International Energy Agency

# Tools and procedures to support decision making 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 coordinates research and development in a number of areas related to energy. The mission of the Energy in Buildings and Communities (EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA-EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

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

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

## The Executive Committee

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

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitant Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)

Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilating Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Environmental Performance of Buildings (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multizone Air Flow Modelling (*)
Annex 24: Heat, Air and Moisture Transport in Insulated Envelope Parts (*)
Annex 25: Real time HEVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Control Strategies for Hybrid Ventilation in New and Retrofitted Office Buildings (HybVent) (*)
Annex 36: Retrofitting in Educational Buildings - Energy Concept Adviser for Technical Retrofit Measures (*)
Annex 37: Low Exergy Systems for Heating and Cooling (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Thermal Insulation (*)
Annex 40: Commissioning of buildings HVAC Systems for Improved Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy-Efficient Future Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (NZEBs)
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods (*)
Annex 54: Integration of Micro-Generation & Related Energy Technologies in Buildings
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost
Annex 56: Cost Effective Energy & CO2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy & CO2 Emissions for Building Construction
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements
Annex 59: High Temperature Cooling & Low Temperature Heating in Buildings
Annex 60: New Generation Computational Tools for Building & Community Energy Systems
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings
Annex 62: Ventilative Cooling
Annex 63: Implementation of Energy Strategies in Communities
Annex 64: Optimised Performance of Energy Supply Systems with Energy Principles
Annex 65: Long-Term Performance of Super-Insulation in Building Components & Systems
Annex 66: Definition and Simulation of Occupant Behaviour in Buildings
Annex 67: Energy Flexible Buildings
Annex 68: Design and Operational strategies for High IAQ in Low Energy Buildings
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in low Energy Buildings

Annex 70: Building Energy Epidemiology
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

Once buildings are responsible for a major share of energy use, they have become a special target in the global actions for climate change mitigation, with the improvement of their energy efficiency and the reduction of carbon emissions being widely promoted. In the case of existing buildings, the cost-effectiveness of the intervention is a major issue which is not adequately considered in existing standards. These are usually focused on energy efficiency measures that many times lead to costly and hard to implement interventions that discourage owners and promoters.

The IEA-EBC project «Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation» intends to develop the basis 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 the cost-effective energy-related renovation of existing residential buildings and low-tech office buildings (without HVAC systems) and one of the objectives of the project is the development of new tools or add-ons to existing ones to allow putting into practice the developed methodology. The main issue is to support owners, promoters and their technicians in the economic evaluation of energy and carbon emissions optimized building renovation as well as to deal with added value related issues.

Within the project, a new tool has been created (A56opt-tool) and three existing tools have been improved (ASCOT, INSPIRE and ECO-SAI). A56opt-tool aims at supporting calculations based on the Annex 56 methodology allowing comparing and evaluating different packages of renovation measures using simulation data that come from other tools (energy performance, costs and environmental impact) and include the capacity to evaluate also the relevance of the co-benefits. ASCOT is based on the original Danish total economy calculation tool, “BYGSOL” developed by Cenergia under the EU-Concerto project; INSPIRE was originally developed within the ERA-NET project INSPIRE within the framework of the EU FP7 program. Both these tools have been adapted to the frame of the Annex 56 methodology; ECO-SAI is a development of Eco-Bat, which was first released for external use in September 2006, developed at the Laboratory of Solar Energy and Building Physics (LESBAT) of the University of Applied Sciences of Western Switzerland (HES-SO).

The use of these tools allow the application of the methodology developed within the Annex 56 project, for the successive steps of the process, providing guidance to help decision makers and promoters on whether is the best solution to carry out a renovation process of their specific projects. Additionally, the report describes some tools that are compatible with some of the steps of the methodology, although not having been used in the project. These tools are also

presented in order to allow users already familiarized with those tools to take advantage of that knowledge.

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# Abbreviations

| Abbreviation | Meaning |
|---|---|
| **BITS** | Building integrated technical systems |
| **CED** | Cumulated energy demand |
| **CH** | Switzerland |
| **DK** | Denmark |
| **DHW** | Domestic hot water |
| **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 - International Energy Agency |
| **IT** | Italy |
| **kWh** | Kilowatt hours: 1 kWh = 3.6 MJ |
| **Λ** | Lambda-value (value for the thermal conductivity of a material) |
| **LC** | Lifecycle |
| **LCI** | Life cycle impact |
| **LCA** | Life cycle impacts analysis |
| **MFB** | Multifamily building |
| **MFH** | Multi-family house |
| **MJ** | Mega joule;  1 kWh = 3.6 MJ |
| **NRE** | Non-renewable energy (fossil, nuclear, wood from primary forests) |
| **NZEB** | Nearly zero energy building or nearly zero emissions building |
| **PE** | Primary energy |
| **PT** | Portugal |
| **PV** | Photovoltaic (cell) |
| **Ref** | Reference |
| **RES** | Renewable energy sources |
| **SFB** | Single-family building |
| **SFH** | Single-family house |
| **STA** | Annex 56 Subtask A |
| **STB** | Annex 56 Subtask B (Tools) |
| **STC** | Annex 56 Subtask C (Case-studies) |
| **STD** | Annex 56 Subtask D (User Acceptance and Dissemination) |
| **U-value** | Thermal transmittance of a building element |
| **WP** | Work Package |

NOTE: Definitions regarding technical terms used in this report, as well as in all reports produced within Annex 56 project, are available for consultation in a separate document (IEA EBC Annex56 project glossary) which can be downloaded from the project website

# 1. Introduction

The IEA-EBC project «Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation» intends to develop the basis 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 the cost-effective energy-related renovation of existing residential buildings and low-tech office buildings (without HVAC systems).

## 1.1. Scope

The aim of the report is to illustrate the application of the methodology developed within the project and present several tools available for the successive implementation of the several steps of the process. The tools include those that have been used by the participating countries in the selected case-studies and also tools that, although not being used in the project, are compatible with the developed methodology.

## 1.2. Contents of the report

Generically this report is divided into 3 Parts: Part 1, which comprehends chapter 1 and 2, presents a summary of the developed methodology focused on the necessary steps needed to put it into practice and lists an overview of the main tools used in the countries participating in Annex 56 for energy calculations, for LCA and for the costs assessment. The remaining sections of part 1 introduce the co-benefits concept and the basics for the operationalization of the decision-making process. The general methodology is described in the report “Methodology for Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation (Annex 56)” (Ott et al. 2015) which can be downloaded from the project website.

Then, there is the second part, which corresponds to chapter 3, where the tools that have been improved during the project are described. The tool INSPIRE has been used for the generic buildings calculations in which the report “Investigation based on calculations with generic buildings and case-studies” (Bolliger and Ott 2016) is based, and also in the analysis of some of the detailed case-studies included in the report “Evaluation of the impact and relevance of different energy-related renovation measures on selected Case-Studies” (Venus et al 2016). The ASCOT tool that has been used for the analysis of the Danish buildings and its adaptation to the Annex 56 concept is also presented.

The third part comprehends chapter 4 which shows an example of the application of the methodology to a case-study and finishes with the conclusions.

# 2. Methodology for Cost Effective Energy and Carbon Emissions Optimization in Buildings Renovation step-by-step

The methodology developed in the IEA EBC Annex 56 Cost Effective Energy and Carbon Emissions Optimization in Building Renovation, provides a framework to assess and evaluate energy-related renovation options. The methodology provides guidance for the integrated evaluation of primary energy use, carbon emissions and costs of energy-related packages of renovation measures, including efficiency measures and measures for the use of energy from renewable sources.

It is focused on residential buildings and office buildings without complex HVAC systems which have not undergone any significant energy renovation yet.

The methodology allows integrating embodied energy use and related carbon emissions and goes beyond the cost optimal reduction of carbon emissions and energy consumption. It focuses also on the overall added value achieved in a renovation process, which means also identifying global quality improvement and additional benefits (here called co-benefits) like comfort improvement (thermal, natural lighting, indoor air quality, acoustics, etc.), increased value of the building and fewer problems related to building physics.

The assessments reveal the trade-offs between costs, energy savings, and renewable energy use, in order to reduce primary energy use and related carbon emissions, allowing exploring the cost optimal and cost effective renovation packages.

***Additional information about the methodology developed in Annex 56 can be found in the project website www.iea-annex56.org and in the specific report "Methodology for Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation"***

Figure 1 shows a generic representation of the results obtained with the application of a life cycle assessment, relating the primary energy use (including operational energy and embodied energy) and global costs (including investment costs, maintenance costs, energy costs, replacement costs and residual value).

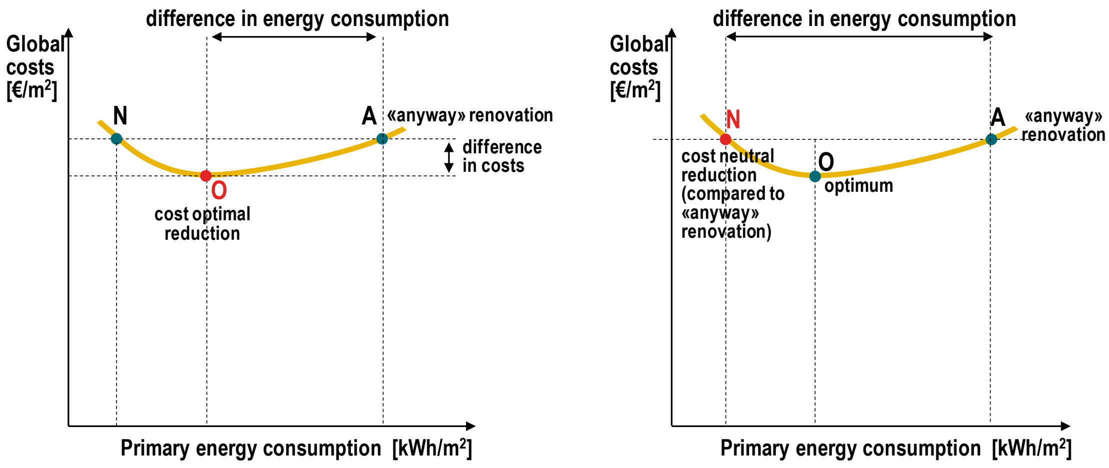



Figure 1 Generic presentation of life cycle assessment

Observing Figure 1, the Annex 56 methodology focuses on the renovation packages which fall in the range between point O (optimum) and point N (cost neutral reduction). The renovation measures or packages within that range are still cost effective, once they present lower costs than the “anyway” renovation. The “anyway” renovation is a renovation that would be done eventually, with the goal of restoring the functionality of the building, without deliberately reducing the energy use and carbon emissions. The global costs of the “anyway” renovation mark the limit of the cost effectiveness of the renovation packages.

In short, the application of Annex 56 methodology consists in comparing renovation packages based on the results of a life cycle cost assessment. This procedure allows obtaining a graphic similar to Figure 1 and from there, the optimization phase starts, considering renovation packages that are cost effective and also approach zero energy use.

For each renovation package, three main steps are necessary:

- Calculation of the energy demand of the building for heating and cooling, considering the climate conditions and the thermal performance of the building envelope;
- Calculation of the primary energy use and the carbon emissions, which includes those related to buildings operation (heating, DHW, lighting, etc.) and those related with the production of materials and their transport;
- Calculation of global costs, including investment costs, energy costs for the buildings life cycle, maintenance costs, replacement costs and eventually disposal costs.

After that, and in order to compare the renovation measures, there are two more steps that are fundamental to a proper application of the methodology:

- Evaluation of the additional value (co-benefits) achieved with the renovation process;
- Optimization process.

For each one of these steps, there are different tools or software that can be used, which are more or less adapted to each country's reality. The present report explores the different steps of the methodology and ways of achieving the necessary calculations to apply it correctly. Besides the analytic analysis, Annex 56 takes into account all the benefits resulting from the energy efficiency related renovation packages, including direct benefits (such as energy use reduction, carbon emissions reduction and energy costs reduction) and additional benefits related to the renovation process. These additional benefits are known as co-benefits.

The co-benefits may be relevant or decisive for the added value brought by energy-related building renovation, but most times they are not considered in the decision-making process. The co-benefits accrue for the building's owner or user (increased comfort, fewer problems with building physics, etc.) and also on the society level (health benefits, energy security, job creation, etc.).

Empirical data on the co-benefits are scarce and their quantification and/or monetization is tedious. Furthermore, in part, the co-benefits depend on the context of the building (for example, reduction of the external noise is only important in buildings located in noisy areas). This level of uncertainty makes it difficult to consider their contribution in a traditional cost-benefit analysis.

Most of the existing methods to determine or quantify the co-benefits rely on self- reporting surveys applying different approaches, such as:

Simple contingent valuation (CV) and willingness to pay (WTP)/ willingness to accept surveys (WTA): The CV method for co-benefits goes from simply asking respondents to estimate the value of the benefits and their WTP or WTA for them.

Relative scaling methods ask respondents to state how much higher they value co- benefits relative to a base. That base may be a monetary amount or another factor known to the respondents.

Ranking based on survey approaches: these surveys ask respondents to rank the co-benefits on a two-way comparison basis or more numerous options in rank order.

Integration into the 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 cost-benefit assessment and subsequent decision making.

## 2.1. Calculation of energy use and carbon emissions during buildings use

The primary energy use is determined from delivered energy to cover the energy demand of the building, considering the national primary energy conversion factor and carbon emissions factors. The primary energy use, concerning the operational energy, must include energy for space heating and cooling, domestic hot water (DHW), ventilation, auxiliary electricity for building integrated technical systems (pumps, control devices, etc.) and artificial lighting. The energy related to built-in appliances, such as lifts, is optional. Plug-in appliances are not considered because their use depends on the user.

Overall primary energy use and carbon emissions are calculated on an annual basis.

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.

The calculation of the energy uses for each end-use service (space heating and cooling, hot water, lighting, ventilation, appliances) and for each energy carrier (electricity, fuel) must take into account the characteristics (seasonal efficiencies) of generation, distribution, emission and control systems. The electricity from RES generated and used on-site must be subtracted.

The energy calculation can have different degrees of approximation depending on the use of dynamic tools or steady-state tools:

Dynamic tools are more complex software, which can calculate all the energy needs considering the fluctuation of the variables over time.

Steady-state tools implement the quasi-steady state method to calculate thermal energy needs (according to ISO 13790).

Carbon emissions related to the energy use resulting from the energy performance after the introduction of the renovation measures can be derived from the primary energy use, by energy carrier, with the help of national carbon emissions conversion factors.

Some examples of dynamic or hourly balance method tools, which are fully or partially freely available, are:

- EnergyPlus (available for download from https://energyplus.net/downloads);
- TRNSYS (available for download from http://sel.me.wisc.edu/trnsys/demos/demo.html)
- ESP_r (available for download from http://www.esru.strath.ac.uk/Programs/ESP-r_overview.htm)
- eQUEST (available for download from http://www.doe2.com/equest/ ) and DOE 2 (available for download from http://doe2.com/download/doe-23/);

To notice that none of these dynamic tools has been used in Annex 56 project simulations.
A brief description of these dynamic tools is presented below:

### EnergyPlus

EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption (for heating, cooling, ventilation, lighting and plug and process loads) and water use in buildings. It allows integrated, simultaneous solution, heat balance-based solutions, sub-hourly, user-definable time steps, combined heat and mass transfer, advanced fenestration models, illuminance and glare calculations, component-based HVAC, different built-in HVAC and lighting control strategies.

### TRNSYS

TRNSYS is a simulation program developed by the University of Wisconsin. One of its original applications is to perform a dynamic simulation of the behaviour of a solar hot water system for a typical meteorological year so that the long-term cost savings of such a system can be ascertained. It is a transient simulation program with a modular structure that recognizes a system description language in which the user specifies the components of the system and the manner in which they are connected. It includes a library of the components commonly found in thermal and electrical energy systems, as well as component routines to handle input of weather data or other time-dependent forcing functions and output of simulation results. TRNSYS is well suited to detailed analyses of any system whose behaviour is dependent on the passage of time. The main application includes solar systems (solar thermal and photovoltaic systems), low energy buildings and HVAC systems, renewable energy systems, cogeneration, fuel cells.

### ESP-r

The ESP-r was developed by the University of Strathclyde and it allows the designer to explore the complex relationships between a building's form, fabric, air flow, plant, and control. It is based on a finite volume, conservation approach in which a problem (specified in terms of geometry, construction, operation, leakage distribution, etc.) is transformed into a set of conservation equations (for energy, mass, momentum, etc.) which are then integrated at successive time steps in response to climate, occupant, and control system influences. ESP-r comprises a central Project Manager around which are arranged support databases, a simulator, various performance assessment tools and a variety of third-party applications for CAD, visualisation and report generation.

### eQUEST based on DOE

DOE was developed by the Department of Energy of the United States government and is a building energy analysis program that can predict the energy use for all types of buildings. DOE-2, a second version, uses a description of the building layout, constructions, operating schedules, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, along with weather data, to perform an hourly simulation of the building and to estimate utility bills. eQUEST is a complete interactive Windows implementation of the DOE-2 program with added wizards and graphic displays to aid in the use of DOE-2.

Concerning the steady-state tools, there are also many ways of performing the energy calculations. The main concern is to use a tool where the method follows the ISO 13790 and it is accepted and certified by the local regulations. Most professionals in European countries are very familiar with these tools, which normally are used for evaluation of compliance with national energy performance requirements and the process of energy certification. In these cases, using these tools to calculate the energy use and related carbon emissions of the renovation scenarios to be compared, is probably the wisest path.

Some are simplified tools, which consist of Excel spreadsheets, that allows calculating the energy needs and the non-renewable primary energy, for each renovation package, based on a monthly or seasonal time step. The carbon emissions can be derived from the net energy deliveries using national conversion factors by energy carrier.

Within the Annex 56 case-studies, the procedure to calculate the energy use of the buildings and related carbon emissions varies from country to country.

**Erro! A origem da referência não foi encontrada.** presents some tools used in each participating country, although not all of them have been used within Annex 56 calculations. Besides these tools, which are of common use in these countries, within Annex 56 calculations also INSPIRE tool has been used. The Ascot tool and INSPIRE tools have been updated according to the developed methodology, for which a detailed description is provided in chapter 3.

Table 1 Summary of the tools used to calculate the energy use in each of the countries

| | Austria | Denmark | Italy | Portugal | Sweden | Switzerland | Switzerland |
|---|---|---|---|---|---|---|---|
| Software Name | **various (e.g. GEQ, ArchiPHYSIK,…)** | **ASCOT** | **Docet** | **excel spreadsheet based on REH** | **beceren** | **Eco-Bat** | **Lesosai** |
| Web page | | | http://www.docet.itc.cnr.it/ | http://www.itecons.uc.pt/p3e/ | | http://www.eco-bat.ch/ | http://lesosai.com/ |
| Energy for heating | yes | yes | yes | yes | yes | yes | yes |
| Energy for cooling | only non-residential buildings | partly | just envelope need | yes | no | yes | yes |
| Energy for lighting | yes | no | no | no | no | yes | yes |
| System losses | yes | yes | yes | no | yes | no | yes |
| Total Primary Energy | yes | yes | yes | yes | no | yes | yes |
| Calculation method | Static simulation | ISO 13790 | Steady state method (Italian Technical Specifications UNI TS 11300) | Steady state method (Portuguese Thermal Regulation DL 118/2013 based in ISO13790) | Static simulation | Pre-sizing method (not compliant with SIA 380/1) | Various Swiss SIA norms e.g., SIA 380/1, ISO13790, French RT norms |
| Time step | Monthly | Monthly | Monthly | Season | Monthly | Yearly | Monthly or hourly |
| Assessment of Law requirements | yes | yes | yes | yes | no | no | yes |

A brief description of these tools is presented below:

**GEQ**

GEQ is a software developed in Austria for energy certification. It is user-friendly and it allows obtaining energy certification for residential and non-residential buildings.

