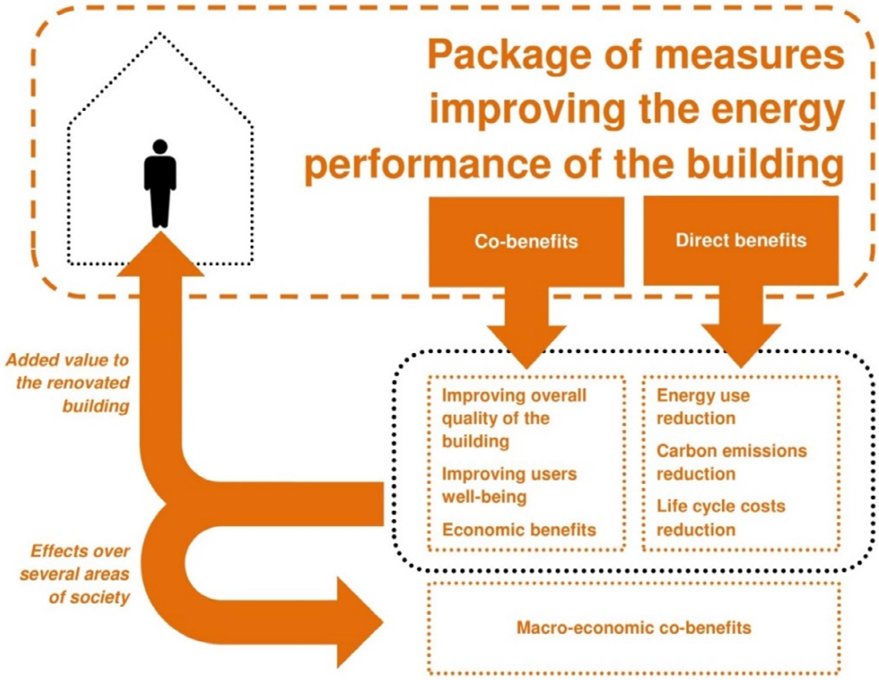

Figure 3 Direct benefits and co-benefits from cost effective energy and carbon emissions related building renovation

Integration of co-benefits into the assessment of cost effective building renovation

Co-benefits, reduced costs from improved energy performance and use of renewable energy contribute to the overall market value of a building. However, when it comes to market value, the two aspects can be distinguished only theoretically. An improvement of the energy performance of a building with identical life-cycle costs and identical energy performance might have different added values at different locations, just because the willingness to pay revealed by users in different markets might vary substantially. Evidence from other markets concerning price variations for energy performance and related co-benefits might not be relevant in a differing context situation.

Empirical data on co-benefits is scarce, quantification and/or monetarization are tedious. Furthermore, co-benefits are to a certain extent context specific. This makes it difficult to add their contribution to a traditional cost-benefit analysis and to the assessment of renovation measures.

Methods to valuate private or microeconomic co-benefits

Existing methods to empirically determine and quantify private microeconomic co-benefits rely on surveys applying different approaches:

- Simple Contingent Valuation (CV) and Willingness to Pay (WTP) / Willingness to Accept (WTA) surveys: The CV method for co-benefit valuation entails in its most basic form simply asking respondents to estimate the value of the benefits and their WTP or WTA for it, respectively. Common shortcomings of these methods are the artificial situation for the respondents, strategic answers and the lacking budget constraint.

- Relative scaling methods ask respondents 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.

Integration into evaluation of renovation measures can be done directly, if estimated monetary values for co-benefits are available. If only qualitative information is available, they can be integrated either by a multi criteria analysis or just as additional (promoting) information in the anyway done cost/benefit assessment and subsequent decision making.

Cost effective optimization of energy use and carbon emissions reductions

Although on a general level the importance of carbon emissions reductions is acknowledged, the main focus in the building sector is still on energy targets and on cost effectiveness. For energy and carbon emission related building renovation, cost reasons require more attention for renewable energy deployment which could be fostered by explicit carbon emissions targets in the building sector. If we assume that

- meeting global carbon emissions targets has high priority,
- the level of cost optimal measures has to be outperformed to meet these targets,
- energy performance of the building, achieved at the cost optimum is sufficient for thermal comfort and the requirements of building physics,

then it appears appropriate to optimize those efficiency and renewable energy deployment measures which are still cost effective, to get as much carbon emissions reductions as possible.

Concluding remarks

The methodology outlined provides the necessary basics for the assessment of existing buildings undergoing energy related renovation processes and for the comparison of possible energy related renovation alternatives. The results of the assessment and evaluations allow for appraising the energy performance of the building, the options to use renewable energy, the trade-offs between measures increasing energy efficiency and renewable energy use and related costs. It provides indications for future standard design or amendments and for target setting in the sector of existing residential buildings and low-tech office buildings. The methodology also delivers guidelines for policy makers, building owners, investors and occupants.

The methodology provides for correct and comprehensive assessments and evaluations of renovation measures. Comprehensive impact assessment means:

- Taking into account all relevant cost elements (also maintenance, repair, replacement costs) and all relevant impacts i.e. also embodied energy of renovation measures;
- Life cycle cost assessment (during the whole life cycle of the building or during the whole calculation period (taking into account residual values)) and life cycle impact assessment as far as feasible (e.g. embodied energy);
- Dynamic cost assessment, discounting future costs and benefits;
- Comparison with a reference case involving «anyway» renovations, which are renovations restoring full functionality of the building, renewing building elements which are at the end of their life time. «Anyway» renovation does not aim at improving energy performance of the building or deployment of renewable energy within building rehabilitation.

The energy and renovation cost perspectives are limited and have some shortcomings, since only costs of renovation measures and direct benefits from energy cost savings are taken into account. A comprehensive assessment and evaluation of energy related renovation measures for a building owner or investor will comprise all benefits, i.e. not only benefits of operational energy cost savings but also all of the co-benefits. In the end, the total value added to a building by energy related building renovation is relevant for building owners. For the owners and investors the value of the building is reflected best by the willingness to pay by users, occupants and owners for using the building. But to make use of the added value of a high energy performance of buildings or of renewable energy use, it is indispensable that potential and current owners, users and potential buyers perceive all benefits.

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Abbreviations

Abbreviations	Meaning
AT	Austria
BITS	Building integrated technical systems
CH	Switzerland
DHW	Domestic hot water
DK	Denmark
EN	European Norm
EPBD	Energy Performance of Buildings Directive
ES	Spain
GHG	Greenhouse gas
HP	Heat pump
GWP	Global warming potential
IEA-EBC	Energy in Buildings and Communities Programme of the International Energy Agency
kWh	Kilowatt hours: 1 kWh = 3.6 MJ
λ	Lambda-value (value for the insulating capacity of a material)
LC	Life cycle
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
MFB	Multi-family building
MFH	Multi-family house
MJ	Mega joule; 1 kWh = 3.6 MJ
NO	Norway
NRE	Non-renewable energy (fossil, nuclear, wood from primary forests)
NRPE	Non-renewable primary energy
NZEB	Nearly zero energy building or nearly zero emissions building
PE	Primary energy
PT	Portugal
PV	Photovoltaic (cell or panel)
Ref	Reference
RES	Renewable energy sources
SE	Sweden
SFB	Single-family building
SFH	Single-family house
STA	Annex 56 Subtask A (Methodology, parametric calculations, LCA, co-benefits)
STB	Annex 56 Subtask B (Tools)

Abbreviations	Meaning
STC	Annex 56 Subtask C (Case Studies)
STD	Annex 56 Subtask D (User Acceptance and Dissemination)
UNFCCC	United Nations Framework Convention on Climate Change
U-value	Thermal transmittance of a building element
WP	Work Package

Definitions

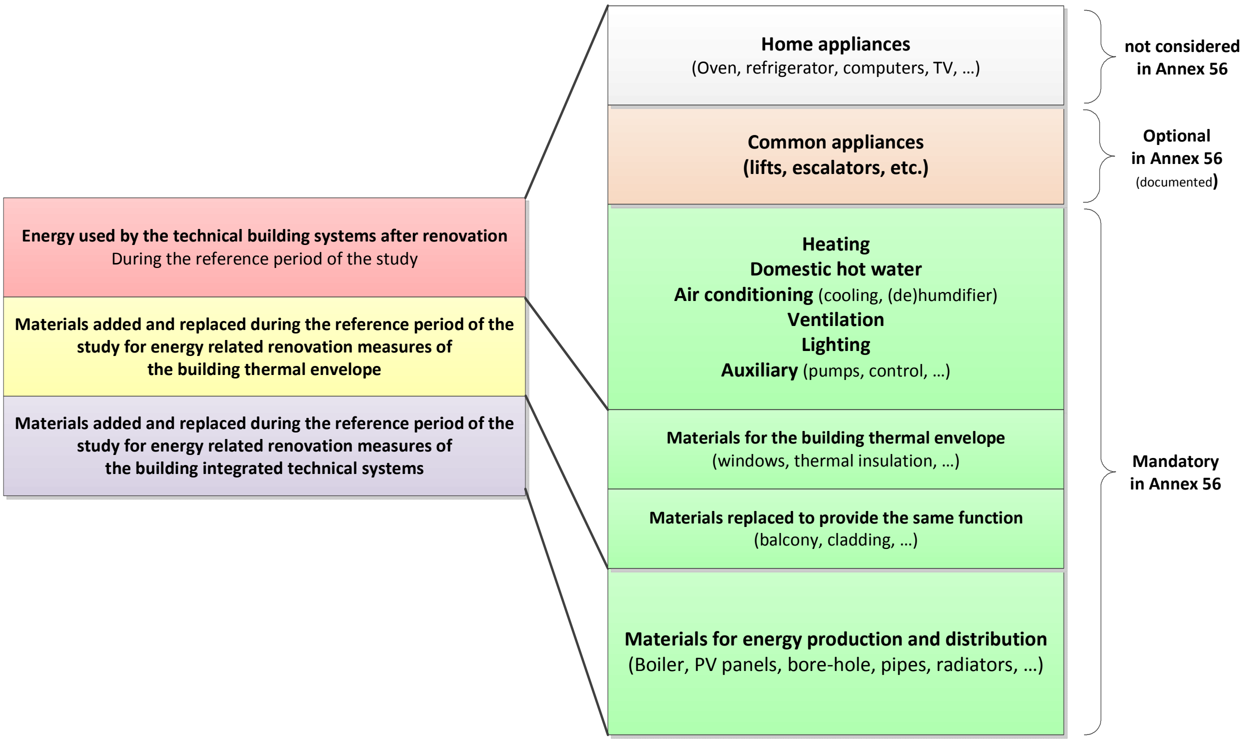
Definitions of energy performance according to EN 15603:2008 (Official Journal of the EU, 19.4. 2012, p. C 115/9):

- **Energy source:** source from which useful energy can be extracted or recovered either directly or by means of a conversion or transformation process.
- **Energy carrier:** substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes.
- **System boundary:** boundary that includes within it all areas associated with the building (both inside and outside the building) where energy is consumed or produced.
- **Energy need for heating or cooling:** heat to be delivered to or extracted from a conditioned space to maintain intended temperature conditions during a given period of time.
- **Energy need for domestic hot water:** heat to be delivered to the needed amount of domestic hot water to raise its temperature from the cold network temperature to the prefixed delivery temperature at the delivery point.
- **Energy use for space heating or cooling or domestic hot water:** energy input to the heating, cooling or hot water system to satisfy the energy need for heating, cooling or hot water respectively.
- **Energy use for ventilation:** electrical energy input to the ventilation system for air transport and heat recovery (not including the energy input for preheating the air).
- **Energy use for lighting:** electrical energy input to the lighting system.
- **Renewable energy:** energy from sources that are not depleted by extraction, such as solar energy (thermal and photovoltaic), wind, water power, renewed biomass. (definition different from the one used in Directive 2010/31/EU).

− **Delivered energy:** energy, expressed per energy carrier, supplied to the technical building systems through the system boundary, to satisfy the uses taken into account (heating, cooling, ventilation, domestic hot water, lighting, appliances, etc.).

− **Exported energy:** Energy, expressed per energy carrier, delivered by the technical building systems through the system boundary and used outside the system boundary.

− **Primary energy:** Energy found in the nature that has not been subject to any conversion or transformation process. It is energy contained in raw fuels and other forms of energy received as input. It can be non-renewable or renewable.



Definitions of embodied energy and embodied carbon emissions (according to IEA Annex 56), life cycle assessment (LCA) and life cycle impact assessment (LCIA) according to ISO 14040:2006:

− **Embodied energy**: Comprises the cumulated primary energy use for the production, transportation, replacement and disposal of building components for the thermal envelope and building integrated technical systems (e.g., renewable energy generation units, heating systems) used in energy related building renovation. In addition, the embodied energy also includes the anyway renovation actions with materials and technical systems added to restore the functionality of the building after renovation (e.g., painting or repair of a wooden frame, replacement of a conventional heating system with a heating system of the same type etc.).

- **Embodied carbon emissions**: Comprises the cumulated greenhouse gases emissions for the production, transportation, replacement and disposal of building components for the thermal envelope and building integrated technical systems (e.g., renewable energy generation units, heating systems) used in energy related building renovation.
- **LCA:** Life cycle assessment: compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.
- **LCIA:** Life cycle impact assessment: phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system.

Note 1: In this report, the term “LCA” will be used for describing the methodology used to assess the environmental impacts of energy related building renovation while the term “LCIA” will only refer to the step of the impact calculations within this methodology.

Note 2: According to the EBC-decision, the term “greenhouse gas emissions” is assumed to be equivalent to the term “carbon emissions”. As a result, this last term “carbon emissions” will solely be used in all Annex 56 reports and results.

1. Introduction

1.1. General context

Extrapolating current trends in energy supply and use suggests that existing goals to mitigate carbon emissions and to reduce non-renewable energy consumption will not be met. To change the looming path it is crucial to identify existing large and promising reduction potentials.

With a share of more than 40% of the final energy use and some 35% of carbon emissions, the building sector represents the largest energy consuming sector and is considered as «the largest untapped source of cost effective energy saving and CO_2 reduction potential (at least) within Europe, yet the sector continues to suffer from significant underinvestment» (BPIE, February 2013, p. 5). This holds particularly for the stock of existing buildings, whose energy related improvement is highly relevant for mitigating carbon emissions and energy use, yet it is a challenge to unleash these potentials.

Up to now, the focus on energy and carbon emissions related strategies in the building sector was largely on tapping and developing efficiency potentials of new buildings, and thereby mainly on improving the energy performance of the building envelope: As for example the European Energy Performance of Buildings Directive (EPBD) and its recast are putting high emphasis on the high energy performance of the building, albeit in its two step approach deployment of renewable energy is also addressed to further decrease non-renewable energy demand in a second step (see e.g. Holl M. 2011, p. 17). However, the question may be raised if such standards are primarily adequate for new buildings but do not respond effectively to the numerous technical, functional and economic constraints of existing buildings. Hence, it might be that taking economic cost and cost optimal solutions as a boundary condition beyond which it will be difficult to oblige building owners to take measures, resulting improvements in energy performance of buildings during renovation might not be sufficient to meet the targets at stake. Furthermore, cost effectiveness of renovation measures on the building envelope may be different if a switch to renewable energies is taken into account. It is therefore interesting to investigate in more detail the reductions of energy use and carbon emissions and related cost effectiveness for renovation measures comprising both, energy efficiency measures and renewable energy based measures.

Given the major challenge of mitigating climate change and the important share of carbon emissions caused by energy consumption in existing buildings, reducing carbon emissions within building renovations is an important objective. Up to now standards for building renovation have focused mainly on the reduction of energy use which also contributes to the reduction of carbon emissions. Given the economic constraints of building renovation it is interesting to compare the effects of renovation packages consisting of measures to reduce energy demand and measures to reduce carbon emissions and put them into perspective. Some measures might reduce carbon emissions significantly but have relative little impact on energy demand (e.g. using wood for heating). Hence, when setting standards for building renovation, taking both perspectives of energy use reduction and carbon emissions reduction may become more important in the future.

As energy performance of buildings increases, the share of embodied energy in the materials used in building renovation becomes more important. Therefore, the methodology to integrate the assessment of embodied energy use will be outlined in Annex 56.

In the case of existing buildings it can be observed that opportunities to significantly improve energy performance of buildings within building renovation are missed too often, despite cost effectiveness if a life cycle cost approach is assumed. Often, this is because of higher initial costs but also because of lacking know-how and awareness regarding (life cycle) cost effectiveness. Hence it is relevant to explore and illustrate the range of cost effective renovation measures to increase efficiency and deployment of renewable energy to achieve the best building performance (less energy use, less carbon emissions, high overall added value achieved by the renovation) at the lowest effort (investment, life cycle costs, intervention in the building, users' disturbance). Thereby it is also interesting to investigate in more detail the co-benefits of building renovation measures for building occupants and how they can be taken into account in the decision making process of building owners.

To investigate related questions within the framework of Annex 56, an adequate methodology for energy and carbon emissions optimized building renovation will be developed which addresses the particular situation of renovation of existing buildings. It is supposed to become a basis for extending and further developing existing standards, to be used by interested private entities and agencies for their renovation decisions as well as by governmental agencies for the policy evaluation and for the definition of their strategies, regulations and their implementation.

The trigger to launch IEA-EBC Annex 56 «Cost effective energy and carbon emissions optimization in building renovation» was to integrate costs in the evaluation of energy and carbon emissions related measures and to investigate the relationship as well as the trade offs between energy efficiency measures and renewable energy measures. For building renovation, the trade-offs and synergies between higher building envelope's efficiency, highly efficient technical building systems and deployment of renewable energy, considering carbon emissions as well as primary energy use, shall be explored.

1.2. Objectives of IEA-EBC Annex 56 for the development and demonstration of a cost, energy and carbon emissions related assessment and evaluation framework

Annex 56 strives to achieve the following objectives:

- Define a methodology for the establishment of cost optimized targets for energy use and carbon emissions in building renovation;
- Clarify the relationship between the emissions and the energy targets and their eventual hierarchy;
- Determine cost effective combinations of energy efficiency measures and renewable energy based measures;
- Highlight the relevance of co-benefits achieved in the renovation process;
- Develop and/or adapt tools to support the decision makers in accordance with the methodology developed;
- Select exemplary case-studies to encourage decision makers to promote efficient and cost effective renovations in accordance with the objectives of the project.

These objectives were pursued by the subsequent four Subtasks (STA – STD):

STA: Development of the methodology and application of the methodology to assess costs, energy and carbon emissions related impacts of building renovation measures by parametric calculations for generic buildings and for detailed case studies from countries participating in Annex 56. The methodology allows including the relevant aspects related to the LCA and the assessment of co-benefits into the overall assessment of cost effective energy related renovation measures.

STB: Development of tools and guidelines to support decision makers (building owners, investors, policy makers).

STC Case studies and shining examples to demonstrate the state of the art in energy related building renovation for the sake of information and motivation of building owners, investors and policy makers.

STD: Exploration of user acceptance and dissemination of the findings of Annex 56.

1.3. Contents of the methodology report

This report delivers the methodological guidelines for Annex 56 and outlines and documents the foundation of the assessment and evaluation methodology to be applied in Annex 56 for:

- the comprehensive evaluation and assessment of cost effective reductions of primary energy use and carbon emissions within energy related building renovation, comprising also lifecycle impacts like embodied energy;
- the clarification of the relationship between emissions and energy targets and their eventual hierarchy;
- the evaluation of cost effective combinations of energy efficiency measures and measures to increase renewable energy use;
- the highlight of the relevance of co-benefits achieved in the renovation process.

The methodological guidelines presented in this report aim at defining and harmonizing scope, notions, system boundaries, approaches, calculation methods and assumptions regarding input values and their future perspectives for evaluating and assessing energy related building renovation activities which aim to achieve cost effective solutions yielding maximum energy and carbon emissions reductions. The guidelines address renovation of the residential building stock comprising also office buildings without complex building technologies. The methodology outlined draws thereby among other sources from the newest developments within the recast of the Energy Performance of Building Directive (EPBD) of the European Union[1] and methodology development in IEA SHC Task 40/EBC Annex 52 «Towards Net Zero Energy Solar Buildings»[2].

The methodology provides the basis for the assessment and evaluation of energy related renovation options, first and foremost with respect to cost, energy use and carbon emissions. Furthermore, it allows also for a broader approach going beyond cost effective reduction of carbon emissions and energy use by taking into account co-benefits and overall added value achieved in a renovation process. It also provides a methodological framework for integrating embodied energy for renovation measures as part of a lifecycle impact assessment. It allows assuming either an individual end-user and investor perspective respectively (financial or microeconomic) or a societal (macroeconomic) perspective. The methodology and resulting fundamentals for renovation standards are applicable to different climatic and country specific situations.

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1 European Parliament and Council of the European Union (2010) Directive 2010/31/EU of the European Parliament and of the council of 19 May 2010 on the energy performance of buildings (recast);
Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012, supplementing Directive 2010/31EU on the energy performance of buildings, establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements;
Directive 212/2/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30EU and repealing Directives 2004/8/EC and 2006/32/EC;
European Commission, Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012, supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings, 2012/C 115/01;
European Commission, Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012, supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings, 2012/C 115/01;
European Commission (2011), Meeting Document for the Expert Workshop on the comparative framework methodology for cost optimal minimum energy performance requirements In preparation of a delegated act in accordance with Art 290 TF EU 6 May 2011 in Brussels;

2 See http://www.ecbcs.org/annexes/annex52.htm

The methodology report presented here comprises the following parts:

- Methodology, calculation procedures, notions, scopes and boundary conditions to be applied within Annex 56;
- Scopes and perspectives for the assessment: Scope of energy use and carbon emissions investigated (chapter 2.1 «Scope of the assessment of energy and carbon emissions related building renovation measures» and chapter 2.2 «System boundaries and metrics for energy and carbon emissions related building assessment»), scope of the cost assessments (chapter 5.1), private and societal perspective for the cost and impact assessment (chapter 5.3);
- Definition of system boundaries for the assessment of costs (chapters 5.1 to 5.3), energy use and supplies as well as for carbon emissions taken into consideration and investigated (chapter 2.2 «System boundaries and metrics for energy and carbon emissions related building assessment» and chapter 4 «Life cycle Assessment (LCA) for energy related building renovation»;
- Definition of concepts, notions and units (chapters 2.2 «System boundaries and metrics for energy and carbon emissions related building assessment», 4.2 «Existing LCA methodologies», 5.1 «Scope of cost evaluation» and chapter 5.3 «Different perspectives: Private costs, social costs and benefits»);
- Definition of metrics and conversion factors (chapter 2.2 «System boundaries and metrics for energy and carbon emissions related building assessment»);
- Definition of calculation procedures (chapter 3.2 «From energy needs to primary energy use and carbon emissions» and chapter 5 «Cost assessment: Methodology framework»;
- LCA methodology and LC-impacts to take into account for the assessment of the impacts of energy related building renovation in Annex 56 (chapter 4 «Life cycle Assessment (LCA) for energy related building renovation»);
- Identification of relevant co-benefits from energy related building renovation and definition of the methods how to integrate these co-benefits into the overall assessment of the renovation measures (chapter 6 «

- Co-benefits»).

2. Scope, system boundaries and definitions

This chapter gives an overview on the scope of the assessments necessary for the elaboration of the basics for cost, energy and carbon optimized renovation standards, on the system boundaries as well as on definitions for these assessment and optimization processes in Annex 56. It aims at developing the prerequisites for a common assessment and evaluation framework for Annex 56. Some definitions introduced in this chapter are based on methodological principles of LCA which are further developed in chapter 4 “Life cycle Assessment (LCA) for energy related building renovation”.

2.1. Scope of the assessment of energy and carbon emissions related building renovation measures

For assessing and evaluating energy related renovation of residential and simple office buildings, the following components of energy use and related carbon emissions are relevant:

- Operational energy use for space heating;
- Operational energy use for space cooling;
- Operational energy use for ventilation (HVAC);
- Operational energy use for domestic hot water (DHW);
- Operational energy use for auxiliary energy use for heating, cooling and DHW (fans, pumps, electric valves, control devices, etc.);
- Operational energy use for artificial lighting;
- Operational energy use for built-in common appliances[3];
- Embodied energy of building materials, technical equipment and appliances (newly built in during building renovation and replaced elements during building operation): This share of primary energy use in the building sector is increasing due to the supposed decrease of energy needs for HVAC. For the sake of a comprehensive assessment it is preferable to include embodied energy in analyses (see chapter 4), even if in the case of building renovation embodied energy is less relevant than in the case of new building construction.

3 Built-in household appliances (like stove, washing machine, refrigerator/freezer, tumbler: In some countries they are provided by the owner/landlord, in other countries they are not built-in but provided by the occupants) and built-in common appliances like lifts, escalators, garage ventilation, etc..

In Annex 56 it is not integrated or integrated by default values into the assessments:

- Operational energy use of individual plug-in appliances is not included in the assessments[4].

2.2. System boundaries and metrics for energy and carbon emissions related building assessment

The system boundaries for the energy related assessment of renovated buildings and the definition of the relevant energy flows are shown in Figure 4 (see below).

Levels of energy flows:

- Energy demand/energy needs of the building (net energy need, see Figure 4), taking into account heat gains and thermal losses;
- Final energy (net delivered energy, see Figure 4), taking into account energy delivered to the building, on-site energy generation and energy exported to grids;
- Embodied energy for energy related building renovation (in the case of new buildings it would be the embodied energy of new building construction). Embodied energy comprises the cumulated primary energy demand for production, transportation and disposal of building components, appliances, renewable energy generation units and building construction measures within building renovation (see chapter 4).

4 See guidelines accompanying Commission Delegated Regulation supplementing EPBD (Directive 2010/31/EU) which proposes that electricity for household appliances and plug loads may be included, but not mandatorily (Official Journal of the EU, 19.4. 2012, p. C 115/8). In many countries, household appliances (like stove, washing machine, refrigerator/freezer, tumbler) are provided by the owner or landlord which suggests that their energy use is included. The share of plug-ins on the energy consumption of buildings will increase with increasing needs for plug-in energy services as well as with decreasing energy use and carbon emissions for heating. Therefore it might be that integration of plug-ins will be reconsidered in the future. Hence plug loads may be included in energy and carbon emissions assessment (possibly with the help of default standard energy use and carbon emission values, to at least roughly illustrate their impact and relevance on the assessment).