It uses data from a construction materials database and performs the analysis using that information. It allows optimizing the level of insulation of the buildings envelope and the HWB (the sound reduction index, acoustic insulation of the buildings envelope and airborne sound reduction index in the bedrooms). It includes ecologic analysis.

**ArchiPHYSIK**

ArchiPHYSIK is an accepted and validated software for buildings energy certification and ecologic analysis, designed for Austrian reality. It is meant to be used in mono-zone buildings or multi-zone residential and non-residential buildings. It allows a holistic approach to the building physics including heat transfer analysis, energy performance, soundproofing and water vapour diffusion. The software takes into consideration incentives to the residential sector in Austria and it is user-friendly, once it has a CAD interface, through ArchiCAD or SketchUP.

**Docet**

Docet is a monthly balance simulation tool for the energy certification of existing residential buildings and apartments in Italy, based on the methodologies developed within CEN (Comité Européen de Normalisation) on implementing the European Directive 2002/91/CE.

Its calculation shows a high simplification of the input data and a repeatability of the analysis, however, maintaining a reasonable accuracy of the results.

The software was developed by ITC-CNR and ENEA and it has been updated according to the simplified calculation method, based on the UNI TS 11300 and the National Guidelines for energy certification (Italian law DM 26 June 2009), and according to the Italian decree DPR 59/2009.

**Excel spreadsheet based on REH**

In Portugal, ITEconst developed for residential buildings an Excel file in accordance with Decree-law nº118/2013 that is part of the transposition of EU EPBD to the Portuguese law (REH). The file uses macros and allows to determine the energy needs for heating, cooling and DHW. The file already contains Portuguese weather data according to the location and altitude selected. By introducing the construction solution, thermal characteristics, dimensions, orientations and types of BITS, it calculates the gains (solar and internal gains) and losses through the envelope and ventilation. By balancing all the buildings exchanges, the file calculates the energy needs of the building and primary energy consumption. It also calculates the reference values for the U-values and energy needs, in accordance with the Portuguese thermal regulation.

**beceren**

beceren is a recent development used in renovation projects in Sweden. This software now also includes life cycle cost assessment.

Efforts have been put on ease to make early calculations through default values for buildings from different time periods. Only a few values on location and size have to be entered to start calculations. If needed, default values can be changed easily.

The main layout is devoted to showing values and graphs regarding conditions before and after renovation measures step by step. A number of possible renovation measures are available in the program, ranging from improving building envelope to installations and energy provision. For each type of measure, a certain service lifetime is appointed after which a new investment is needed to keep the performance.

Yearly cash flow before and after renovation has been chosen to show life cycle economy. Since the life cycle cost (LCC) outcome depends on future interest rates and in the evolution of the energy price, which are mutable values, these parameters can easily be changed and the result is immediately shown in the diagram. This possibility paves the way for an informed choice of renovation measures based on the analysis of different future scenarios.

**Lesosai**

Lesosai is a software used in Switzerland from 1984 for the certification and thermal balance calculation of buildings containing one or more heated or cooled zones. It is designed primarily for building engineers, HVAC engineers, and architects.

Lesosai allows the calculation of environmental impacts of the energy consumption, taking into account the energy used in the building, but also the building's construction materials (life cycle impacts analysis / environmental assessment). This calculation is based on a building life cycle approach and uses the list of impacts maintained by KBOB (extracted from the EcoInvent database) and the methodology according to Swiss draft standard

SIA2032 (Life Cycle Impacts Analysis complete with ECO+® module). To calculate the heat transfer coefficient (U-value) it integrates the software USai, which allows the creation of construction solutions and materials while controlling condensation. It also allows synchronizing the database with those of the many materials producers who participate in the materialsdb.org project. To simulate buildings anywhere in the world, Lesosai includes the meteorological data generator, Meteonorm. Lesosai also includes many official meteorological data. Lesosai can also calculate required heating power, following EN 12831 and SIA 384.201by zone or by room. The hourly calculations according to ISO 13790 are validated with the help of tests according to EN 15265. Lesosai offers the possibility of calculating the thermal inertia of the building by introducing layers of walls (calculation possible under the standard SIA180 and EN ISO 13786).

**Eco-Bat** and **ASCOT,** as tools specially adapted to Annex 56 concept**,** will be presented in more detail in chapter 2.

## 2.2. Calculation tools for environmental Life Cycle Assessment for buildings

The Annex 56 methodology allows including a life cycle assessment for the operational energy use of each renovation package, focused on embodied energy and related carbon emissions.

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 (such as changing the kitchen sinks) are not included in the assessment of the energy-related renovation measures.

The service life of the buildings components included in the LCA calculations must be reported and documented, once it has a direct effect on the results. The number of replacements has to be included in the LCA and depends on the estimated life cycle.

For each renovation package, it is necessary to quantify the impact in terms of GWP (global warming potential) and Total Primary Energy.

For the calculation of carbon emissions (GWP) the following must be considered:

- Impact of the production and transport to the construction site, of materials that affect the energy performance of the building including BITS;
- The impact of the production and transport of energy, by energy carrier, for heating, DHW, cooling, air conditioning, ventilation, lighting, auxiliary systems and white appliances when available.

For the calculation of the total primary energy, following the operational energy calculated in the first step of the methodology, it is necessary to quantify the LCA of the renovation package taking into account the embodied energy (and carbon emissions) and the operational primary energy (and carbon emissions).

*The inclusion of LCA in the assessment of building renovation options has been treated in a specific task of the project and a report is available in the project website www.iea-annex56.org*

### *2.2.1.* Short review of existing LCA tools for buildings

As the LCA of a building can be time-consuming and should be done by building stakeholders, a growing amount of decision-making tools have been developed in Europe and internationally. This enables to switch from general LCA tools such as SimaPro[1], GaBi[2] or Umberto[3], which allow all kinds of LCAs, to more specific building-level LCA tools. These LCA tools are more and more connected to the green building labelling schemes as BREEAM, DGNB in Germany, SNBS in Switzerland and HQE in France. As the LCA of buildings needs the values of their energy consumption, some tools are linked to energy simulation software.

Previous EU and international projects have already proposed an analysis and ways of development for these building LCA tools. Most of them aimed at adapting the methodological rules for LCA studies in the construction sector and enabling the development of user-friendly tools that can be used by building stakeholders, who are usually not LCA experts. These projects include, for example, REGENER, IEA Annex 31, PRESCO, IMPRO-Building, ENSLIC Building and LoRe-LCA. More recently, the EeBGuide project and its related InfoHub (Lasvaux et al, 2014)[4], proposed a new guidance document for the LCA of energy efficient buildings. During this project, a detailed review of existing LCA tools for buildings was conducted (Lasvaux et al, 2014)[5].

### *2.2.2.* Comparison of the contents of LCA tools and Annex 56 requirements (in terms of indicators, system boundaries, etc.)

The analysis of these LCA tools e.g., in Lasvaux et al (2012), showed that they use different methodologies and indicators. However, in the scope of the IEA Annex 56 project, most of them propose the primary energy and carbon emissions[6] indicators as part of their results.

In principle, they could be used according to the Annex 56 LCA methodology by ensuring that only the primary energy and carbon emissions of the energy-related renovation

1 www.pre-sustainability.com
2 www.lbp-gabi.de
3 www.ifu.com/en
4 http://link.springer.com/article/10.1007%2Fs11367-014-0786-2
5 http://www.eebguide.eu/eebblog/wp-content/uploads/2012/12/D-4.3.-Requirements-for-Building-LCA-tool-designer.pdf
6 The term « carbon emissions is used in Annex 56 in the meaning of « greenhouse gases emissions »

measures (thermal envelope, building integrated technical systems, energy use for on-site production and delivered energy) are taken into account.

Different LCA data can be used in the decision-making tools (e.g., LCA software). Most of the time they depend on the geographical context (e.g., the impact of the electricity mix varies according to the country). Different LCA databases exist such as ecoinvent or GaBi (generic databases) but also sector-specific and country-specific (e.g., the KBOB data in Switzerland, the Ökobaudat in Germany, the different EPD databases in Europe e.g., INIES FDES in France, etc.).

Table 2 shows an overview of the tools/software used in the construction context based on previous state-of-the-art reports on LCA tools for buildings. More information on the tools' characteristics can be found in Lasvaux et al (2012).

Table 2 Compilation of some of the available LCA tools for buildings

| **Overview of building related LCA software tools based on previous state-of-the-art reports (in ENSLIC Building, LoRe-LCA or EeBGuide: Lasvaux et al, 2012)** | | | |
|---|---|---|---|
| **Software** | **Developer** | **Country code** | **Website** |
| **Athena** | Athena Sustainable Materials Institute | CA | www.athenasmi.org |
| **BEES** | National Institute of Standards and Technology (NIST) | USA | www.nist.gov/el/economics/ BEESSoftware. cfm |
| **Eco-bau / Eco-sai** | Univ. of Applied Sciences of Wester Switzerland (HES-SO), HEIG-VD LESBAT | CH | www.eco-bat.ch<br>www.eco-sai.ch (new version) |
| **Ecoeffect** | KTH / Univ. of Gävle | SE | http://www.ecoeffect.se/ |
| **Eco-Quantum** | IVAM | NL | www.ivam.uva.nl |
| **ECOSOFT** | IBO | AT | http://www.ibo.at/de/ecosoft.htm |
| **ELODIE** | Centre Scientifique et Technique du Bâtiment (CSTB) | F | www.elodie-cstb.fr |
| **novaEQUER** | ARMINES / Izuba Energies | F | http://www.izuba.fr/logiciel/novaequer |
| **Gabi Build-IT** | PE International / Thinkstep | DE | https://www.thinkstep.com/industries/building-construction/building |
| **Greencalc** | Stichting Sureac | NL | www.greencalc.com |
| **Impact (replacing Envest tool)** | Building Research Establishment (BRE) | UK | www.impactwba.com/ |
| **Legep Software** | LEGEP Software GmbH (WEKA) | DE | www.legep.de |

| | | | |
|---|---|---|---|
| **SBI's LCA-Tool** | Danish Building Research Institute | DK | in development |
| **SBS** | Fraunhofer IBP | DE | https://sbs-prod.elasticbeanstalk.com/ |

Some databases only contain impact assessment values like the GWP or primary energy values while other provide a complete list of elementary flows[7] and impact values[8] .

For the LCA performed in the context of Annex 56, different LCA tools were used including one general LCA tool (SimaPro) and three dedicated tools for buildings (ASCOT[9], Eco-bat, and Lesosai). Some of the tools perform both energy performance calculations and the LCA. For each of these tools, the Annex 56 partners apply the Annex 56 LCA methodology meaning that for SimaPro, they have to carefully calculate the LCA as the tool is general. For Eco-bat, as the tool already takes into account the Annex 56 methodology, the implementation is more straightforward[10].

## 2.3. Life cycle costs analysis (calculation of the global costs)

The Annex 56 methodology is based on a lifecycle approach and the cost assessment can be performed assuming either a private or societal cost perspective. 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. The societal perspective includes external costs and benefits but it excludes taxes and subsidies. This perspective is relevant for policy makers to set targets, for designing policy programs and it may also be relevant for investors and users who assume a societal or a long-term perspective.

The life cycle cost analysis must include the following cost elements:

- Initial investment costs (planning and construction costs, professional fees, taxes, etc.)
- Replacement costs during the building's lifetime (periodic investments for replacement of building elements at the end of their lifetime) and residual value of the replaced elements.
- Running costs (energy costs, maintenance costs, and operational costs).

Global costs consist of 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. The lifetime of a

7 Elementary flows like $CO_2$, $CH_4$, $N_2O$ etc.

8 This is for instance the case of general LCA software like SimaPro or GaBi

9 Please see chapter 3 for more information on ASCOT tool

10 Please see chapter 3 for more information on Eco-bat tool

building corresponds to the residual expected lifetime at the moment of building renovation. When the residual lifetime is unknown, a calculation period of 60 years is assumed [11].

The life cycle cost assessment can be performed dynamically, i.e. future costs and benefits have to be discounted to yield correct results. It can be done using two methods: the global cost method, which uses the net present value (NPV), or the annuity method. In NPV a uniform calculation period is used, being necessary to use residual values for the building elements that have a lifespan longer than the calculation period. With the annuity method, the cost of each building element is annualized according to its life spam. During the calculations in the project the annuity method has been used. The next section explains the basis for each one of the methods.

### *2.3.1.* Net Present Value method

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 lifespan 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. 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 to the discounted cash flow method commonly used in the realm of building development and management.

Global costs (private cost perspective):

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

$t$: Calculation period

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

$C_l$: 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*

*r:* Discount rate

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

---

[11] IEA EBC Methodology For Cost-effective Energy and Carbon Emissions Optimization in Building Renovation

Example:

In a simplified way, in order to apply the NPV, it is necessary to determine the investment costs, the maintenance costs and the energy costs for year 1, 2, 3 and so on, until the last year of calculation. When necessary, replacement cost must be considered. In the end of the calculation period, it is also necessary to take into account the residual value of the elements. Usually, the residual value is discounted in the costs for the last year of the calculation period. In this sense considering t=20 years, r=0,03, investment cost = c(t0), replacement costs (ac), energy cost = e(n), maintenance costs = m(n) and residual value (rv) where n corresponds to each year, this results in:

$$NPV = C(t0) + \frac{(e1+m\,1)}{(1+0.03)^1} + \frac{(e2+m2\,)}{(1+0.03)^2} + \frac{(e3+m3\,)}{(1+0.03)^3} + \frac{(e4+m4\,)}{(1+0.03)^4} + \cdots + \frac{(e15+m15+ac15\,)}{(1+0.03)^{15}} + \cdots + \frac{(e20+m20-rv\,)}{(1+0.03)^{20}}$$

### *2.3.2.* Annuity method

The annuity method transforms investment costs into average annualized costs, yielding constant annual costs during the lifespan of the investment considered. The 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[12] to take into account real future energy price increases or real future cost increases.

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

***a*** *annuity for constant real prices (corresponding to constant yearly capital cost c)*

***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 factor 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***

[12] The general average adjustment factor for price or cost increases applying the annuity method

*which has to be multiplied by 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 corresponding to an annual rate of 2%):*

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

Example:
For a real interest rate i = 0.03 (3% per year), an initial investment I and a calculation period t (or weighted average lifetime t) results in constant yearly capital costs **c** (annuity) during the calculation period t of: **c = a · I**

For a real interest rate i = 0.03 (3% per year), yearly price or cost increases r of 0.04/a (4% per year) during the calculation period t of 20 years, the resulting average price (cost) increase factor m is: **m = 1.49**

If yearly energy costs ***e*** are increasing by 4% p.a., the real interest rate ***i*** is 3% p.a. and the calculation period is 20 years, the adjusted average annual energy costs ***ea*** during period t are: ***ea = e*m = 1.49 · e***

By using the annuity method, it is not necessary to determine residual values at the end of a present 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).

### *2.3.3.* Anyway renovation (the base for cost comparison)

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.

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 economic or technical life of building elements has been achieved or the functionality or service quality of a building element is not sufficient anymore. Measures applied in this reference case do not aim at improving the energy performance of the building nor at deploying renewable energy sources (even if they may sometimes improve energy efficiency since the replaced elements are more efficient because of technological progress – this is common when windows or technical systems are replaced because the market no longer offers the efficiency level of the replaced element).

### *2.3.4.* Category of costs for the LCC

Briefly, the LCC analysis can be generically represented by the following formula:

***LCC = Investment + NPV (replacement + residual value, when available) + NPV (total of energy + operating + maintenance + repair costs)***

The investment costs include costs for planning and approval, purchase of building elements, connection to suppliers, installation and commissioning processes.

The running costs include energy costs, maintenance, repair, replacement costs, disposal costs and residual value at the end of the life cycle. For the macroeconomic perspective, besides all the referred costs, the carbon emissions costs should also be considered. The evolution of the energy costs (future costs) can be done according to the Commission Delegated Regulation nº244/2012 of 16 January supplementing the Directive 2010/31/EU of the European Parliament and of the Council on the Energy Performance of Buildings, but the base costs must be calculated in accordance with the national energy market costs for the moment when the analysis begins.

It is possible to omit the following costs once their inclusion would not introduce any difference on the comparison among packages:

- 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.;
- Costs that are the same for all renovation options assessed for a certain reference building, for examples scaffolding, demolition cost, etc..

### *2.3.5.* LCC tools

In order to compare the annuity of the investment with increasing savings of energy costs, the savings of energy costs are discounted and converted into annual costs. The calculations are based on real prices, real interest rates and typical lifetimes of the building elements. Concerning the tools, it is possible to perform LCC by using an Excel file. It may take some time to program it but it is simple to use. In Table 3, some of the available tools to perform an LCC analysis are listed. For the purpose of the Annex 56 case-studies, the tools used to carry out the LCC are listed in Table 4.

Table 3 Tools for LCC

| Name | Description | website |
|---|---|---|
| **Harvard Life Cycle Costing Calculator** | It's a primary tool developed by Harvard Energy & Facilities for meeting Harvard's Green Building Standards and optimizing the performance of existing buildings. | Download from Harvard.edu website. |
| **Building Life-Cycle Cost (BLCC)** | Economic analysis tool developed by the National Institute of Standards and Technology for the U.S. Department of Energy Federal Energy Management Program (FEMP). | Download from the Department of Energy website. |
| **ENTRANZE Cost_Energy Calculation** | The cost-energy spreadsheet allows assessing the policy impact of renovation packages in existing buildings, by cost/energy curves and clouds. It is developed in the Entranze research project, by eERG - end-use Efficiency Research Group, Politecnico di Milano | Download from the Entranze project website. |
| **ASCOT** | A detailed description is given in chapter 2. | Download from the Annex 56 website: http://www.iea-annex56.org/ |
| **INSPIRE** | A detailed description is given in chapter 2. | Download from the Swiss Federal Office of Energy website |

Table 4 Summary of LCC tools used within Annex 56 analysis

| | **Denmark** | **Italy** | **Portugal** | **Sweden** | **Switzerland** |
|---|---|---|---|---|---|
| **Software Name** | **ASCOT** | **Docet** | **Excel file** | **Excel file** | **INSPIRE** |
| **Energy Use cost assessment** | yes | yes | yes | yes | yes |
| **Renovation cost assessment** | yes | yes | yes | yes | yes |

| | | | | | |
|---|---|---|---|---|---|
| **Total cost assessment of renovation** | yes | no | yes | yes | yes |
| **Cost assessment method** | NPV | Simple Payback | NPV | Yearly cash-flow | NPV |
| **Commercial or Free** | free | free | not public | not public | free |

## 2.4. Inclusion of the co-benefits in the decision-making process

***Additional information about the co-benefits can be found on the project website www.iea-annex56.org and in the specific report "Co-benefits of energy related building renovation"***

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. These benefits can be felt at the building level by the building owner or user (like increased user comfort, fewer problems with building physics, improved aesthetics), but also at the society level (like health benefits, job creation, energy security, impact on climate change).

The co-benefits refer to all benefits (positive or negative) resulting from renovation measures related to energy and carbon emissions optimized building renovation, beyond or as a consequence of energy efficiency improvement, carbon emissions reduction or costs reduction.

The inclusion of the co-benefits intends 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.

The private perspective takes into account the concerns of owners, promoters, and users and is mainly focused 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. It is relevant that decision makers are fully aware of the potential 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. **Erro! Auto-referência de marcador inválida.** shows a co-benefits matrix, in the private perspective. The matrix presents a valuation of the co-benefits impact whether they are positive (+) or negative (-). The number of signs intends to show the intensity of the co-benefits impact. Some present different signs, once both negative and positive co-benefits can happen depending on the specific context of each renovation project.