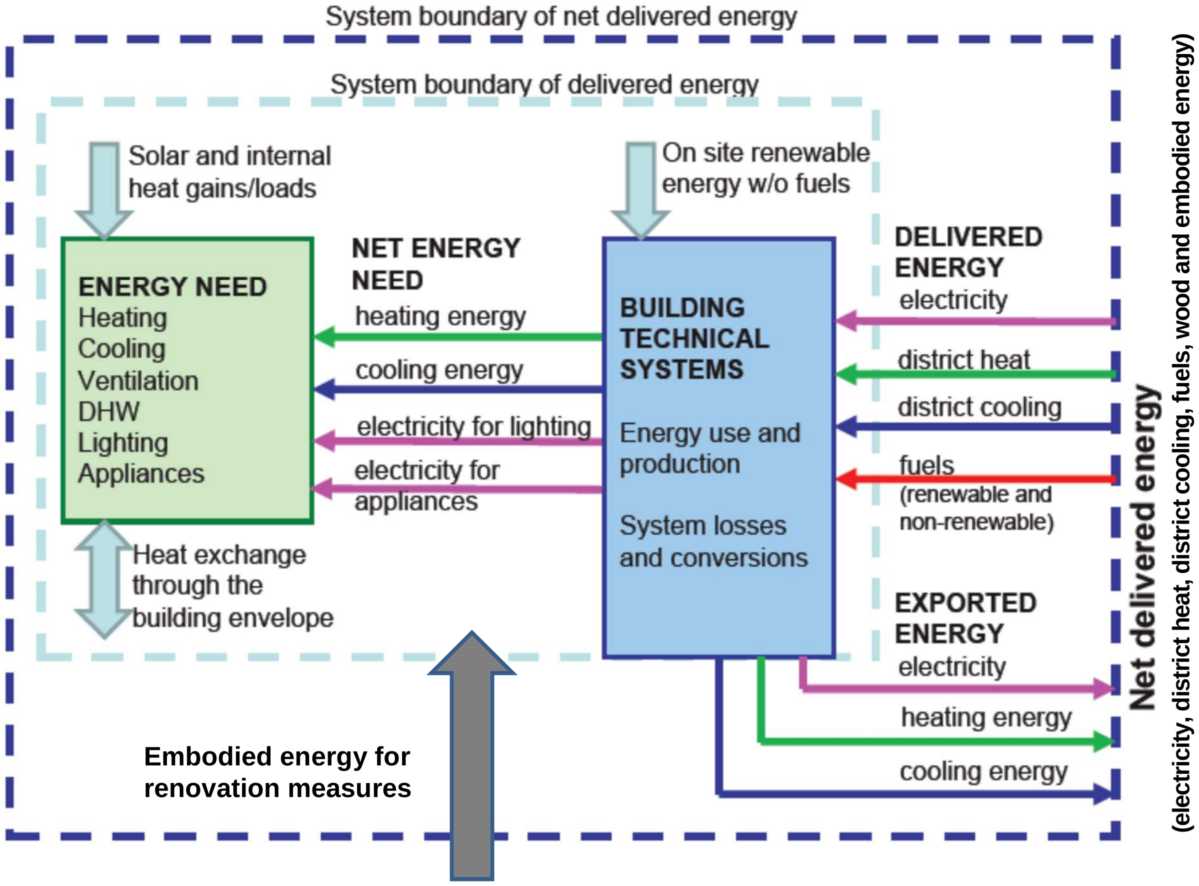


Figure 4 Definition of the levels and system boundaries of energy use in buildings being renovated, including on-site renewable energy generation, passive heat gains, exported energy and embodied energy for renovation measures (see Kurnitski J., 2011, REHVA Task Force, supplemented for Annex 56 for the case of building renovation).
Net delivered energy (dashed dark blue line) comprises energy carriers delivered to the building minus energy exported from the building to the grid or to a heating/cooling energy distribution system.

2.2.1. Primary energy conversion factor for energy carriers

The conversion from final energy use to **primary energy** use of energy carriers is performed with the help of primary energy conversion factors per energy carrier, which take into account upstream energy use for extraction, processing, transportation and distribution of energy carriers. They vary by country, depending on the share and on the origin of the energy carriers consumed in the particular country.

In some countries «political» primary energy conversion factors or conversion factors defined for specific labels or energy related requirements are employed which differ from the «physical» or «ecological» conversion factors based on a detailed analysis of the upstream processes. Such detailed analyses require conducting life cycle assessment studies of the energy carriers to determine the primary energy factors. Usually they are determined and documented by LCA databases for the particular country.

For the sake of consistency with the LCA methodology for building renovation (see chapter 4), only physical conversion factors based on LCA principles should be employed within Annex 56. These factors should be derived from the actual input share of the energy carriers and energy sources used.

2.2.2. Primary energy conversion factor for electricity

Primary energy conversion factors for electricity depend on the way electricity is generated and on the mix of generation technologies employed and consumed by the end users. For the assessment of energy related building renovation, the national mix of electricity *consumed* is most appropriate to determine national primary energy conversion factors for electricity[5]. In Europe national production mixes for electricity range from about 1.15 to 4.45 (see Figure 5).

5 Only if the mix of electricity consumed is not known, the mix of national electricity produced might be used as second best solution and proxy, even if this might differ substantially from the mix of electricity effectively consumed (especially in countries with a relevant share of electricity imported).

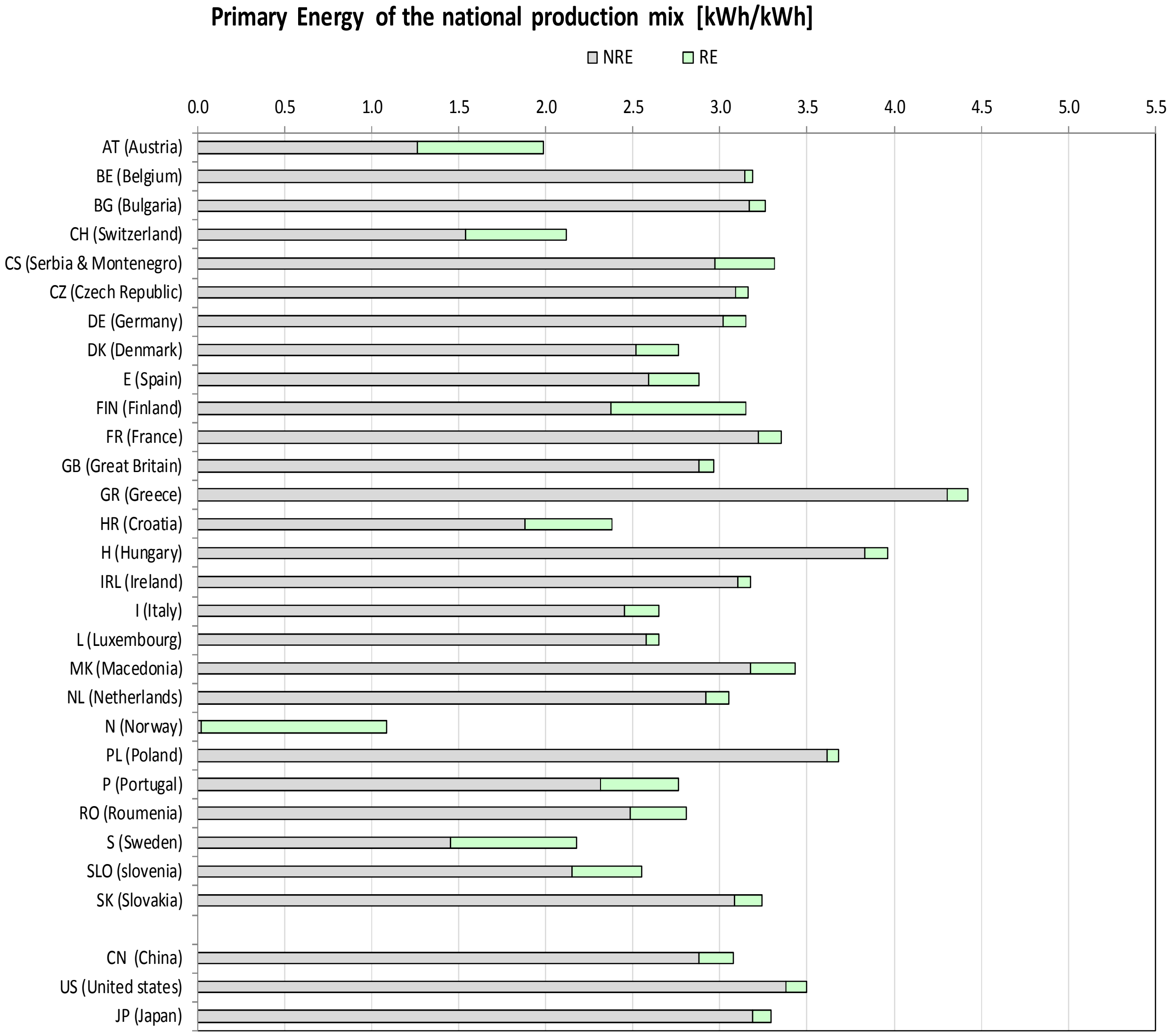


Figure 5 Primary energy/final energy conversion factor of electricity for the **national generation mix** (Ecoinvent v2.2)

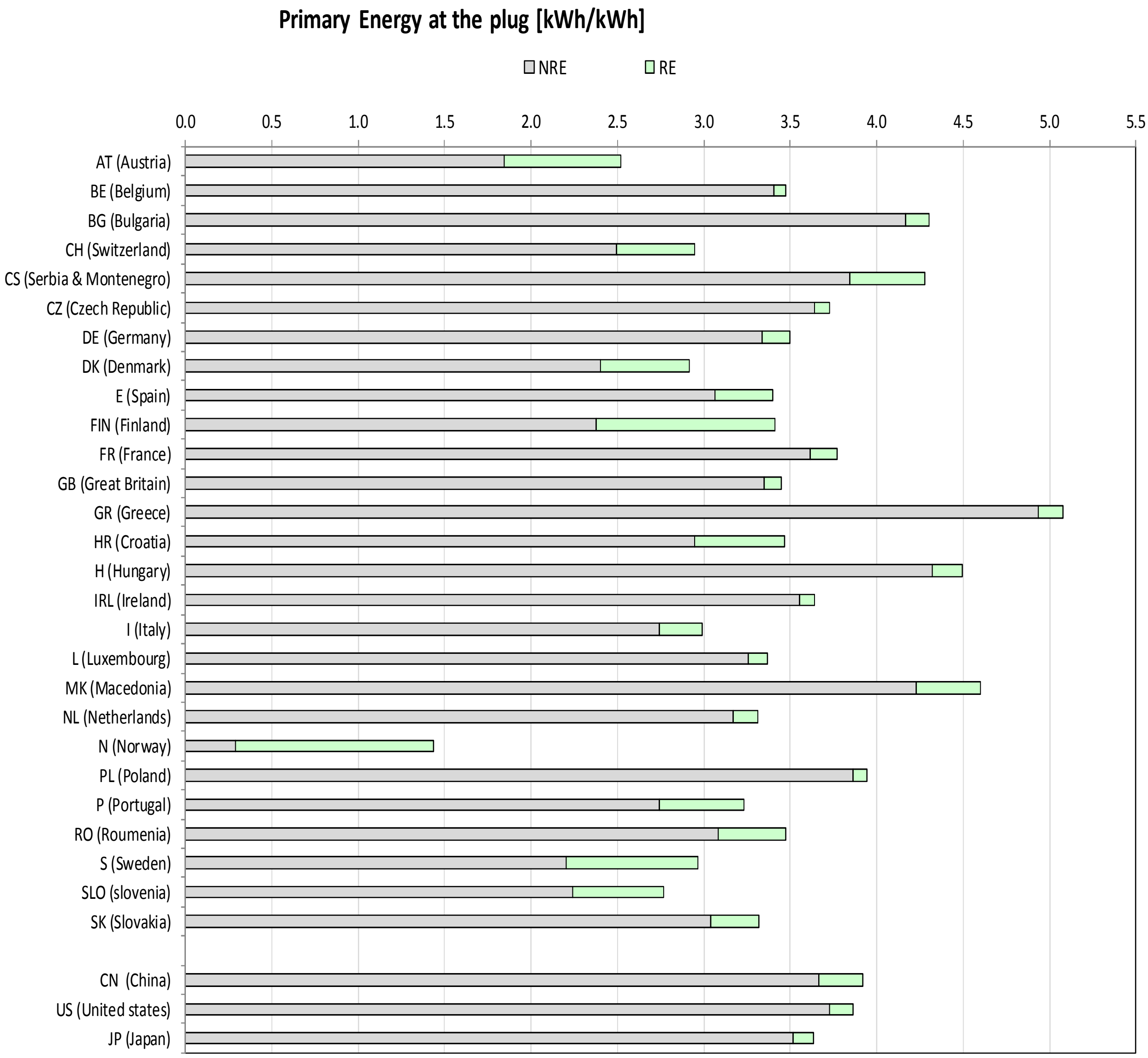


Figure 6 Primary energy/final energy conversion factor of **delivered electricity at the plug of the end users** (Ecoinvent v2.2).
NRE: Non-renewable energy; RE: Renewable energy

The primary energy conversion factors normally do not yet take into account trade in green certificates. This may lead to biased results for some countries having a large import or export of such certificates. An example for such a case is Norway, which exports a large share of the «ecologic value» of its hydropower based electricity production in the form of green certificates to other European countries. On a case by case basis, it can therefore be appropriate to take into account a perspective including trade in green certificates.

2.2.3. District heating and cooling

The primary energy conversion factor of district heating and cooling is determined by the input share of the energy carriers to generate district heat or cold and by the corresponding LCA-based primary energy factors. Additionally, distribution losses and embodied energy of the heat distribution system have to be included.

2.2.4. System boundaries for on-site energy generation and deployment of renewable energy

Usually the scope and the boundary for on-site generation of renewable energy is the building lot (boundary II in Figure 7), while boundary III allows for the use of off-site produced renewable energy (e.g. biomass) within the building lot. For the boundaries II and III it might be appropriate in certain situations to pool several buildings which have a common heating and/or cooling system to attain (economically) more favourable conditions for renewable energy generation and use. On-site generated electricity fully sold to an off-site owner of the generation unit is not accounted for in the building assessment (since electricity generated is allocated to the (external) owner of the system, using the building only as a carrier for his generating system).

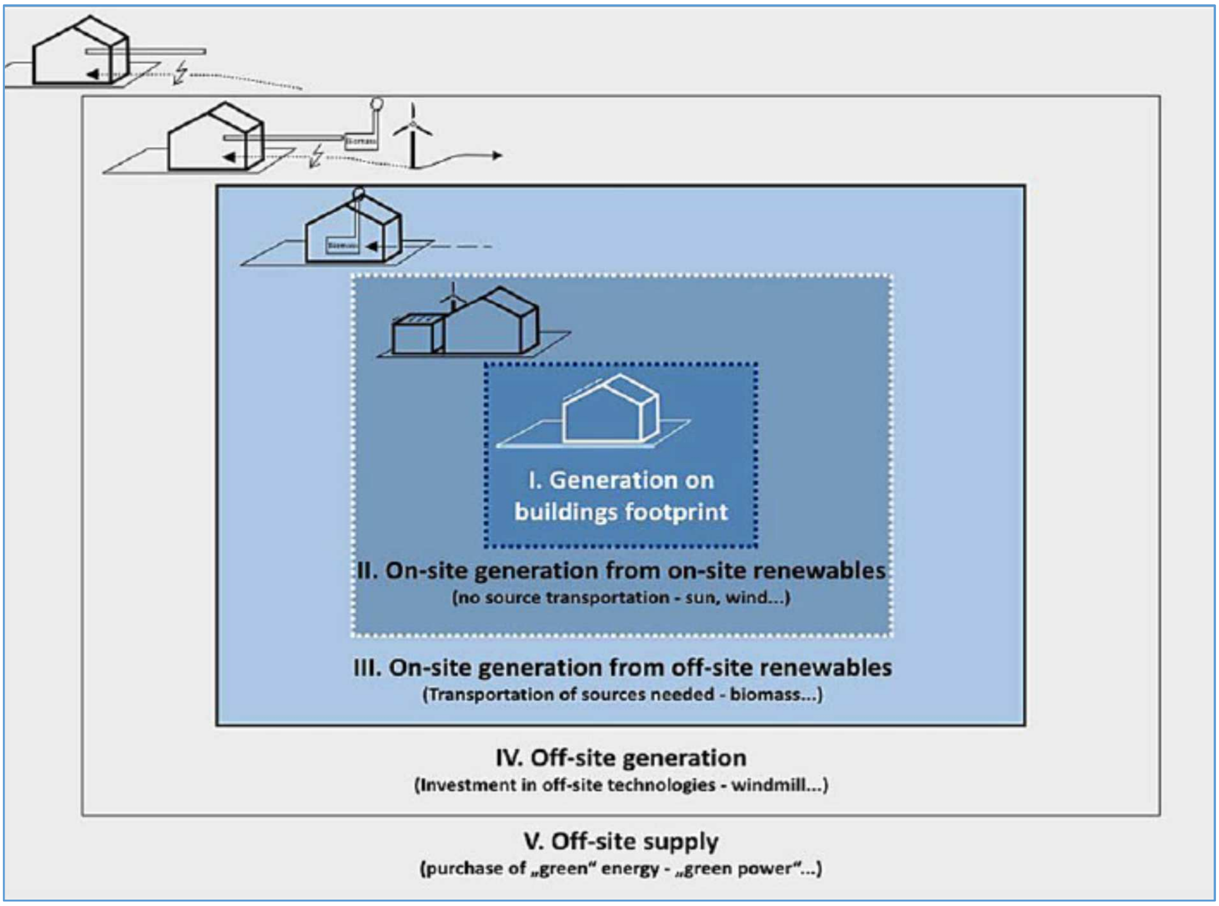


Figure 7 Overview of possible renewable supply options (Marszal A.J. et al. 2011, p. 975)

2.2.5. Carbon emissions of energy related building renovation measures

The impact of energy related building renovation measures on carbon emissions is determined from the impact of the measures on *net delivered energy use plus embodied energy*. For net delivered energy LCA-based carbon emission factors for the final energy carriers consumed are applied. Embodied carbon emissions have to be determined by a LCA of the corresponding construction materials or technical systems, using available LCA databases (see chapter 4.4). There are two levels of carbon emission conversion factors:

- Carbon emissions conversion factors according to the UNFCCC (CO_{2e});
- Country specific carbon emissions conversion factors comprising also upstream emissions for the delivery of final energy carriers to the building. As far as available, carbon emissions conversion factors comprising upstream emissions of the energy carriers and based on LCA shall be employed in Annex 56.

2.2.6. Functional unit

In LCA, according to ISO 14040, the "functional unit" is defined as the quantification of the performance of a product system, and specifies what is used as the reference unit for the LCA and any comparative assessment. It has a quantity (e.g. 1 m^2), a duration (e.g. "maintaining the function during 50 years") and a quality e.g. "to ensure a thermal resistance of 2 m^2/W K"). The term "functional equivalent" is also defined in the 15978 standard (CEN, 2011) and denotes the technical characteristics and functionalities of the building that is being assessed.

In practice, units and target values for energy use and carbon emissions are usually expressed in **MJ/m^2a** or **kWh/m^2a** and **kg CO_2-equivalents per m^2*a (kg CO_{2e}/m^2a)**. In certain cases it might be preferable to have additionally "**person**" as functional unit since DHW and electricity use are rather depending on the number of persons than on the area [m^2] of (conditioned) net or gross floor area.

Hence, in Annex 56 all results are expressed per unit of surface area per year after having divided the LCA results calculated for the reference study period of the building (see chapter 4 for more information).

For the sake of clarity, some definitions of floor area are given below:

Conditioned gross floor area:
Sum of the covered area of all conditioned floors of a building (including exterior walls). Unconditioned rooms within the conditioned envelope are included too. Unoccupied, unheated basements, attics, garages outside the thermal envelope are excluded.

Conditioned net floor area:
Total conditioned floor area inside the building envelope excluding the external and internal walls

and vents, shafts, stairs, (unoccupied) attics, basements, garages. The area is not reduced by moveable partition walls or other moveable furnishing (see Figure 8).

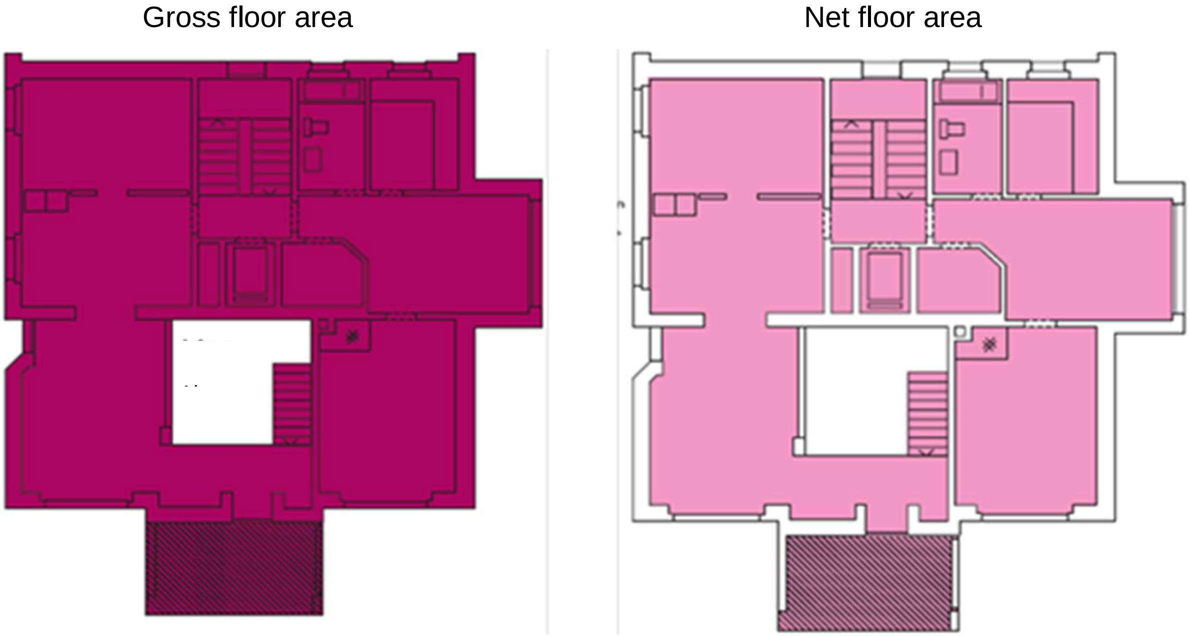


Figure 8 Illustration of (conditioned) gross floor area and net floor area. Hatched areas: Non conditioned exterior gross and net floor area respectively

For the time being, it is suggested to apply gross floor area as functional unit for energy and carbon emissions analyses in the building sector. In Europe, this is the usual unit used in the energy and in the construction sector for energy calculations, for building design and for unit cost calculations: From 9 countries, answering to the survey launched in Annex 56 within STC concerning indicators and metrics, 5 use gross floor area (AT, CH, DK, NO and SE (FI is unclear)) and 4 use net floor area (AT (for energy demand), ES, IT, PT). Approximate national conversion factors can be determined for the sake of changing between net and gross floor area. If necessary, other units (e.g. per person) might also be used occasionally or for special purposes.

3. Calculation of primary energy use and related carbon emissions of renovated residential buildings

The following sections give a short overview on the calculation procedures and the relevant boundaries needed to determine energy needs and energy demand of a building. The calculations of energy needs are based on a steady state approach, determining yearly energy demand. Some concepts introduced in this chapter are based on methodological principles of LCA that are further developed in chapter 4 "Life cycle Assessment (LCA) for energy related building renovation".

3.1. Life cycle approach

Overall primary energy use and carbon emissions are calculated on an annual basis. In general all analyses of emissions, energy use, costs and benefits are supposed to use a life cycle approach, either based on the life time of the respective building[6] or on the technical or service life time of renovation measures. Life cycle impacts have to be broken down to the different stages and the various building systems, elements or products. They are determined as yearly units during the life cycle or yearly units per square meter gross or net floor area (see above and chapter 4 « Life cycle Assessment (LCA) for energy related building renovation»).

3.2. From energy needs to primary energy use and carbon emissions

Calculation of primary energy use is widely aligned with the methodology defined by the EPBD (Official Journal of the EU, 19.4. 2012, p. C 115/9) but is extended for the inclusion of primary energy use for components (embodied energy use, see chapter 4):

The calculation of the energy performance of a building starts with the calculation of energy demand for heating and cooling. Then the final energy use for all energy needs is determined. The primary energy input for all of the final energy as well as for materials and BITS components (embodied energy) deployed within building renovation is calculated.

Carbon emissions related to the renovation measures can be derived from the primary energy use by energy carrier with the help of carbon emissions conversion factors. Embodied carbon

6 Lifetime of the building: Either expected lifetime of the building (if shorter than 60 years) or 60 years (see chapter 0)

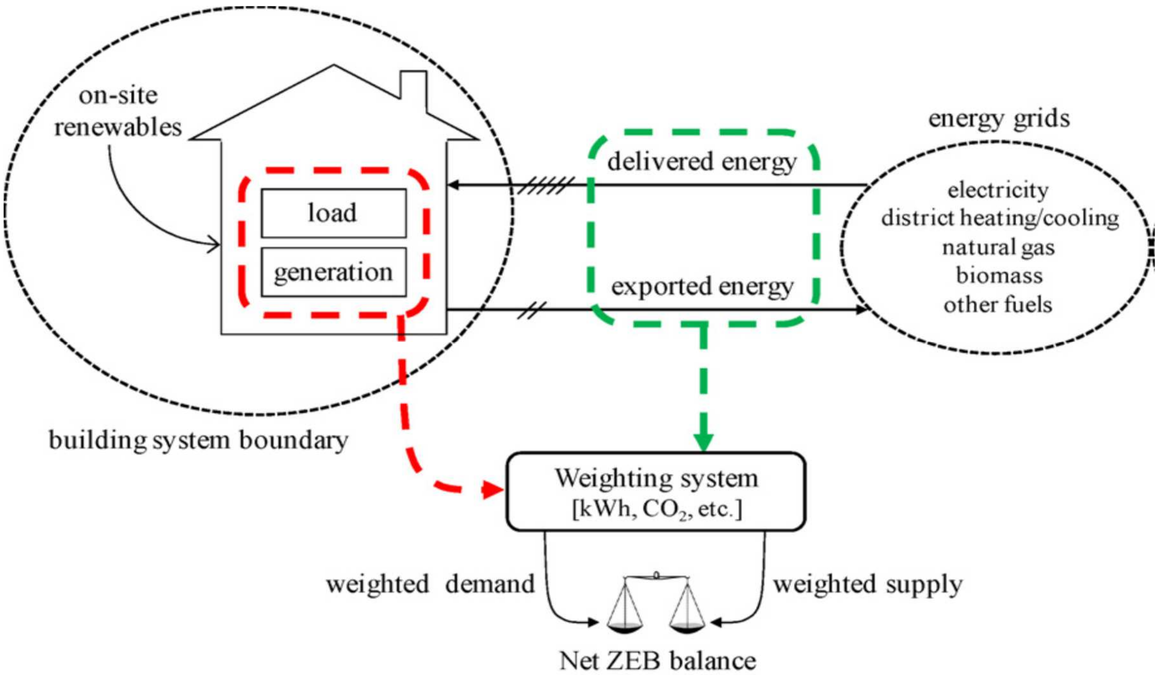
emissions of materials and BITS are determined with the help of LCA in the same way as embodied energy.

Usually, the calculation goes from the needs to the source (i.e. from the building's and components energy needs to the primary energy use and related carbon emissions), depending on the national calculation procedures. Electrical systems (such as lighting, ventilation, auxiliary) and thermal systems (heating, cooling, domestic hot water) are considered separately inside the building's boundaries.

Delivered primary energy is determined from delivered energy carriers, as well as from their transport and distribution, by the use of national primary energy conversion factors and data for embodied energy.

Electricity exported from the building site into the grid is converted into primary energy by using either:

- an appropriate conversion factor for grid electricity substituted by the surplus electricity generated on-site and provided to the grid or
- embodied energy of on-site generation system.



Sartori 2012

Figure 9 Terminology for building related energy use and renewable energy generation (Sartori I. et al. 2012)

Steps to calculate the energy performance of buildings according to the guidelines accompanying Commission Regulation (EU) No 244/20121 (Official Journal of the European Union, 16.1. 2012,

p. C 115/10, supplemented for embodied energy by econcept) are the following and can be seen in Figure 10:

1. Calculation of the building's net thermal energy demand to fulfil the user's requirements, based on an annual balance. The energy demand in winter is calculated as energy losses via the envelope and ventilation minus the internal gains (from appliances, lighting systems and occupancy) as well as 'natural' energy gains (passive solar heating, natural ventilation, etc.).
   The energy demand for cooling in the summer time is calculated from the solar radiation heat gains and the internal heat gains, taking into account thermal heat storage and heat losses by transmission and venting (see chapter 9.2 and Figure 29).

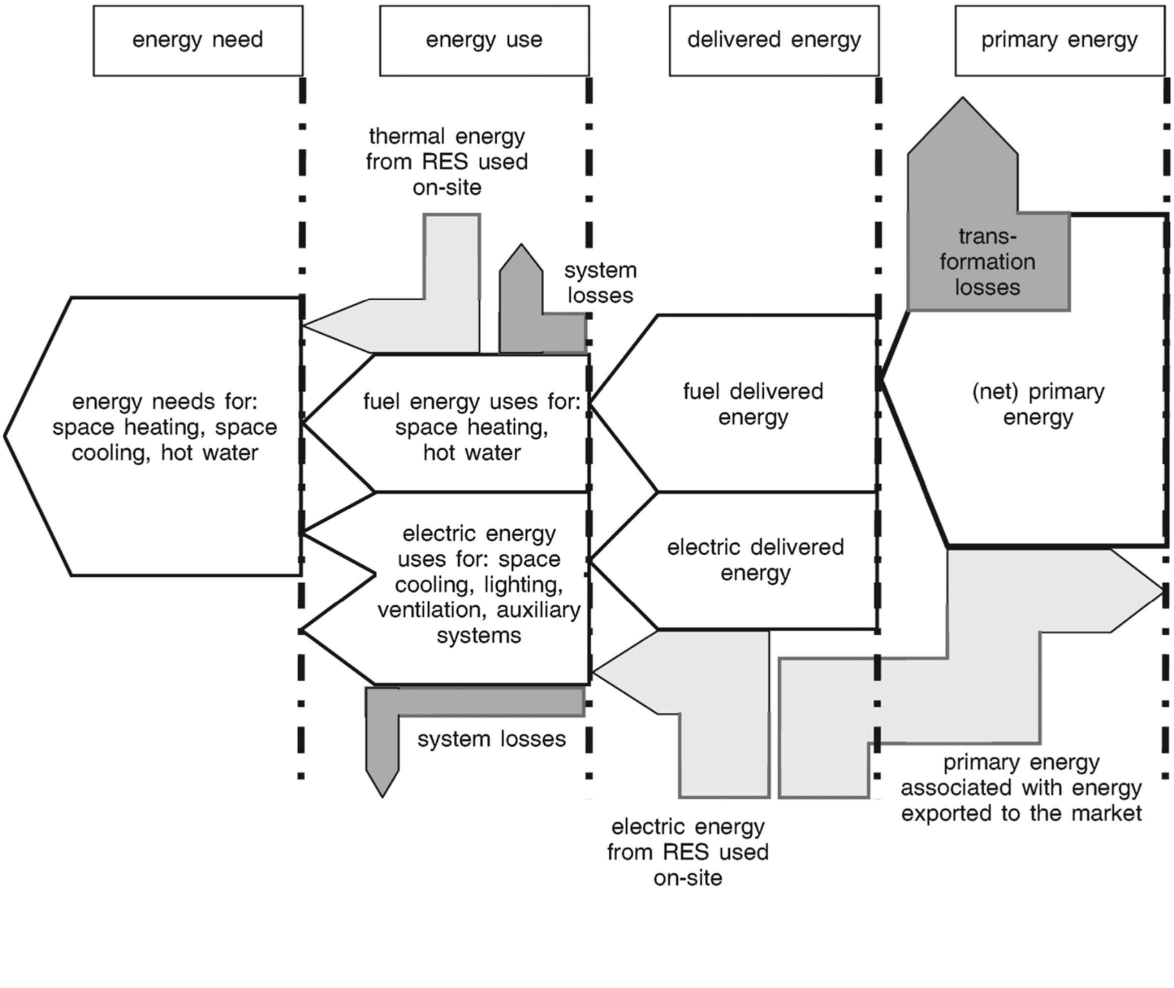


Figure 10 Illustration of the calculation scheme (Official Journal of the EU, 16.1. 2012, p. C 115/11; supplemented for embodied energy by econcept)

2. The thermal energy from renewable energy sources (RES) generated and used on-site (e.g. from solar collectors) should be subtracted from (1).

3. Calculation of the energy uses for each end-use (space heating and cooling, hot water, lighting, ventilation, appliances) and for each energy carrier (electricity, fuel) taking into account the characteristics (seasonal efficiencies) of generation, distribution, emission and control systems.
4. Subtraction of the electricity from RES, generated and used on-site (e.g. from PV panels), from (hypothetical) electricity use without such on-site electricity production.
5. Calculation of the delivered energy for each energy carrier as sum of energy uses (not covered by on-site renewable energy generation).
6. Calculation of the primary energy associated with the delivered energy, using national conversion factors (e.g. conversion factor for national mix of consumed electricity).
7. Calculation of primary energy associated with energy exported to the grid, which is based on an annual energy balance (e.g. on-site generated by RES or co-generators). The conversion factor of electricity exported to the grid corresponds to the conversion factor of substituted deliveries of grid electricity (see above; for more details on the LCA calculation rules for on-site generation systems please refer to chapter 4.3.4).
8. Calculation of primary energy use: The difference between the two previously calculated amounts: (6) - (7).
9. Calculation of (primary) embodied energy which is determined by the materials used for renovation (including embodied energy for on-site renewable energy generation units according to the allocation rules of chapter 4.3.4).
10. Calculation of carbon emissions is done with national carbon emissions conversion factors, yearly carbon emissions are expressed as units of CO_2-equivalents (CO_{2e}) or units of $CO_{2e}/m^2_{\text{floor area.}}$

In accordance with the UNFCCC, carbon emissions shall account for carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O, ammonia NH_3, hydro-fluorocarbons HFC, perfluorocarbons PFC and sulphur hexafluoride SF_6. Carbon emissions shall be related to CO_{2e} by international harmonised conversion factors for non-CO_2 emissions.

3.3. Cooling in residential buildings - increasing relevance of cooling in residential buildings

While the determination and calculation of heating demand is widely outlined and performed, coping with cooling needs and determination of cooling demand is not as common, at least for residential buildings. For these reasons this paragraph explains briefly the relevance of cooling of residential buildings and small office buildings which has to be considered at the time being particularly in southern countries with hot summer climate. The basis to determine cooling demand, possible measures and corresponding decision paths is outlined in this chapter supplemented with further explanations in Appendix 9.2.

Currently, primary energy demand of the existing building stock in the colder northern region of Europe is mainly driven by the heating demand (see Table 3 for the electricity consumption for cooling) while already today the primary energy demand in southern regions of Europe is also affected by the cooling demand. Due to the climate change, the average surface temperatures in Europe are expected to rise in the next years.

Table 3 Breakdown of residential electricity consumption in EU-27 countries in 2007 (Bertoldi et al. 2009) and 2009 (Bertoldi et al. 2012)

EU-27 residential electricity consumption	2007		2009	
	[TWh/a]	[%]	[TWh/a]	[%]
Cold appliances (refrigerators & freezers)	122.0	15.2%	122.2	14.5%
Washing machines (2007) and drying (2009)	51.0	6.4%	60.7	7.2%
Dishwashers	21.5	2.7%	25.3	3.0%
Electric ovens & hobs	60.0	7.5%	55.6	6.6%
Air-conditioning	**17.0**	**2.1%**	**39.6**	**4.7%**
Ventilation	**22.0**	**2.7%**		
Water heaters	68.8	8.6%	74.1	8.8%
Heating systems/electric boilers	150.0	18.7%	160.9	19.1%
Lighting	84.0	10.5%	84.3	10.0%
Television; entertainment	54.0	6.7%	69.9	8.3%
Set-top boxes	9.3	1.2%	14.3	1.7%
Computers, office equipment	22.0	2.7%	60.7	7.2%
External power supplies	15.5	1.9%		
2007: Home appliances stand-by 2009: Vacuum cleaners and coffee machines	43.0	5.4%	40.4	4.8%
Others	60.6	7.6%	34.5	4.1%
Total residential electricity consumption	**800.7**	**100%**	**840.5**	**100%**

Table 3 illustrates that for the time being cooling in residential buildings in Europe has a limited relevance. It is less important than cooling in commercial buildings with more interior heat sources. But this relevance is fast increasing because of rising and more widespread comfort needs and higher temperatures due to climate change (Bertoldi et al, 2012, p. 63f.). Consequently, the next challenge regarding the refurbishment of buildings in Europe is to either prevent cooling or to provide efficiently cooling with the least primary energy demand possible and the lowest additional carbon emissions.

The current refurbishment of the buildings in warmer climate zones of Europe, which targets a reduction of the primary energy demand for heating, also affects the primary energy demand for cooling. Additionally, many house owners in this region will not only refurbish their buildings to meet certain energy standards or reduce the costs for the building operation, but to provide a higher standard of comfort. Contrary to heating, the primary energy demand for cooling of residential buildings in Europe is less monitored. As a result, the cooling demand of buildings in European countries is currently only estimated.

According to the status reports «Electricity Consumption and Efficiency Trends in European Union, Status Report 2009» (Bertoldi and Atanasiu, 2009) and Status Report 2012 (Bertoldi, Hirl, Labanca, 2012), air-conditioning and ventilation only accounted for about 4.8% and 4.7% respectively of the total power consumption in 2007 and 2009 in the EU-27 households, which is equivalent to approximately 39.0 TWh/a 2007 and 39.6 TWh/a in 2009 as shown in Table 3. This is less than the 6% of the total power consumption for air-conditioning in American households in 2009 (IEA 2009).

The cooling demand of residential buildings largely depends on the climate conditions and the cooling standards of the country. The contour map shown in Figure 11 on the left represents the European Cooling Index. An index value of 100 represents «average» European climate conditions with average outdoor temperatures just above 10ºC, which occurs for example in Strasbourg and Frankfurt (ecoheatcool, work package 2, 2006). This index is based on the climatic conditions of 80 urban locations in Europe. According to this index, a large difference exists between the cooling demand of the northern and southern European countries, which is also expressed by the following comment (Ecodesign Lot10, 2008):

- Northern and central Europe: air-conditioners are mostly installed in offices and light commercial buildings. The market for «renting» portable units is quite significant.
- Southern France and Mediterranean area: installations in private dwellings are also relevant. This explains well the high sale volumes recorded in these countries.

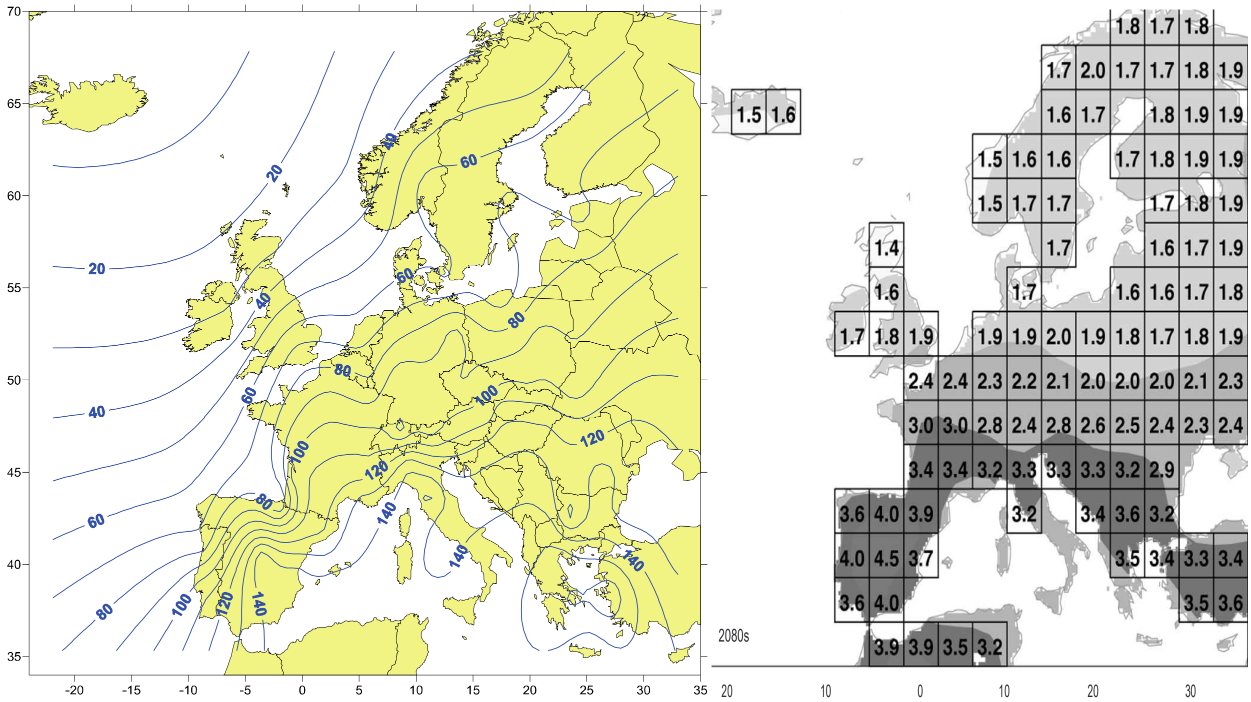


Figure 11 **On the left**: Contour map representing the European Cooling Index that illustrates the large differences of the cooling demand of buildings in Europe. The index is normalised, thus 100 is equal to an average European condition, which occurs for example in Strasbourg and Frankfurt (ecoheatcool, work package 2, 2006).

On the right: Map with increasing temperatures, presenting a possible scenario of projected temperature changes in Europe for 2080 relative to the average temperatures in the period 1961–1990. According to this scenario, the average surface temperatures are expected to increase in absolute terms more in southern Europe (Parry et al., 2000).

4. Life cycle Assessment (LCA) for energy related building renovation

The purpose of this section is to present the methodology applied in Annex 56 for assessing the environmental impacts of renovated buildings. The proposed methodology is based on the state of the art of the life cycle assessment (LCA) for buildings. But to stay pragmatic, it includes only processes having a relevant contribution to the total environmental impacts of the renovated building that can be put into practice in a reasonable amount of time to assess the environmental impacts of renovated buildings.

The methodology subsequently outlined addresses also stakeholders not involved in Annex 56, who would like to know the details of the approach used in Annex 56. The following considerations aim at summarizing the relevant information for LCA in Annex 56 without going into all of the details but making clear how the necessary calculations have to be performed. Some methodological principles of LCA have already been described in the chapters 2 and 3 and provide additional information to the LCA methodology presented in this chapter.

4.1. LCA of energy related renovation measures

The assessment of the performance of a building can be based on several indicators, such as cost, operational energy use, environmental impacts and energy use of building components and materials. Whatever the indicators used, the generic pattern of its time evolution can be schematised as shown in Figure 12.

Building construction generates certain initial impacts and costs. During the building operation, there is a flow of yearly operational impacts and costs, primarily due to the energy use. After carrying out a building renovation, there is a new step-like increase of the impacts and costs due to the refurbishment of building elements and technical systems. The importance of this contribution depends on the implemented renovation scenario. During the building operation after renovation, the flow of yearly impacts and costs mainly due to energy use will also depend on the implemented scenario as shown in Figure 12 (the more complete and ambitious the energy related renovation package the higher is the initial step of impacts due to the renovation and the lower are the impacts of subsequent building operation).

The final goal of the optimisation is to find scenarios with the lowest impacts and costs during the reference study period. The reference case is based on “anyway renovations” (concept described in the Annex 56 Methodology Report), which restore the full functionality of the building but do not improve the energy performance of the building.

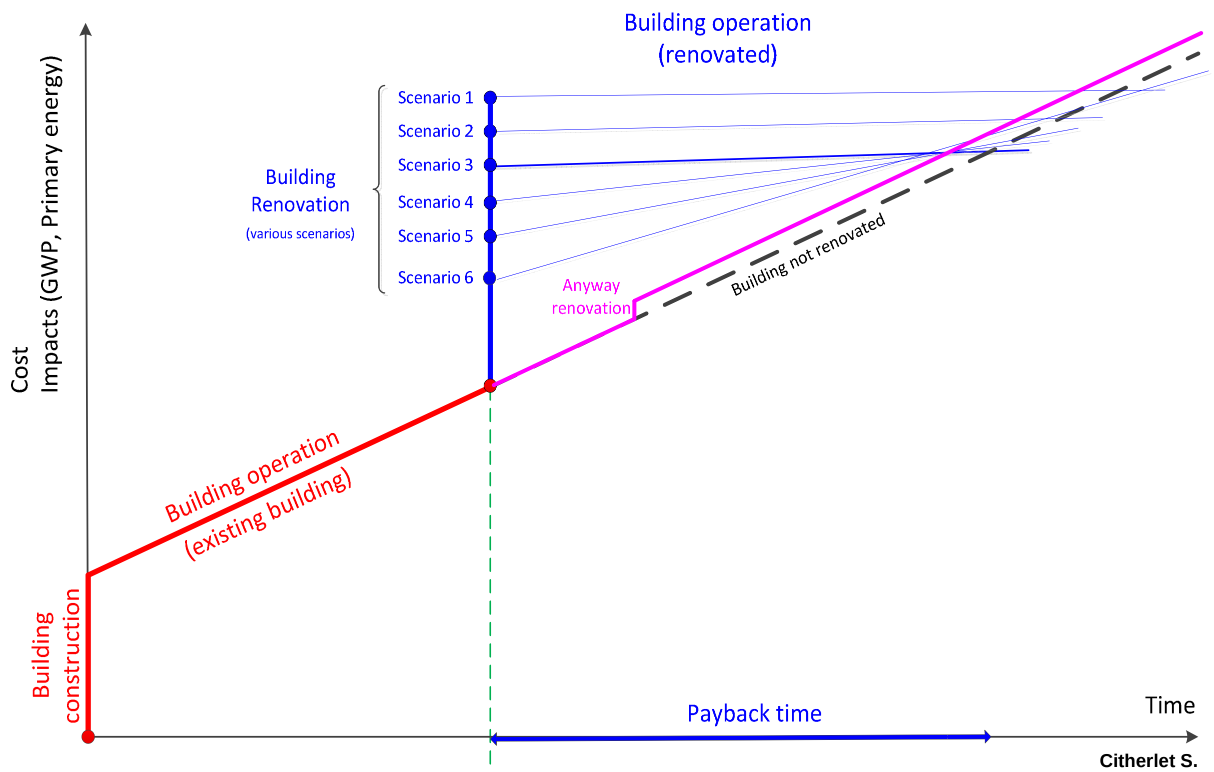


Figure 12 Schematic representation of the effect of energy related renovation measures compared to the existing situation.
Usually, the more sophisticated efficiency related renovation measures, the higher the (initial) investment costs at this point of time and the lower operational energy costs over time (can be observed in the graph by a less inclined cost curve). Scenario 1 increases energy performance most. Consequently initial investment costs are the highest but yearly operational cost the lowest (flattest cost curve over time).

In Annex 56, the LCA is used to compare the environmental impacts of energy related renovation measures. Therefore, it will take into account only measures that affect the energy performance of the building (thermal envelope, building integrated technical systems and energy use for on-site production and delivered energy). Renovation measures which are not related to the energy performance of the building (e.g. such as changing the kitchen sinks) are not included in the assessment of the energy related renovation measures.

4.2. Existing LCA methodologies

During the last decade, many LCA methodologies have been published at national and international levels in order to present solutions to perform building LCA. These include, for instance, generic approaches such as presented in ISO 14040 and followings (ISO 14040, 2006), ILCD Handbook (European Commission, 2011) or EeBGuide – Products (Wittstock et al., 2012a).

There are also more building oriented approaches such as the EN 15978 (EN 15978, 2012) or "EeBGuide –Buildings" (Wittstock et al., 2012b) published recently.

Although these approaches tend to present a methodology as complete as possible, it is generally not fully applicable in practice, because of the lack of information required or the time and resources needed to put it into practice. At national level, some methodologies have been developed.

The aim of the following considerations is not to inventory and to compare all existing methodologies but to present the approach used in Annex 56 to perform the LCA of existing buildings. The methodology used in Annex 56 is a compromise, taking into account several constrains such as:

- Coherence with existing approaches;
- Inclusion of the relevant sources of impacts in the case of building renovation;
- Availability of information (especially for existing buildings);
- Time and resources required to find the information.

In the framework of Annex 56, a pragmatic approach has been considered to perform the LCA of a renovated building. Subsequently this methodology is presented in more detail.

4.2.1. Object of assessment, physical and temporal system boundaries

To perform an LCA of a package of renovation measures, it is mandatory to define the following system boundaries:

- Temporal system boundary (see chapter 4.2.2): It defines the elementary stages which have to be included, occurring during the life cycle of the building;
- Physical system boundary (see chapter 4.2.3): It defines all materials and energy flows to be included in the assessment.

The following chapters define these system boundaries in more detail. The object of assessment is the renovation package with resulting energy savings, carbon emissions reductions and possibly with its embodied energy effects over its life cycle.

4.2.2. Temporal system boundary (life cycle of building renovation)

Categorization of life cycle stages:

Many breakdowns of the building life cycle into the relevant stages have been proposed within the last decade (Citherlet, 2001; EN 15978, 2012; Wittstock et al., 2012b) and similar breakdowns can be used for building renovation. A generic breakdown into elementary stages and the boundaries of the main stages are presented in Figure 13.

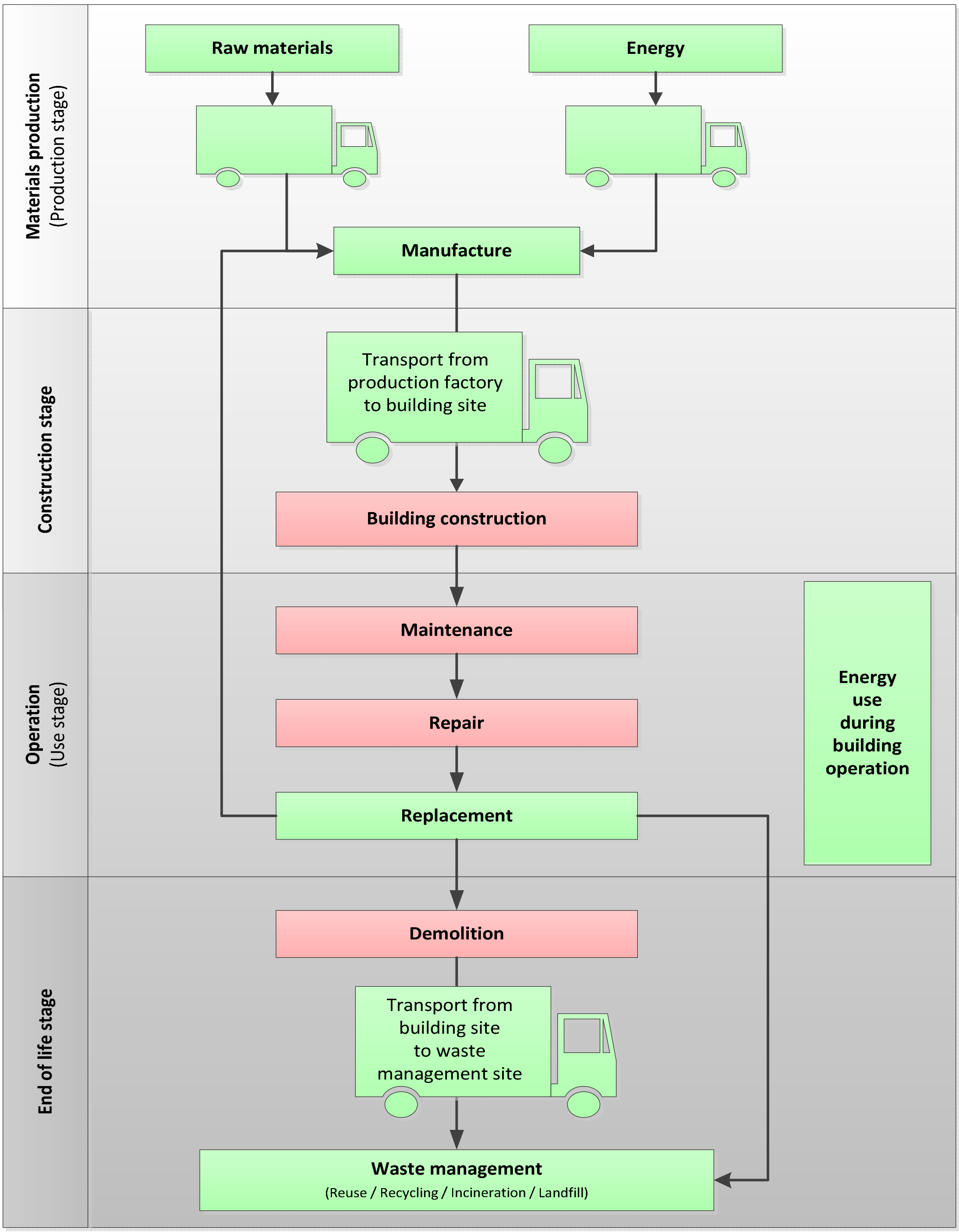


Figure 13 Schematic breakdown of a building's life cycle into elementary stages.