Table 5 Matrix of the co-benefits that accrue from energy-related 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) | +++ | | + | + + | - | + + | | + + | - - + | | | + + | |
| Façade insulation (internal) | - + + | | | | - | + + | | + + | | - - | | + | |
| Roof insulation | +++ | | | + | - | + + | | + + | | | | + + | |
| Ground floor insulation | +++ | | | | | | | + + | | | | + | |
| Cellar ceiling insulation | +++ | | | | | | | + + | | | | + | |
| Windows replacement | +++ | | | + | - | +++ | | + | + | | + + | + | |
| Insulation of entire building envelope | +++ | | | | - | +++ | | + + | - + | | | + + | |
| Larger window areas | - | +++ | | | | | | | | | | | |
| Roof light or Sun pipes | | + + | | | | | | + | | | | | |
| External shading | + + | | | | | + | | + | +++ | | | | |
| Balconies and loggias | - + + | - - | | + + | | +++ | | | + + | + + | | | |
| Air/air and air/water HP | | | | | | | | + | | | | | + + |
| Ground-coupled HP | | | | | | | | + | | | | | - - |
| Biomass heating system | | | | | | | | + | | | | | |
| Efficient DHW system | | | | | | | | + + | | | | + | |
| Automatic control systems | | | | | | | + | | | | | | |
| Air renewal systems | + + | | +++ | + + | - - | | - | + | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MVHR systems | + + | | + | + | - - | | + | | + | |
| Solar Thermal systems | | | | | | | + + | | + + | + + |
| Photovoltaic systems | | | | | | | | | | +++ |

Based on this matrix it is possible to perform a qualitative analysis of the co-benefits that accrue from each renovation measure. The analysis of a package will result from the sum of all the co-benefits. It is also important to take into consideration the buildings context, once the impact of the co-benefit may be affected by it.

The co-benefits analysis normally is performed manually, selecting the renovation measures that best suit the owner's / investor's best interests.

## 2.5. Decision-making process

The optimization process is more a trade-off analysis of costs and benefits of energy efficiency measures versus measures deploying renewable energy while reducing carbon emissions. The base to the optimization process [13] is to set a target based on the reduction of the energy use and/or reduction of carbon emissions that is intended to achieve.

The EPBD suggests that priority should be given to energy efficiency measures, at least up to a cost optimal package of related efficiency measures, clearly reducing the energy use. Carbon emissions are reduced too, but the extent of the reduction is dependent on the energy carrier used to cover the energy demand.

The priority given to energy targets is being questioned based on the possibility that there may be solutions that reduce the carbon emissions more effectively and be still cost-effective. Usually, this requires the use of renewable energy sources (RES) and starts to fall within the nZEB concept.

From a societal perspective, the transition from the cost optimal concept to nZEB must happen in order to fulfill the European requirements concerning the reduction of carbon emissions. In this sense, it may be relevant to prioritize an effective carbon reduction still in a cost effective way.

Cost effective optimization of carbon emissions reduction and energy use reduction can be carried out based on a market approach or in a normative approach. Considering the market approach, the focus is on energy, since energy has a price and the reduction of energy use by investing in better energy-related renovation measures can benefit from lower energy costs. On the other hand, carbon emissions do not have a price or, if they

[13] For further information on the optimization process please check the IEA EBC Methodology for Cost-effective Energy and Carbon Emissions Optimization in Building Renovation (Annex 56)

have, it is usually not adequate, which is the reason why carbon emissions reduction is disregarded on the market. If the range of economically viable solutions is extended to cost effective solutions, the question on to what extent further renovation measures shall focus on the energy performance of the building or on the reduction of carbon emissions arises.

To optimize among the range of possible measures, costs and benefits of these measures have to be aggregated and compared. This can be done by a multi-criteria analysis.

Considering a normative approach, cost optimality means to minimize the costs to achieve the energy reduction and $CO_2$ targets. 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 considering additional boundary conditions regarding energy performance of the building and its envelope, which have to be taken into account while optimizing cost-effective measures.

Given the targets being world-wide settled for carbon emissions reduction, more attention should be paid to 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 priority over energy targets and that 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 that are beyond cost optimal but still cost effective, maximizing possible carbon emissions reduction.

The optimization relays on a certain target and usually there is not a tool for that.

Within the Annex 56 project, the optimization process was based on the comparison of the measures that go beyond the cost-optimal level and on the related co-benefits achieved in the renovation process. Despite the lack of a monetary value for the co-benefits, a qualitative analysis was carried out.

The main step for the optimization is to set a target and chose renovation measures that are more appropriate for the pre-set conditions.

# 3. Tools developed or improved based on Annex56 methodology

Some existing tools have been further developed and updated within Annex 56 project in order to comply with the methodology. The following sections describe in a more detailed way these tools and their main features.

## 3.1. A56opt-tool

A56opt-tool aims at supporting calculations based on the Annex 56 methodology allowing comparing and evaluating different packages of renovation measures.

The software was developed as a Microsoft Excel spreadsheet structure, providing maximal flexibility and a familiar working environment for the user. The interface was built using a combination of customized Excel functions: options can be selected through drop-down menus or inserting user inputs into yellow-marked cells.

The Excel sheet is designed as a tool that uses simulation data that come from other tools related to each renovation scenario under analysis, such as: area of intervention, energy performance (energy needs or use), costs (investment, maintenance, energy) and environmental impact (GWP and / or embodied energy).

The spreadsheet allows understanding and then applying the operations as defined in section 3. The tool can also be coupled with the use of Ascot (described further in the report) because it should bring the outputs of each improvement action to identify the optimal solution.

ENERGY: Price, Emission & P.E. factors

| Country | Italy | | | |
|---|---|---|---|---|
| Energy carrier | Conversion factors | | Price | Emission factors |
| | Primary non-renewable energy factor | Primary energy factor | €/kWh | kg CO2e / kWh |
| Electricity | 2,420 | | 0,164 | 0,483 |
| Natural gas | 1,050 | | 0,081 | 0,202 |
| Wood pellets | 1,000 | | 0,043 | |
| Oil | 1,070 | | 0,105 | 0,267 |
| Electricity REN | 1,000 | 1,000 | | |
| District heating | 1,500 | | 0,105 | |

Figure 2 ENERGY: Price, Emission & P.E. factors

In the Excel file, in the "INTRO" sheet, a legend and a short guide support the filling of the file; the sheet "Price, Emission & Primary Energy conversion factors" contains specific data for each country involved in the renovation process: for each energy carrier, data regarding primary energy conversion factors, energy price, and emission factors should be filled in (Figure 2).

The sheet “REFERENCE BUILDING” collects information about the area and performances that are relevant for the renovation process, while the renovation measures are described in “RENOVATION PACKAGES” sheet in terms of actions on the envelope and systems.

“ENERGY CONSUMPTION” sheet collects information about Primary Energy use for each renovation package, considering the energy needs for heating, cooling, DHW and lighting systems (Figure 3).

| Renovation Package | Heating energy | | | Conversion carrier | Conversion factors | Primary Energy | |
|---|---|---|---|---|---|---|---|
| | need | system efficiency | use | | | use | |
| | kWh/m² * y | % x 100 | kWh/m² * y | | | kWh/m² * y | |
| | Total | n/COP | | Heat | Heat | Heat | Total (kWh/m² * y) |
| Reference | 84,92 | 1,00 | 84,92 | Natural gas | 1,05 | 89,17 | **89,17** |
| 1 | 25,65 | 0,93 | 27,58 | Electricity | 1,95 | 53,78 | **53,78** |
| 2 | 20,97 | 0,93 | 22,55 | Electricity | 1,95 | 43,97 | **43,97** |
| 3 | 25,65 | 4,1 | 6,26 | Oil | 1,07 | 6,69 | **6,69** |
| 4 | 20,97 | 4,1 | 5,11 | Oil | 1,07 | 5,47 | **5,47** |
| 5 | 25,65 | 3,9 | 6,58 | Oil | 1,07 | 7,04 | **7,04** |
| 6 | 20,97 | 3,9 | 5,38 | Oil | 1,07 | 5,75 | **5,75** |
| 7 | 25,65 | 0,92 | 27,88 | Wood pellets | 1,00 | 27,88 | **27,88** |
| 8 | 20,97 | 0,92 | 22,79 | Wood pellets | 1,00 | 22,79 | **22,79** |
| 9 | 33 | 4,1 | 8,05 | Oil | 1,07 | 8,61 | **8,61** |
| 10 | 29 | 4,1 | 7,07 | Oil | 1,07 | 7,57 | **7,57** |

Figure 3 ENERGY CONSUMPTION summary for each renovation package

In “COST” sheet, it must be inserted the costs related to investment, maintenance, and energy use during the 30 years period of evaluation, considering each component involved in the renovation measures and the change of the energy price during this period. The calculation of costs is automatically done for each renovation measure and the Payback time and the Net Present Value (NPV) are also shown. Within the Annex 56 calculations, in order to allow comparing the different case-studies in the different participating countries, the NPV of each renovation package is transformed into an annuity value (Figure 4).

| NPV Costs | Investment | Operation (Energy) | Operation (Maintenance) | Global | Annualised Global costs* | Primary Energy |
|---|---|---|---|---|---|---|
| | €/m² | €/m² | €/m² | €/m² | €/m² | kWh/m2 * y |
| Reference | € 5.774,80 | € 945,81 | € 8.512,29 | € 15.232,90 | 1107 | 143 |
| 1 | € 6.478,60 | € 636,68 | € 2.900,42 | € 10.015,70 | 728 | 134 |
| 2 | € 9.591,20 | € 1.035,35 | € 2.946,75 | € 13.573,30 | 986 | 125 |
| 3 | € 9.820,20 | € 1.585,49 | € 3.077,71 | € 14.483,40 | 1052 | 123 |
| 4 | € 12.932,80 | € 2.159,81 | € 2.982,59 | € 18.075,20 | 1313 | 110 |
| 5 | € 14.593,80 | € 909,30 | € 909,30 | € 16.412,40 | 1192 | 92 |
| 6 | € 17.706,40 | € 1.330,98 | € 963,82 | € 20.001,20 | 1453 | 108 |
| 7 | € 8.064,40 | € 2.175,76 | € 1.120,84 | € 11.361,00 | 825 | 99 |
| 8 | € 11.177,00 | € 2.781,51 | € 977,29 | € 14.935,80 | 1085 | 96 |
| 9 | € 10.529,40 | € 4.403,07 | € 966,53 | € 15.899,00 | 1155 | 83 |
| 10 | € 10.686,55 | € 5.130,00 | € 570,00 | € 16.386,55 | 1190 | 66 |

Figure 4 Annualised Global cost calculation

In the “IMPACT” sheet, each component involved in the renovation is evaluated in terms of GWP and embodied energy. The tool uses LCA data sources according to databases given by SimaPro results for each of the renovation materials including the energy needed for heating, cooling, DHW and lighting. It is also possible to insert individual data from producers.

The main results of different renovation packages are shown in “A56 charts”, presenting in graphs emissions data in relation to the life cycle costs for each renovation package and primary energy use in relation to the life cycle costs of each renovation package. It is then possible to compare different renovation packages with reference cases and to build up a renovation strategy in order to find out the optimal package of intervention.

In the sheet “CO-BENEFITS”, the matrix developed within the Annex 56 Methodology is inserted, allowing identifying the positive and/or negative impacts of each renovation measure, helping in the decision-making process of finding an adequate renovation package.

This tool is available online in the Annex56 webpage (http://www.iea-annex56.org/).

## 3.2. ASCOT

“ASCOT” is based on the original Danish total economy calculation tool, “BYGSOL” developed by Cenergia under the EU-Concerto project, where a number of European climates have been added as the basis of the CEN standard based calculation. The principle behind the calculations is the same as for the Danish Be10 calculation program, but with an added database on costs for different alternative energy saving measures.

The calculation tool ASCOT - Assessment tool for additional construction cost in sustainable building renovation – was originally developed for dwellings. The purpose of the ASCOT tool is to assist the user in evaluating and thereby optimize the economic costs of a building renovation project, in relation to sustainable development issues. The tool is based on earlier development work in various EU and Danish projects.

The tool is designed to take into consideration:

- all investment and operation costs over the total lifetime of the building;
- the savings from the investments with respect to sustainable issues (energy, water, waste) over the total lifetime of the building;
- the reduced environmental impact from the energy savings;
- the social or environmental and other external costs incurred by the project (not included in the first prototype but an option that can be added at a later stage).

The ASCOT model allows a comparison between a traditional (reference) building renovation and different sustainable concepts for its renovation. This comparison takes into account usage savings during the total lifetime of the building and the frequency of future replacing of building components and systems. The tool is primarily intended for use in the early stage of the design process. It can be used for both new constructions and renovation projects. Figure 5 shows an example of the ASCOT file.

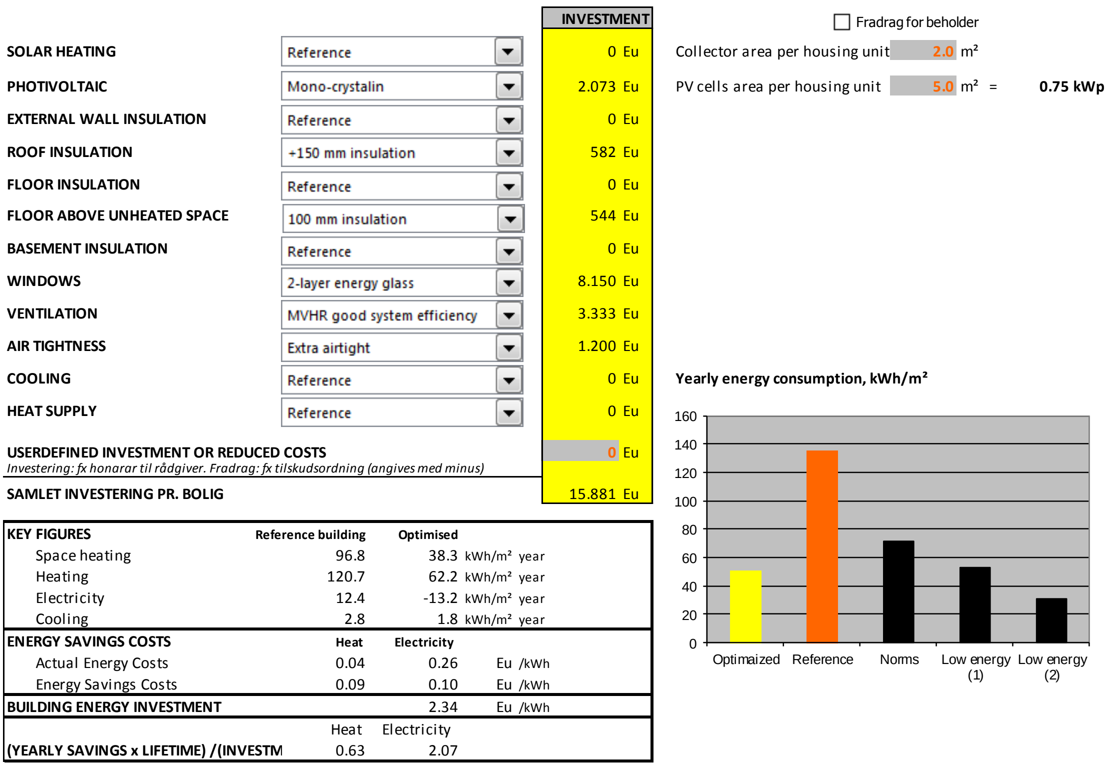



Figure 5 Example of ASCOT results for optimization of a building renovation with Annex56 methodology (Mørck, 2015)

The ASCOT tool can be used to define sustainability categories and to classify buildings according to these categories, based on the calculated reduced environmental impacts. It is characterized by a simple structure that is very flexible to future changes and upgrading. Its use and results are easy to understand - enabling a steep learning curve.

The ASCOT tool will be continuously developed with the intention of adapting it to all European countries. This means that it will be possible to introduce new climates and to adjust energy prices and building component prices to local conditions.

The ASCOT tool calculations are based on international standards for energy calculation, namely ISO 13790 (Thermal performance of buildings – calculation of energy use for space heating and cooling) and prEN 15316 (heating systems in buildings – method for calculation of system energy requirements and system efficiencies: heat generation system, thermal solar systems). Figure 6 shows some of the data that the ASCOT tool provides.

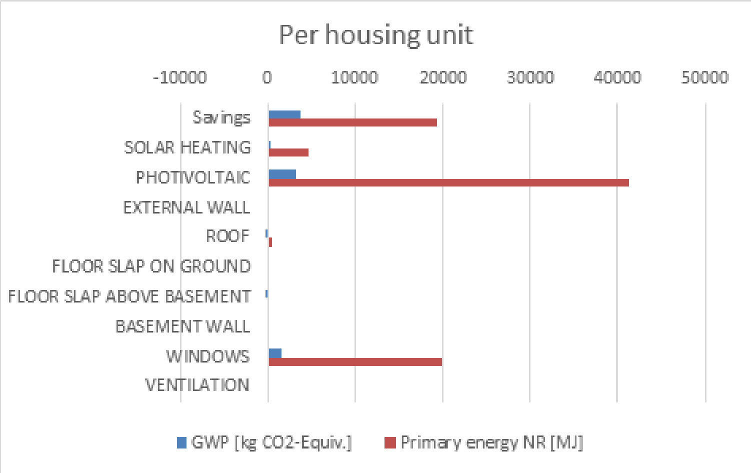
| INSULATION STANDARD | | User defined | no insulation | low insulation | med insulation | high insulation | new build | Super insulation | Refe-rence | Wall thickness |
|---|---|---|---|---|---|---|---|---|---|---|
| External wall (light construction) | W/m²K | 0.20 | 1.10 | 0.50 | 0.30 | 0.20 | 0.20 | 0.15 | 0.50 | 0.253 |
| External wall (heavy construction) | W/m²K | 0.20 | 1.60 | 1.10 | 0.40 | 0.30 | 0.20 | 0.15 | 1.10 | |
| Basement wall | W/m²K | 0.20 | 0.40 | 0.34 | 0.34 | 0.30 | 0.20 | 0.15 | 0.34 | |
| Floor | W/m²K | 0.15 | 0.40 | 0.40 | 0.30 | 0.20 | 0.15 | 0.10 | 0.40 | |
| Floor with floor heating | W/m²K | 0.12 | 0.40 | 0.40 | 0.30 | 0.15 | 0.12 | 0.10 | 0.40 | |
| Floor to inheated room | W/m²K | 0.40 | 0.80 | 0.50 | 0.40 | 0.40 | 0.40 | 0.40 | 0.50 | |
| Roof | W/m²K | 0.15 | 1.90 | 0.40 | 0.20 | 0.15 | 0.15 | 0.10 | 0.40 | |
| Windows and doors | W/m²K | 1.20 | 4.20 | 3.10 | 2.90 | 1.80 | 1.20 | 0.90 | 3.10 | |
| Losses foundations | W/mK | 0.15 | 0.50 | 0.30 | 0.25 | 0.25 | 0.15 | 0.12 | 0.30 | |
| Losses around windows | W/mK | 0.03 | 0.10 | 0.10 | 0.10 | 0.10 | 0.03 | 0.03 | 0.10 | |
| Air tightness, 50Pa | l/sm² | 1.50 | 4.0 | 4.0 | 4.0 | 3.0 | 1.5 | 1.5 | 4.00 | |

Figure 6 Energy Data in Ascot

About cost of energy saving measures, cost data is included in the tool and it can be modified.