Definition of the different stages shown in Figure 13**:**

Materials production stage: The boundary of this stage covers the 'cradle to gate' processes for manufacturing the materials used in the construction elements and technical systems. It includes all processes from the raw materials extraction to the final products (brick, insulation panel, boiler, pipes, etc.) at the gate of the factory ready to be delivered.

Building construction stage: The boundary of this stage encompasses the transportation of the materials and construction equipment (cranes, scaffolding, etc.) to the building site and all processes needed for the construction/renovation of the building.

Building operation stage: The boundary of this stage comprises the period during which the building is used by occupants, i.e. from the end of building renovation to the demolition of the building. This stage also includes the maintenance, repair and replacement of the construction materials. It also includes energy used by technical systems during the building operation period (heating, lighting, domestic hot water production, etc.).

Building end-of-life stage: This stage covers the end-of-life of the building from its demolition to the materials elimination. It includes the processes for building decommissioning and waste transport and management (recycled, reused, incinerated or dumped in a landfill).

It should be kept in mind that Figure 13 is a generic representation of the complete life cycle of a building, in which each elementary stage may use energy and materials.

Furthermore, not all of the elementary stages contribute to the same extent to life cycle impacts of a building (new or renovated). Negligible impacts should be excluded from the assessment and calculations, even more so if they require information difficult to access.

Life cycle stages used in Annex 56:

In order to facilitate the application of LCA, the methodology used to assess the effects of energy related renovation measures is pragmatic and takes into account only the relevant stages.

There are several stages that should be definitely taken into account in the LCA of energy related building renovation and which are mandatory in Annex 56 (green boxes in Figure 13):

Material production for new materials and for periodic replacement during the reference study period, i.e. all stages required for the materials used (construction elements or BITS) for energy related renovation measures. It includes the extraction of raw materials, transport and transformation required to have the components ready to be used. For the sake of simplification, these stages are grouped in one stage called «material production».

Materials transportation between the production site and the building site. To calculate the corresponding impacts, it is necessary to know the transportation distance(s) and the mean(s) of transport used for each material or component. The corresponding data can be either based on known information or on default values based on realistic hypotheses. These data should be reported and documented (type of transport, distance). During this stage, some materials may be lost (damage, broken) and have to be replaced (new production). These losses can be neglected.

Energy used during building operation for the reference study period.

Transportation of wasted materials **at the end of the building's life** (materials added during the reference study period for energy related renovation measures). This corresponds to the transport from the building site to the waste management site. To calculate the corresponding impacts, it is necessary to know the transport distance(s) and the mean(s) of transport used for each material. The corresponding data can be either based on known information or on default values based on realistic hypotheses. These data should be reported and documented (type of transport, distance).

Waste management of removed materials (removed energy related renovation measures during the reference study period).

On the opposite, the following stages can be neglected (red boxes in Figure 13) due to their marginal contribution:

Maintenance: The maintenance stage includes the processes for maintaining the functional, technical and aesthetic performance of the building fabric and building integrated technical systems (BITS), such as painting work, replacement of filters (ventilation), etc. This stage does not take into account the replacement of a building component that must be changed because it has reached the end of its service life. The replacement impacts are included in the replacement stage (green boxes in Figure 13).

The life cycle impacts from the maintenance stage of energy related renovation measures is insignificant (compared to the total building’s LCA) and therefore can be neglected, contrary to the cost assessment, for which the maintenance must be taken into account.

Repair: Repair of a building element cannot be easily analysed because by definition it happens randomly and there is no reliable information that could help to assess precisely its contribution. In addition, this contribution happens seldom and therefore, it can be neglected.

Building construction and demolition: These stages take place on the building's construction site. It should be reminded that the construction equipment will be used not only for one building. Therefore, their contribution per building is highly reduced and these stages can be omitted. In addition, energy used on-site during building construction and demolition can be neglected compared to the energy embodied in the construction materials or the energy used during building operation.

In Annex 56, these three previous stages are not mandatory, but if they are included in the calculation, it should be reported.

4.2.3. Physical system boundary

The physical system boundary defines the materials and energy fluxes which must be taken into account for the LCA. Figure 14 shows a synthetic building model which includes construction elements and building integrated technical systems (BITS). The construction elements consist of one or more materials. The BITS consist of components (boilers, pumps, etc.) which are made of materials. In addition, these components use one or more energy vectors.

In order to perform an LCA of a renovated building, the two following main contributions should be taken into account:

Construction elements: LCA includes the materials of the building elements that are affected by the energy related renovation measures. Each element (roof, facade, etc.) is made of one or more layers and each layer corresponds to a material.

Building-integrated technical systems (BITS): LCA includes the installed technical equipment to support the operation of a building (as defined for instance in EN 15978). BITS usually comprise different systems, such as heating and ventilation. The LCA also includes the on-site energy production (solar collectors, PV, heat pump). Each system consists of components (boiler, pump, etc.) and each component is composed of materials and may consume energy.

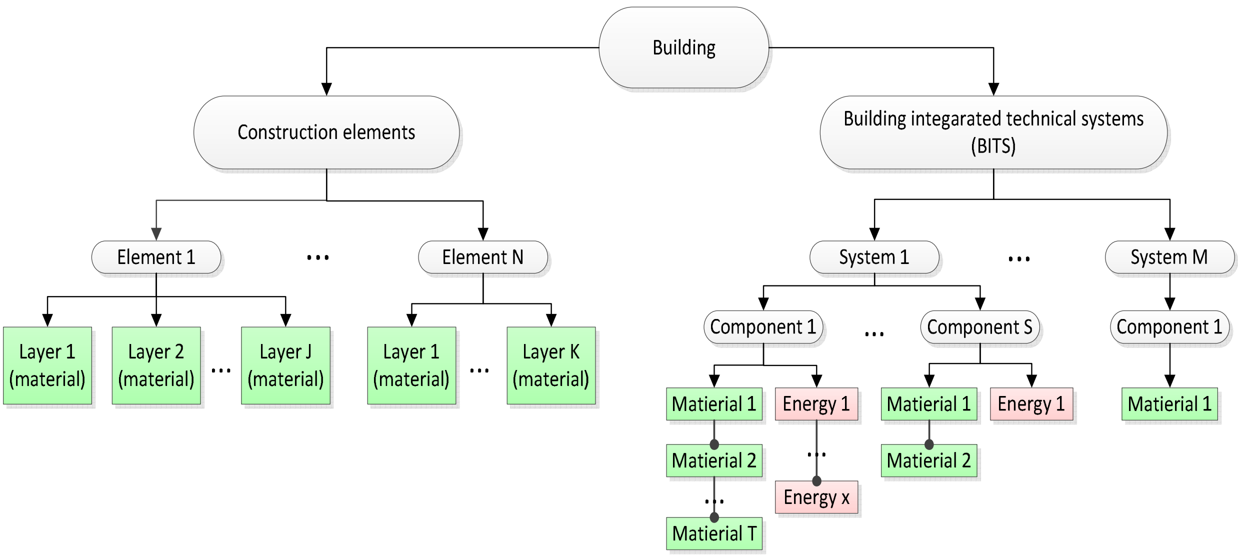


Figure 14 Structure of the building model

In order to calculate the corresponding impacts, the following contributions have to be included in the LCA:

Materials: Materials added or replaced for energy related renovation measures for building elements (envelope) and for BITS-components (for more details see Appendix 9.1). The stages corresponding to manufacturing, replacement and waste disposal of these components must be included in the calculation. (It should be noticed, that the LCA is influenced by the service life time of the construction materials and of the components of the BITS (this aspect is detailed in Appendix 9.1).

Operational energy: Energy used by BITS during building operation. This includes the energy used by the BITS to deliver the expected energy services (heating, cooling, DHW production, etc.) during building operation.

Figure 15 shows the materials contribution to take into account in the LCA of a renovated building.

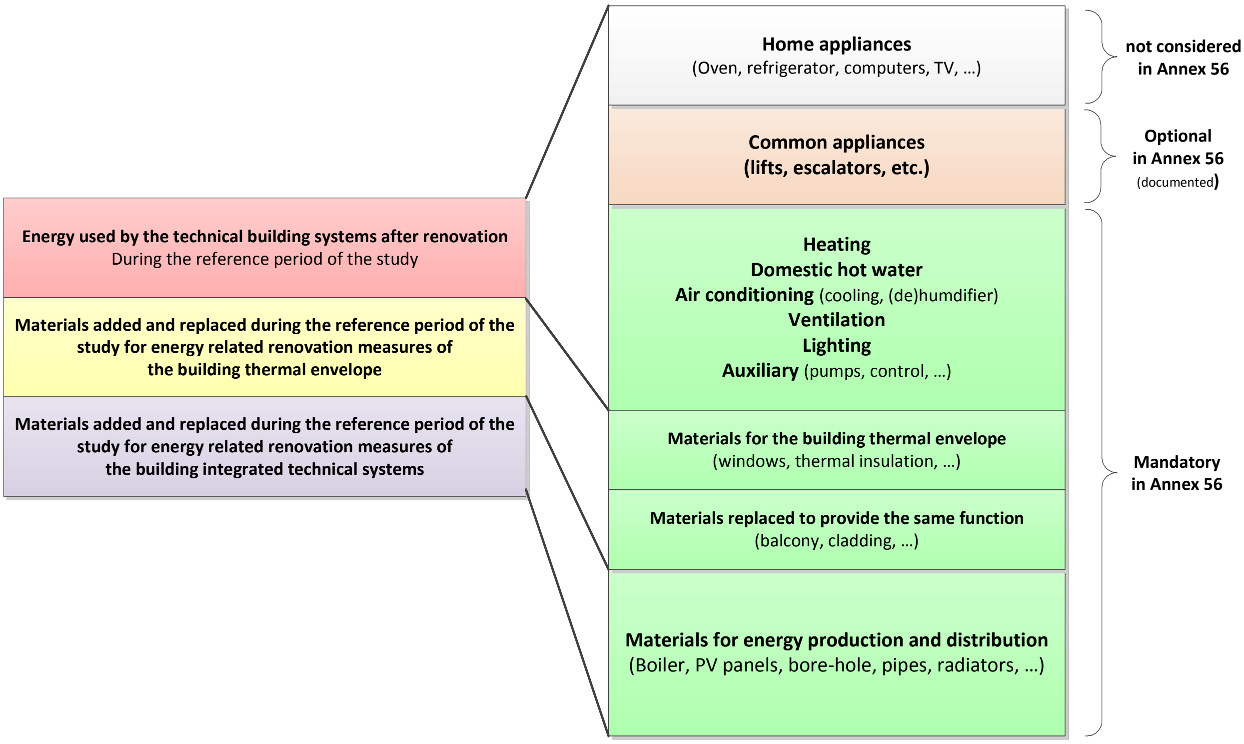


Figure 15 Aspects to be included in the LCA of renovated buildings in Annex 56

4.3. Operational energy

This section presents the energy services included in the LCA, the rules for calculating the energy balance and the associated primary energy and carbon emissions especially for electricity and on-site renewable energy generation systrems.

4.3.1. Energy services included

Energy use of building operation comprises energy use for several energy services which can be separated into occupant-related energy use and building-related energy use, as shown in Figure

16. Occupant-related means that the occupants decide on buying and installing the energy consuming device. Building related means that the building owner decides on installing it and that the device is used by all building occupants.

In many countries the "white appliances" like stove, refrigerator, sometimes freezer, washing machine, tumbler or dryer are built in appliances and therefore building related. But there are countries where the tenants rent an apartment without the "white appliances", which they buy and install by themselves. Calculation of heating energy needs require assuming at least a default energy use by appliances to account for internal heat sources. Even if the inclusion of these appliances is not mandatory in the Annex 56 methodology, it seems adequate to include them in the assessment by using default values, to account for their increasing share on remaining energy use of buildings.

LCA in Annex 56 comprises mandatorily the following kinds of operational energy use:

- Heating;
- Domestic hot water (DHW);
- Air conditioning (cooling & (de)humidifying);
- Ventilation;
- Lighting;
- Auxiliary (pumps, control devices, etc.);
- Integration of energy use from white appliances is optional, it might be included if reported and documented.

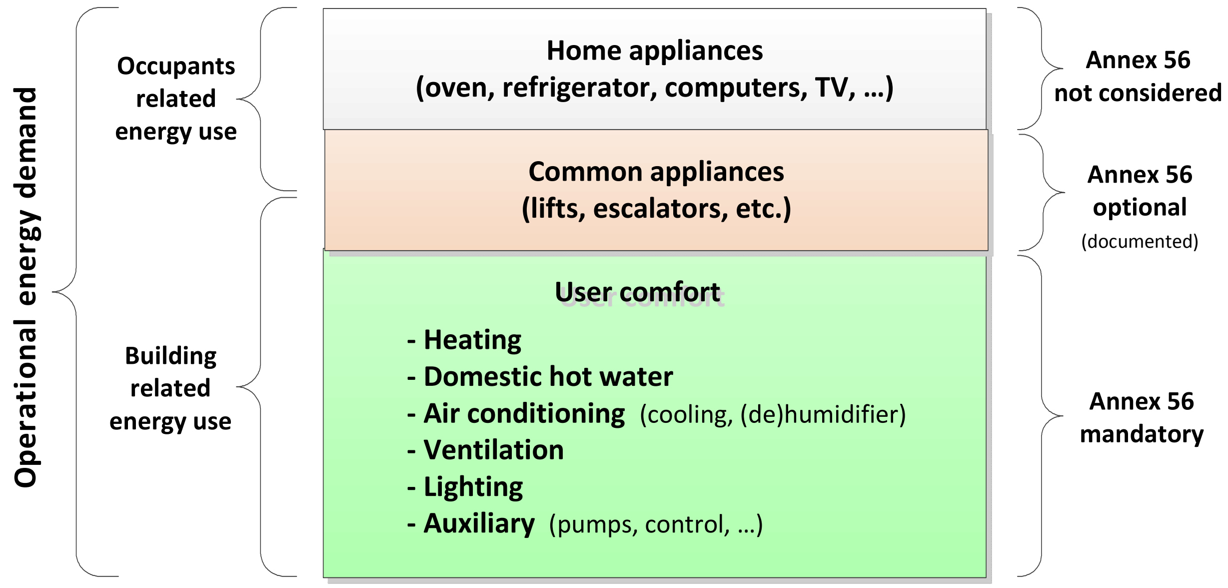


Figure 16 Building system boundary for building energy use in Annex 56

In the LCA methodology of Annex 56, the on-site produced energy is in priority allocated to the building related energy use to comply with EN 15978 (2011), the rest being allocated to the non-building related energy use.

4.3.2. Time step for the energy balance including building renovation scenarios with on-site renewable energy generation

This sub-chapter deals with the calculation rules for energy related building renovation using on-site renewable energy generation (e.g., PV, wind mills, ground or air source type heat pumps etc.). The energy balance as shown in Figure 17 includes the energy demand of the building (load), delivered energy from the grid (imported energy), on-site energy generation and exported energy of on-site generated renewable energy to the grid.

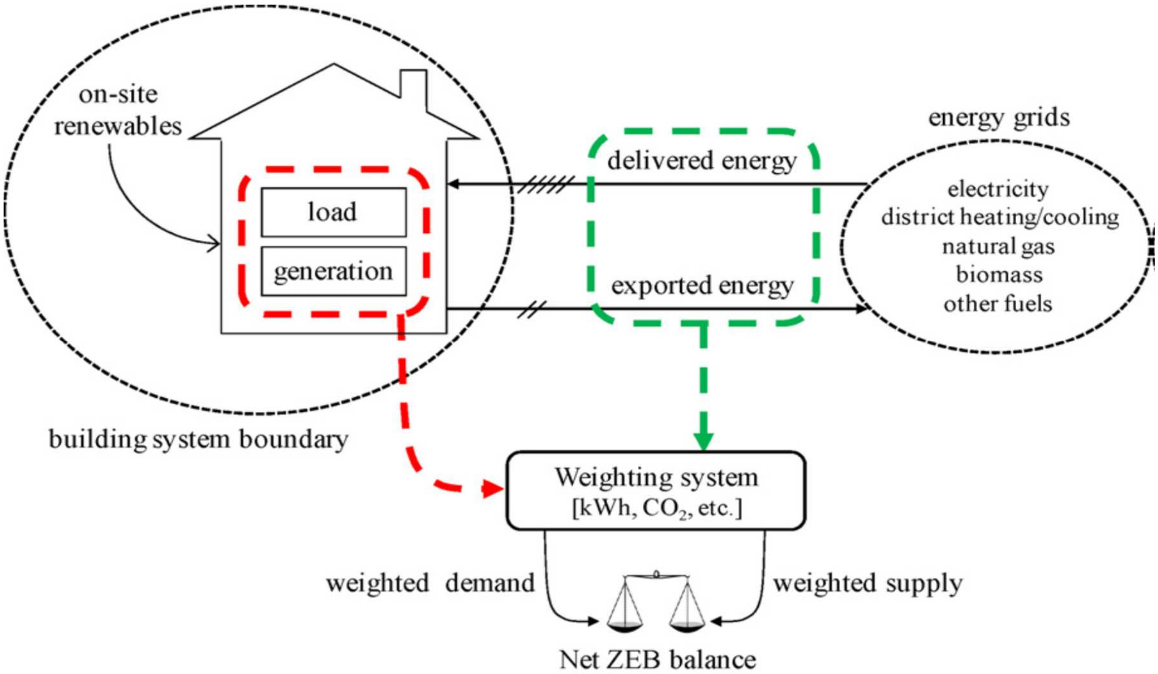


Figure 17 Terminology for building related energy use and renewable energy generation (Sartori I. et al. 2012)

In today's practice, the operational energy consumption can be estimated according to either an annual or an hourly balance using different steady state or dynamic energy calculation methods. Current studies (e.g., Voss et al, 2010) show that depending on the time step (hourly, monthly or annual) used for the calculation of the energy consumption of a building and for the on-site renewable electricity generation, the self-consumption can pretty much vary as well as the import/export balance of energy (noted as delivered and exported energy in Figure 17).

For an annual balance, it is possible to reach virtually 100% self-consumption by ensuring that the amount of on-site renewable energy generation matches the amount of the energy consumption of the building. This case typically applies for the electricity consumption of new or renovated buildings equipped with PV systems. However, in order to characterize such nearly zero energy building (NZEB) renovation, it is also possible to use an hourly or monthly time step for the calculations. Such approaches allow taking into account the hourly, daily and monthly variation of both building energy consumption and on-site renewable energy production. As shown in Figure 18 the building's on-site energy generation (e.g. by PV systems) varies across the months as does also the building's load (or building's energy needs). In the subsequent graph, self-consumption would not reach 100% since a part of the on-site energy generation is exported to the grid.

In the subsequent Figure 18 three different areas are distinguished:

- The excess PV production fed back to the grid is represented by an orange area noted “A”;
- The building loads that need to be covered by the grid are represented with the blue area noted “B”;
- The building load self-covered by the on-site PV generation is represented by the grey-brown area noted “C”;

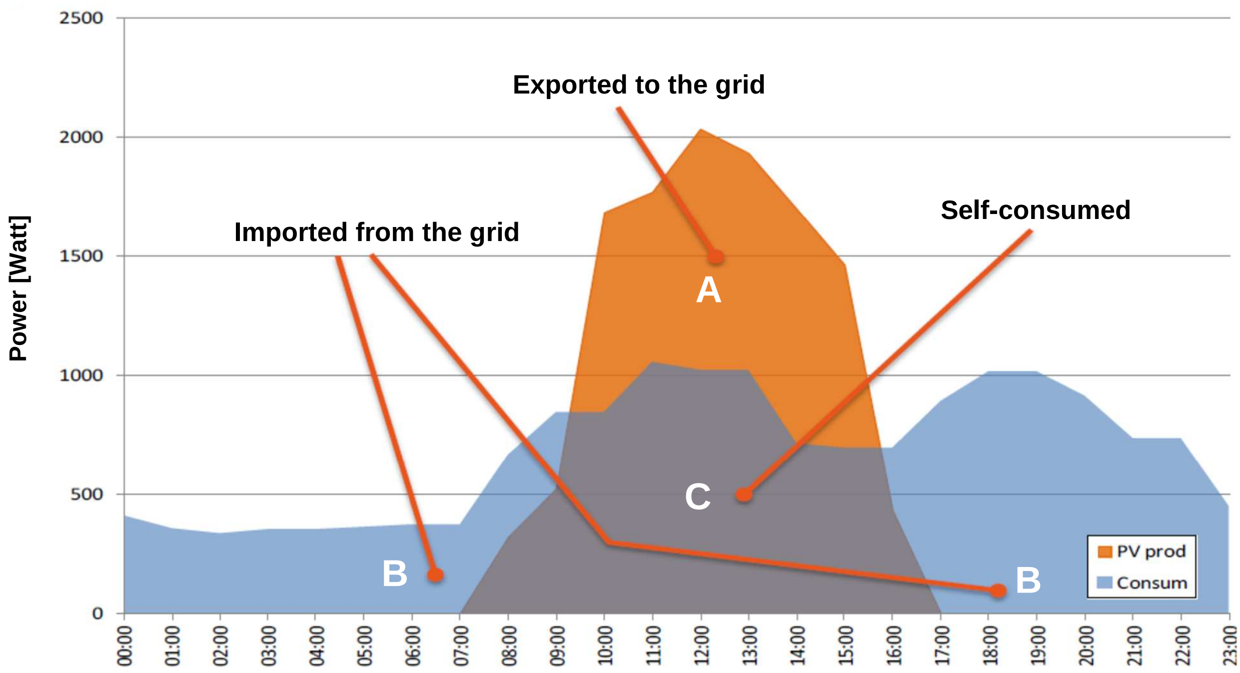


Figure 18 Comparison of a daily building energy generation and consumption profile adapted from the IEA Photovoltaic Power Systems Programme (PVPS) (Masson et al, 2016)

From Figure 18, two ratios can be defined to determine self-consumption and self-sufficiency of a building, using the surface area A, B, C:

$$self - consumption\, ratio = \frac{C}{A + C}$$

$$self - sufficiency\, ratio = \frac{C}{B + C}$$

These two terms should not be confused. The self-consumption ratio represents the share of the on-site energy generation matching the building's energy loads divided by the total building's on-site energy generation[7]. Findings from IEA-SHC Task 40 and IEA-EBC Annex 52 projects showed that the load match index (equivalent to the self-consumption index) in net zero energy buildings varies from about 35% in an hourly energy calculation up to 100% for an annual balance (Voss et al, 2010). In opposite, the self-sufficiency ratio represents the share of the on-site energy generation (e.g., PV) which matches the building's energy load divided by the total building energy load. As stated by Sørnes et al (2014), the self-consumption and self-sufficiency ratio should normally be calculated for a hourly time step.

Annex 56 choice for the LCA methodology of energy-related building renovation:

While an hourly approach is probably the most accurate according to the findings of the IEA Task 40/Annex 52 project, the current energy codes or regulations do not require it as a compulsory approach. In Annex 56, the calculation rules for the LCA are thus based on the energy needs calculated with a steady state approach, determining yearly energy demand as some building energy codes and labels only calculate the energy consumption and on-site generation on an annual balance.

4.3.3. Primary energy and carbon emissions factors for the electricity mix

Next to the determination of the share of self-consumption, a renovated building with on-site renewable electricity generation systems has also some imports of electricity from the grid to meet its electricity needs.

As mentioned by Sartori et al (2012), while it is already common praxis to have seasonal or hourly fluctuating energy prices, for primary energy use and carbon emissions this is not common praxis today but it may become more common in the future. Carbon emissions and primary energy factors of the electricity mix vary depending on the day, the month and the season. It varies due to the import/export of electricity between a country and the neighbouring countries and due to the running or not of the different energy generation capacities during the year. Electricity grid

7 It is important to highlight that other definitions for defining the self-consumption and the self-production aspects may be found in the literature.

managers at national level sometimes provide the hourly production mix of the electricity allowing the estimation of hourly primary energy and carbon emissions factors of the electricity e.g., in the US[8], in Spain[9] or in France[10]. It is then possible to match them with the hourly energy consumption and hourly on-site renewable energy generation of a building.

Annex 56 choice for the LCA methodology of energy-related building renovation:

As this more accurate approach (i.e., hourly primary energy and carbon emissions factors for electricity) has been to date only briefly discussed and not all the countries have publicly available data on that topic, the LCA methodology of Annex 56 applies the annual average primary energy and carbon emissions factors for the electricity consumption mix.

In Annex 56, the primary energy and carbon emissions factors of other energy carriers are also based on an annual average.

4.3.4. Allocation rules for on-site renewable energy generation systems

Different allocation rules can be applied in LCA. A renovated nearly zero energy building equipped with on-site renewable energy systems becomes a multifunctional system as the building becomes an energy producer. According to ISO 14044, two approaches can be used to deal with this issue: the avoided burden approach (extension of system boundaries) and the co-product allocation.

- For the co-product allocation, exported electricity is considered as a “co-product” of the building system. The embodied primary energy and embodied carbon emissions of the on-site energy generation systems are allocated to the building according to the self-consumed[11] on-site renewable energy and added to the primary energy use and the carbon emissions of electricity imported from the grid.

  Using the terms introduced in Figure 18 in the case of a PV system, the primary energy (PE)[12] of a renovated building is calculated as follows:

$$PE_{building} = PE_{imported\ electricity} + \frac{C}{A+C} \times PE_{PV} + PE_{other\ energy\ use} + PE_{other\ BITS} + PE_{materials}$$

  With

8 En.openei.org/datasets/dataset/hourly-energy-emission-factors-for-electrictiy-generation-in-the-united-states

9 www.ree.es/en/activities/realtime-demand-and-generation

10 Clients.rete-france.com/lang/fr/visiteurs/vie/bilan_RTE.jsp

11 A similar approach as proposed in the EN 15978 standard (2011) for building LCA is to allocate 100% of the embodied energy of on-site energy generation BITS to the building whatever is the self-consumption value.

12 It can be either total primary energy use (TPE) or non-renewable primary energy use (NRPE)

$PE_{imported\ electricity}$	the primary energy of the imported electricity from the grid
PE_{PV}	the primary energy of the on-site RES system
$PE_{other\ energy\ use}$	the primary energy of the other operational energy use not covered by the on-site RES and covered by other systems
$PE_{other\ BITS}$	the primary energy of the other BITS, excluding the on-site RES system

- The second allocation method is the avoided burden approach. It considers the export of the building's on-site renewable energy (electric, thermal) as an energy which does not need to be produced for the grid, leading to "credits" for the building which depend on the quantity avoided. In that case, 100% of the embodied primary energy and embodied carbon emissions related to the on-site RES systems are taken into account in the building-LCA. Embodied energy (and related carbon emissions) is added to the difference between the imported (delivered) electricity from the grid and the export of on-site generated RES electricity multiplied by the primary energy (or carbon emissions) factor of the electricity grid.

  Using terms introduced in Figure 18 in the case of a PV system, the primary energy (PE)[13] of a renovated building is calculated as follows:

$$PE_{building} = \left(C_{imported\ electricity} - C_{exported\ PV\ electricity}\right) \times PE_{grid\ mix} + PE_{PV} + PE_{other\ energy\ use} + PE_{other\ BITS} + PE_{materials}$$

  With

$C_{imported\ electricity}$	amount of the imported electricity from the grid
$C_{exported\ PV\ electricity}$	amount of the exported PV electricity to the grid
$PE_{grid\ mix}$	the primary energy factor of the electricity grid mix

In addition to the two ISO 14040 allocation methods, the EN 15978 standard for building LCA also introduces its own method:

- The EN 15978 allocation method considers that 100% of the on-site RES embodied energy and embodied carbon emissions are allocated to the building even if a part of the on-site energy production is exported to the grid (e.g., in the case of a building where the on-site energy production excess the total building energy consumption).

In that case the equation simply becomes:

$$PE_{building} = PE_{imported\ electricity} + PE_{PV} + PE_{other\ energy\ use} + PE_{other\ BITS} + PE_{materials}$$

The same three equations also apply for the carbon emissions calculations.

13 It can be either total primary energy use (TPE) or non-renewable primary energy use (NRPE)

Annex 56 choice for the LCA methodology of energy-related building renovation:

A first study has been conducted in 2014 by Fouquet et al (2014) in this topic. The authors showed the influence of the allocation rules for the on-site renewable energy system on comparative LCA, comparing alternatives with and without PV systems for a single family house in the French context. The results do not show any differences in the ranking of the alternatives “single-family without PV” and “single-family house with PV” between using the avoided burden allocation and the co-product allocation

As a result, in Annex 56, the user of the LCA methodology can either use the avoided burden approach or the co-product allocation. The choice should be motivated by the goal and scope of the study[14].

In addition, on-site generated electricity fully sold to an off-site owner of the generation unit is not accounted for in the building LCA (since electricity generated is allocated to the (external) owner of the system, using the building only as a carrier for his generating system).

4.4. Embodied energy

To summarize, the system boundary to perform an LCA of a renovated building should include the following elements:

- The materials added for energy related renovation measures of the thermal envelope of the building;
- The materials added for energy related renovation measures for the building integrated technical systems (BITS), including on-site energy generation units[15] (PV, solar thermal, etc.);
- The materials added to provide the same building function before and after renovation.

Figure 15 shows the energy related and the components related impacts to take into account in the LCA and in the assessment of overall energy use related to a renovated building.

4.5. Service life and replacement

The service life is defined as the time during which a building component (construction material, BITS component (boiler, etc.)) fulfils its function. At the end of its service life, the product must be replaced. The service life of the building components included in the LCA calculation (construction

14 A sensitivity check will however be performed in the Annex 56 case studies results with on-site renewable energy systems to ensure the choice of the allocation rules for e.g., PV systems does not bias the comparative LCA results.

15 According to the allocation rules introduced in the previous chapter

materials & building integrated technical systems) must be reported and documented, as it has a direct effect on the results.

4.5.1. Service life of constituent parts of buildings

In a construction element, not all layers (materials) are replaced at the same time and some are never replaced. This is for instance the case for the bearing structure that will probably never be replaced during the life cycle of the building. As shown in Figure 19, the construction element can be divided in different parts.

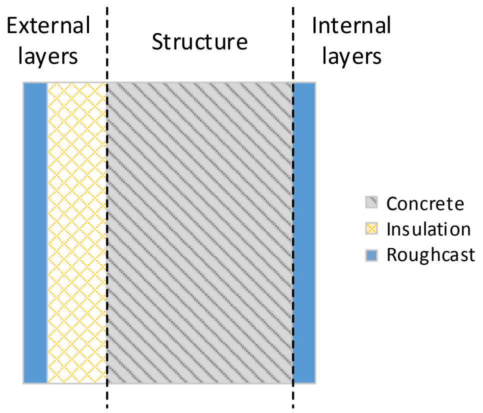


Figure 19 Example of a construction element with a bearing layer (structure) and non-bearing materials

It is not realistic to use a constant service life time for a particular type of material. For instance, the same insulation material doesn't have the same service life when placed in a roof or in an external wall. For a specific material, its service life will depend on its physical properties (water resistance, moisture sensitivity, etc.) and its context of use (exposed to the outside, the soil, etc.). In order to define the service life of materials, it is therefore important to take into account the following parameters:

- Type of construction element (wall, floor, roof, etc.);
- Location of the construction element (against ground, exterior, interior);
- Position of material layer within the construction element.

Different sources of information can be used to define the service life of building constituents: Official documents such as ISO 15686 and followings ("ISO 15686 Buildings and constructed assets -- Service life planning," 2012) or national documents. Appendix 9.1.2 also gives guidelines regarding the service life of internal, external as well as structure layers of construction elements.

Here are some examples that need to be correctly analysed to perform a correct LCA:

- Some heavy layers which are not part of the bearing structure might be replaced during the life cycle of the building. In the case of a wall with concrete and terracotta bricks on either side of the insulation, the bricks could be replaced during a massive renovation. A floor screed could also be replaced in such a situation. In both cases, the bearing structure is not replaced.

- The insulation between two concrete layers will have the same service life as the two concrete layers, which may probably not be replaced during the building life cycle.
- A construction element might have been designed to allow for the possibility to easily replace some internal parts. In this case, only the replaced material is taken into account in the calculation.

4.5.2. Number of replacements

Due to a limited service life, construction materials will usually be replaced once or several times during the study period. These additional replacements have to be included in the LCA. For the calculation of the number of replacements the following statements need to be taken into account:

- The number of replacements for construction materials and components of a building integrated technical system (BITS) depends on their estimated service life (ESL) and the reference study period for the building.
- No replacement is required when the service life of the building element meets or exceeds the reference study period (foundations, bearing wall, etc.).
- In practice, only a whole number of replacements (no partial replacements) is allowed to calculate the contribution of the replacement stage. In the case of a partial number of replacements resulting from the estimated service life of the component and the reference study period of the building, the value obtained is rounded upward.

$$N_R = Round\left(\frac{SP}{SL} - 1\right)$$

N_R Number of replacements of the element

Round Function that rounds to the nearest integer value

SP Study period of the building

SL Service life of the element (material or building technical system)

4.6. Reference study period of the renovated building

Cost and LCA are carried out on the basis of a chosen reference study period, for which all contributions of materials and energy consumed are calculated. Therefore, the reference period has an important and direct influence on the results.

For new buildings, the reference study period is usually defined as the estimated service life of the building. For renovated buildings, the reference study period can be:

- The period between the current renovation and the next one. A typical value is 30 years, which corresponds to the period between the building construction and the first important renovation, which could be motivated by energetic purposes.
- The period between the current renovation and the end of building's life. A typical value is 60 years.

It should be noticed, that the number of energy related renovations during the building's life is limited. The more the building achieves low energy consumption after renovation, the less a major energy related renovation will be undertaken in the future. It is impossible to know, which materials will be used to replace the energy related construction material in the future. It is also impossible to know which future energy vectors will be used when the boiler will be replaced (in about 30 year).

One recent example is related to electrical heating. Thirty years ago it was subsidised or at least promoted by local authorities in several countries. But now, due to political reasons after the nuclear power plant accident in Fukushima, some governments are willing to promote the substitution of electrical heating. The same uncertainty occurs for the replacement of construction materials that will take place in several decades.

The reference study period should be equal or longer than the service life of the energy related building components analysed in order to avoid any misinterpretation of the results. Therefore, in Annex 56, it is suggested to use a reference study period of **60 years**. If another reference study period is used, it should be reported and documented.

5. Cost assessment: Methodology framework

The methodology for the overall cost assessment is outlined in the subsequent paragraphs. It is based on a life cycle cost approach, assuming either a private perspective or a societal perspective. Cost calculations are performed dynamically, discounting future costs and benefits. The methodology to calculate energy and carbon emissions related costs of building renovation draws inter alia from EPBD Art. 4, Annex I and Annex III, methodology provided by European Commission in 2011, as well as further literature (BPIE 2010; Hermelink A.H. 2009 and Boermans T. et al. 2011).

5.1. Scope of cost evaluation

The scope of cost evaluation is based on a **lifecycle cost** approach and comprises in accordance with the guidelines to the EPBD (Official Journal of the European Union, 19.4. 2012, p. C 115/16; (EU) No 244/2012) the following cost elements (see Figure 20):

- *Global cost* means the sum of the present value of the initial investment costs plus the present value of the sum of running costs during the calculation period (energy, operational and maintenance costs), replacement costs (referred to the starting year), disposal costs (if applicable) and for macroeconomic cost assessments external costs (due to contributions to climate change, air pollution etc.);
- *Annuity:* The annuity method transforms any costs to average annualized costs depending on the initial costs, the interest rate and the life time of the investment. Its application requires projections on the energy costs and the interest rates for the particular time spans;
- *Initial investment costs*, comprising all costs incurred up to the point when the building or building element is renovated and ready to use for the user. Initial investment costs include costs for planning and approval, purchase of building elements, connection to suppliers, installation and commissioning processes (see Figure 20);
- *Replacement costs* during the life of the building: Substitute investments for building elements according to their economic lifecycle during the calculation period;
- *Running costs*, comprising:
- Annual *energy costs*, including fixed and peak charges for energy as well as national taxes (VAT, energy and greenhouse gas taxes)) and costs for auxiliary energy use;

- *Operational costs*, including annual costs for insurance, utility charges and other standing charges and taxes (see Figure 20) and
- *Maintenance costs*, including annual costs for measures for preserving and restoring the desired quality of the building or building element. This comprises annual costs for inspection, cleaning, adjustments, repair and consumable items (see Figure 20).
- *Disposal costs*: The costs for deconstruction at the end-of-life of a building or building element including deconstruction, removal of building elements that have not yet come to the end of their lifetime, transport and recycling;
- *Cost of carbon emissions* (for macroeconomic cost assessments): External costs incurred by the monetary value of environmental damage caused by carbon emissions related to the energy consumption in buildings or for building elements (if there is a carbon emissions tax the cost of carbon emissions is the residuum of the monetary value of environmental damage caused by carbon emissions minus the tax).
- Definitions for cost evaluation see Figure 20:

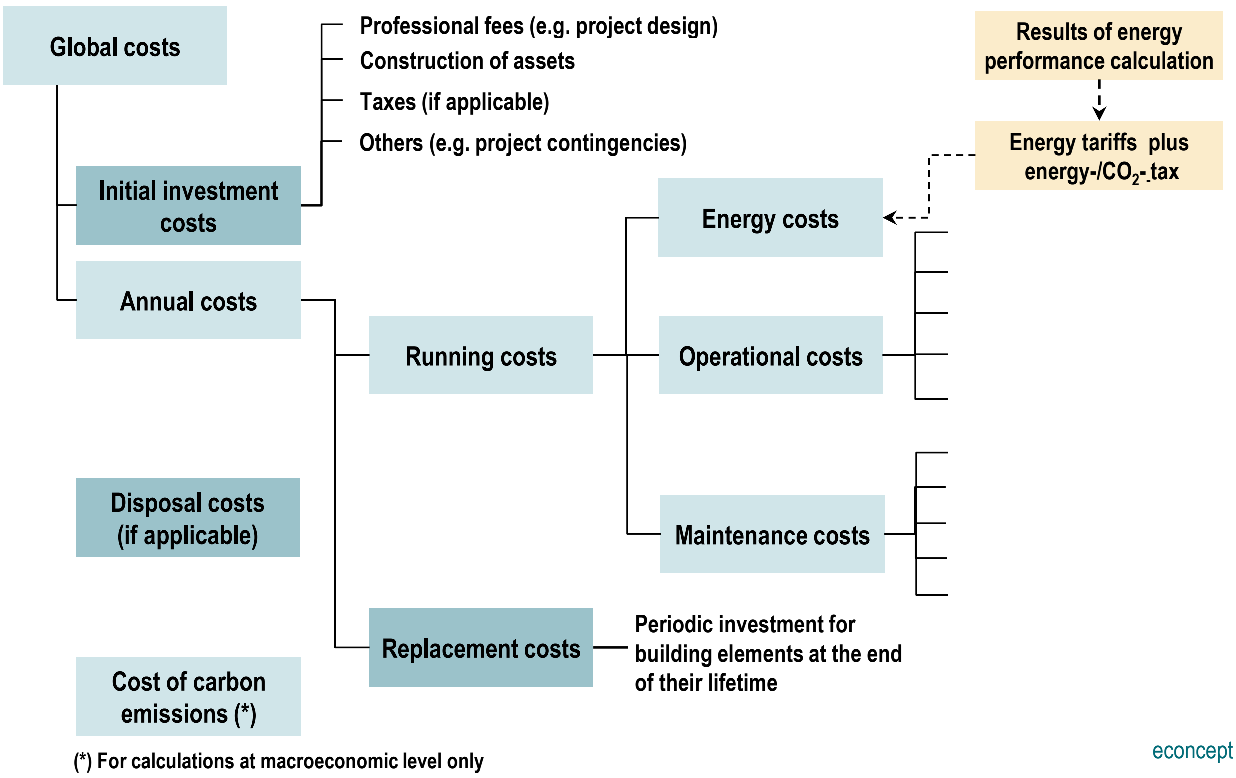


Figure 20 Cost categorization according to the framework methodology of EPBD recast (Official Journal of the EU, 19.4. 2012, p. C 115/16)

- *Residual value* of a building means the sum of the residual values of the building and building elements at the end of the calculation period;

- *Lifetime of a building* corresponds to the residual expected lifetime at the moment of building renovation. If residual lifetime is unknown a calculation period of 60 years is assumed (for the sake of analysis);
- Starting year is the year in which the calculation period starts.

Besides the cost perspective there is the value perspective which is for building owners often even more comprehensive and more relevant. Increased value due to building renovation means the increased economic value of the building as a result of its global quality improvement, especially regarding energy and emission related renovation actions.

5.2. Cost assessment of energy and carbon emissions related renovation measures

5.2.1. Full cost approach

For assessing cost and economic efficiency of energy and carbon related renovation measures, it is necessary to define a reference situation to properly determine the effects of energy related renovation on energy use, carbon emissions and costs by comparing the impacts on the building after the energy related renovation with the impacts in the reference case. In principle the assessment is based on a **full cost** approach which is in line with the regulation prescribed by the EPBD recast (see European Commission, Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012, p. 115/16f.). This means that for each assessed renovation measure or package of renovation measures applied to a building, full costs of renovation and costs of subsequent operation of the building (energy costs and energy related maintenance costs) have to be calculated. Since the focus is on the evaluation of energy related renovation measures or packages of renovation measures for the investor and building user, a reference case has to be determined which comprises all renovation measures **except** the measures which are specifically chosen to increase energy efficiency and/or renewable energy use. This reference case is called an **«anyway» renovation** and comprises only renovation measures which have to be carried out «anyway» because the end of the economical or technical life of building elements has been achieved or the functionality or service quality of a building element is not sufficient any more)[16]. The following cost items may be omitted from the calculation (see : European Commission, Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012, p. 115/16f.):

16 In the case of major renovations, the “reference case” or "«anyway» renovation case" might already comprise energy related renovation measures. In many countries there are regulations, requiring from larger renovation projects to comply with energy related targets (e.g. in Portugal: If the renovation has an investment value above 25% of the building value or in Switzerland: If the investment is larger than 25% of the assurance value of the building or larger than 200'000 CHF). In such cases the question arises, if the reference can be chosen to be a renovation which just complies with existing energy requirements to be met mandatorily.

- Costs related to building elements which do not have an influence on the energy performance of the building, for example: costs of floor covering, costs of wall painting, etc. (if the energy performance calculation does not reveal any differences in this respect; EN C 115/16 Official Journal of the European Union 19.4.2012);
- Costs that are the same for all renovation options assessed for a certain reference building (even if the related building elements have or could have an influence on the energy performance of the building). Since these cost items do not make a difference in the comparison of the renovation measures, it is not required to take them into account. Examples could be cost of scaffolding, demolition cost, etc., again under the precondition that no differences in these cost items can be expected between the renovation measures assessed and the reference case.

5.2.2. Additional cost approach

For calculating the cost optimality of minimum energy performance requirements, the **additional cost** approach is not suitable for the following reasons (European Commission, Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012, p. 115/17):

- The characteristics of the building have an impact on the results of the assessment of cost optimality;
- The additional cost calculation approach cannot fully reflect the scope of assessed measures: Many energy efficiency measures are to be seen as an integral part of the building design. This is particularly true for measures that are related to 'passive heating or cooling' approaches, such as the choice of the window area and the placement of window areas according to the orientation of the building, the activation of thermal mass, the package of measures related to night cooling, etc. The additional cost approach makes it difficult to show inter-linkages between certain building characteristics, e.g. the choice of a certain type of façade requires certain static preconditions; thermo-active building systems for heating and cooling require a certain level of net energy demand, etc. (this holds also for the case of building renovation, albeit to a lesser extent).

5.2.3. Reference situation: «Anyway» renovation

The **reference situation** for the evaluation of energy and carbon related renovation costs comprises those building renovation measures which are not carried out with the purpose to reduce energy use and carbon emissions but which are carried out for maintaining the building and its functionality. For the determination and assessment of the effects of energy related renovation solutions, it is assumed that energy related measures are undertaken in the moment in which a building needs **anyway** a retrofit because of functional reasons (replacement of building elements because of wear-out or because of modernization to meet the needs of the users or because of failure or damages like break down of heating system, replacement of piping, etc.). This **anyway** needed renovation solution, comprising the so-called **anyway renovation measures,** serves as reference situation for determining and assessing the impacts of an energy related renovation solution on energy use, carbon emissions, materials, costs and possible benefits. The energy related solution comprises on the one hand those retrofit measures of the anyway renovation which are not changed by the energy related measures. On the other hand it comprises additionally the energy related measures, which might be additional to the anyway measures or which might substitute some anyway necessary measures by measures which improve also energy performance and do not only restore original functionality of the particular building element. Building renovation comprising energy related measures is compared to the anyway reference case to determine the effects of the energy related measures.

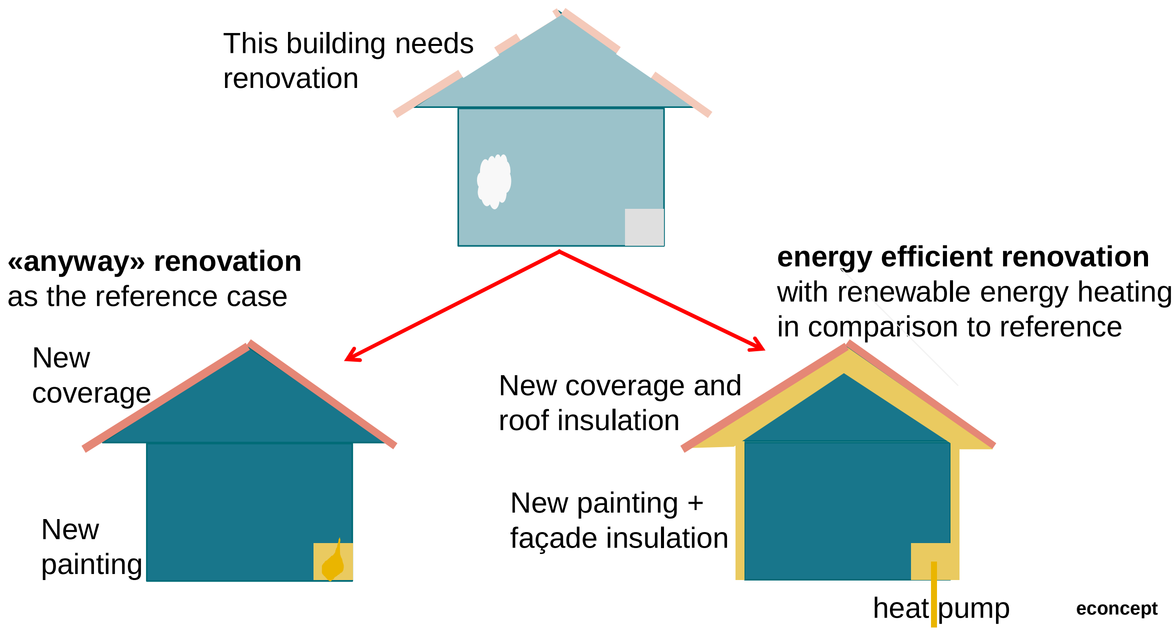


Figure 21 «Anyway renovation» vs. «energy related renovation» in the case of an anyway necessary building renovation due to functional reasons or building elements at the end of their service life.

5.3. Different perspectives: Private costs, social costs and benefits

5.3.1. Private cost perspective

Assessing building renovation and operation solutions, building owners, investors and sometimes even policy makers assume a private cost perspective. This is an individual perspective relying on the prevailing political and economic framework conditions for individuals, as for example indirect taxes (VAT), subsidies, energy taxes or emission taxes, etc.

5.3.2. Social (macroeconomic) cost perspective:

Policy makers, government bodies, public companies etc. are supposed to comply with existing political goals and targets as might also private owners and investors endeavouring to be a front runner or shining example.

Table 4 Cost categories relevant from a private and from a societal cost perspective, respectively.

Cost elements depending on scope: Private cost perspective	Social cost perspective
Investment costs: Initial investment cost Replacement costs	**Investment costs:** Initial investment cost Replacement costs
Utilization costs of building: Energy costs + existing energy-/ CO_2-taxes Maintenance costs Operational costs	**Utilization costs of building:** Energy costs + existing energy-/CO_2-taxes Maintenance costs Operational costs
Co-benefits: Higher user comfort (temperature, air draft and quality), less problems with building physics, reduction of exterior noise, higher aesthetic value, etc. **Indirect taxes and subsidies**	**External costs** (e.g. health damages, building damages, ecological damages due to air pollution) and **benefits** (direct and indirect job creation[17], local economic impacts, less dependence on energy imports)[18]

From the social cost perspective, building renovation is assessed more comprehensively. Therefore, external costs and benefits are taken into account but at the same time neither financing taxes[19] nor subsidies[20] are considered. Energy and emission taxes are taken into account for the private as well as for the social perspective, since they internalize external costs (for climate change effects, air pollution effects, biodiversity losses, etc.). To integrate into the cost assessment private co-benefits as well as social costs incurred by external effects is a big

17 Wei, M.; Patadia, S.; Kammen, D.M. (2009) synthesized 15 job studies, covering renewable energy, energy efficiency, carbon capture and storage and nuclear power with respect to their job creation potential. They found that all non-fossil fuel technologies (energy efficiency, renewable energy and low carbon) create more jobs per unit energy used or saved than coal and natural gas.

18 Job creation studies have to be interpreted carefully. Very often they do not really determine net job creation by energy efficiency and renewable energy taking adequately into account job losses in the economy if financial resources are reallocated for energy efficiency and renewable energy. Studies applying a general computable equilibrium model for Switzerland and assuming a high energy taxing policy to transform the energy sector until 2050 to about 2 tons of CO2 per capita per year yield high reductions of non-renewable energy demand combined with slight job losses (until 2050 -0.7% compared to a business as usual scenario) and slight GDP losses (-0.08% per year until 2050; Ecoplan 2012).

19 Financing taxes are levied with the aim to raise money for the government. From a macroeconomic point of view this is only a distributive effect and not macroeconomic or social costs due to resource consumption

20 From a macroeconomic point of view, subsidies lead to a different distribution of finances and not to resource consumption which incurs macroeconomic costs.

challenge because quantification and even more monetarization of these effects is usually not available and complex to appraise.

For the global cost assessment, direct costs incurred by investments and building operation ought to be supplemented by costs or benefits from external effects (social costs) and co-benefits (private benefits). Energy related renovation measures have typically quite different costs and benefits compared to non-energy related «anyway» renovation measures: Higher capital costs due to higher investments but lower energy costs due to better energy performance, higher co-benefits and lower external costs (see Figure 22).

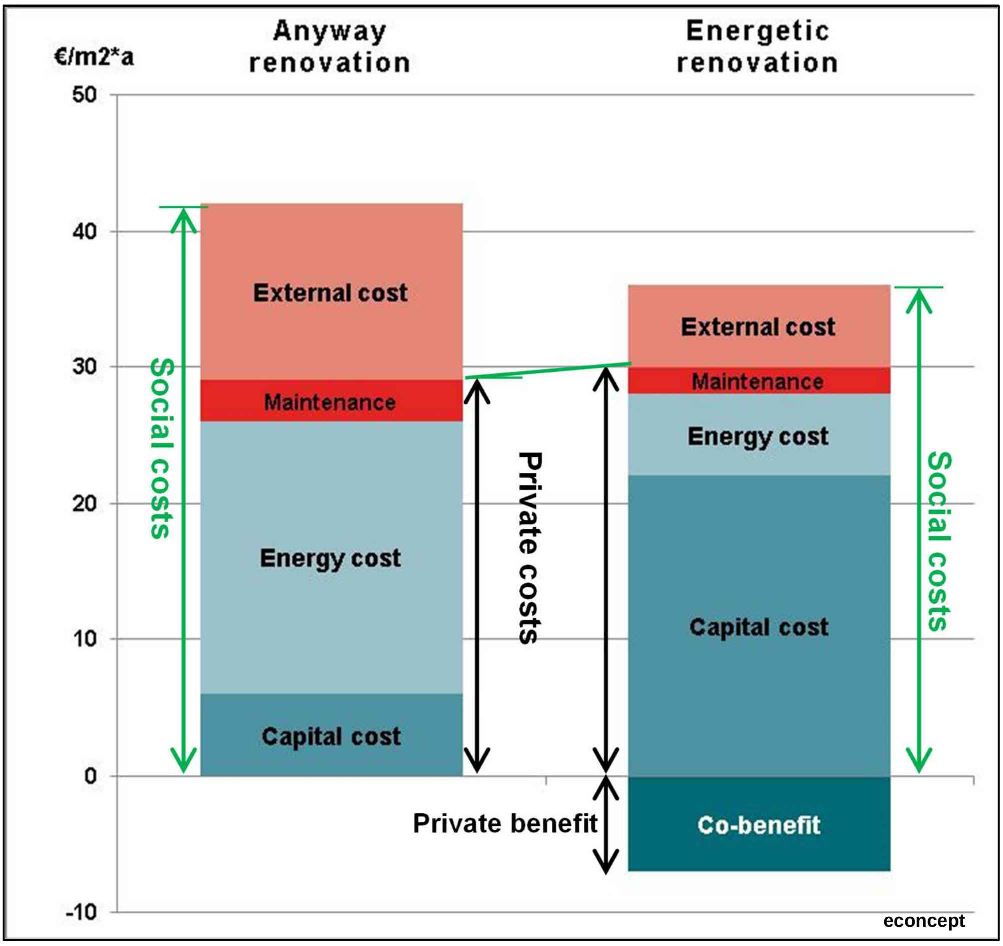


Figure 22 Anyway renovation compared to energy and carbon emissions related renovation: Private yearly costs and co-benefits and social yearly costs (including also external costs without already internalized financial payments for CO_2-allowances or taxes)

5.4. Cost calculation method: Dynamic cost calculation

Adequate lifecycle cost calculation has to be performed dynamically, i.e. future costs and benefits have to be discounted to yield economically correct results. Neither payback methods with typically much too short static payback times nor static cost calculations are adequate for cost assessment of energy conservation measures which have long lives. According to EN 15459 (Energy performance of buildings – economic evaluation procedure for energy systems in buildings) it is adequate to apply either the ***global cost method*** or the ***annuity method*** for dynamic cost calculations:

5.4.1. Global cost method

By applying the **global cost method**, the present value of all investment costs (initial investment costs and replacement costs) and of the running costs (energy, operational and maintenance costs; see Figure 20) during a predefined calculation period or during the remaining life of the building are determined. Thereby all future costs, cost savings and monetary benefits are discounted to the starting year and summarized which yields the present value of the corresponding cost and benefit flows during the assessment period.
Often buildings or certain building elements have a longer life span than the calculation period assumed. In such cases it is necessary to estimate a residual value for the building or for building elements at the end of the calculation period. To estimate residual values at the end of the calculation period, linear depreciation is applied as proposed by the guidelines for the EPBD recast. Discounted residual values have to be added to the net present value. For the calculation period energy prices and interest rates as well as operational and maintenance costs have to be projected for every year of the evaluation period to be taken into account and discounted properly. This method corresponds with the discounted cash flow method commonly used in the realm of building development and management.