The costs calculation is automatically made for each measure and the results are added to a total, also presenting the Payback and the Net Present Value (NPV).

This way, it is possible to calculate the real impact of an intervention consisting of some measures and it allows an optimization for energy and cost. At last, the tool makes an LCA analysis of measures and it gives some results about the environmental impacts and the payback years for the total renovation package (Figure 7).




| | |
|---|---|
| GWP, Global Warming Potential [kg CO2-Equiv] | 1,3 years |
| ODP, Ozone Depletion Potential [kg R11-Equiv.] | 1,5 years |
| POCP, Photochemical Ozone Creation Potential [kg Ethene-Equiv. | 1,5 years |
| AP, Acidification Potential [kg SO2-Equiv.] | 2,9 years |
| EP, Eutrification Potential [kg Phosphate-Equiv.] | 0,9 years |
| ADP, Abiotic Depletion Potential [kg Sb-Equiv.] | 0,0 years |
| Primary energy NR [MJ] | 3,4 years |

Figure 7 LCA results: Payback years for the total renovation package

The ASCOT tool uses LCA data sources according to databases such as ESUCO, Ökobau and it also has the possibility of inserting individual data from producers.

## 3.3. INSPIRE

The focus of the INSPIRE tool is on assessing the cost-effectiveness of strategies to increase energy efficiency and mitigate greenhouse gas emissions in buildings. It is freely available as a tool for application in Switzerland with versions in German and French. A customized version of the INSPIRE tool was used to carry out the generic calculations with reference buildings in Annex 56 project. It was also applied in one case-study of Annex 56, for Austria. The tool was originally developed within the ERA-NET project INSPIRE within the framework of the EU FP7 program.

INSPIRE is a comprehensive calculation tool in which calculation of energy need follows the principles of ISO 13790 and takes into account energy performance of a building envelope, outdoor climate, target indoor temperature, and internal heat gains. The tool allows to investigate trade-offs and synergies between different types of measures and to identify strategies aiming at reducing cost-effectively primary energy use and greenhouse gas emissions. The tool includes a database of empirical techno-economic characteristics of several types of measures. Measures are categorized in seven categories:

- building envelope insulation
- heating systems

- ventilation system with heat recovery
- electricity based services (lighting, cooling, and appliances)
- energy supply mix
- building automation control and regulation
- on-site electricity or heat production.

Up to eight packages of renovation measures and two reference cases can be calculated and compared simultaneously in terms of economic and environmental indicators: investment costs and life-cycle costs, total and non-renewable primary energy consumption, and greenhouse gas emissions. The economic effectiveness and economic viability of advanced retrofit measures and up-stream options can be assessed from a life-cycle-cost point of view. As default data for costs, empirical cost data and energy prices from Switzerland are provided. However, this data can be adjusted by users to carry out investigations based on user-specific economic framework conditions. With the tool, the impact of factors such as starting situation, scope and costs of measures, interest rate and energy price expectations, can be revealed.

The output of the tool supports the user in developing strategies for different building types and for different contexts to reach ambitious environmental targets at the least life cycle costs. However, the tool is limited to a general approach in the early planning phase and cannot be used in detailed design studies.

The INSPIRE Tool focuses on residential buildings and simple office buildings without cooling needs. The methodology applied does not account for building related mobility. Embodied energy use, upstream life cycle primary energy use for energy carriers and related carbon emissions are included. Co-benefits of retrofit measures are not included as such; it is, however, possible to take into account co-benefits of renovation measures by specifying a factor that indicates to which extent a renovation measure is carried out for energy-related reasons or to which extent it is carried out for other reasons such as aesthetic reasons. This allows excluding from the cost-effectiveness calculations extra costs due to specific reasons not related to energy.

The software was developed as a Microsoft Excel spreadsheet, providing maximal flexibility and a familiar working environment for the user. For easy updating and maximum performance, default data is stored in a separate file and accessed from Microsoft Excel by using industry-standard SQL commands.

Using a combination of programming in Visual Basic for Applications (VBA) and customized Excel functions, an interactive user interface was built. Options can be selected through drop-down menus, and for most user inputs, default values are provided, which can be adjusted by the user. The interface is dynamic, as it reacts to the user's input, e.g. if the option «building has a ventilation» is selected, the related input fields are shown and corresponding default values are computed.

Building data and techno-economic data of greenhouse gas emissions mitigation and primary energy efficiency measures are used to calculate heating energy needs, final energy consumption, greenhouse gas emissions, primary energy use, and life-cycle-costs.

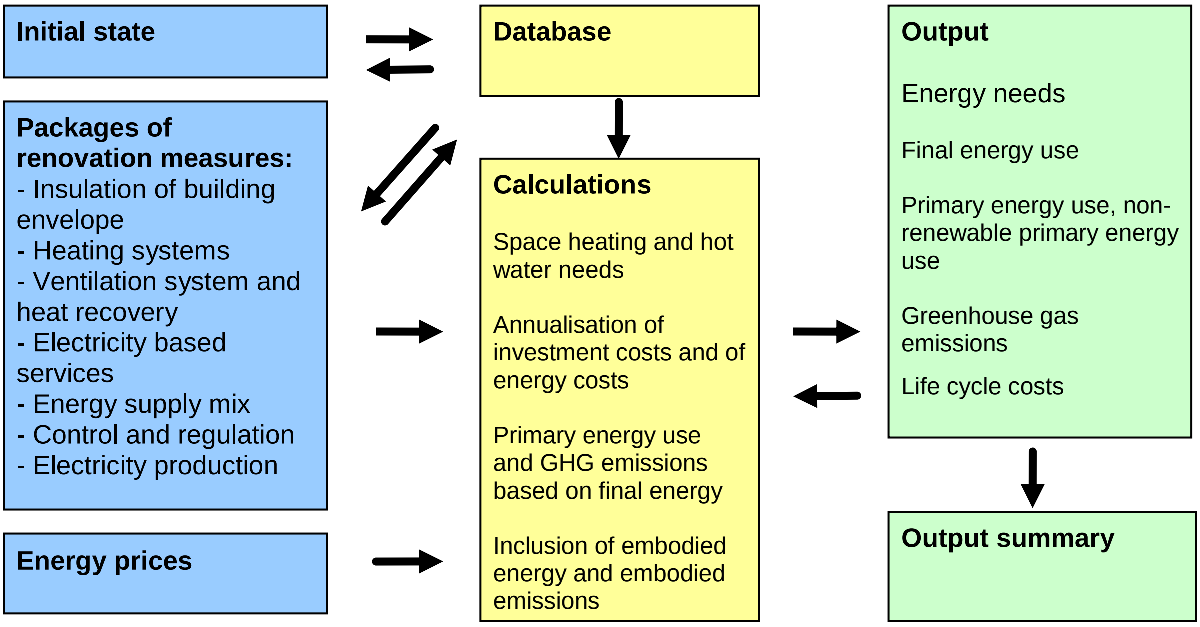



Figure 8 Schematic structure of the INSPIRE tool. The input section is shown in blue; the calculation section is shown in yellow; the output section is shown in green. In the input section and the output section, different boxes represent different worksheets in the Excel-based tool. The calculation section is not visible as such in the tool.

In Figure 8, the schematic structure of the INSPIRE tool is shown. The main components are the input sections (left, blue background), the calculation sections (middle, yellow background), and the output sections (right, green background). The arrows from the blue boxes refer to the user definitions, which are used to derive corresponding data from the database as default values. These default values can be overwritten. The arrows from databases and calculation boxes towards the input boxes refer to default values. The arrow from the calculations box to the output box refers to the presentation of results. The arrow from the output box towards the calculations box refers to user preferences selected in the output sheet to modify the presentation of the results.

The inputs section consists of three different worksheets in the Microsoft Excel based INSPIRE tool; the output section consists of two worksheets. The calculation sections are not visible. Consequently, there are five main worksheets for the user in the tool.

The «Initial state sheet» is used to define the initial state of a building. Inputs related to building specific data, occupancy, building envelope area, previously undertaken building envelope measures, and building technology, are provided by the user.

Packages of renovation measures and reference cases can be defined in the «Measures sheet». The possible measures are related to (i) building envelope insulation, (ii) heating systems, (iii) ventilation system and heat recovery, (iv) electricity based services (lighting, cooling, and appliances), (v) energy supply mix, (vi) building automation control and regulation, and (vii) onsite electricity or heat production.

The energy prices of the different energy carriers are defined in the «Energy prices sheet» using five interpolation values: default values are provided. From the interpolation values, the tool calculates the annuities of the energy cost savings, depending on the interest rate and the lifetime of the measures selected.

The «Output sheet» is used to collect and present the results of the calculations. To cover different needs concerning the level of detail besides the comprehensive «Output sheet» a more manager-style «Output summary sheet» is also available.

The INSPIRE tool allows the presentation of calculation results with respect to greenhouse gas emissions, primary energy use and costs of various packages of renovation measures, in comparison with one or two reference cases.

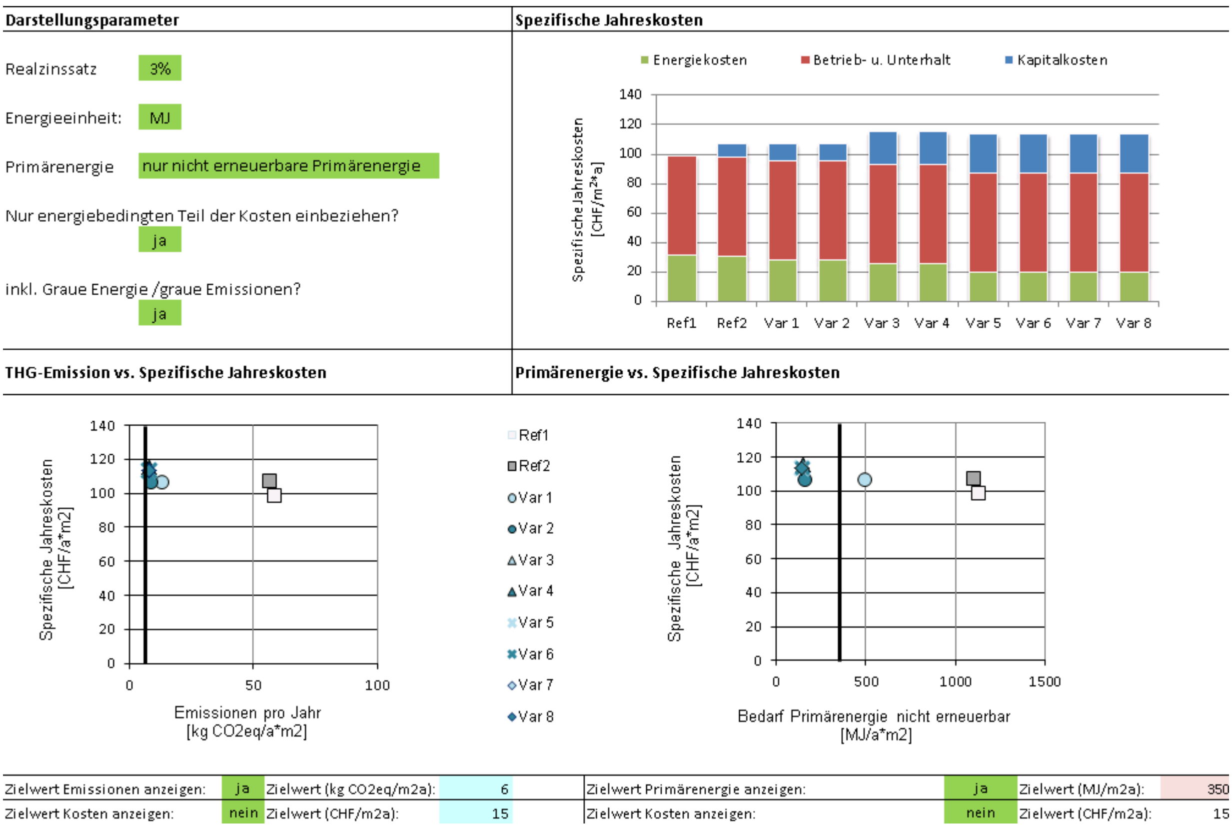



Figure 9 Screenshot from the Output sheet of the INSPIRE tool. As the main result, impacts of different renovation packages are shown with the graphs at the bottom. On the left-hand side, emissions are shown in relation to the life cycle costs for each renovation package; on the right-hand side, primary energy use is shown for each renovation package in relation to the life cycle costs.

Figure 9 gives an example of the presentation of the results that can be obtained with the tool.

As the main result, impacts of different renovation packages are shown in graphs which present emissions in relation to the life cycle costs for each renovation package and primary energy use in relation to the life cycle costs of each renovation package. Other outputs include also numerical results, for example concerning the total life cycle costs per $m^2$ and year and a differentiation of costs in capital costs, operating and maintenance costs, and energy costs.

## 3.4. ECO-BAT (new version following Annex 56: ECO-SAI)

Eco-Bat was first released for external use in September 2006. It was developed at the Laboratory of Solar Energy and Building Physics (LESBAT) of the University of Applied Sciences of Western Switzerland (HES-SO). This tool allows the user to quickly define a building and evaluate its environmental impacts, taking into account the energy consumed during the building life as well as the materials used. Eco-Bat is specially designed to be used during the conception phase. It can be used by architects and engineers at the early stages of the design process, in order to define priorities and to choose environment-friendly solutions.

The life cycle assessment approach is in accordance with the ISO 14040 standards and SIA 389.201. The main phases of the building life are taken into account in the calculation of:

- Construction: manufacturing and transport of materials used for construction elements and technical systems;
- Use: replacement of materials and technical systems components, building operating energy;
- End of life: materials elimination.

The calculation can be performed for any kind of building. The thermal envelope, internal floors, and walls, as well as all the non-heated zones, have to be defined precisely. All the construction elements have to be characterized by layer (material, thickness, density), as shown in Figure 10. The tool contains around 200 generic construction materials.

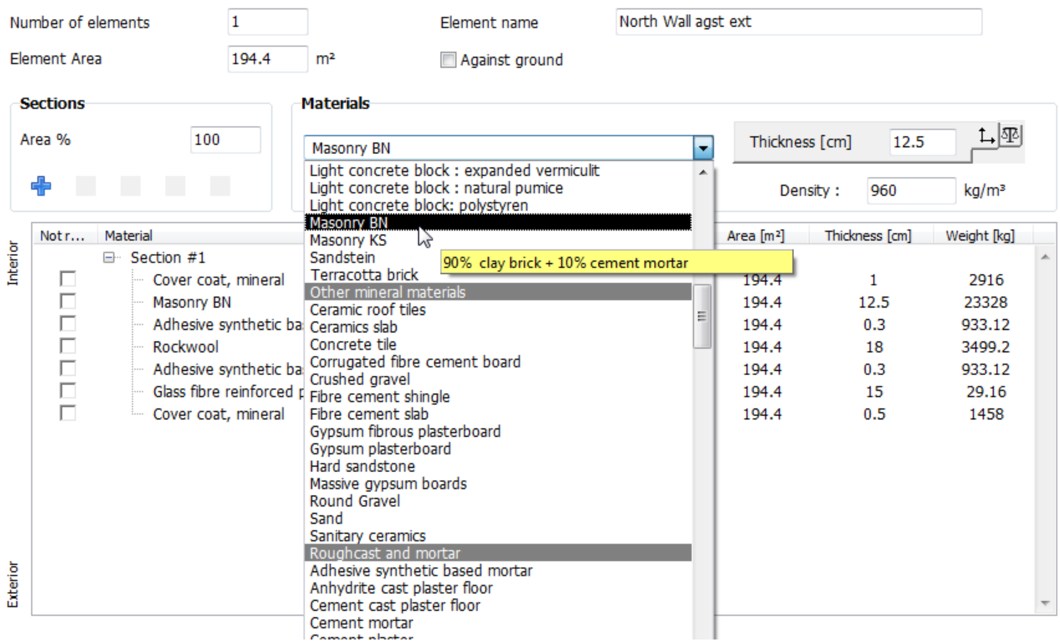


Figure 10 Definition of a construction element

The life cycle impact assessment data used by the tool comes from the ecoinvent and Swiss KBOB databases. They provide material manufacturing and elimination impact values for four environmental indicators used by the tool (Figure 11): total primary energy consumption (labelled CEDtot in the tool), the non-renewable primary energy consumption (labelled CEDnre in the tool), and the greenhouse gases emissions (labelled as Global Warming Potential (GWP) in the tool) and the total environmental impact according to the Swiss Ecological Scarcity method (labelled as UBP in the tool).

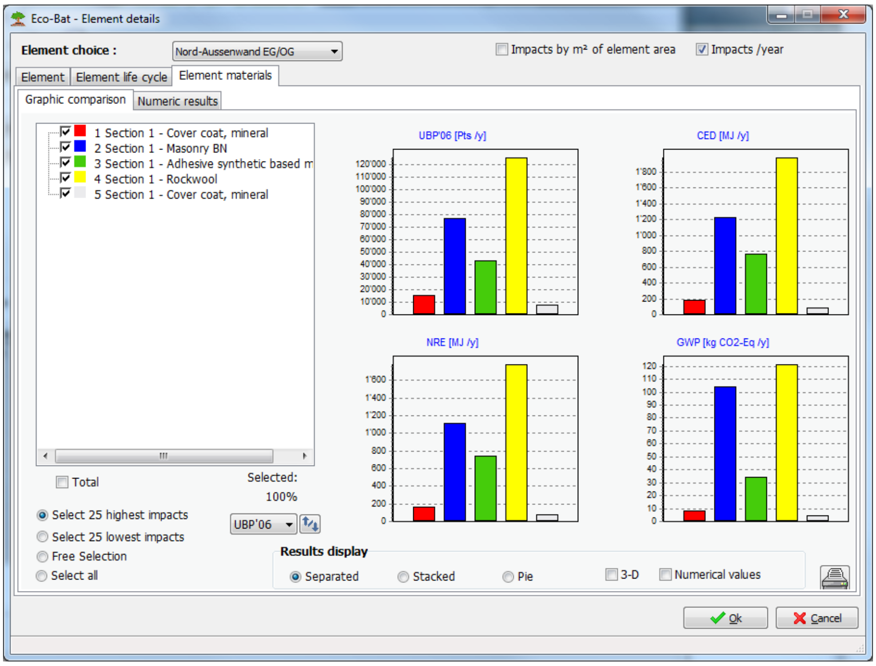



Figure 11 LCA comparison of a construction element's materials

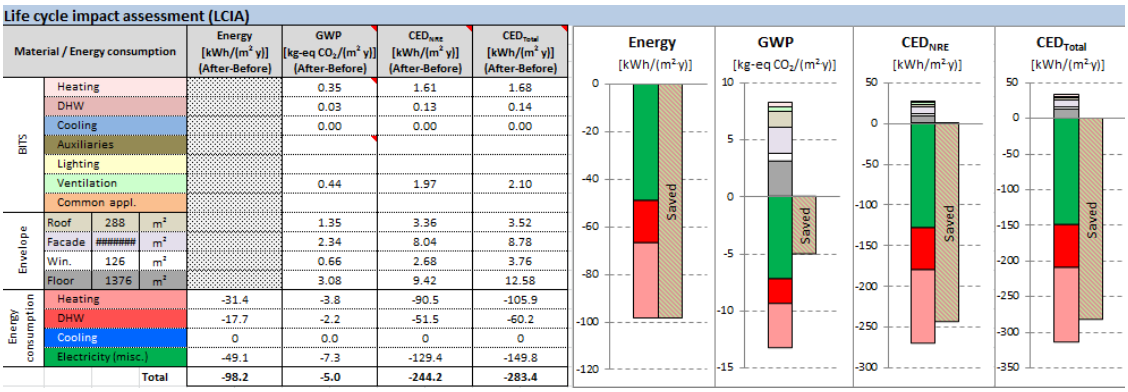
Up until its use in the IEA EBC Annex 56 project, Eco-Bat was mainly used in Switzerland to perform calculations related to the Minergie-ECO ecological standard, which methodology is based on the Swiss SIA 2032 technical book. In the framework of Annex 56, Eco-Bat has been adapted in order to be compliant with the Annex 56 LCA Methodology (Figure 12).