Global costs (private cost perspective):

$$Global\ cost\ \ C_g(t) = C_I + \sum_k \left[\sum_{j=1}^{t} \left(C_{a,j}(k) \times \left(\frac{1}{1+\frac{r}{100}} \right)^j \right) - V_{f,t}(k) \right]$$

t: Calculation period

$C_g(t)$: Global cost (referred to starting year t_0) over the calculation period

C_I: Initial investment costs for measure or set of measures *k*

$C_{a,j}(k)$: Annual cost during year *j* for measure or set of measures *k*

$V_{f,t}(k)$: Residual value of measure or set of measures *k* at the end of the calculation period (discounted to the starting year t_0)

If a societal or macroeconomic cost perspective is assumed, taxes (except internalising taxes), charges, subsidies have to be excluded but external costs (for carbon emissions or pollution) have to be included.

Global cost (macroeconomic/societal perspective):

$$C_g(t) = C_l + \sum_k \left[\sum_{j=1}^{t} \left(\left(C_{a,j}(k) + C_{c,j}(k) \right) \times \left(\frac{1}{1 + \frac{r}{100}} \right)^j \right) - V_{f,t}(k) \right]$$

$C_{c,j}(k)$ Carbon cost for measure or set of measures *k* during year *j*

5.4.2. Annuity method

The **annuity method** transforms investment costs into average annualized costs, yielding constant annual costs during the life span of the investment considered. Minimal time horizon for the calculation period is usually the service life of the building element with the longest life expectancy. Yearly energy costs, operational costs and maintenance costs are added to yearly annuity costs of initial investment, yielding constant yearly global costs during the evaluation period. If energy prices as well as yearly operational costs and maintenance costs are not constant during the calculation period, it is necessary to determine and apply an adjustment factor[21] to take into account real future energy price increases or real future cost increases.

General average adjustment factor for price or cost increases applying the annuity method:

a *annuity for constant real prices (costs)*

m *general average adjustment factor*

t *time range of cost evaluation*

i *real interest rate*

r *rate of yearly increase of energy prices, maintenance costs or operational costs*

Annuity a: $a = \frac{i*(1+i)^t}{(1+i)^t-1}$

If the energy prices or the costs are rising, it is necessary to calculate an average energy price or cost value, which dynamically takes into account the price or cost increases in the period t. This can be done by calculation of an average or medium adjustment factor ***m*** *which has to be multiplied with the energy price or the annual costs at the beginning of period t with prices or costs increasing annually by a rate r (e.g. 0.02 for an annual rate of 2%):*

21 The general average adjustment factor for price or cost increases applying the annuity method

$$m = \frac{\left(\mathbf{1}+\frac{i-r}{1+r}\right)^{t}-\mathbf{1}}{\left(\frac{i-r}{1+r}\right)*\left(\mathbf{1}+\frac{i-r}{1+r}\right)^{t}} * \mathbf{a}$$

***Example**:*

*For a real interest rate **i** = 0.03 (3% per year), price or cost increases **r** of 0.04 (4% per year) during the calculation period **t** of 20 years, the resulting average price (cost) increase factor **m** is:*

m = 1.49

*Hence yearly capital cost **c** for an initial investment **I** are:* ***c = a*I***

*If yearly energy costs **e** are increasing by 4% p.a. and the real interest rate **i** is 3% p.a. the adjusted average annual energy costs e_a during period t are:* $e_a = e * m$

The guidelines of the EPBD-recast propose to apply the global cost method.

In Annex 56 the annuity method is used for parametric cost calculations within the evaluation of various packages of renovation measures for generic buildings. By using the annuity method, it is not necessary to determine residual values at the end of a preset calculation period for measures which have a longer life than the assumed time horizon of the cost calculation. Hence it is easy to obtain average yearly costs (or costs/m^2 per year) for measures with different service lives. Thereby, the annuity method assumes that building elements are replaced at the end of their element-specific service life (i.e. corresponding replacement investment is taken into account).

6. Co-benefits

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 a major responsible.

Although existing buildings represent a huge potential in these areas (BPIE, 2011), it has been found hard 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 fact, renovation works improving the energy performance of the existing buildings trigger substantial benefits that can be felt not only at a financial level, but also at the environmental and social levels (IEA, 2012a). These 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 under development 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.

6.1. Direct benefits and co-benefits of energy related building renovation

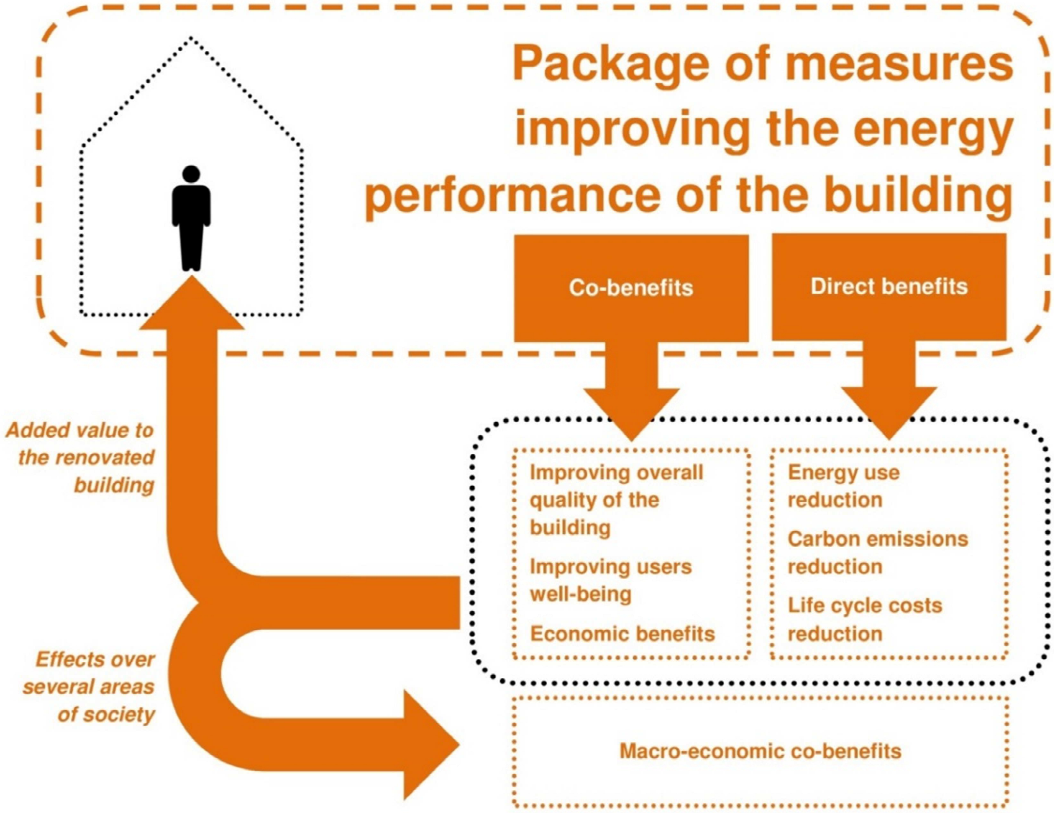
According to the International Valuation Standards, the market value of a property is the ‘‘estimated amount for which a property should exchange on the date of valuation between a willing buyer and a willing seller in an arm’s length transaction after a proper marketing where parties had each acted knowledgeably, prudently, and without compulsion’’ (International Valuation Standards Committee, 2007). Considering this definition, the added value due to 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 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 23.



M. Ferreira

Figure 23 Direct benefits and co-benefits from cost effective energy and carbon emissions related building renovation

6.2. Identified co-benefits within energy related renovation measures

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 important to be made is between the 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 have impact on these indicators present a private perspective.

6.2.1. Co-benefits observed from a macroeconomic perspective

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 achievement of many other policy goals (IEA, 2012b; Goodacre, 2001). But, 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.

If cost savings are spent again for additional goods or services there will be additional energy consumption for these goods and services producing a 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 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, two 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, particularly when considering LCA in the evaluation of renovation measures, leads to reduction, reusing and recycling of waste if compared to the replacement of existing buildings by new ones.
	Increased comfort	Normalizing humidity and temperature indicators; less air drafts, more air purity; reduced heat stress through reduced heat islands.
Economic	Lower energy prices	Decrease in energy prices due to reduced energy demand driven by energy efficient measures implemented.
	New business opportunities	New market niches for new companies such as energy service companies (ESCOs) resulting in higher GDP growth.
	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 is heavily subsidized).
	Improved productivity	GDP/income/profit generated as a consequence of new business opportunities and employment creation.
	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.
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.

6.2.2. Co-benefits observed from a private perspective

The private perspective takes into account the concerns of owners, promoters and users and mainly focuses on the financial aspects for these stakeholders, namely the reduction of the global cost of the renovation works or in adding the most value to the building.

The reduction of the global cost of the renovation works to the possible minimum corresponds to the cost optimal level, which 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 or might trigger investments which would have been substituted otherwise by economically more profitable investments.

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 6 presents an overview of co-benefits at building level from renovation measures improving the energy performance of the building, and their grouping in three categories. Some of the co-benefits in Table 6 have to be attributed to anyway renovations too and accrue for packages of energy related renovation measures as well as for a package of anyway renovation measures (e.g. aesthetic improvement and enhanced pride or prestige because of a higher aesthetic value of building because of façades newly painted in the anyway case as well as in the case of a façade renewal with new additional insulation). Co-benefits which might also emanate from anyway renovations are marked with ***)** in the subsequent Table 6).

Table 6 Typology of private benefits of cost effective energy and carbon emissions optimization in building renovation

***)** These co-benefits might also accrue (at least partly) in the case of an anyway renovation

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.

Category	Co-benefit	Description
	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. Although, aesthetics and architectural quality of a building may also be reduced by energy related renovation 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 just the replacement of the balconies by others with bigger areas, but it also can occur with the replacement of building equipment by other with smaller dimensions. 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.
	Natural lighting and contact with the outside environment	Day lighting, 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 natural lighting and views from the liveable areas and therefore produce a negative co-benefit.
	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 intrusion, and the annoyance from internal noise.

Category	Co-benefit	Description
		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

Based on the list of co-benefits in Table 6 and the corresponding literature review, on the evaluation of the Annex 56 Shining Examples and also on the contributions of Annex 56 participants, a matrix of relationship between co-benefits and specific renovation measures has been developed and is presented in Table 7. This matrix is intended to be used by decision-makers during the decision-making process, so that they can be fully aware of the co-benefits of each possible renovation measure.

Table 7 Relationships between co-benefits and specific renovation measures (signals "**+**" for positive co-benefits and "**–**" for negative co-benefits, indicating their relevance, reinforced by colours with orange for positive and purple for negative (increased relevance with stronger colours). Above the signals, the source supporting the link between the co-benefit and the renovation measures).

CO-BENEFITS	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
Façade insulation (external)	1,2,6,7 ,SE +++		SE +	*, SE + +	* -	6, SE + +		5, SE + +	6 - - +			7, SE + +	
Façade insulation (internal)	1,2,6,7 - + +				* -	6 + +		5 + +		3 - -		7 +	

CO-BENEFITS	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
Roof insulation	1,2,6,7 ,SE +++			SE +	* -	6, SE + +		5, SE + +				7, SE + +	
Ground floor insulation	1,2,6,7 +++							5, SE + +				7, SE +	
Cellar ceiling insulation	1,2,6,7 +++							5 + +				7 +	
Windows replacement	1,2,6,7 +++			SE +	* -	1,6,7 +++		5,7,SE +	7 +		7 + +	7, SE +	
Insulation of entire building envelope	* +++				* -	* +++		* + +	* - +			* + +	
Larger window areas	* -	6, SE, * +++											
Roof light or Sun pipes		3 + +						5 +					
External shading	5 + +					5 +		5 +	* +++				
Balconies and loggias	6 - + +	6 - -		6 + +		* +++			6 + +	6, SE + +			
								5,7 +					7 + +
Ground coupled HP								5,7 +					* - -
Biomass heating system								5 +					
Efficient DHW system								5,SE + +				SE +	
Automatic control systems							SE +						
Air renewal systems	*, SE + +		1,4,5, SE, * +++	1, SE + +	* - -		* -	5 +					
MVHR systems	*, SE + +		SE +	SE +	3 - -			5 +				SE +	
Solar Thermal systems								7,SE + +				7,SE + +	7 + +
Photovoltaic systems													* +++
Active cooling systems	* + +												

* Annex 56 participants experience

[SE] Identified in Annex 56 Shining Examples

[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

6.3. Co-benefits integration in cost effective energy and carbon emissions optimization

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 might have different added values in different locations, just because the willingness to pay revealed by consumers in different markets might vary substantially. Therefore, one needs to keep in mind that evidence from other markets concerning price variations for energy performance and related co-benefits might not be relevant.

Considering these constraints, these benefits are often difficult or nearly impossible to accurately quantify making it much more difficult to add their contribution into a traditional cost-benefit analysis. Nevertheless, a growing interest in this theme has been leading to several studies aiming for 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.

6.3.1. 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". For a macro-economic perspective, co-benefits represent indirect benefits from investments in the improvement of energy performance of buildings accruing to society at large. For 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). These methods are the following:

- 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 do 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).

6.3.2. Co-benefits in the evaluation of renovation packages towards nZEB beyond cost optimum

Analysing 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.

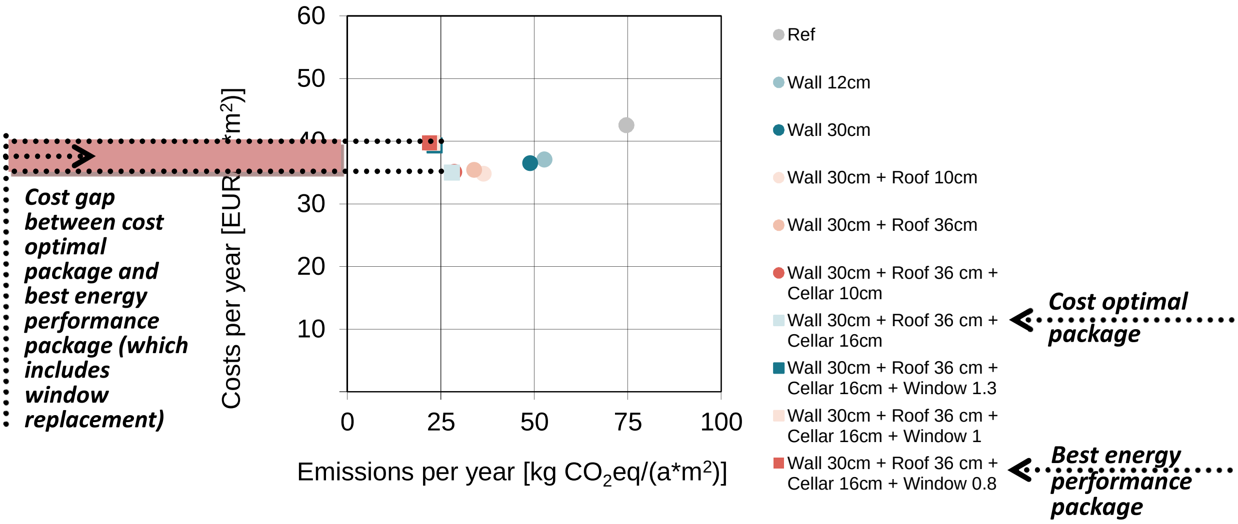


Figure 24 - Integration of comparison of cost effectiveness of energy efficiency renovation measures with oil heating system and related impacts on carbon emissions in Switzerland, for single -family building

Figure 24, 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 until the 6th package of renovation measures. 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 30cm + roof 36cm + cellar 16cm), with the package of measures with the best energy performance among the tested packages (wall 30cm + roof 36cm + cellar 16cm + window 0.8), 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 7^{th}, 8^{th} and 9^{th} 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 24, around 5 € per year and m^2 or 1000 € per year (this building has $210m^2$ of gross floor heated area).

From the matrix of co-benefits (Table 7), window replacement is a renovation measure that produces several co-benefits, some of which resulting also from the previous steps of renovation measures.

7. Cost effective energy and carbon emissions optimization in building renovation

Subsequent explanations highlight the difference between cost optimal and cost effective packages of energy related renovation measures. The range of measures being still cost effective but not cost optimal any more is illustrated, indicating possible options for target setting which considers costs. To reduce carbon emissions **and** energy use costs effectively is not a clear cut optimization task. It is much more a trade-off analysis of costs and benefits of energy efficiency measures versus measures deploying renewable energy while reducing carbon emissions. Trade off analysis can be turned into an optimization task if one target is set for optimization of costs and benefits. At the same time a boundary condition with respect to the second target dimension is set. Optimization of costs and benefits with respect to target has then to comply with the boundary condition. E.g. if the target is to get a zero emissions building, prioritising the emission target, carbon emissions can be reduced cost optimally to zero. But simultaneously the building has then to fulfil a boundary condition which is related to the resulting energy need of the zero emission building, which is supposed to ensure satisfactory thermal comfort and prevent problems with building physics (e.g. mould, thermal bridges, etc.).

7.1. Cost optimal vs. cost effective energy and carbon emissions related building renovation

7.1.1. Cost optimal efficiency measures within a two-step approach to nearly zero energy and/or emissions buildings

For the time being in Europe, the concepts of the recast of the Energy Performance of Building Directive (EPBD) prevail in the discussion on future energy performance standards for buildings. The directive is based on a two-step approach (illustrated in Figure 25) which assumes that the improvement of energy related building performance starts first with cost effective energy related efficiency measures, up to at least an efficiency level which corresponds to the cost optimal package of energy related renovation measures (see Official Journal of EU from 21.3. 2012 and 19.4. 2012). This cost optimum can be assessed on a private financial level (relevant for building owners, investors and users) or on a societal macroeconomic level (relevant for the policy makers and the society)[22].

To achieve zero or nearly zero energy or emissions buildings, either additional efficiency measures or the supply of renewable energy, as possible generated on-site, can be applied to further reduce carbon emissions and remaining non-renewable energy use (this results in the two-step approach, mentioned above and illustrated in Figure 25).

In the case of building renovation, it has to be explored in more detail if the priorities in the two step approach still hold considering cost effectiveness. At the time being, stepwise renovation practices are widespread and often favour the choice of renewable energy use for the next upcoming renovation step (especially if the heating system has to be replaced). Thereby, carbon emissions and non-renewable primary energy use can already be reduced significantly and cost effectively. This choice might especially be recommendable if the building envelope is not at the end of its service life and does not have to be renewed yet.

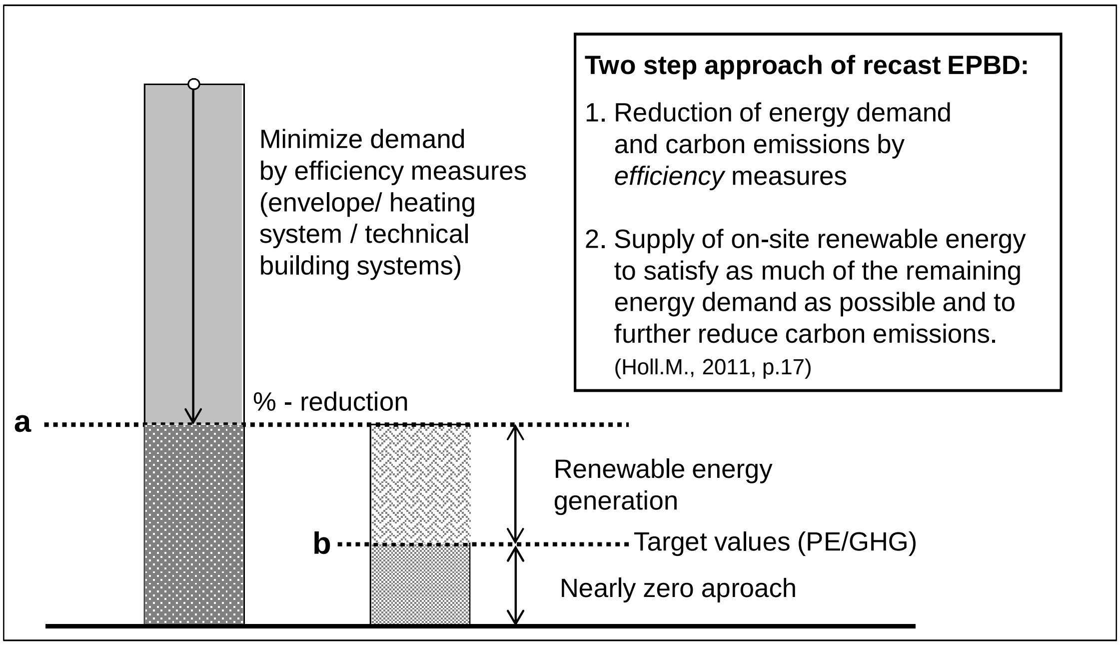


Figure 25 Two-step approach of EPBD recast (Holl M. 2011, p. 17).
PE: Primary energy; GHG: Greenhouse gases/carbon emissions

22 According to the recast EPBD, EU Member States are obliged to implement energy related building performance standards which achieve at least the cost optimal or least cost performance level.

7.1.2. Global cost effectiveness approach for building renovation to achieve nearly zero energy and nearly zero emissions buildings

In the case of building renovation cost optimal energy related renovation measures will usually not yet allow to achieve NZEB's. Therefore, the range of economically viable renovation measures, has to be extended to comprise the evaluation of all renovation measures, being still cost effective. This means to either apply further demand reducing measures and/or to deploy renewable energy.

Figure 26 illustrates the cost effectiveness approach to determine minimal energy and/or emission standards. Minimal requirements depend on the performance level which can be achieved economically viable compared to anyway renovations which represent the reference renovation situation. In Figure 26 resulting primary energy reductions A→N are remarkably higher than in the case of the economic most favourable minimal cost solution O with a primary energy reduction A→O.

Moreover, resulting savings depend on the cost perspective assumed (see subsequent chapter 7.2). If a social cost perspective is assumed which comprises also external costs, they will be higher than in the case of a private cost perspective (depending on the degree of internalisation of external cost in the private costs, e.g. by carbon taxes or a emission cap and trade regime).

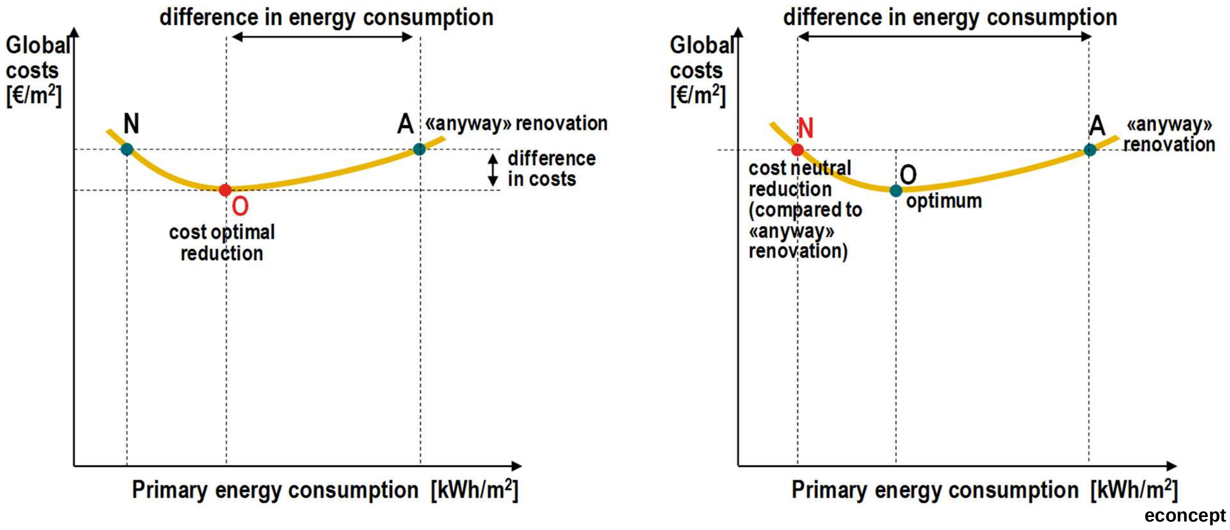


Figure 26 Global cost curve after renovation (yearly costs for interest and amortization, energy costs, costs for operation and maintenance of the renovation measures), starting from the reference situation **A** («anyway» renovation) towards energy related renovation options yielding less primary energy use after renovation than in the case of the anyway renovation. **O** represents the cost optimal renovation option. **N** represents the renovation option with the highest reduction of primary energy still not having higher costs than the anyway renovation (BPIE 2010, p. 15, supplemented by econcept).
Left: **O** = cost optimal reduction and right: **N** = cost neutral reduction

7.2. Cost effective optimization of energy use and carbon emissions reduction in the course of building renovation

7.2.1. Market based or normative optimization and standard setting

Market based approach:
The optimization task relies on market prices and costs[23]. It explores the range of renovation measures which are most cost optimal (see EPBD) or which are cost effective and economic viable (as proposed above, see Figure 26). Market based optimization strives for contributions to energy and/or carbon emissions targets which are cost optimal (first step in the EPBD-framework) or cost effective compared to an anyway renovation serving as reference.