Previously, only new building projects could be evaluated by Eco-Bat. A new “Annex 56 Renovation” mode has been created, where the user has to choose which components are part of the renovation. Only these new materials or technical systems will be taken into account in the calculation. The energy needs before and after the renovation, as well as the energy vectors used, have to be defined in order to evaluate the environmental gain of the renovation. The main vectors such as natural gas, light fuel oil, wood, coal, electricity (direct or from heat recovery) or district heating can be selected in order to take into account energy used for heating, domestic hot water, cooling, lighting or ventilation. The systems efficiency and the presence of solar thermal and photovoltaic collectors can also be taken into account in the evaluation. Eco-Bat is not a building energy calculation tool. Therefore, the annual energy needs have to be evaluated using a separate tool and exported to Eco-Bat.

The tool’s database cannot be edited but additional data or databases, such as materials or energy vectors, can be added and customized upon request. For example, a particular kind of district heating network was integrated into Eco-Bat in order to be used by one of the Annex 56 participants.


Figure 12 Annex 56 energy-related renovation LCA balance

Eco-Bat provides results on different levels: the whole building, each construction element or technical system and each material. The impacts of the different phases of the materials life cycle (manufacturing, transport, replacement, elimination) can be evaluated and compared. A comparison of materials, elements, technical systems or whole buildings is also possible, which can help the user in his construction choices. For the Annex 56 project, results are displayed as shown in Figure 13. The operating energy saved is shown in negative in red and impacts from materials and technical systems added during the renovation are shown in positive in blue and black. The balance of the renovation is displayed in green. If the balance is negative, the operating energy saved compensates the impacts of the added components. Results can also be exported to IPV (integrated Performance View) Excel file, a file that summarizes the LCA and LCC information of a building renovation, as shown in Figure 13. A description of this Excel file can be found in Annex 56 LCA Report available on the project website.


Life cycle impact assessment (LCIA)

| Material / Energy consumption | | | | Energy [kWh/(m² y)] (After-Before) | GWP [kg-eq $CO_2$/(m² y)] (After-Before) | $CED_{NRE}$ [kWh/(m² y)] (After-Before) | $CED_{Total}$ [kWh/(m² y)] (After-Before) |
|---|---|---|---|---|---|---|---|
| BITS | Heating | | | | 0.35 | 1.61 | 1.68 |
| | DHW | | | | 0.03 | 0.13 | 0.14 |
| | Cooling | | | | 0.00 | 0.00 | 0.00 |
| | Auxiliaries | | | | | | |
| | Lighting | | | | | | |
| | Ventilation | | | | 0.44 | 1.97 | 2.10 |
| | Common appl. | | | | | | |
| Envelope | Roof | 288 | m² | | 1.35 | 3.36 | 3.52 |
| | Facade | ####### | m² | | 2.34 | 8.04 | 8.78 |
| | Win. | 126 | m² | | 0.66 | 2.68 | 3.76 |
| | Floor | 1376 | m² | | 3.08 | 9.42 | 12.58 |
| Energy consumption | Heating | | | -31.4 | -3.8 | -90.5 | -105.9 |
| | DHW | | | -17.7 | -2.2 | -51.5 | -60.2 |
| | Cooling | | | 0 | 0.0 | 0 | 0 |
| | Electricity (misc.) | | | -49.1 | -7.3 | -129.4 | -149.8 |
| | | | Total | **-98.2** | **-5.0** | **-244.2** | **-283.4** |



Figure 13 Annex 56 IPV exported by Eco-Bat

New version of Eco-Bat: Eco-sai

Following the Annex 56 developments, the Eco-Bat tool was updated and uses now a new name - Eco-sai, which is the natural successor of Eco-Bat. It includes most LCA features from Eco-Bat and new features like:

- building physics capabilities such as static and dynamic U-Value calculation, thermal capacity calculation;
- evaluation of the risk of condensation inside construction elements.

It is up to now the only LCA tool to combine these characteristics altogether. For architects and other building design planners, Eco-sai (unlike Eco-Bat) now integrates a Plugin for the computer aided design Autodesk® Revit®. It allows easing the calculations of the LCA from a 3D model of a building. Figure 14 presents a screenshot of Eco-sai plugin in Revit®.

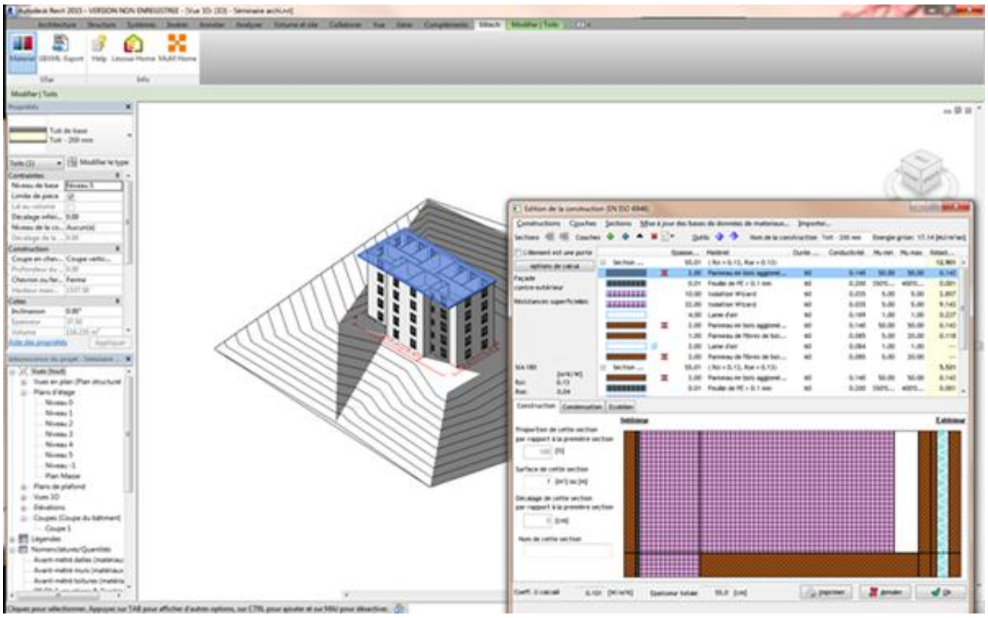


Figure 14 Screenshot of Eco-sai Plugin in Revit®

# 4. Example of the application of the methodology to a case-study

This chapter of the report intends to illustrate the application of the Annex 56 methodology to a case-study.

The following case-study is located in Portugal and there was already an accepted renovation project at the time the study was conducted. In this sense, a survey related to the user perception of the renovation was also possible to perform. The survey intended to support the co-benefits analysis.

## 4.1. Description of the case-study

The case-study consists of a building built before 1960 and it belongs to a social neighborhood located in Porto, in the north of Portugal. The building presented signs of significant degradation and the living areas were not adjusted to current living standards. Due to these facts, the decision of undertaking a renovation was taken. The building had two floors and four apartments, two in each floor. Figure 15 shows the general aspect of the building before and after the renovation.

a) b)

Figure 15 a) Building before renovation and b) after the renovation

The building had no insulation on the envelope and there were no building integrated technical systems (BITS) for heating and cooling. The only systems available were portable electric systems such as electric heaters and fan coils. The domestic hot water was provided by an electric heater with a storage tank.

Concerning the building envelope, the exterior walls consisted of single hollow brick walls with plaster on both sides and the roof was composed of a lightweight slab and a wooden structure that supports the fiber cement plates. The floor consists of a solid ground floor and the windows are wood framed with single glazing with exterior PVC shutters. Table 6 presents the U-values for the building elements before the renovation. The exterior walls present two different U-values because the wall has different thicknesses in both floors.

Table 6 U-values of the building's elements before renovation

| Element | U-values before [W/m$^2$K] |
|---|---|
| Exterior walls | 1,38/1,69 |
| Roof | 2,62 |
| Windows | 5,10 |
| Ground floor | 2,11 |

## 4.2. Application of the methodology

To start, the energy performance of the building for the reference scenario (without improvement of its energy performance) was calculated. In this case, the energy calculations followed the Portuguese regulations (decree-Law nº 18/2013, in accordance with ISO13790), using a seasonal method. For the energy calculations, it was used an Excel-based tool that after introducing the geometric characteristics of the elements of the building and also the information on the BITS performance, calculates the energy needs and the primary energy.

Using the same Excel-based tool, each of the renovation packages described in Table 7 was analyzed in terms of energy needs and primary energy use.

Table 7 Energy efficiency measures and technical systems composing the renovation packages

| Package | Wall | Roof | Floor | Windows | BITS |
|---|---|---|---|---|---|
| Reference | maintenance | maintenance | _ | maintenance | Multi split + Electric heating |
| Package 1 | EPS 10 cm | MW 14cm | MW 8cm | maintenance | Multi split + Solar thermal backed by electric heating |
| Package 2 | EPS 10 cm | MW 14cm | MW 8cm | maintenance | Natural gas boiler |
| Package 3 | EPS 10 cm | MW 14cm | MW 8cm | maintenance | Heat Pump + Photovoltaic |
| Package 4 | EPS 10 cm | MW 14cm | MW 8cm | maintenance | Biomass boiler |
| Package 5 | ICB 8cm | ICB 8cm | ICB 8cm | wood U=2,4 [W/m$^2$K] | Multi split + Solar thermal backed by electric heating |
| Package 6 | ICB 8cm | ICB 8cm | ICB 8cm | wood U=2,4 [W/m$^2$K] | Natural gas boiler |
| Package 7 | ICB 8cm | ICB 8cm | ICB 8cm | wood U=2,4 [W/m$^2$K] | Heat Pump + Photovoltaic |
| Package 8 | ICB 8cm | ICB 8cm | ICB 8cm | wood U=2,4 [W/m$^2$K] | Biomass boiler |
| Chosen | EPS 6 cm | XPS 5cm | _ | wood U=3,9 [W/m$^2$K] | Multi-split + Solar thermal backed by electric heating |

*EPS = Expanded polystyrene; MW = Mineral wool; XPS = Extruded polystyrene; ICB = Insulation Cork Board

Table 8 shows the energy needs for each renovation package and the primary energy, with the conversion factors in accordance with the energy carrier.

The total primary energy is a result of the sum of the energy use (energy needs divided by the efficiency of the systems used) affected by the energy conversation factor. In addition, the energy for lighting was also taken into account but using a fixed value that is the average value observed in residential dwellings in Portugal (32,33 kWh/m² y). Except for the reference renovation package, no cooling needs were considered in the other renovation packages. This is possible because, in the region where the building is located, the summer is very mild and if there is a balance between heat gains and heat losses together with an appropriate thermal mass, the overheating risks are very low. This situation is foreseen in the Portuguese thermal regulation through the quantification of a heat gains utilization factor that when above a certain value disregards the overheating risks and cooling needs are not accounted in the calculation of the energy performance of the building. Therefore, in the reference case there is the risk of overheating and therefore the cooling needs are considered in the calculation of the primary energy, while in the rest of the packages is not considered. However, the cooling demand is always calculated and therefore described in table 8.

Table 8 Summary of the building's energy performance with each of the analyzed renovation packages

| Renovation package | Heating (kWh/m².y) | | Cooling (kWh/m².y) | | DHW (kWh/m².y) | | Conversion factors | | | Total PE (kWh/m².y) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total | η/ COP | Total | η/ EER | Total | η/ COP | Heat | Cool | DHW | Total |
| Reference | 84,92 | 1,00 | 16,52 | 3,50 | 28,85 | 0,80 | 3,28 | 3,28 | 3,28 | 518,35 |
| Package 1 | 25,65 | 0,93 | 8,14 | 3,50 | 28,85 | 0,93 | 1,12 | 3,28 | 1,12 | 171,68 |
| Package 2 | 20,97 | 0,93 | 8,59 | 3,50 | 28,85 | 0,93 | 1,12 | 3,28 | 1,12 | 166,04 |
| Package 3 | 25,65 | 4,10 | 8,14 | 3,50 | 28,85 | 0,80 | 3,28 | 3,28 | 3,28 | 244,85 |
| Package 4 | 20,97 | 4,10 | 8,59 | 3,50 | 28,85 | 0,80 | 3,28 | 3,28 | 3,28 | 241,10 |
| Package 5 | 25,65 | 3,90 | 8,14 | 3,50 | 28,85 | 3,90 | 3,28 | 3,28 | 3,28 | 151,88 |
| Package 6 | 20,97 | 3,90 | 8,59 | 3,50 | 28,85 | 3,90 | 3,28 | 3,28 | 3,28 | 147,94 |
| Package 7 | 25,65 | 0,92 | 8,14 | 3,50 | 28,85 | 0,92 | 1,20 | 3,28 | 1,12 | 174,62 |
| Package 8 | 20,97 | 0,92 | 8,59 | 3,50 | 28,85 | 0,92 | 1,20 | 3,28 | 1,12 | 168,52 |
| Chosen | 33,00 | 4,10 | 11,00 | 3,50 | 28,85 | 0,80 | 3,28 | 3,28 | 3,28 | 250,73 |

After the energy calculations, it was necessary to calculate the global costs for the building's life cycle. The considered calculation period was 30 years, with a discount rate of 6% per year. In order to bring future costs to the present moment, it was calculated the net present value for each renovation package.

The investment and maintenance costs were calculated using CYPE® software that generates prices for construction work in Portugal. The maintenance costs include the work provided for preventive maintenance in the maintenance schedule, as well as the costs of inspections, reviews, reports and related advice. Does not include any costs related to corrective maintenance, corresponding to reparations as a result of vandalism, accidents or natural disasters. The works that are common to all renovation packages were not considered in these calculations, once they do not affect the results. The costs of the replacement of BITS were considered and also the residual value after the calculation period for all the measures that had a lifetime beyond the calculation period.

The energy costs for the first year were in accordance with the predictions of the Portuguese entity that rules the energy prices (ERSE). The evolution of the energy prices followed the predictions from EU Energy trends 2030/2050 for electricity and Energy Outlook 2010 for gas. The costs of the pellets were estimated based on the Portuguese market with an increase of 3% per year.

The energy costs result from the multiplication of the energy use by the related costs (by energy carrier) in each year.

## 4.3. Example of calculation of the different types of costs: using renovation package 2

### *4.3.1.* Investment cost

The investment costs result from the following parts: the cost of investment in the renovation materials for the walls, roof, windows and BITS. In renovation package 2, the BITS need to be replaced after 20 years, which is the predicted limit for their usage. Once the calculations were performed for 30 years, after that period the BITS still have a residual value which was calculated considering a linear depreciation. All costs must be taken into account in the investment costs (Table 9).

Table 9 Investment costs for package 2

| Year | Envelope (€) | Windows (€) | BITS (€) | RES (€) | Total (€) |
|---|---|---|---|---|---|
| **T0** | 22900 | 717 | 7530 | 0 | 31147 |
| **T1 to T19** | 0 | 0 | 0 | 0 | 0 |
| **T20** | 0 | 0 | 5540 | 0 | 5540 |
| **T21 to T29** | 0 | 0 | 0 | 0 | 0 |
| **T30** | 0 | 0 | -2770 | 0 | -2770 |
| **NPV** | | | | | **32393** |

### *4.3.2.* Maintenance costs

The maintenance costs of building elements, systems, and equipment, had the same source as the investment costs and it was established a fixed value per year. For package 2, the annual value for the maintenance is 603€.

Applying the NPV formula to the maintenance costs for 30 years:

NPV $=\Sigma \frac{maintenance\ costs}{(1+r)^{\wedge}t}$ + Investment, where r = 6% e t=30

NPV = $\frac{Man\ (t1)}{(1+6\%)^{\wedge}1} + \frac{Man\ (t2)}{(1+6\%)^{\wedge}2} + \frac{Man\ (t3)}{(1+6\%)^{\wedge}3} + (\ldots) + \frac{Man\ (t30)}{(1+6\%)^{\wedge}30}$

NVP = $\frac{603}{(1+6\%)^{\wedge}1} + \frac{603}{(1+6\%)^{\wedge}2} + \frac{603}{(1+6\%)^{\wedge}3} + (\ldots) + \frac{603}{(1+6\%)^{\wedge}30}$ = 8299 €

### *4.3.3.* Energy costs

Concerning the energy costs for each year, the values are shown in Table 10.

Table 10 Annual energy costs by energy carrier

| Energy Costs [€/kWh] | t1 | t2 | t3 | t4 | t5 | t6 | t7 | t8 | t9 | t10 | t11 | t12 | t13 | t14 | t14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electricity | 0,21 | 0,22 | 0,23 | 0,23 | 0,24 | 0,25 | 0,25 | 0,26 | 0,27 | 0,28 | 0,29 | 0,29 | 0,30 | 0,31 | 0,32 |
| Gas | 0,08 | 0,08 | 0,08 | 0,08 | 0,09 | 0,09 | 0,09 | 0,09 | 0,10 | 0,10 | 0,10 | 0,11 | 0,11 | 0,11 | 0,12 |
| Pellets | 0,06 | 0,06 | 0,07 | 0,07 | 0,07 | 0,07 | 0,07 | 0,08 | 0,08 | 0,08 | 0,08 | 0,09 | 0,09 | 0,09 | 0,09 |
| | t16 | t17 | t18 | t19 | t20 | t21 | t22 | t23 | t24 | t25 | t26 | t27 | t28 | t29 | t30 |
| Electricity | 0,33 | 0,34 | 0,35 | 0,36 | 0,37 | 0,38 | 0,40 | 0,41 | 0,42 | 0,43 | 0,45 | 0,46 | 0,47 | 0,49 | 0,50 |
| Gas | 0,12 | 0,12 | 0,13 | 0,13 | 0,13 | 0,14 | 0,14 | 0,15 | 0,15 | 0,16 | 0,16 | 0,17 | 0,17 | 0,18 | 0,18 |
| Pellets | 0,10 | 0,10 | 0,10 | 0,11 | 0,11 | 0,11 | 0,11 | 0,12 | 0,12 | 0,13 | 0,13 | 0,13 | 0,14 | 0,14 | 0,15 |

For each year, the energy costs were obtained multiplying the energy that is used for each of the usages by the respective cost of the energy in that year. It can be expressed by the fallowing formula:

Electricity x cost (tn) + Gas x cost (tn) + Pellets x cost (tn) (where n varies from 1 to 30)

For example, for year 1 (t1) the energy costs would be:

General data:

- heated floor area of 123,60m$^2$
  - Heating energy use = 25,65 (gas heating $\eta$ = 0.93)
  - DHW = 28,85 (gas heating $\eta$ = 0.93)
  - Lighting = 32,33

Energy Costs t1 = ( $\frac{heating}{\eta} + \frac{DHW}{\eta}$ ) x (heated floor area) x (costs of gas (t1)) + (lighting) x (heated floor area) x (costs of electricity)

Energy costs t1 = ( $\frac{25,65}{0,93}$ + $\frac{28,85}{0,93}$ ) x123,60 x 0,08 + ( 32,33) x 123,60 x 0,21 = 1407 €

After these steps, conditions were gathered to determine the sum of the costs for the first year, which for package 2 would be:

Total costs t1 = investment + maintenance + energy = 0 + 603 + 1407 = 2009 €

**Erro! Auto-referência de marcador inválida.** summarizes the calculation of the total costs for the 30 years, per year.

### *4.3.4.* Global costs

After the calculation of the energy costs for each year, all the values were added and considering the discount rate of 6%, the NPV was calculated:

NPV =$\Sigma \frac{total\ costs\ (t)}{(1+r)\text{^}t}$ + Investment, where r = 6% and t=30

NPV package 2 = $\frac{total\ costs\ (t1)}{(1+6\%)\text{^}1} + \frac{total\ costs\ (t2)}{(1+6\%)\text{^}2} + \frac{total\ costs\ (t3)}{(1+6\%)\text{^}3} + (\ldots)$ + investment costs (t0)

NPV package 2 = $\frac{2009}{(1+6\%)\text{^}1} + \frac{2052}{(1+6\%)\text{^}2} + \frac{2095}{(1+6\%)\text{^}3} + (\ldots) + \frac{1148}{(1+6\%)\text{^}30}$ + 31147 = 67763 €

Table 11 Summary of the cost per year for package 2

| Package 2 | Costs (€) | | | |
|---|---|---|---|---|
| | Investment | Energy | Maintenance | Total |
| $t_0$ | 31147 | - | - | 31147 |
| $t_1$ | 0 | 1407 | 603 | 2009 |
| $t_2$ | 0 | 1449 | 603 | 2052 |
| $t_3$ | 0 | 1492 | 603 | 2095 |
| $t_4$ | 0 | 1537 | 603 | 2140 |
| $t_5$ | 0 | 1583 | 603 | 2186 |
| $t_6$ | 0 | 1631 | 603 | 2234 |
| $t_7$ | 0 | 1680 | 603 | 2282 |
| $t_8$ | 0 | 1730 | 603 | 2333 |
| $t_9$ | 0 | 1782 | 603 | 2385 |
| $t_{10}$ | 0 | 1835 | 603 | 2438 |
| $t_{11}$ | 0 | 1890 | 603 | 2493 |
| $t_{12}$ | 0 | 1947 | 603 | 2550 |
| $t_{13}$ | 0 | 2005 | 603 | 2608 |
| $t_{14}$ | 0 | 2066 | 603 | 2669 |
| $t_{15}$ | 0 | 2128 | 603 | 2731 |
| $t_{16}$ | 0 | 2191 | 603 | 2794 |
| $t_{17}$ | 0 | 2257 | 603 | 2860 |
| $t_{18}$ | 0 | 2325 | 603 | 2928 |
| $t_{19}$ | 0 | 2395 | 603 | 2998 |

| | | | | |
|---|---|---|---|---|
| $t_{20}$ | 5540 | 2466 | 603 | 8610 |
| $t_{21}$ | 0 | 2540 | 603 | 3143 |
| $t_{22}$ | 0 | 2617 | 603 | 3220 |
| $t_{23}$ | 0 | 2695 | 603 | 3298 |
| $t_{24}$ | 0 | 2776 | 603 | 3379 |
| $t_{25}$ | 0 | 2859 | 603 | 3462 |
| $t_{26}$ | 0 | 2945 | 603 | 3548 |
| $t_{27}$ | 0 | 3033 | 603 | 3636 |
| $t_{28}$ | 0 | 3124 | 603 | 3727 |
| $t_{29}$ | 0 | 3218 | 603 | 3821 |
| $t_{30}$ | -2270 | 3315 | 603 | 1148 |
| **NPV** | **32393** | **27072** | **8299** | **67763** |

Within the Annex 56 calculations, and to allow the comparison between the Portuguese case-study and other participating countries, the NPV of each renovation package was transformed into annuity value by using the following formula:

$\frac{(NPV * r)}{(1-(1+r)^{-n})}$ , r = discount rate (6%); n = life cycle (30 years)

The global costs are of each renovation package are shown in Table 12 and the annualised global costs for each renovation package are shown in Table 13.

Table 12 Summary of the global costs using NPV

| Costs | Investment (€) | Operation (€) | Global(€/m²) * |
|---|---|---|---|
| Reference | 28874 | 94581 | 999 |
| 1 | 49101 | 46632 | 775 |
| 2 | 32393 | 35371 | 548 |
| 3 | 72969 | 18186 | 738 |
| 4 | 40322 | 32966 | 593 |
| 5 | 64664 | 51424 | 939 |
| 6 | 47956 | 39821 | 710 |
| 7 | 88532 | 22948 | 902 |
| 8 | 55885 | 37588 | 756 |
| Chosen | 52647 | 53696 | 860 |

*the heated floor area is 123,60m²

Table 13 Annualised global costs

| Annualised Global costs (€/m²) | Reference | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Chosen |
|---|---|---|---|---|---|---|---|---|---|---|
| | 73 | 40 | 52 | 56 | 68 | 54 | 66 | 43 | 55 | 63 |

Besides all the costs, it was necessary to calculate the global warming impact and the total primary energy (including the embodied energy), which is shown in the next section.

### *4.3.5.* Example of the calculation of GWP impact and total primary energy for package 2

The impacts for the LCA were calculated using SimaPro. The software gave the unitary impact of each material that affects the energy performance of the building. Table 14 shows the impacts, by analyzed item.

The total amount of the GWP and embodied energy resulted from the multiplication of the SimaPro results by the total amount of material used, in each renovation package, including the energy needed for heating, cooling, DHW and lighting.

### *4.3.6.* Calculation of the amount of material used (kg):

To obtain the amount of material used it was necessary to obtain the weight of the material. This calculation was done, using the specific weight of each material, using the following formula:

Kg = quantity ($m^2$) x thickness x specific weight ($kg/m^3$) x nº of replacements

For example, for EPS, the total weight is: kg = 96,55 x 0,10 x 18 x 1 = 164,14 Kg

For the BITS, the impact does not consider their weight but how many equipments are used and the number of replacements foreseen in the life cycle period (30 years).

### *4.3.7.* Calculation of GWP

5. After the calculation of the amount of material used, the GWP is calculated by multiplying the values in Table 15 by the related values of Table 14.

Table 14 SimaPro results for each of the renovation materials

| | | GWP [kg-ep $CO_2/(m^2y)$] | $CED_{NRE}$ [$kWh/(m^2y)$] | $CED_{TOTAL}$ [$kWh/(m^2y)$] |
|---|---|---|---|---|
| Materials | Exterior walls painting | 0..00073625 | 0.00401160 | 0.00431347 |
| | Repairing and painting windows wood frames | 0.00073625 | 0.00401160 | 0.00431347 |
| | Black agglomerated cork | 0.00031014 | 0.00186009 | 0.00390097 |
| | XPS | 0.00283172 | 0.00743888 | 0.00753970 |
| | Rockwool | 0.00029126 | 0.00141811 | 0.00148105 |
| | EPS | 0.00111650 | 0.00787037 | 0.00794589 |

| | | | | |
|---|---|---|---|---|
| | ETICS (without the insulation) | 0.00002211 | 0.00011552 | 0.00013023 |
| | PVC window | 0.00069919 | 0.00446324 | 0.00464488 |
| | Wood window | 0.00043715 | 0.00216430 | 0.00441308 |
| | Aluminium Window | 0.00253729 | 0.01066813 | 0.01223329 |
| | glass (single) | 0.00026348 | 0.00093117 | 0.00095673 |
| | glass (double) | 0.00038001 | 0.00152551 | 0.00160222 |
| | Windows sills (aluminium) | 0.00224919 | 0.00844274 | 0.01020455 |
| | PVC membrane under floor cork insulation | 0.00076861 | 0.00698195 | 0.00712377 |
| BITS | Gas Boiler | 0.10194175 | 0.47420149 | 0.51307390 |
| | Heat Pump | 0.42610572 | 0.57758049 | 0.60964330 |
| | Biomass Boiler | 0.78748652 | 2.44816564 | 2.59510020 |
| | Electric heaters | _ | _ | _ |
| | Radiators | _ | _ | _ |
| | Fan coils | _ | _ | _ |
| | Electric water heater | _ | _ | _ |
| | Solar Thermal | 0.35868393 | 1.57469143 | 1.76631914 |
| | Photovoltaic | 0.10463862 | 0.47894751 | 0.55048452 |
| | HVAC | _ | _ | _ |
| | MVHR | _ | _ | _ |
| Energy | Electricity (PT energy mix) | 0.69120000 | 2.73500157 | 3.22440157 |
| | Natural gas | 0.26172000 | 1.23620161 | 1.24055561 |
| | Biomass | 0.04500000 | 0.24230018 | 1.33757018 |

The next calculations show the calculation of the GWP of each material involved in package 2.

1 - GWP Paint = (59,74+14,42) x 0,0007362 =0,054596592 [$kgCO_{2eq}/m^2.y$]

2 - GWP RW = (1120+640) x 0,0002913 = 0,512688 [$kgCO_{2eq}/m^2.y$]

3 - GWP EPS = 164,14 x 0,0011165 = 0,183262 [$kgCO_{2eq}/m^2.y$]

4 - GWP Sills = 243 x 0,0022491 = 0,546507 [$kgCO_{2eq}/m^2.y$]

5 - GWP gas boiler = 4 x 0,1019417 = 0,4077668 [$kgCO_{2eq}/m^2.y$]

Table 15 Quantity of material for renovation package 2

| Element | Material | Life time (y) | Thickness (m) | Quantity (m²) | ρ (kg/m³) | Nº replacem. (in 30 years) | Quantity (kg) |
|---|---|---|---|---|---|---|---|
| Maintenance | Paint (exterior walls) | 10 | _ | 96,55 | 1,65 | 3 | 59,74 |
| Maintenance | Repairing and painting windows wood frames | 10 | _ | 23,31 | 1,65 | 3 | 14,42 |
| Roof | 140mm Rockwool | 30 | 0,14 | 80,00 | 100,0 | 1 | 1120,00 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Floor | 80mm Rockwool | 30 | 0,08 | 80,00 | 100,0 | 1 | 640,00 |
| Wall | ETICS_10mm EPS | 30 | 0,10 | 96,55 | 18,00 | 1 | 164,14 |
| Extras | Windows sills for 100mm ETICS | 30 | _ | 10 | 2700 | 1 | 243,00 |
| | | **Life time (y)** | **Thickness (m)** | **Quantity (m²)** | **ρ (kg/m³)** | **Nº replacem. (in 30 years)** | **Quantity (un)** |
| BITS | Gas Boiler | 20 | _ | 2 | * | 2 | 4,00 |
| BITS | AVAC | 20 | _ | 1 | * | 2 | 2,00 |

The GWP of the material in Package 2 = Σ (plots 1 to 4) = 1,29705 [$kgCO_{2eq}/m^2.y$] plus the BITS that is 0,4077668 [$kgCO_{2eq}/m^2.y$].

There was not enough information about the impact of the AVAC systems. So this impact was not considered in any of the packages. Concerning the carbon emissions related to the energy use, the procedure is similar.

6 - GWP energy for heating = (25,65/0,93) x 0,261720 = 7,2184 [$kgCO_{2eq}/m^2.y$]

8 - GWP energy for DHW = (28,85/0,93) x 0,261720 = 8,1189 [$kgCO_{2eq}/m^2.y$]

9 – GWP energy for lighting = (32,33) x 0,6912 = 22,32576 [$kgCO_{2eq}/m^2.y$]

The total GWP for Package 2 results from the sum of the GWP for the materials, BITS and energy use included in package 2. Numerically the calculation is equal to:

Σ (plots 1 to 9). = 1,29705 + 0,4077668 + 7,2184 + 8,1189 + 22,32576 = 39,3886 [$kgCO_{2eq}/m^2.y$]

For the CDE $_{NRPE}$, the calculation was exactly the same, but instead of using the values of GWP presented in Table 10, it was necessary to use the values on the next column for the CDE $_{NRPE}$.

For CDE $_{total}$, the procedure is also similar, but the value of the impacts are presented in the third column of Table 10. The next lines show the calculation procedure:

1 - CDE $_{total}$ Paint = (59,74+14,42) x 0,0043134 = 0,322106 [$KWh/m^2.y$]

2 - CDE $_{total}$ RW = (1120+640) x 0,0014811 = 2,606736 [$KWh/m^2.y$]

3 - CDE $_{total}$ EPS = 164,14 x 0,0079458 = 1,3042236 [$KWh/m^2.y$]

4 - CDE $_{total}$ Sills = 243 x 0,01020454 = 2,47970322 [$KWh/m^2.y$]

5 - CDE $_{total}$ gas boiler = 4 x 0,5130739 = 2,0522956 [$KWh/m^2.y$]

The CDE $_{total}$ of the material in Package 2 = Σ (parcels 1 to 4) = 6,71276 [$KWh/m^2.y$] and for the BITS the CDE $_{total}$ is 2,05296 [$KWh/m^2.y$]

6 - CDE $_{total}$ energy for heating = (25,65/0,93) x 3,224401 = 34,2153 [$KWh/m^2.y$]

8 - CDE $_{total}$ energy for DHW = (28,85/0,93) x 1,240555 = 38,4839 [$KWh/m^2.y$]

9 – CDE total energy for lighting = (32,33) x 1,33757 = 104,14817 [KWh/m².y]

The total CDE total for Package 2 = Σ (parcels 1 to 9) = 6,71276 + 2,0522956 + 34,2153 + 38,4839 + 104,14817 = 185,70688 [KWh/m².y]

Using these calculations for all the renovation packages, the LCA results for the GWP and for the NRPE and CDE total are illustrated in Figure 16 and Figure 17.

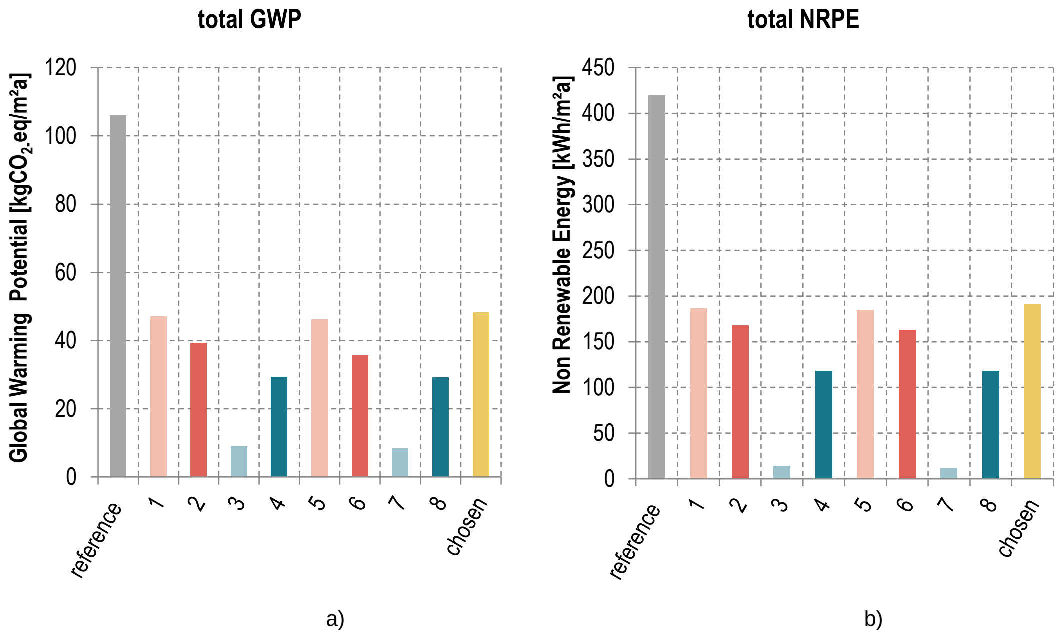



Figure 16 a) Graphic results of the GWP analysis and b) NRPE for the renovation measures

After the LCA analysis, it is possible to draw a curve similar to the cost optimal results, relating the primary energy or emissions and the annualized global costs. The difference is that the primary energy includes the embodied energy corresponding to the values of the CDEtotal.

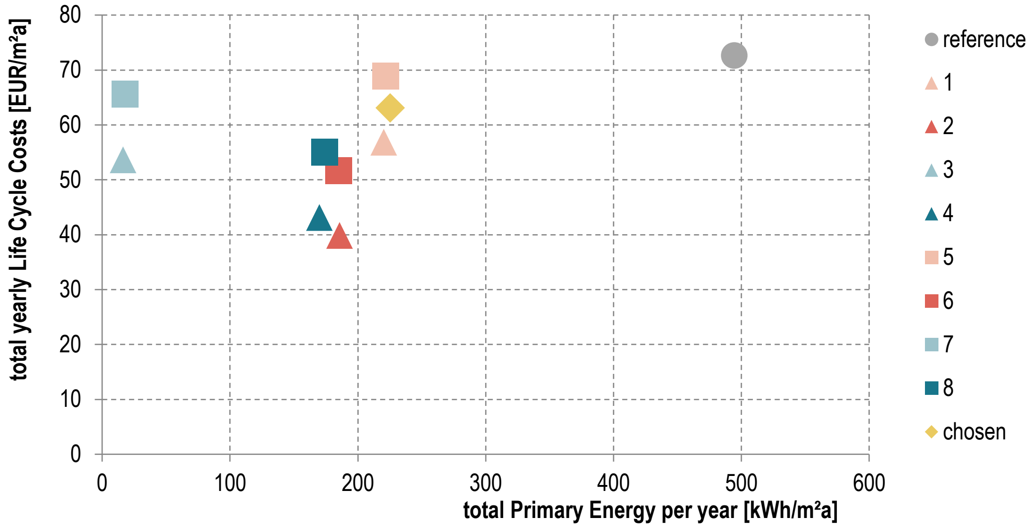



Figure 17 Results for the total primary energy for all the analysed renovation packages

After these calculations, the renovation measures were evaluated concerning the co-benefits. The co-benefits evaluation was based on the co-benefits matrix presented in chapter 5 of the present report.

The evaluation was performed using a system of signs, where the green triangles represent a positive impact and the red triangles represent a negative impact. The number of triangles represents the degree of the impact. Table 16 shows the results of the evaluation of the co-benefits achieved with the reference renovation package, with the chosen renovation (the one that has been implemented), with the cost optimal package and with the solution that leads to the lowest energy use, based on a questionnaire performed among the residents.

Table 16 Co-benefits analysis for some of the selected renovation packages

| Building elements | Reference | Chosen | Cost optimal | Lowest energy use |
|---|---|---|---|---|
| **Façade** | Maintenance | 6 cm of RW | 10 cm of EPS | 10 cm of EPS |
| **Roof** | Maintenance | 8 cm of RW | 14 cm of RW | 14 cm of RW |
| **Floor** | Maintenance | 5 cm of RW | 8 cm of RW | 8 cm of RW |
| **Windows** | Maintenance | New windows U 2.4 | Maintenance | New windows U 2.4 |
| **Heating system** | Electric heater | Electric heater | Gas boiler | Heat pump + PV |
| **DHW system** | Gas boiler | Electric heater + Solar Thermal panels | Gas boiler | Heat pump + PV |
| **Co-benefits** | | | | |
| **Aesthetics** | ▲ | ▲ | ▲ | ▲ ▼ |
| **Pride/prestige** | ▲ ▲ | ▲ ▲ | ▲ ▲ | ▲ ▲ |
| **Thermal comfort** | | ▲ ▲ ▲ | ▲ ▲ ▲ | ▲ ▲ ▲ |
| **Building physics** | | ▲ ▲ | ▲ ▲ | ▲ ▲ |
| **Internal noise** | | ▼ | ▼ | ▼ |
| **Price fluctuation** | | ▲ ▲ | ▲ | ▲ ▲ ▲ |
| **Air Quality** | | ▲ | ▲ | ▲ |
| **External noise** | | ▲ | | ▲ |
| **Safety** | | ▲ | | ▲ |

Regarding the aesthetics/architectural integration, the posit ive co-benefit was also present in the reference case once it includes the renovation of the facades and windows (although not improving its energy performance). In the lowest energy use renovation package, the existence of photovoltaic panels may be a problem due to the required dimensions and the characteristics of the buildings, performing a negative impact.