Basically it is possible to extend this approach which relies on a private cost perspective by an approach which strives for internalizing (at least partially) external cost into market cost and prices, for example by energy price surcharges, energy taxes, CO_2- taxes, pollution taxes or costs for emission certificates within a cap and trade system for emissions. At the time being, external costs are not or only partially internalized. Full internalization would lead to higher energy costs which would foster investment and operational decisions to reduce energy consumption and carbon emissions.

Normative approach:
Within a normative approach, explicit energy and carbon emissions targets are set normatively (motivated politically and/or ecologically). Optimization seeks least cost energy related renovation measures to comply with the targets.

7.2.2. Reduction of energy demand vs. reduction of carbon emissions

The priorities with respect to reduction of primary energy use and carbon emissions reduction are not clearly determined. EPBD suggests priority for building efficiency measures, at least up to a cost optimal package of energy related efficiency measures, thereby clearly reducing energy use. Carbon emissions are reduced too, but the extent of the reduction is depending on the energy carriers deployed to cover energy demand.

Considering current trends in Europe as well as previous strategies in the realm of increased energy performance of buildings and associated resource and climate policy, the topic of reducing energy demand dominates so far the discussions (e.g. recast of EPBD with the concept of "nearly zero energy buildings"). However, this priority may be put into question based on the possibility that there may be cost-effective solutions to reduce carbon emissions significantly in building

23 Depending on the prevailing institutional national framework external cost may be partially internalised in the market prices.

renovation by making use of renewable energy sources, combined with less far-reaching energy efficiency improvements.

With respect to the relationship between energy efficiency measures and RES-based measures, the EPBD guidelines state:

> *"Under the cost optimal methodology, the modified system boundary allows expressing all energy uses with a single primary energy indicator. As a result, the RES-based active technologies enter into direct competition with demand-side solutions, which is in line with the purpose and intention of the cost optimal calculation to identify the solution that represents the least global costs without discriminating against or favouring a certain technology.*
>
> *This would lead to a situation where certain RES-based measures show better cost efficiency than some energy demand reduction measures, whilst the general picture should still be that measures reducing energy demand will be more cost effective than measures adding RES-based supply. Thus, the overall spirit of the EPBD (i.e. reduce energy use first) would not be compromised and the nearly zero-energy definition (i.e. a building with a very high energy performance and the nearly zero or very low amount of energy still needed to be covered to a large extent by renewables) is complied with.*
>
> *If a Member State would want to clearly avoid the risk that active RES installations replace energy demand reduction measures, the calculation of cost optimality could be done in steps gradually expanding the system boundary to four levels: energy need, energy use, delivered energy and primary energy. With this, it will become clear how each measure/package of measures contributes to the buildings energy supply in terms of costs and energy."*

Thus, whereas the EPBD does have a focus on a two-step approach putting an emphasis on energy efficiency measures in its wording, at the very end it approaches technological neutrality, because of its focus on cost effectiveness.

Addressing the relationship between nearly zero energy and nearly zero CO_2-emissions and the EU energy policy in the building sector BPIE states (Nov. 2011, p. 24): "The intent of the EPBD is clearly to achieve (nearly) zero CO_2 emissions through reductions in energy use, i.e. even if energy was not an issue CO_2-emissions still would be. Therefore it is important to establish how a move towards "nearly zero energy" will affect CO_2-emissions (zero energy will inadvertently result in zero CO_2, however the definition of zero is typically not the "ideal and absolute" zero, but instead a zero over a period of time and a zero that might be a balance of energy production and use)." This insinuates that also within the framework of EPBD, reduction of carbon emissions is most important. BPIE derives a target value for CO_2-emissions for new NZEB of <3 kg CO_2/m^2a for the sake of achieving the long term targets for 2050 in the building sector, thereby assuming that existing buildings will have higher emissions in the average. For operational energy use in 2050 Switzerland has target values of 2.5 kg CO_2/m^2a and 5 kg CO_2/m^2a for new and for renovated buildings respectively and for embodied energy 8.5 and 5 kg CO_2/m^2a for new and for renovated buildings (SIA 2040, 2011).

From a societal perspective, evidence suggests for the time being that the challenge to cope with climate change will possibly be higher than to solve future resource problems in the energy sector (e.g. see BP, «Energy Outlook 2030»; shale gas revolution and new fossil energy reserves due to new drilling technologies in the USA and Europe, etc.). At the same time there are various energy related measures to reduce carbon emissions, which are attractive from a cost perspective, especially in the case of building renovation (marginal cost of efficiency measures increase exponentially with increasing efficiency level and are often higher than (marginal) costs of renewable energy use, which increase less or might sometimes even decrease).

It has to be acknowledged that the country specific situation may vary widely among participating countries. It might be relevant for the focus of the future development of standards and for target setting, whether more weight is put on reduction of non-renewable energy use or on reduction of carbon emissions. Besides differing climate conditions the following characteristics of country specific building sectors will be important for future standards and targets in the case of building renovation:

- Overall energy use and level of energy performance of existing building stock;
- Current energy sources (potential) and energy carriers used to meet energy demand of the building stock;
- Share of electricity use for heating, cooling and DHW;
- National electricity mix (fossil, renewable and nuclear) to cover electricity demand of existing buildings;
- National carbon emissions reduction targets and possibly national energy reduction targets;
- Prevailing types of construction of buildings, building categories as well as the age of the building stock and of major building types or categories;
- Potential of renewable energy sources which are exploitable with economic viability.

Implications for the definition of low energy and low carbon standards:

- Above considerations suggest to develop a comparative methodology framework which allows for different country specific situations and thereby allows for prioritizing either renovations leading to nearly zero energy or to nearly zero carbon emissions buildings;
- Reduction of energy demand as well as reduction of carbon emissions are both important within building renovation. It has to be decided if they shall be of equal importance and if this importance depends on the particular countries and their context conditions. From a global perspective a priority on the carbon emissions mitigation in the building sector can be justified.

7.2.3. *Cost effective optimization of energy use and carbon emissions within building renovation*

As outlined above, cost effective optimization of carbon emissions reduction and energy use reduction takes place either

- from a market perspective within the range of cost-effective energy and carbon emissions related renovation measures. Thereby, costs will be a major driver for the choice as well as for the evaluation of energy and carbon emissions related renovation measures and packages (market approach);

or

- with respect to a normatively set energy and/or emission target (ecological approach, if the target is derived ecologically, political approach if the target is set politically, whereupon political targets are usually also based on ecological targets or limits).

Market based approach:
In theory it can be expected that market based solutions yield least cost solutions, reducing energy demand to a level which is cost optimal for the prevailing political and economic context (regulations, energy prices, interest rate, possible energy and carbon taxes, etc.). The focus is on energy since energy has a price and reduction of energy use by costly energy related renovation measures can benefit from lower energy costs. On the other hand, carbon emissions don't have a price or if they have it is usually not adequate, which is the reason why carbon emissions reduction is disregarded on the market.

In theory[24], market based solutions tend to **cost optimal** solutions. If the range of economic viable solutions is extended to **cost effective** solutions, which are beyond the cost optimum but which are still economic viable, the question then arises to what extent further renovation measures shall focus on energy performance of the building or if they rather should focus on the reduction of carbon emissions[25]. Marginal costs of further reducing non-renewable energy demand by energy efficiency measures beyond the cost optimum are often fast increasing and are economically less favourable in reducing non-renewable energy demand and carbon emissions than renewable energy generation on-site or deployment of off-site renewable energy sources.

To optimize among the range of possible measures, costs and benefits of these measures have to be aggregated and compared. This requires the assessment and valuation of resulting effects, especially the valuation of savings of primary energy compared to reductions of carbon emissions. This can be done with approaches established by multi criteria analysis:

24 In the real world barriers like information and transaction costs, principal agent problem, etc. lead to suboptimal solutions.

25 Thereby it has to be considered that measures which increase energy efficiency of a building often yield co-benefits (like higher comfort). The above question arises mainly if a good level of energy performance and comfort is achieved and further efficiency measures would increase thermal comfort only marginally.

Distance to target approach for the valuation of environmental goods and services:
To assess the contribution of 1 t CO_2 emissions reduction per year compared with primary energy savings of 1 MWh per year, existing targets to reduce carbon emissions and primary energy use respectively are taken as objectives to be achieved (if existing). The higher the need for savings or reductions to achieve the respective target the higher is the value of a unit reduction.

Shadow pricing:
Within shadow pricing, external costs of primary energy use and of carbon emissions are determined and added to the energy costs. If all externalities could be determined and monetized, resulting shadow prices would represent global social costs of resource use and could be used directly for cost optimization. External costs can be estimated directly by valuation of external effects or by determining avoidance costs incurred by meeting a preset energy saving target or a carbon emission target.

Normative approach:
If we assume a normative approach, cost optimality means to minimize the costs to achieve preset energy or carbon emissions targets. This will yield minimum cost packages of renovation measures which meet the normatively pre-set carbon emissions or energy demand target.

If an emission target has to be achieved, user comfort and compliance with requirements regarding building physics and energy demand must be assured. This can be done by additional boundary conditions regarding energy performance of the building and its envelope which have to be taken into account while optimizing cost effective measures.

Priority on the reduction of carbon emissions:
At the time being the main focus still is on energy target and on cost effectiveness although on a general level the importance of carbon emissions reductions is acknowledged. For energy and carbon emissions related building renovation which have very high relevance, cost reasons ask for more attention on renewable energy deployment which could be fostered by explicit carbon emissions target in the building sector. If we assume that

- meeting global carbon emissions targets has priority,
- the level of cost optimal measures has to be outperformed to meet these targets,
- energy performance of the building, achieved at the cost optimum is sufficient for thermal comfort and building physics reasons

then it appears appropriate to optimize among the range of efficiency and renewable energy deployment measures which are still cost effective, maximising possible carbon emissions reduction.

8. Concluding remarks

8.1. Aims and principles

The methodology outlined has to provide the necessary basics for the assessment and evaluation of existing buildings undergoing energy related renovation processes. The assessment comprises as main impact categories the *cost*, *primary energy use* and *carbon emissions* impacts of energy related building renovation for the entire life cycle. The results of the assessment shall allow for appraising the energy performance of the building and the options to use renewable energy as well as the level of reduction of primary energy use, carbon emissions mitigation and related costs of building renovation strategies or measures for the sake of:

- Evaluating and optimizing different renovation measures, taking into account costs, primary energy use and carbon emissions impacts for a specific building or renovation project;
- Appraise the outcome of energy and carbon emissions related policy programs targeted at mobilizing mitigation potentials from the renovation of the stock of existing buildings;
- Explore the range of possible energy related renovation measures with respect to their costs, energy savings and emissions reductions as well as exploring the trade-offs between efficiency measures and renewable energy deployment considering the costs of these renovation measures;
- Standard design and target setting to improve energy performance of existing buildings and to increase renewable energy deployment to reduce primary energy use and carbon emissions;
- Guidelines for building owners and investors seeking cost effective building renovation measures with the highest reductions of energy use and carbon emissions at lowest possible costs.

The methodology aims at combining primary energy, carbon emissions and cost impacts of energy related building renovation measures/packages of measures. Striving for zero energy and emissions buildings ultimately calls for a strong cost focus. To identify and to combine the most cost effective measures is a prerequisite for getting the chance to transform the existing building stock by energy related renovation measures in a way which allows achieving the (nearly) zero energy and emissions targets in the future.

The methodology shall provide for correct and comprehensive assessments and evaluations of renovation measures. Comprehensive impact assessment means:

- Taking into account all relevant cost elements (also maintenance, repair, replacement costs) and all relevant impacts (also embodied energy use) of renovation measures;

- Life cycle cost assessment (during the whole life cycle of the building or during the whole calculation period (taking into account residual values)) and life cycle impact assessment (e.g. embodied energy);
- Dynamic cost assessment, discounting future costs and benefits;
- Comparison with a reference case involving «anyway renovations».

It has to be acknowledged that the energy and renovation cost perspective is limited and has some shortcomings, since only costs of renovation measures and direct benefits from energy cost savings are taken into account. A comprehensive assessment and evaluation would comprise all impacts of building renovation, either from a private or from a societal perspective, i.e. all costs and benefits. For building renovation this corresponds to the total value added to a building by energy related building renovation, which also includes the numerous possible co-benefits being the result of energy related building renovation. Sometimes these so-called co-benefits are actually the trigger or the main driver of building renovation. Even if they are often not quantified or monetized yet they have to be accounted for in the case of building design, considering commensurability and acceptance of policy measures and target setting.

8.2. Scope and boundaries of the assessment

The **scope** of assessments and evaluations comprises costs, primary energy use and carbon emissions of building renovation measures as well as resulting co-benefits (at least qualitatively if quantitatively not available):

8.2.1. Operating energy to be taken into account:

The assessment of energy related renovation measures and resulting energy performance of the building comprises mandatorily the energy use for

- *space heating;*
- *space cooling;*
- *ventilation*
- *domestic hot water* (DHW);
- operational energy use (electricity for fans, pumps, building automation) in the building;
- *common appliances* (lifts, escalators) and if they are common appliances: Washing machines, dryers, refrigerators, etc.;
- *artificial lighting.*

Energy use of *common building appliances* like lifts, escalators, washing machines, dryers, artificial light, etc. is suggested to be at least monitored, since their share on the overall energy use of a building increases with decreasing energy demand of renovated buildings. For the calculation of internal heat gains, their inclusion is a prerequisite. Full integration in the assessment taking into account different renovation options and associated impacts has to be decided depending on the context, since appliances like washing machines, dryers, refrigerators, etc. are installed sometimes by the building owners and sometimes by the occupants.

Embodied primary energy of building components used for building renovation is suggested to be integrated in the assessment if necessary LCA-data are available. The share of embodied energy with respect to total use of primary energy is increasing with decreasing operational energy use due to energy related building renovation. But the relevance of embodied energy is lower than in the case of new buildings.

Plug-in appliances (home appliances) are not integrated in the assessment, apart from their inclusion in the calculation of internal heat gains, although their relevance is given and even increasing with decreasing energy demand of the building. Electricity demand of plug-in appliances depends highly on the users and not on the building.

8.2.2. Boundaries of the assessment

The *system boundary for energy demand of buildings* corresponds to the consumption of net delivered energy after renovation plus embodied energy for building renovation. Net delivered energy comprises final energy deliveries minus exported energy to the grid.

Primary energy (PE) use has to be determined from final energy use of energy carriers by a PE-conversion factor. The primary energy factor takes into account energy used for the upstream processes necessary between the energy source and the delivery of final energy to the building. It is crucial to determine the PE-conversion factor as precisely as possible for each country. «Political» factors or factors used for specific labels should not be applied. Special attention has to be paid to the PE-conversion factor of electricity. It should represent the mix of electricity consumed in a particular country[26] and not the production mix[27].

Carbon emissions are determined by country specific carbon emissions conversion factors comprising upstream emissions for the delivery of final energy carriers to the building.

26 This is relevant for countries with a relevant share of exported and imported electricity (like e.g. Switzerland) or which trade green certificates/guarantees of origin of electricity from renewable sources (e.g. NO).

27 For on-site generated electricity from renewable sources exported to the grid it could be appropriate to use the PE-conversion factor of the marginal generation technology in the grid: I.e. the kind of electricity production which is substituted by the on-site production which is exported to the grid.

8.2.3. Cost assessment of energy related renovation measures

The costs are determined dynamically (i.e. future costs are discounted) on a life cycle cost basis. They comprise initial investment costs and replacement costs of energy related renovation measures during the period considered as well as energy costs, operational costs and maintenance costs.

Assuming a *private cost perspective*, taxes and fees are included and subsidies are excluded (for the sake of transparency). Within a *societal cost perspective* taxes and subsidies are not taken into account, except taxes internalizing external costs.

For assessing cost and economic efficiency of energy and carbon related renovation measures, it is crucial to define a *reference case* to properly determine the effects of an energy related renovation on energy use, carbon emissions reductions and costs. The assessment is based on *a full cost approach*, comprising full costs of renovation and costs of subsequent operation (energy costs and maintenance costs of energy related building components). The *reference case* comprises renovation measures to the extent necessary to restore the functionality of the building, without improving the energy performance of the building. This reference case is called an *«anyway» renovation* and comprises only renovation measures which would have to be carried out «anyway» in a hypothetical scenario if no energetic renovation is carried out, because the end of the technical life of building elements has been achieved or the functionality or service quality of a building element is not sufficient any more.

Besides the cost perspective, for investors and building owners it is basically the value of a building, which is of interest at the very end. For the owners and investors the value of the building is reflected best by the willingness to pay by users, occupants, owners for using the building, comprising an implicit monetary valuation of the building quality for the particular use (like useful area, thermal comfort, indoor air quality, natural lighting comfort, comfort for the users (lifts, technical building systems, etc.). To make use of the value of high energy performance of buildings it is indispensable to get it perceived by potential and current owners, users and potential buyers. This requires information and supporting measures like energy labels.

Acknowledging the primacy of the value of the building, it is indispensable to supplement the cost, energy and carbon emissions assessment of building renovation measures with coexisting quality aspects of these energy related renovation measures, called co-benefits of energy performance improvements.

9. Appendices

9.1. Selected aspects of life cycle assessment LCA for energy related building renovation

9.1.1. Components and materials included in the LCA of energy related renovation measures

When performing a comparative LCA of energy related renovation measures, it is important to define which components have to be included in the calculation.

One of the objectives of taking into account building components in an LCA is to analyse the trade-offs between increased environmental impacts due to components added to improve the energy performance of the building and decreased environmental impacts due to the reduction of operational energy demand.

Materials and components to be included in the LCA

Annex 56 focuses on cost and environmental benefits of energy related renovation measures. Therefore, the LCA must at least include the environmental impacts of the following components:

- Materials added for the renovation of the thermal envelope of the building (see below) and components for building integrated technical systems (see subsequent paragraphs);
- Materials /components that need to be replaced due to energy related building renovation to provide the same building function before and after energy related renovation (see subsequent paragraphs).

Materials for the thermal envelope

Since the focus of the assessment is on renovation measures that affect the energy use of the building, the impacts of renovating the thermal envelope (walls, windows, roofs, ground floor, etc.) is one major subject of LCA. Thereby, construction elements that do not affect the building's energy performance, like internal walls or doors, are not taken into account.

A wall as an element of the thermal envelope can be decomposed in layers, as schematised in Figure 27.

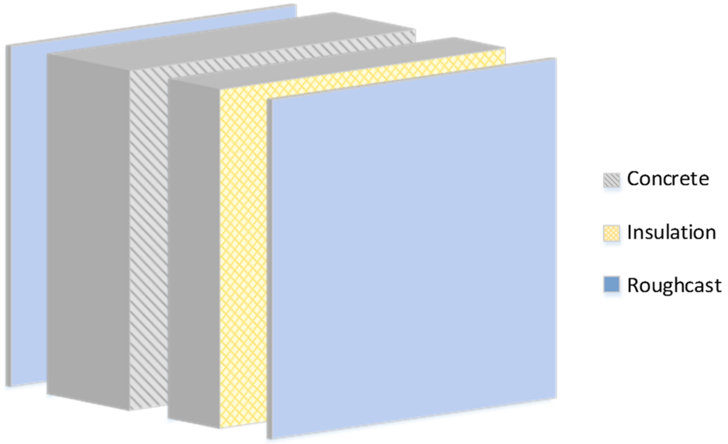


Figure 27 Example of a construction element composed of different materials (layers)

The weight of the layer can be easily calculated. For a homogeneous layer (constant thickness) it can be deducted from the element's surface area, the material's thickness and density. For non-homogenous layers the percentage of area occupied by each material must be defined.

The service life of the materials should also be reported and allows calculating the number of replacements during the life of a building (see subsequent paragraph). The position and role of a material in the construction element, will affect its service life of the component.

Components for building integrated technical systems (BITS)

The components for building integrated technical systems include the components replaced or added, which have an effect on the building's energy performances. For instance:

- Replacing existing components: new radiators; adding insulation of pipes, etc.;
- Adding new components: mechanical ventilation, a solar thermal or PV system, etc.

Components which have no particular influence on energy use, production, distribution and on carbon emissions are not taken into account (for instance: sinks, bathtub, replacement of piping, etc.). If in any renovation scenario (including "anyway" renovation) energy related measures have to be replaced, it is assumed, that they are replaced by the same components not aiming at higher energy efficiency (corresponding to the cost calculations).

Environmental impact data for BITS components might be difficult to find. One possible source of information is the Swiss-KBOB database ("KBOB database"), which provides a complete set of information for energy related BITS. The information is easy to apply in the calculation. Table 8 describes the information required to model the technical equipment of a building using the KBOB database.

Table 8 Information required for assessing the environmental impacts of building integrated technical systems (BITS)

BITS	Example of components	Information required
Heat production	Boiler, heat pump, storage, borehole heat exchanger	Power needed [W/m^2 heated floor area] Presence of borehole heat exchanger
Heat distribution	Radiators, heated floors, distribution pipes, etc.	Type of distribution (radiators, heated floor, air)
Ventilation	Mechanical air handler, ducts, heat exchanger, etc.	Type of channels (steel, synthetic) Channels' length Specific air flow rate [m^3/(h m^2)] Presence of ground-coupled heat exchangers and tubes length
Solar thermal systems	Collectors, assembly, piping	Type of use (DHW, DHW + heating) Type of building (single family house, multiple dwelling, etc.)
PV systems	Collectors, assembly, inverter, wiring	Collector type (single-Si, multi-Si, etc.) Collector area [m^2] Mountings type (wall, flat or slanted roof)

Materials/components added to provide the same function.

To compare renovation scenarios, the buildings should fulfil the same functions. In reality this might not exactly be the case. During renovation, some building elements are removed, replaced or added due to energy related renovation measures. One typical example is the case of a balcony, which is an extension of the internal storey slab before the renovation. In order to prevent this thermal bridge, the original balcony is removed. The thermal envelope is improved and a new balcony is added alongside the renovated façade. Subsequently, there are some more examples:

- The construction of a larger energy storage room (for instance replacing an electric heating system, with a pellet boiler requiring the construction of additional storage space);
- Reinforcing the roof structure to install solar thermal collectors;
- Etc.

Two different situations can occur:

- If new materials and components, indirectly related to energy related renovation measures, are added to provide the same building function (before and after renovation): In this case the impacts of these materials and components have to be included in the LCA;
- If a material/component, indirectly related to energy related renovation measures, is removed during the renovation and is not replaced, it cannot be included in the LCA (for instance a balcony removed to prevent the thermal bridge). In this case, it must be documented as negative or positive co-benefit.

9.1.2. Service life and replacement period

The service life is defined as the time during which a building component (construction material, BITS component) fulfils its function. At the end of its service life, the product must be replaced.

Service life of construction components suggested in Annex 56

Even if there are values for the average service life for particular types of materials or products, the real service life depends on economic aspects and the conditions of use (in contact with the outside, solar radiation, weather influences, etc.).

Table 9 lists average service life times of BITS and Table 10 average service life times of construction components suggested to be used. The basis taken into account to define these values is the Swiss SIA 2032 technical book regarding embodied energy in buildings (SIA Merkblatt 2032 «Graue Energie von Gebäuden», 2010). They have been reviewed by Annex 56 contributors and adapted in order to comply with a global energy renovation context.

Table 9 Service life time of building integrated technical systems suggested in Annex 56

Building integrated technical system (BITS)	Service life time [years]
Heat production	20
Heat distribution	30
Ventilation	30
Solar thermal	25
Solar PV	30
Geothermal probe (heat-pump)	30

Figure 28 shows an example for the service life of different layers of a floor in contact with the ground.

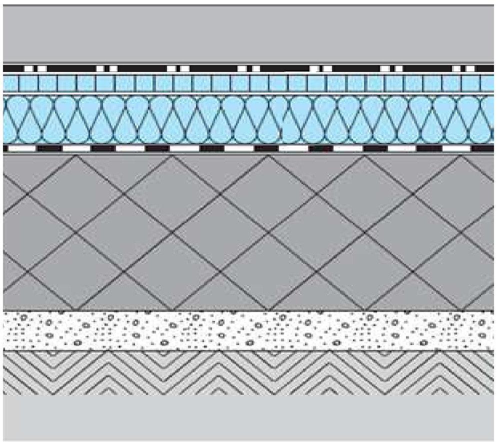


Figure 28 Examples for the service life of components in a construction element

Table 10 Service life time of construction products for the thermal envelope (*RSP = Study period in the reference case, assuming that the product will not be replaced)

Type of element	Position of the material (relative to the structural layer)	Location	Service life [years]	Example(s)
Roof	Structure	-	RSP	Concrete, rafters
Roof	External	Against exterior, flat roof	30	Insulation, waterproofing, vegetal layer, vapour barrier
Roof	External	Against exterior slanted roof	40	Tiles, lathing and counter-lathing, weatherproofing
Roof	External	Against ground	40	
Roof	Internal	-	40	Insulation, vapour barrier, coatings
Wall	External	Against ground	40	
Wall	External	With external insulation	30 15	Insulation, roughcast, boarding Paint, varnish
Wall	External	Without external insulation	40 15	Roughcast, boarding Paint, varnish
Wall	Structure	Bearing or not	RSP	Concrete, bricks, wooden frame
Wall	Internal	-	30	Insulation, vapour barrier, coatings
Window / Door	-	Against exterior	20	
Floor	Internal		30 25 15	Hard coating: Ceramic tiles Medium coating: Wooden or synthetic parquets Soft coating: Carpets
Floor	Internal	Between the structure and interior	30	Floating screed, water sealing, insulation
Floor	Structure	Above ground or cellar	RSP	Concrete, wooden beams
Floor	External	Above ground	RSP	Under floor insulation, light concrete, etc.
Floor	External	Against exterior	40	Insulation, coating

9.1.3. Reference assessment period of the renovated building

LCA is carried out on the basis of a chosen reference study period, for which all impacts of materials/components and energy consumed are determined.

For new buildings, the reference study period is usually defined as the estimated service life of the building. For renovated buildings, the reference study period can be:

- The period between the current renovation and the next major upcoming one. A typical value is 30 years, which corresponds to the period between the building construction and the first important renovation, which could be motivated by energy purposes or more likely motivated by wear and tear.
- The period between the current renovation and the end of the life of the building. A typical value is 60 years.

The number of energy related renovations is limited by the life of a building. The lower energy demand after renovation, the less a major energy related renovation will be undertaken in the future. It is impossible to know, which products will be used to replace current energy related construction elements in the future. It is also impossible to know which energy vectors will be used if e.g. the boiler will be replaced (in about 30 year).

The reference study period should be equal or longer than the service life of the (energy related) building components analysed in order to avoid any misinterpretation of the results. Therefore, it is suggested to assume a reference study period of **60 years** in Annex 56. If another reference study period is assumed, it should be reported and documented.

Number of replacements during the assessment period

Due to a limited service life, construction products will usually be replaced one or several times before the end of the building's life. The number of future replacements depends on their estimated service life (ESL) and the study or assessment period for the building (SP). No replacement is required if the service life of a building element meets or exceeds the required service life of the building (foundations, bearing wall, etc.).