In the chosen renovation package, the introduction of new frames with double glazing represented a co-benefit in terms of safety and also in terms of reduced external noise. However, in the interviews performed among the residents, these positive co-benefits have never been mentioned. In fact, once the neighborhood is located in a very quiet area, noise reduction and safety were not considered relevant issues and so, not valued. In this case, the potential co-benefits that could arise from the improvement of the windows were not felt. Therefore, the relevance of these co-benefits was reduced when compared with the same measure in other detailed case-studies.

In the reduction of the exposure to the energy price fluctuation, the lowest energy use package is the most independent one, due to the use and production of renewable energy.

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

In the end, it is up to the decision-maker to complement the objective data shown in Figure 17 with the qualitative analysis of the related co-benefits. From Figure 17, renovation package #2 presented the lowest global costs. If compared with renovation package #3, a small gap exists in costs. This costs gap has to be put into balance with the valuation of the decision maker on the significant reduction of energy costs that may bring a significant comfort regarding future energy price fluctuations and the potential benefits regarding external noise protection and safety. On the other hand, the aesthetic impact of the photovoltaic panels in renovation package #3 may work as a negative impact that also as to be considered.

# 5. Conclusions

The main goal of EBC IEA Annex 56 was the development of a new methodology for energy and carbon emissions optimized building renovation, as a basis for future standards. This methodology was developed to be used by interested private entities and agencies for their renovation decisions as well as by governmental agencies for the definition of regulations, being focused on residential buildings and office buildings without complex HVAC systems, which have not undergone any significant energy renovation yet.

The methodology provides guidance for the integrated evaluation of primary energy use, carbon emissions and costs of energy-related packages of renovation measures, including efficiency measures and measures for the use of energy from renewable sources. It further allows integrating embodied energy use and related carbon emissions and focuses also on the overall added value achieved in a renovation process. The assessments reveal the trade-offs between costs, energy savings, and renewable energy use, in order to reduce primary energy use and related carbon emissions, allowing exploring the cost optimal and cost effective renovation packages.

As described in this report, the methodology implies the calculation of energy use, carbon emissions, and lifecycle costs for distinct renovation packages. Each of these calculations can be done with the support of a significant amount of tools, making the developed methodology strongly flexible and adaptable. These characteristics allow its integration on the existing routines of the various decision-makers in the definition of their renovation strategies.

Although, the use of different tools for the calculation of the energy performance, environmental impact and costs for several renovation scenarios might become a tedious process, and several inputs for the calculation of each of parameter are necessary for the calculation of the other parameters. Taking this fact into consideration, the improvement of existing tools to incorporate the capacity of calculating additional parameters was one of the tasks of the project.

In this context, three existing tools have been further developed to allow the calculation of additional parameters, and therefore simplifying its use within the scope of Annex 56 methodology:

- The ASCOT tool, which intends to assist the user in evaluating and thereby optimize the economic costs of a building renovation project, is now designed to take into consideration all investment and operation costs over the total lifetime of the building, the savings from the investments with respect to sustainable issues (energy, water, waste) over the total lifetime of the building, the reduced environmental impact from the energy savings, the social or environmental and other external costs incurred by the project;
- INSPIRE is a comprehensive calculation tool in which calculation of energy need follows the principles of EN ISO 13790 and takes into account energy performance

of a building envelope, outdoor climate, target indoor temperature, and internal heat gains. The tool allows to investigate trade-offs and synergies between different types of measures and to identify strategies aiming at reducing cost-effectively primary energy use and greenhouse gas emissions. The tool includes a database of empirical techno-economic characteristics of several types of measures. Embodied energy use, upstream life cycle primary energy use for energy carriers and related carbon emissions are included;

- ECO-SAI tool allows the user to quickly define a building and evaluate its environmental impacts, taking into account the energy consumed during the building life as well as the materials used. Eco-Bat is specially designed to be used during the conception phase and can be used by architects and engineers at the early stages of the design process, in order to define priorities and to choose environment-friendly solutions. It includes most LCA features from Eco-Bat and new features like building physics capabilities such as static and dynamic U-Value calculation, thermal capacity calculation and evaluation of the risk of condensation inside construction elements. It is up to now the only LCA tool to combine these characteristics altogether. For architects and other building design planners, Eco-sai (unlike Eco-Bat) now integrates a Plugin for the computer aided design Autodesk® Revit®. It allows easing the calculations of the LCA from a 3D model of a building.

Besides the improvement of these existing tools, professional homeowners and technicians can follow the step-by-step guidance of this report to adapt their current practice to the optimization process presented by the methodology by using A56opt-tool. This tool has been fully developed to support calculations based on the Annex 56 methodology allowing comparing and evaluating different packages of renovation measures with input data calculated from other tools. The tool was developed as a Microsoft Excel spreadsheet structure, providing maximal flexibility and a familiar working environment for the user. The interface was built using a combination of customized Excel functions and uses simulation data from other tools related to each renovation scenario under analysis, providing a step-by-step guidance to the application of Annex 56 methodology.

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SIA 384.201. Verfahren zur Berechnung der Norm-Heizlast (Method for calculation of design heat load)

UNI TS 11300 Norme tecniche di riferimento per la stima delle prestazioni energetiche degli edifici (Technical norm for the calculation of the energy performance of buildings)

SAI 380/1 Thermische Energie im Hochbau (Thermal energy in buildings)

SIA 180 Wärmeschutz, Feuchteschutz und Raumklima in Gebäuden(bisher: Wärme- und Feuchteschutz im Hochbau) (heat protection, moisture protection and indoor climate in buildings)

Venus D. et al., 2016 Evaluation of the impact and relevance of different energy related renovation measures on selected Case Studie

# Appendix

# A56opt tool

International Energy Agency

EBC
Energy in Buildings and Communities Programme

**ANNEX56**
**Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation**

## A56 - Tool to support decision making for cost-effective energy and CO2 emissions optimization in building renovation

**CODE OF THE COLOURS**

| | |
|---|---|
| Grey | Descriptions |
| Yellow | Country's key information for the calculations, that must not change during the charts fillin |
| Blue | Key information for renovation measures analysis (changes according to each case) |
| Red | Important notes for a correct use of the tool |
| Light green | Additional information just for general knowledge |

**Introduction:** This tool was developed within Annex 56 context. The Annex 56 methodology provides t basis for the assessment and evaluation of energy related renovation options. The methodology consi life cycle approach and takes into account not just the energy use and carbon emissions, but also the embodied energy and the overall added value that may come to the building from a renovation proce: this sense and based in the energy consumption of each renovation measure, this tool allows to comp renovation options, considering the global costs, the embodied energy, the energy use during the ope period and the co-benefits of each renovation measure. In order to use this tool it is necessary to intr

**a) key information on each country's energy conversion factors, carbon emissions 'conversion factor the predicted evolution for the energy costs; b) Key information on each renovation options related energy use, BITS' efficiency, different types of costs (investment, maintenance, replacement, energy disposal) and impact of the materials involved in the renovation package.**

Concerning the impacts, the Annex 56 methodology allowed a simplification of considering just the im the production and transport of the materials, once these two indicators are the ones with higher imp the LCA. For the calculation of the impacts is necessary to know the amount of each material involved

INTRO

ENERGY: Price, Emission & P.E. factors

In table 1, data about the energy conversion factors related to the grid must be provided

| | | | |
|---|---|---|---|
| (yellow) | Fill in according to your case | Country | (yellow) |
| (blue) | Fill in according to your case (dropdown menu) | | |

**Table 1**

| Country | | 2 | | | Italy | | | | Portugal | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Energy carrier | Conversion factors | | Price | Emission factors | Conversion factors | | Price | Emission factors | Conversion factors | | Price | Emission factors |
| | Primary non-renewable energy factor | Primary energy factor (grid) | €/kWh | kg $CO_{2eq}$ / kWh | Primary non-renewable energy factor | Primary energy factor | €/kWh | kg $CO_{2eq}$ / kWh | Primary non-renewable energy factor | Primary energy factor (grid) | €/kWh | kg $CO_{2eq}$ / kWh |
| Electricity | 0,000 | 1,280 | 0,207 | 0,691 | 1,950 | | 0,210 | 0,483 | | 1,280 | 0,207 | 0,691 |
| Natural gas | 0,000 | 1,120 | 0,075 | 0,262 | 1,050 | | 0,075 | 0,202 | | 1,120 | 0,075 | 0,262 |
| Wood pellets | 0,000 | 1,120 | 0,060 | 0,045 | 1,000 | | 0,042 | | | 1,120 | 0,060 | 0,045 |
| Oil | 0,000 | 1,120 | 0,000 | 0,000 | 1,070 | | 0,105 | 0,267 | | 1,120 | | |
| Electricity REN | 0,000 | 0,000 | 0,000 | 0,000 | 1,000 | 1,000 | | | | | | |
| District heating | 0,000 | 0,000 | 0,000 | 0,000 | 1,500 | | 0,105 | | | | | |

In Tables 2, 3, 4 and 5, the energy carrier must be adapted to the buildings reality and the annual cost must be expressed in€/kWh.

**Table 2**

| | | Electricity | |
|---|---|---|---|
| | conversion | MWh --> kWh | 1000,000 |
| | year | €/MWh | €/kWh |
| | 2014 | 207,000 | 0,21 |
| 3,000% | 2015 | 213,210 | 0,21 |
| 3,000% | 2016 | 219,606 | 0,22 |
| 3,000% | 2017 | 226,194 | 0,23 |
| 3,000% | 2018 | 232,980 | 0,23 |
| 3,000% | 2019 | 239,970 | 0,24 |
| 3,000% | 2020 | 247,169 | 0,25 |
| 3,000% | 2021 | 254,584 | 0,25 |
| 3,000% | 2022 | 262,221 | 0,26 |
| 3,000% | 2023 | 270,088 | 0,27 |
| 3,000% | 2024 | 278,191 | 0,28 |
| 3,000% | 2025 | 286,536 | 0,29 |
| 3,000% | 2026 | 295,133 | 0,30 |
| 3,000% | 2027 | 303,986 | 0,30 |
| 3,000% | 2028 | 313,106 | 0,31 |
| 3,000% | 2029 | 322,499 | 0,32 |
| 3,000% | 2030 | 332,174 | 0,33 |
| 3,000% | 2031 | 342,139 | 0,34 |
| 3,000% | 2032 | 352,404 | 0,35 |
| 3,000% | 2033 | 362,976 | 0,36 |
| 3,000% | 2034 | 373,865 | 0,37 |
| 3,000% | 2035 | 385,081 | 0,39 |
| 3,000% | 2036 | 396,633 | 0,40 |
| 3,000% | 2037 | 408,532 | 0,41 |
| 3,000% | 2038 | 420,788 | 0,42 |
| 3,000% | 2039 | 433,412 | 0,43 |
| 3,000% | 2040 | 446,414 | 0,45 |
| 3,000% | 2041 | 459,807 | 0,46 |
| 3,000% | 2042 | 473,601 | 0,47 |
| 3,000% | 2043 | 487,809 | 0,49 |
| 3,000% | 2044 | 502,443 | 0,50 |
| | | TOT | 10,35059 |

**Table 3**

| | | Natural gas | |
|---|---|---|---|
| | conversion | Smc --> kWh | 1,000 |
| | year | €/Smc | €/kWh |
| | 2014 | 0,08 | 0,08 |
| 3,00% | 2015 | 0,08 | 0,08 |
| 3,00% | 2016 | 0,08 | 0,08 |
| 3,00% | 2017 | 0,08 | 0,08 |
| 3,00% | 2018 | 0,08 | 0,08 |
| 3,00% | 2019 | 0,09 | 0,09 |
| 3,00% | 2020 | 0,09 | 0,09 |
| 3,00% | 2021 | 0,09 | 0,09 |
| 3,00% | 2022 | 0,10 | 0,10 |
| 3,00% | 2023 | 0,10 | 0,10 |
| 3,00% | 2024 | 0,10 | 0,10 |
| 3,00% | 2025 | 0,10 | 0,10 |
| 3,00% | 2026 | 0,11 | 0,11 |
| 3,00% | 2027 | 0,11 | 0,11 |
| 3,00% | 2028 | 0,11 | 0,11 |
| 3,00% | 2029 | 0,12 | 0,12 |
| 3,00% | 2030 | 0,12 | 0,12 |
| 3,00% | 2031 | 0,12 | 0,12 |
| 3,00% | 2032 | 0,13 | 0,13 |
| 3,00% | 2033 | 0,13 | 0,13 |
| 3,00% | 2034 | 0,14 | 0,14 |
| 3,00% | 2035 | 0,14 | 0,14 |
| 3,00% | 2036 | 0,14 | 0,14 |
| 3,00% | 2037 | 0,15 | 0,15 |
| 3,00% | 2038 | 0,15 | 0,15 |
| 3,00% | 2039 | 0,16 | 0,16 |
| 3,00% | 2040 | 0,16 | 0,16 |
| 3,00% | 2041 | 0,17 | 0,17 |
| 3,00% | 2042 | 0,17 | 0,17 |
| 3,00% | 2043 | 0,18 | 0,18 |
| 3,00% | 2044 | 0,18 | 0,18 |
| | | TOT | 3,75020096 |

**Table 4**

| | | Wood pellets | |
|---|---|---|---|
| | conversion | kg --> kWh | 1,000 |
| | year | €/kg | €/kWh |
| | 2014 | 8,263 | 0,06 |
| 3,00% | 2015 | 8,511 | 0,06 |
| 3,00% | 2016 | 8,766 | 0,06 |
| 3,00% | 2017 | 9,031 | 0,07 |
| 3,00% | 2018 | 9,301 | 0,07 |
| 3,00% | 2019 | 9,581 | 0,07 |
| 3,00% | 2020 | 9,868 | 0,07 |
| 3,00% | 2021 | 10,165 | 0,07 |
| 3,00% | 2022 | 10,469 | 0,08 |
| 3,00% | 2023 | 10,784 | 0,08 |
| 3,00% | 2024 | 11,107 | 0,08 |
| 3,00% | 2025 | 11,440 | 0,08 |
| 3,00% | 2026 | 11,783 | 0,09 |
| 3,00% | 2027 | 12,137 | 0,09 |
| 3,00% | 2028 | 12,501 | 0,09 |
| 3,00% | 2029 | 12,876 | 0,09 |
| 3,00% | 2030 | 13,263 | 0,10 |
| 3,00% | 2031 | 13,660 | 0,10 |
| 3,00% | 2032 | 14,070 | 0,10 |
| 3,00% | 2033 | 14,492 | 0,11 |
| 3,00% | 2034 | 14,927 | 0,11 |
| 3,00% | 2035 | 15,375 | 0,11 |
| 3,00% | 2036 | 15,836 | 0,11 |
| 3,00% | 2037 | 16,311 | 0,12 |
| 3,00% | 2038 | 16,800 | 0,12 |
| 3,00% | 2039 | 17,304 | 0,13 |
| 3,00% | 2040 | 17,824 | 0,13 |
| 3,00% | 2041 | 18,358 | 0,13 |
| 3,00% | 2042 | 18,909 | 0,14 |
| 3,00% | 2043 | 19,476 | 0,14 |
| 3,00% | 2044 | 20,061 | 0,15 |
| | | TOT | 3,000161 |

**Table 5**

| | | Oil | |
|---|---|---|---|
| | | | |
| | year | | €/kWh |
| | 2014 | | 0,000 |
| 101% | 2015 | | 0,000 |
| 102% | 2016 | | 0,000 |
| 103% | 2017 | | 0,000 |
| 104% | 2018 | | 0,000 |
| 105% | 2019 | | 0,000 |
| 106% | 2020 | | 0,000 |
| 107% | 2021 | | 0,000 |
| 108% | 2022 | | 0,000 |
| 109% | 2023 | | 0,000 |
| 110% | 2024 | | 0,000 |
| 111% | 2025 | | 0,000 |
| 112% | 2026 | | 0,000 |
| 113% | 2027 | | 0,000 |
| 114% | 2028 | | 0,000 |
| 115% | 2029 | | 0,000 |
| 116% | 2030 | | 0,000 |
| 117% | 2031 | | 0,000 |
| 118% | 2032 | | 0,000 |
| 119% | 2033 | | 0,000 |
| 120% | 2034 | | 0,000 |
| 121% | 2035 | | 0,000 |
| 122% | 2036 | | 0,000 |
| 123% | 2037 | | 0,000 |
| 124% | 2038 | | 0,000 |
| 125% | 2039 | | 0,000 |
| 126% | 2040 | | 0,000 |
| 127% | 2041 | | 0,000 |
| 128% | 2042 | | 0,000 |
| 129% | 2043 | | 0,000 |
| 130% | 2044 | | 0,000 |
| | | TOT | 0 |

**REFERENCE BUILDING**

Table 6 requires data related to geometric features and thermal performance of the building

Table 6

| Parameter | Unit | PT |
|---|---|---|
| Building period | | 1950 |
| Gross heated floor area (GHFA) | $m^2$ | 123,6 |
| Façade area (excl. windows) | $m^2$ | 117,26 |
| Pitched Roof area | $m^2$ | 74,7 |
| Flat Roof area | $m^2$ | 0 |
| Attic floor | $m^2$ | 0,00 |
| Area of windows to N | $m^2$ | 0,00 |
| Area of windows to NE | $m^2$ | 0,00 |
| Area of windows to E | $m^2$ | 14,84 |
| Area of windows to SE | $m^2$ | 0 |
| Area of windows to S | $m^2$ | 0 |
| Area of windows to SW | $m^2$ | 0 |
| Area of windows to W | $m^2$ | 4,00 |
| Area of windows to NW | $m^2$ | 0,00 |
| Area of cellar ceiling | $m^2$ | 0 |
| Ground floor | $m^2$ | 61,8 |
| Average heated gross floor area per person | $m^2$ | 20,60 |
| Typical indoor temperature (for calculations) | °C | 18 |
| U-value façade | $W/(m^2*K)$ | 1,585 |
| U-value roof pitched | $W/(m^2*K)$ | 2,67 |
| U-value attic floor | $W/(m^2*K)$ | 0 |
| U-value roof flat | $W/(m^2*K)$ | 0 |
| U-value windows | $W/(m^2*K)$ | 4,4 |
| g-value windows | Factor 0.0 – 1.0 | 0,85 |
| U-value ceiling of cellar | $W/(m^2*K)$ | 0 |
| U-value Ground floor | $W/(m^2*K)$ | 2,11 |