In practice, only a full number of replacements (no partial replacements) can be taken into the assessment of the impacts of building elements replaced. In the case of a partial number of replacements, the number of replacements is rounded upward.

Environmental indicators for the LCA of renovated buildings

Many indicators have been developed in LCA, describing environmental impacts (global warming, ozone depletion, acidification, etc.), resource use (energy and raw materials depletion, etc.) or additional environmental information (hazardous waste, etc.). Some documents, such as EN 15978, may recommend to use a wide range of indicators. But from a practical point of view, comparing different renovation scenarios would become very tedious if more than a few indicators are compared. Therefore, it is important to remain pragmatic and to reduce the number of indicators according to the following principles:

- The indicators have achieved widespread consensus and acceptance among the scientific communities. This would reject indicators such as human toxicity, biodiversity, Eco-indicator, Environmental Priority Strategies in Product Design (EPS) or Ecoscarcity (UBP).
- The building sector must have a significant share on the world or local contribution for this indicator (the latter if local impacts matter most).
- The data for components and energy vectors used in the building sector should be available for the indicator.

According to these criteria, the number of indicators used in Annex 56 has been limited to the three following indicators:

- **Primary Energy total (PE_t)**. It represents total primary energy used, renewable or not. It includes the non-renewable part (fossil, nuclear, primary forests) as well as the renewable part (hydro, solar, wind, biomass). In Annex 56 PE_t is expressed in [kWh].
- **Primary Energy non-renewable (PE_{nr})**. It represents the non-renewable part of the total primary energy, i.e the non-renewable primary energy used. It indicates the depletion of non-renewable energy sources (at a human scale), such as fossil fuels, nuclear resources and primary forests. PE_{nr} is also expressed in [kWh].
- **Greenhouse gases emissions (GHGe).** This indicator is related to the emissions of greenhouse gases. It is not measured in an absolute unity, because each gas has a different global warming potential on the greenhouse effect (for the same quantity). In Annex 56, their potential is compared to the CO_2 used as reference for a period of time of 100 years. GHG is expressed in [kg- CO_{2e}].

These indicators describe primary energy consumption and carbon emissions. They are consistent with the work and recommendations of the IEA Annex 57 "Evaluation of Embodied Energy and CO_2 Emissions for Building Construction"[28] (Lützkendorf et al, 2014).

28 For the primary energy assessment, other terms and abbreviations can be found in the existing literature (e.g., the Cumulative Energy Demand concept) but it is beyond the scope of the Annex 56 to present all of them.

9.2. Cooling in residential buildings

9.2.1. Standards to determine the cooling demand

The European standard EN ISO 13790 defines methods for calculating the «energy use for space heating and cooling» of buildings. It has been adopted in national standards like the SIA 380.104:2008[29] (Switzerland). The described methods allow determining the sensible heating and cooling demand for the entire building or for each individual area in the building. The EN ISO 13790 describes 3 methods for calculating the annual cooling demand. Typically, the national building codes determine which method has to be applied. The calculation methods are:

- Quasi steady state calculation method per month;
- Simplified dynamic calculation method per hour;
- Detailed dynamic calculation method (i.e. per hour).

The quasi steady state calculation method per month results in correct annual results, but individual results per month can contain considerable errors. The simplified dynamic calculation method per hour results in more accurate results per month, but is not validated regarding the hourly results. The detailed dynamic calculation method gives the most accurate results, as the thermal inertia of the building is most realistically reflected (response time due to the thermal capacity of the building). However, this method can be time intense and sumptuous.

The results from the quasi steady state calculation method are sufficient to determine the annual cooling demand, which affect the three indicators primary energy, cost and carbon emissions. The detailed dynamic calculation method can be applied in addition to determine what cooling capacity is needed to provide thermal comfort in the building at any time. Figure 29 illustrates the calculation steps to determine the cooling demand $Q_{C,nd}$ according to the quasi steady state calculation method, which is applied in the calculation tool for generic examples in Annex 56. The method includes the calculation of:

- The heat transfer by transmission and ventilation of the building zone when heated or cooled to a constant internal temperature;
- The contribution of internal and solar heat gains to the building heat balance;
- The annual energy demand for heating and cooling, to maintain the specified set-point temperatures in the building – latent heat not included.

29 The DIN V 18599 regulates the EU directive 2002/91/EG in Germany. The standard EN ISO 13791:2012 allows with a simplified method to calculate the room temperature of buildings if the building is not mechanically ventilated.

Besides the necessary input values of climatic data, building use, geometry, construction and context, the desired interior temperature, also known as set point temperature for cooling ($\theta_{int,set,C}$), is an important input value for the calculation. This threshold considerably influences the cooling demand and is defined by the respective national building code(s). The purpose of limiting the room temperature to a certain threshold is to ensure thermal comfort permanently for the majority of occupants/users. However, it is important to realize that this temperature is not an arbitrary number, but notably the result of technological development. Before the invention of cooling devices, higher interior temperatures have been accepted.

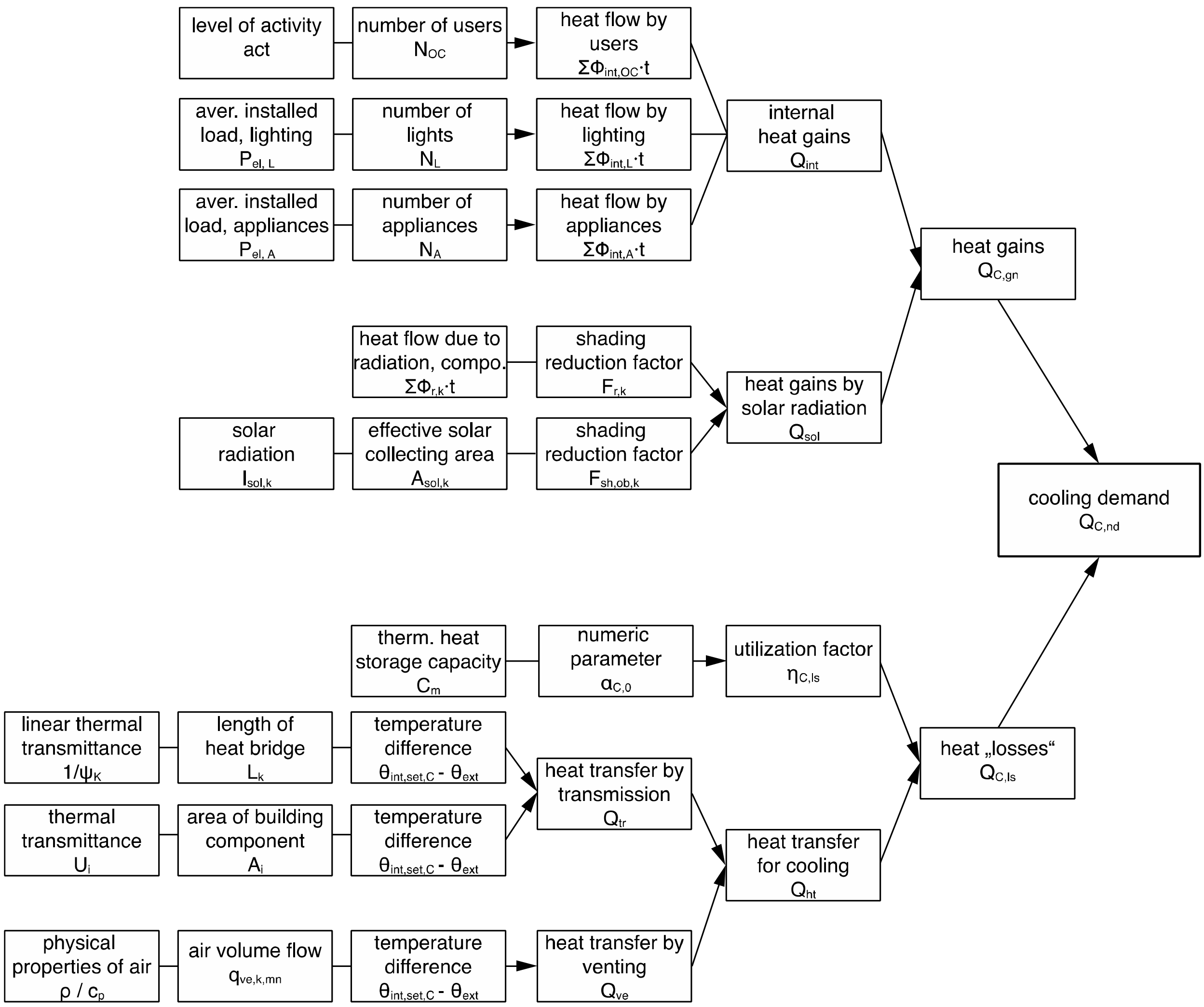


Figure 29 Overview of the relevant determinants of cooling demand according to the quasi steady state calculation method.

Today, cooling buildings at the expense of vast consumption of fossil fuels is scrutinized. However, since the power from renewable resources is more costly and also not permanently available (wind or solar power generation is more fluctuating than the instantaneously available power from fossil fuels), a constant set point temperature is questionable. As a result, some national building codes have been revised to allow for an adaptive set point temperature relative to the exterior temperature and seasonal clothing of the building users with more but clearly limited deviations. Besides, accepting a higher set point temperature in general during hot periods affects the number of days, where active cooling is necessary. The national standards define the set point temperature ($\theta_{int,set,C}$) depending on the building use. In absence of a regulation, the EN ISO 13790 proposes $\theta_{int,set,C}$ = 26°C for residential buildings. The DIN V18599-10 also defines a maximal temperature $\theta_{int,C,max}$ of 26°C for the interior spaces, but gives also a nominal temperature of 25°C ($\theta_{\mathrm{int,C,nominal}}$). The Swiss norm 382/1 (SIA 382/1, 2007, p. 28) defines a range for the room temperature, which is between:

- 21.0 – 24.5°C for average exterior daily temperatures up to16°C;
- 22.0 – 26.5°C for exterior temperatures above 30°C and
- a transitional range between external temperatures of 16.0 - 30°C.

9.2.2. Measures for reducing the cooling demand

Based on the calculation method of the cooling demand presented in the previous chapter, various measures exist for reducing the actual cooling demand. They can be categorized in three groups:

- Passive measures, which require the installation or the replacement of certain permanent building components (see Table 11);
- Active measures, which also require the installation of some devices, but can be adjusted in operation according to the demand (see Table 12);
- Measures with focus on the user behaviour (see Table 13).

The costs for installing or replacing appliances and devices are typically higher than the implementation of methods or control devices to change the user behaviour. Depending on the availability of products which affect the labour cost, the installation costs can considerably differ between countries. Furthermore, the costs for installing components in a refurbishment project also depend on the specific building. The installation of glazing with low solar energy transmittance for example can also require in certain projects the replacement of the complete window, which is considerably more costly than just replacing the glazing. The impact on the cooling demand also depends highly on the building type and the context. It is difficult to generalize the efficiency of certain measures[30]. Depending on the orientation of the windows, measures on the windows are more or less effective. Because of different construction costs in Europe and different settings of existing buildings, the rating of cost and impact of the following

30 For example: The potential for reducing the cooling demand by reducing the solar irradiation compared by reducing the internal heat gains is considerably higher in buildings where the cooling demand is driven by solar heat gains.

tables is partly subjective. The table lists various measures, which affect different parameters regarding the calculation method of the cooling demand.

Table 11 **Passive measures** for reducing cooling demand. In the column «Cost», an estimate regarding the costs is given, distinguishing low costs (+), medium costs (++), and high costs (+++). In the column «Impact», an estimate regarding the impact is given, distinguishing low impact (+), medium impact (++), and high impact (+++).

Purpose:	Measures	Affected parameter	Cost	Impact
Reducing Q_{sol}	Installing fixed sun-blinds, trees etc.	This increases the shading reduction factor $F_{sh,ob,k}$.	+	+++
	Reducing the window size	This reduces the effective collecting area of the surface $A_{sol,k}$ (but it has to be checked if the net effect on yearly energy demand considering the smaller radiation gains in the winter time for heating is positive, especially if sun blinds are used)	++	+(+)
	Applying a different external surface material to lower the absorption coefficient	This lowers the absorption coefficient $\alpha_{S,c}$ of the surface $A_{sol,k}$	+	+
	Increasing the thermal resistance of the building envelope	This is equivalent to reducing the thermal transmittance U_c, which reduces the effective collecting area of the surface $A_{sol,k}$	+/+++	+/++
	Installing of solar glazing	This lowers solar energy transmittance g_{gl}	++	++
Reducing Q_{tr}	Increasing the compactness of the building	This reduces relatively the area of the envelope A_i, which subsequently reduces heat transfer coefficient H_x	+/++	+
	Reducing thermal bridges	This is done by reducing the linear thermal bridge l_k, its according linear thermal transmittance ψ_k or the local point thermal transmittance χ_j, which reduce the heat transfer coefficient H_x	+	+
	Increasing the thermal resistance of the envelope	This is equivalent to reducing the thermal transmittance U_c, which reduces heat transfer coefficient H_x	+/ +++	+
	Passive free cooling by evaporation	This reduces the heat gains by radiation	+	+
	Increasing/reducing natural ventilation	This increases (reduces) natural venting, which affects heat transfer	+	+/++

Table 12 **Active measures** for reducing the cooling demand. In the column «Cost», an estimate regarding the costs is given, distinguishing low costs (+), medium costs (++), and high costs (+++). In the column «Impact», an estimate regarding the impact is given, distinguishing low impact (+), medium impact (++), and high impact (+++).

Purpose:	Measures	Affected parameter	Cost	Impact
Reducing Q_{sol}	Installing movable sun-blinds,	This increases the shading reduction factor $F_{sh,ob,k}$.	+	+++
Reducing Q_{ve}	Installing earth tubes, HRV, ERV, passive evaporative cooling etc.	This reduces the supplied exterior temperature θ_e, which reduces the temperature difference to the set point temperatures, $\theta_{int,set,C}$.	++	+
	Installing CO_2 sensors, presence detectors etc.	This reduces the mean volume flow $q_{ve,k,mn}$ by selective venting according to actual demand, which affects the heat transfer coefficient $H_{ve,adj}$	+	++
	Increasing/reducing natural ventilation	This increases (reduces) natural venting, which affects heat transfer	+	+/++
Reducing Q_{int}	Installing efficient lighting (bulbs, dimmers and systems)	This reduces the heat flow rate from electrical lighting heat flow rate $\phi_{int,L}$.	-	+
	Reducing the number of light bulbs to a minimum	This reduces the heat flow rate from electrical lighting heat flow rate $\phi_{int,L}$.	-	+
	Installing efficient electrical appliances and production devices	This reduces the heat flow rate from appliances $\phi_{int,A}$ and the heat flow rate from production processes $\phi_{int,proc}$	-/+	+
	Allow for standby and off operation during idling phases	This reduces the heat flow rate from appliances $\phi_{int,A}$, potentially the heat flow rate from production processes $\phi_{int,proc}$	-	+

Table 13 Measures on the **user behaviour** level. In the column «Cost», an estimate regarding the costs is given, distinguishing low costs (+), medium costs (++), and high costs (+++). In the column «Impact», an estimate regarding the impact is given, distinguishing low impact (+), medium impact (++), and high impact (+++).

Purpose:	Measures	Affected parameter	Cost	Impact
Reducing Q_{int}	Reducing the level of activity (if possible)	This reduces the heat flow rate from occupants $\phi_{int,OC}$		(+)
	Reducing clothing factor to adapt to climate (if possible)	This increases the personal heat flow rate at the skin of the occupants by increasing evaporation and convection		
	Reducing the operation time with presence detectors etc.	This reduces the heat flow rate from electrical lighting $\phi_{int,L}$. Potentially, this also reduces the heat flow rate from appliances $\phi_{int,A}$, from HVAC $\phi_{int,HVAC}$ and from hot water systems $\phi_{int,WA}$.	+	+
	Use of sun-blinds during the solar exposure	This increases shading (reduction factor $F_{sh,ob,k}$)	-	++(+)
	Natural ventilation when outside temperature is lower than the interior temperature	This increases natural venting, which affects heat transfer	+	+(+)

9.2.3. Methods to reduce the energy demand for cooling processes

The efficiency of cooling processes is affected by two elements. One is the efficiency of the machine, which is typically rated in classes (like A, A++ etc.). This efficiency is also expressed by the process efficiency η and the Carnot efficiency ς of the respective machine. The other aspect is the efficiency of the process, which depends highly on the temperature lift the machine has to provide ($T_H - T_C$). Since the set point temperature of the space determines the source temperature in the process, the efficiency is more affected by the temperature of the heat sink.

9.2.4. Decision path for cooling processes

Generally speaking: The higher the cooling demand and the lower the temperature of the available heat sink, the more mechanical cooling is needed. Since this can cause higher installation and operational costs, the balance of energy use and of carbon emissions tends to be higher with mechanical cooling systems. Nevertheless, this is not necessarily the case. Under certain conditions mechanical cooling with powerful heat sinks and efficient systems might cause lower primary energy demand and result in less carbon emissions than further reducing cooling demand. Thus, the expenditures for reducing cooling demand need to be balanced with the expenditures for efficient cooling processes.

As discussed above, the cooling methods can be categorized as passive, hybrid or active strategies. Due to the maximum cooling power that each method can provide, the applicable methods cannot be chosen arbitrarily, but it depends on the required cooling demand and the context conditions (first and foremost on the power of the heat sink). Figure 30 illustrates decision trees to determine the cooling strategy of a building (based on Plato 1995). Natural cooling power by night considerably depends on the temperature difference between the interior set temperature and the exterior ambient temperature$\left(\theta_{\mathrm{int,set,C}} - \theta_{\mathrm{e}}\right)$. Further criteria, like air quality, noise and security issues determine if window ventilation is possible. If mechanical ventilation is installed, air exchange can artificially be increased to increase cooling. Adiabatic cooling is only possible if the temperature difference between the exterior temperature and the wet bulb temperature is big enough$(\theta_{\mathrm{e}} - \theta_{\mathrm{wb}})$. If window or mechanical ventilation is not possible, the supply air can be (pre-)cooled with a heat exchanger connected to a natural heat sink, i.e. lake, river, ground water or ground or an artificial heat sink (e.g. for the production of hot water.) Due to the installation costs of sophisticated heat sinks, like cooling towers, they are typically only installed for bigger residential apartment blocks. While the dry cooling towers require night time temperatures below 20°C to be operable, the wet cooling towers require low relative humidity and a lot of water for operation. Systems connected to powerful heat sinks can be operated in free cooling mode, which is determined by its temperature. In case of a heat sink with low power, air-conditioning systems or hydraulic systems connected to a chiller or reversible heat pump need to be installed to provide cooling (systems operating with Carnot-cycles). This is also necessary if the cooling demand is higher than 250 Wh/(m^2d).

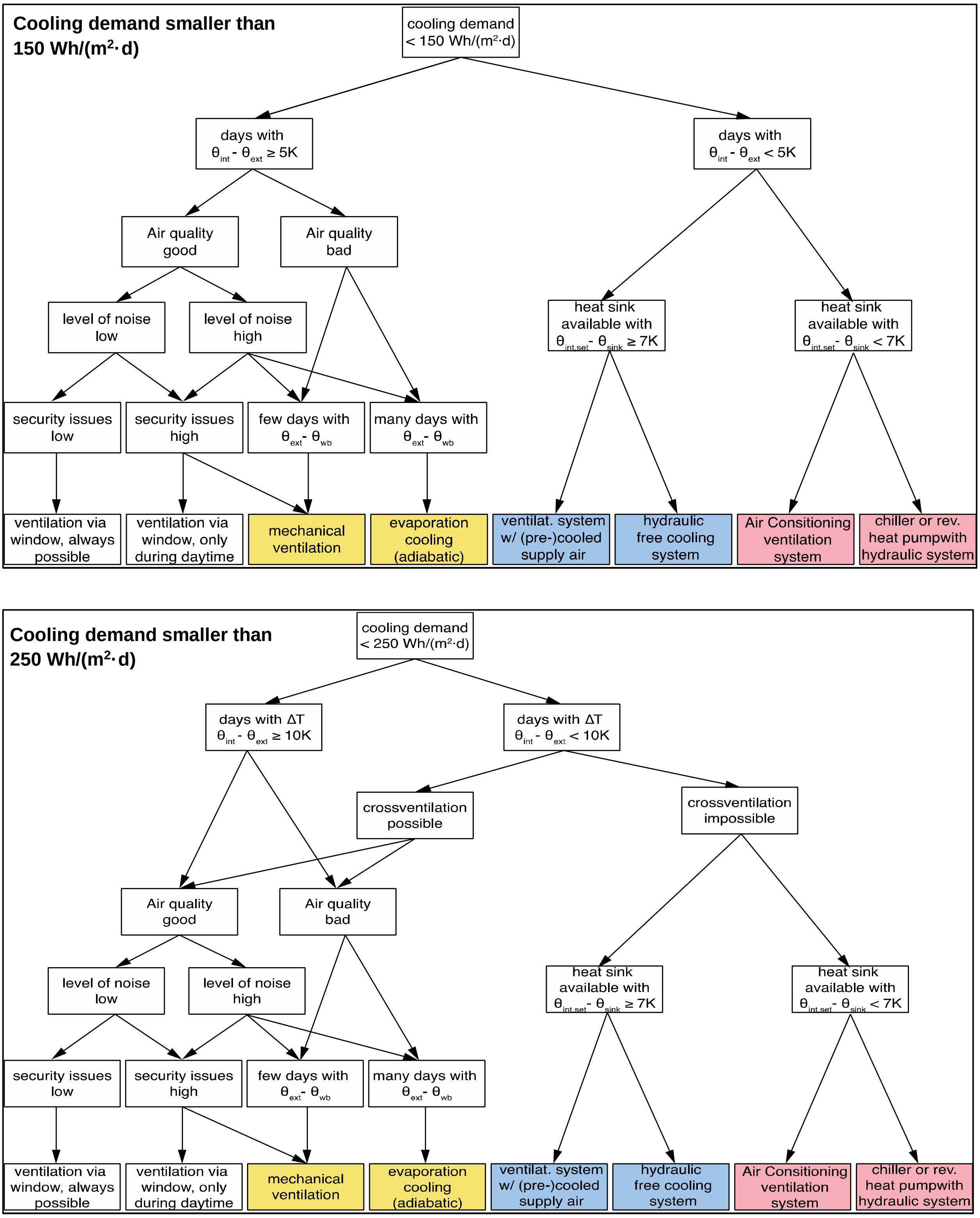


Figure 30 Decision tree to determine possible and reasonable methods to provide cooling for a building with a **cooling demand smaller than 150 Wh/(m²·d)** (above) **and 250 Wh/(m²·d)** (below) respectively. The colours indicate the amount of primary energy required to operate the systems (white =without, yellow=low, blue=medium, red=high).

9.2.5. Cooling of buildings in the Mediterranean area

According to chapter 3.3, in Europe cooling in residential buildings has a limited relevance for the time being. It is less important than cooling in commercial buildings with more interior heat sources. But the relevance of cooling is fast increasing because of rising and more widespread requested comfort needs and higher temperatures due to climate change (Bertoldi et al, 2012, p. 63f.). Consequently, the next challenge regarding the refurbishment of buildings in Europe, is to either prevent cooling or to provide efficiently cooling with the least primary energy demand possible and the lowest additional carbon emissions. This holds especially for Southern Europe, where due to the prevailing climatic conditions energy demand for cooling may often be higher than energy demand for heating.

In Central and Northern Europe, the assessment of the building heating energy needs is mainly dependant on the amount of air changes to be considered to comply with the indoor air quality (IAQ) requirements and on the performance of the building envelope in preventing heat loss by transmission.

In the Mediterranean climatic area, where a daily variation of the thermal flux direction throughout the building can occur during large periods, the thermal capacity of the building can play an important role and significantly affects the yearly energy performance (during summer and intermediate seasons buffer effect with respect to cooling needs; De Rosa et al., 2014; Ferrari et al., 2013; Libbra et al., 2013). Moreover, the useful effect of thermal mass during the hot season depends on the way the building is ventilated in the hot season: For instance if it is possible to increase ventilation beyond the requirements for proper IAQ (e.g. night cooling strategies) which requires varying schedules and amounts of air changes (which is more complex to take into consideration and needs simulations).

For residential buildings and user habits in the Mediterranean climatic context, the following peculiarities have to be taken into account:
Existing residential buildings are widely naturally ventilated, even if active cooling systems (individual splits) are installed. They are usually already equipped with movable window shading devices. Under these conditions, the real cooling needs strongly depend on the comfort mitigation strategies adopted by users and the user behaviour, which are also based on the thermal expectations due to the outside mean climatic conditions (adaptive approach; Ferrari et al., 2012; Carlucci et al., 2012): The indoor air velocity significantly affects the occupants' thermal comfort, despite unfavourable air temperatures, while shaded openings allow to keep in touch with the external environment, avoiding too much solar gains. With this in mind, prevalent conventional air set-point temperatures (values and time schedules), adopted for the assessment of cooling energy needs based on shared standards, ought to be questioned. This aspect also affects the effectiveness of some common retrofit measures:

For instance, if the windows are already equipped with shading devices, the adoption of glazing with low solar energy transmittance is generally not attractive. Besides, because the split system often is consciously activated for the sake of increasing natural ventilation while the windows are open, providing opening detectors for reducing the cooling systems operation time will in such cases not really be accepted (contrary to buildings equipped with forced primary air ventilation systems).

Summarizing, simplified procedures have been common practice for a long time to assess the energy balance of residential buildings in Europe: Currently, the quasi-steady state calculation method (the most simple among the ones provided by EN ISO 13790) is still the main reference for implementing procedures at national level and is widely adopted also for the building energy certifications (Ferrari et al., 2010). Consistently, the same method has been taken also for evaluating the energy performances of the Annex 56 reference buildings. But to properly take into account daily variations of thermal fluxes, the assessment of the energy balance would have to be based on a detailed dynamic calculation method which normally is too complex to be widely used in common practice. By using proper simulation tools, in-depth knowledge is needed as well as the collection of detailed data (at least hourly based) for an accurate characterization of the thermal behaviour of the building, taking into account building usage patterns, climate conditions, etc. Furthermore, for analysing the effect of air flows employing passive and/or active cooling strategies (such as vented roofs, night free ventilation, ceiling fan installation, etc.) other advanced modelling tools are needed. Generally, these detailed and sophisticated approaches are only applied in the residential building sector for detailed energy audits.

Nevertheless, detailed evaluation of retrofit measures, which would be cooling effective for residential buildings in the Mediterranean area, would have to be significantly more complex, even more under a cost optimal perspective. Considering the widespread increase of cooling demand in the residential sector, these criticisms should be taken into account at European standardization level, for providing proper differentiations in the upcoming national implementations.

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