REFERENCE BUILDING

## RENOVATION PACKAGES

Table 7 demands the description of the renovation packages into analysis

| Building | PT_Bairro Rainha D. Leonor |
|---|---|

| Table 7 | | | | | | |
|---|---|---|---|---|---|---|
| Renovation Package code | Description | Wall | Roof | Floor | Windows | BITS (including RES) |
| Actual | *There are not interventions on the building with the exception of only routine maintenance costs.* | | | | | |
| Reference | *The wall is refurbished by high-pressure cleaner, repairing and preparing the surface to apply the new coating system, the pitched roof is repaired by replacing the cover material and the windows are repainted. These measures do not improve the energy performance of the building.* | *maintenance* | *maintenance* | - | *maintenance* | *Multi split + Electric heating* |
| 1 | *requirement according to REH (DL nº118/2013) + gas boiler (heat + DHW)* | *EPS 10 cm* | *RW 14cm* | *RW 8cm* | *maintenance* | *Natural gas boiler* |
| 2 | *Alternative insulation material (cork boards) + gas boiler (heat + DHW)* | *ICB 8cm* | *ICB 8cm* | *ICB 8cm* | *wood U=2,4* | *Natural gas boiler* |
| 3 | *requirement according to REH (DL nº118/2013) + HVAC for heating + elect. Heater for DHW+ST* | *EPS 10 cm* | *RW 14cm* | *RW 8cm* | *maintenance* | *Multi split + Solar thermal backed by electric heating+ST* |
| 4 | *Alternative insulation material (cork boards) + HVAC for heating + elect. Heater for DHW* | *ICB 8cm* | *ICB 8cm* | *ICB 8cm* | *wood U=2,4* | *Multi split + Solar thermal backed by electric heating + ST* |
| 5 | *requirement according to REH (DL nº118/2013) + Heat pump + PV* | *EPS 10 cm* | *RW 14cm* | *RW 8cm* | *maintenance* | *Heat Pump + Photovoltaic* |
| 6 | *Alternative insulation material (cork boards) + Heat pump + PV* | *ICB 8cm* | *ICB 8cm* | *ICB 8cm* | *wood U=2,4* | *Heat Pump + Photovoltaic* |
| 7 | *requirement according to REH (DL nº118/2013) + biomass* | *EPS 10 cm* | *RW 14cm* | *RW 8cm* | *maintenance* | *Biomass boiler* |
| 8 | *Alternative insulation material (cork boards) + biomass* | *ICB 8cm* | *ICB 8cm* | *ICB 8cm* | *wood U=2,4* | *Biomass boiler* |
| 9 | *Minimal requirement according to REH (DL nº118/2013)* | *EPS 6 cm* | *XPS 5cm* | - | *wood U=3,9* | *Multi split + Solar thermal backed by electric heating* |
| 10 | | | | | | |

RENOVATION PACKAGES

# ENERGY CONSUMPTION

ENERGY CONSUMPTION

Table 8 requires the energy needs and the definition of the systems efficiency. The contribution of RES must be taken into account. **In the case of solar thermal energy, it must be deducted directly in the energy use.**

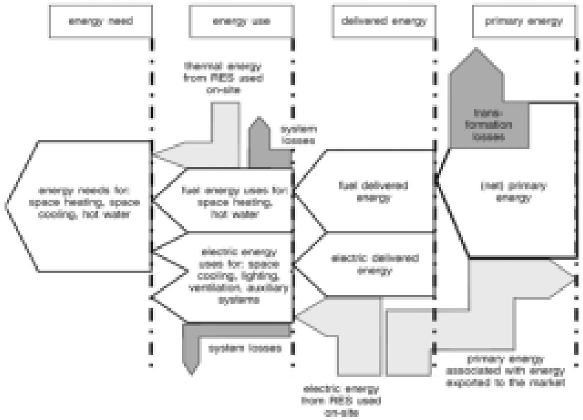
**Fill adapting to your case**

Table 8

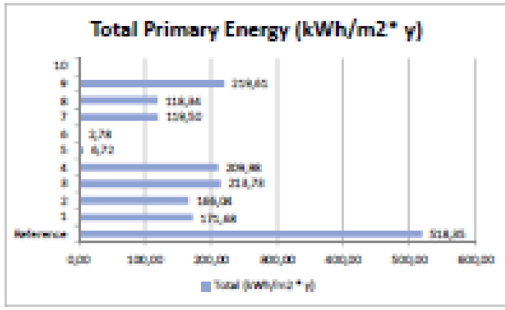
| Renovation Package | Heating energy | | | Cooling energy | | | DHW energy | | |
|---|---|---|---|---|---|---|---|---|---|
| | Energy needs | system efficiency | Energy use | need | system efficiency | use | need | system efficiency | use |
| | kWh/m$^2$ * y | % x 100 | kWh/m$^2$ * y | kWh/m$^2$ * y | % x 100 | kWh/m$^2$ * y | kWh/m$^2$ * y | % x 100 | kWh/m$^2$ * y |
| | Total | η/COP | | Total | η/EER | | Total | η/COP | |
| Reference | 84,92 | 1,00 | 84,92 | 16,52 | 3,50 | 4,72 | 28,85 | 0,80 | 36,06 |
| 1 | 25,65 | 0,93 | 27,58 | 0 | 3,50 | 0,00 | 28,85 | 0,93 | 31,02 |
| 2 | 20,97 | 0,93 | 22,55 | 0 | 3,50 | 0,00 | 28,85 | 0,93 | 31,02 |
| 3 | 25,65 | 4,1 | 6,26 | 0 | 3,50 | 0,00 | 21,26 | 0,8 | 26,58 |
| 4 | 20,97 | 4,1 | 5,11 | 0 | 3,50 | 0,00 | 21,26 | 0,8 | 26,58 |
| 5 | 25,65 | 3,9 | 6,58 | 0 | 3,50 | 0,00 | 28,85 | 3,9 | 7,40 |
| 6 | 20,97 | 3,9 | 5,38 | 0 | 3,50 | 0,00 | 28,85 | 3,9 | 7,40 |
| 7 | 25,65 | 0,92 | 27,88 | 0 | 3,50 | 0,00 | 28,85 | 0,92 | 31,36 |
| 8 | 20,97 | 0,92 | 22,79 | 0 | 3,50 | 0,00 | 28,85 | 0,92 | 31,36 |
| 9 | 33 | 4,1 | 8,05 | 0 | 3,50 | 0,00 | 21,26 | 0,8 | 26,58 |
| 10 | | | | | | | | | |

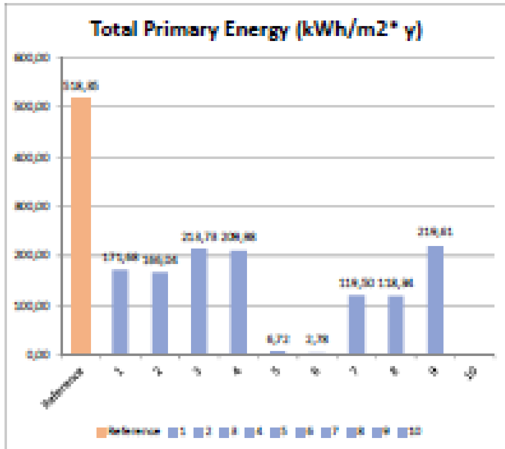
| Renovation Package | Lighting | Total Energy use | Energy delivered | Conversion carrier | | | | |
|---|---|---|---|---|---|---|---|---|
| | use | energy use | RES (PV and biomass) | | | | | |
| | kWh/m$^2$ * y | kWh/m$^2$ * y | | | | | | |
| | | Total | | Heat | Cool | DHW | Lighting | RES |
| Reference | 32,33 | 158,03 | 0,00 | Electricity | Electricity | Electricity | Electricity | Electricity |
| 1 | 32,33 | 90,93 | 0,00 | Natural gas | Electricity | Natural gas | Electricity | Electricity |
| 2 | 32,33 | 85,90 | 0,00 | Natural gas | Electricity | Natural gas | Electricity | Electricity |
| 3 | 32,33 | 65,16 | 0,00 | Electricity | Electricity | Electricity | Electricity | Electricity |
| 4 | 32,33 | 64,02 | 0,00 | Electricity | Electricity | Electricity | Electricity | Electricity |
| 5 | 32,33 | 46,30 | 145,16 | Electricity | Electricity | Electricity | Electricity | Electricity |
| 6 | 32,33 | 45,10 | 145,16 | Electricity | Electricity | Electricity | Electricity | Electricity |
| 7 | 32,33 | 91,57 | 59,24 | Wood pellets | Electricity | Wood pellets | Electricity | Wood pellets |
| 8 | 32,33 | 86,48 | 54,15 | Wood pellets | Electricity | Wood pellets | Electricity | Wood pellets |
| 9 | 32,33 | 66,95 | 0,00 | Electricity | Electricity | Electricity | Electricity | Electricity |
| 10 | | | | | | | | |

| | |
|---|---|
| Electricity | 3,28 |
| Natural gas | 1,12 |
| Wood pellets | 1,12 |
| Oil | 1,12 |
| Electricity REN | 0 |
| District heatin | 0 |



| Conversion factors (energy prices) | | | | Primary Energy | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | use | | | | | |
| | | | | kWh/m² * y | | | | | |
| Heat | Cool | DHW | Lighting | Heat | Cool | DHW | Lighting | RES | Total (kWh/m² * y) |
| 3,28 | 3,28 | 3,28 | 3,28 | 278,54 | 15,48 | 118,29 | 106,04 | 0,00 | 518,35 |
| 1,12 | 3,28 | 1,12 | 3,28 | 30,89 | 0,00 | 34,74 | 106,04 | 0,00 | 171,68 |
| 1,12 | 3,28 | 1,12 | 3,28 | 25,25 | 0,00 | 34,74 | 106,04 | 0,00 | 166,04 |
| 3,28 | 3,28 | 3,28 | 3,28 | 20,52 | 0,00 | 87,17 | 106,04 | 0,00 | 213,73 |
| 3,28 | 3,28 | 3,28 | 3,28 | 16,78 | 0,00 | 87,17 | 106,04 | 0,00 | 209,98 |
| 3,28 | 3,28 | 3,28 | 3,28 | 21,57 | 0,00 | 24,26 | 106,04 | 145,16 | 6,72 |
| 3,28 | 3,28 | 3,28 | 3,28 | 17,64 | 0,00 | 24,26 | 106,04 | 145,16 | 2,78 |
| 1,12 | 3,28 | 1,12 | 3,28 | 31,23 | 0,00 | 35,12 | 106,04 | 52,89 | 119,50 |
| 1,12 | 3,28 | 1,12 | 3,28 | 25,53 | 0,00 | 35,12 | 106,04 | 48,35 | 118,34 |
| 3,28 | 3,28 | 3,28 | 3,28 | 26,40 | 0,00 | 87,17 | 106,04 | 0,00 | 219,61 |
| | | | | | | | | | |




ENERGY CONSUMPTION

COST: INVESTMENT + MAINTENANCE + ENERGY

Fill adapting to each case

Table 12 to Table 21 serve to determine the global costs for each renovation package. However, the unitary costs must be provided by the user. Please verify if the energy carriers match the buildings situation. Table 11 and Table 22 are filled automatically.

| Table 9 | | | |
|---|---|---|---|
| S | 123,6 | m2 | Heated floor area |
| r | 0,06 | % x 100 | Discount rate |
| t | 30 | years | Life cycle |

**Table 12**

Reference PACKAGE

INVESTMENT COST

| | Envelope | Windows | BITS | RES | Total | NPV |
|---|---|---|---|---|---|---|
| Year | (€) | (€) | (€) | (€) | (€) | (€) |
| 0 | € 11.475,00 | € 717,00 | € 13.139,00 | | € 25.331,00 | € 25.331,00 |
| 1 | | | | | € - | € - |
| 2 | | | | | € - | € - |
| 3 | | | | | € - | € - |
| 4 | | | | | € - | € - |
| 5 | | | | | € - | € - |
| 6 | | | | | € - | € - |
| 7 | | | | | € - | € - |
| 8 | | | | | € - | € - |
| 9 | | | | | € - | € - |
| 10 | | | | | € - | € - |
| 11 | | | | | € - | € - |
| 12 | | | | | € - | € - |
| 13 | | | | | € - | € - |
| 14 | | | | | € - | € - |
| 15 | | | € 3.067,00 | | € 3.067,00 | € 1.279,75 |
| 16 | | | | | € - | € - |
| 17 | | | | | € - | € - |
| 18 | | | | | € - | € - |
| 19 | | | | | € - | € - |
| 20 | | | € 10.072,00 | | € 10.072,00 | € 3.140,50 |
| 21 | | | | | € - | € - |
| 22 | | | | | € - | € - |
| 23 | | | | | € - | € - |
| 24 | | | | | € - | € - |
| 25 | | | | | € - | € - |
| 26 | | | | | € - | € - |
| 27 | | | | | € - | € - |
| 28 | | | | | € - | € - |
| 29 | | | | | € - | € - |
| 30 | | | -€ 5.036,00 | | -€ 5.036,00 | -€ 876,82 |
| TOTAL | € 11.475,00 | € 717,00 | € 21.242,00 | € - | € 33.434,00 | € 28.874,43 |

MAINTENANCE COST

| | Total | NPV |
|---|---|---|
| Year | (€) | (€) |
| 0 | € - | € - |
| 1 | € 1.058,00 | € 998,11 |
| 2 | € 1.058,00 | € 941,62 |
| 3 | € 1.058,00 | € 888,32 |
| 4 | € 1.058,00 | € 838,04 |
| 5 | € 1.058,00 | € 790,60 |
| 6 | € 1.058,00 | € 745,85 |
| 7 | € 1.058,00 | € 703,63 |
| 8 | € 1.058,00 | € 663,80 |
| 9 | € 1.058,00 | € 626,23 |
| 10 | € 1.058,00 | € 590,78 |
| 11 | € 1.058,00 | € 557,34 |
| 12 | € 1.058,00 | € 525,79 |
| 13 | € 1.058,00 | € 496,03 |
| 14 | € 1.058,00 | € 467,95 |
| 15 | € 1.058,00 | € 441,47 |
| 16 | € 1.058,00 | € 416,48 |
| 17 | € 1.058,00 | € 392,90 |
| 18 | € 1.058,00 | € 370,66 |
| 19 | € 1.058,00 | € 349,68 |
| 20 | € 1.058,00 | € 329,89 |
| 21 | € 1.058,00 | € 311,22 |
| 22 | € 1.058,00 | € 293,60 |
| 23 | € 1.058,00 | € 276,98 |
| 24 | € 1.058,00 | € 261,30 |
| 25 | € 1.058,00 | € 246,51 |
| 26 | € 1.058,00 | € 232,56 |
| 27 | € 1.058,00 | € 219,40 |
| 28 | € 1.058,00 | € 206,98 |
| 29 | € 1.058,00 | € 195,26 |
| 30 | € 1.058,00 | € 184,21 |
| TOTAL | € 31.740,00 | € 14.563,19 |

**Table 13**

1 PACKAGE

INVESTMENT COST

| | Envelope | Windows | BITS | RES | Total | NPV |
|---|---|---|---|---|---|---|
| Year | (€) | (€) | (€) | (€) | (€) | (€) |

| | Total | NPV |
|---|---|---|
| Year | (€) | (€) |

COST

| Table 10 |
|---|
| Energy Carries |
| Electricity |
| Natural gas |
| Wood pellets |
| |
| |
| |

| Table 11 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Energy use | Heating | Carrier | Cooling | Carrier | DHW | Carrier | Lighting | Carrier | RES |
| Reference | 84,92 | Electricity | 4,72 | Electricity | 36,06 | Electricity | 32,33 | Electricity | 0,00 |
| 1 | 27,58 | Natural gas | 0,00 | Electricity | 31,02 | Natural gas | 32,33 | Electricity | 0,00 |
| 2 | 22,55 | Natural gas | 0,00 | Electricity | 31,02 | Natural gas | 32,33 | Electricity | 0,00 |
| 3 | 6,26 | Electricity | 0,00 | Electricity | 26,58 | Electricity | 32,33 | Electricity | 0,00 |
| 4 | 5,11 | Electricity | 0,00 | Electricity | 26,58 | Electricity | 32,33 | Electricity | 0,00 |
| 5 | 6,58 | Electricity | 0,00 | Electricity | 7,40 | Electricity | 32,33 | Electricity | 145,16 |
| 6 | 5,38 | Electricity | 0,00 | Electricity | 7,40 | Electricity | 32,33 | Electricity | 145,16 |
| 7 | 27,88 | Wood pellets | 0,00 | Electricity | 31,36 | Wood pellets | 32,33 | Electricity | 52,89 |
| 8 | 22,79 | Wood pellets | 0,00 | Electricity | 31,36 | Wood pellets | 32,33 | Electricity | 48,35 |
| 9 | 8,05 | Electricity | 0,00 | Electricity | 26,58 | Electricity | 32,33 | Electricity | 0,00 |
| 10 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |

20,37822976

ENERGY COST

| | Electricity | Natural gas | Wood pellets | Heating | Cooling | DHW | Lighting | Energy Cost | Energy NPV |
|---|---|---|---|---|---|---|---|---|---|
| Year | €/kWh | €/kWh | €/kWh | € annual | € annual | € annual | € annual | € annual | € annual |
| 0 | 0,21 | 0,08 | 0,060 | | | | | | |
| 1 | 0,21 | 0,08 | 0,062 | 2237,88 | 124,39 | 950,35 | 851,98 | € 4.164,59 | € 3.928,86 |
| 2 | 0,22 | 0,08 | 0,064 | 2305,01 | 128,12 | 978,86 | 877,54 | € 4.288,53 | € 3.817,67 |
| 3 | 0,23 | 0,08 | 0,066 | 2374,16 | 131,96 | 1008,22 | 903,87 | € 4.418,22 | € 3.709,62 |
| 4 | 0,23 | 0,08 | 0,068 | 2445,39 | 135,92 | 1038,47 | 930,99 | € 4.550,76 | € 3.604,63 |
| 5 | 0,24 | 0,09 | 0,070 | 2518,75 | 140,00 | 1069,62 | 958,92 | € 4.687,28 | € 3.502,61 |
| 6 | 0,25 | 0,09 | 0,072 | 2594,31 | 144,20 | 1101,71 | 987,68 | € 4.827,90 | € 3.403,48 |
| 7 | 0,25 | 0,09 | 0,074 | 2672,14 | 148,52 | 1134,76 | 1017,31 | € 4.972,74 | € 3.307,16 |
| 8 | 0,26 | 0,10 | 0,076 | 2752,31 | 152,98 | 1168,81 | 1047,83 | € 5.121,92 | € 3.213,56 |
| 9 | 0,27 | 0,10 | 0,078 | 2834,87 | 157,57 | 1203,87 | 1079,27 | € 5.275,58 | € 3.122,61 |
| 10 | 0,28 | 0,10 | 0,081 | 2919,92 | 162,29 | 1239,99 | 1111,65 | € 5.433,85 | € 3.034,23 |
| 11 | 0,29 | 0,10 | 0,083 | 3007,52 | 167,16 | 1277,19 | 1145,00 | € 5.596,86 | € 2.948,36 |
| 12 | 0,30 | 0,11 | 0,086 | 3097,74 | 172,18 | 1315,50 | 1179,35 | € 5.764,77 | € 2.864,91 |
| 13 | 0,30 | 0,11 | 0,088 | 3190,68 | 177,34 | 1354,97 | 1214,73 | € 5.937,71 | € 2.783,83 |
| 14 | 0,31 | 0,11 | 0,091 | 3286,40 | 182,66 | 1395,62 | 1251,17 | € 6.115,84 | € 2.705,04 |
| 15 | 0,32 | 0,12 | 0,093 | 3384,99 | 188,14 | 1437,48 | 1288,70 | € 6.299,32 | € 2.628,49 |
| 16 | 0,33 | 0,12 | 0,096 | 3486,54 | 193,79 | 1480,61 | 1327,36 | € 6.488,30 | € 2.554,09 |
| 17 | 0,34 | 0,12 | 0,099 | 3591,13 | 199,60 | 1525,03 | 1367,19 | € 6.682,95 | € 2.481,81 |
| 18 | 0,35 | 0,13 | 0,102 | 3698,87 | 205,59 | 1570,78 | 1408,20 | € 6.883,44 | € 2.411,57 |
| 19 | 0,36 | 0,13 | 0,105 | 3809,83 | 211,76 | 1617,90 | 1450,45 | € 7.089,94 | € 2.343,32 |
| 20 | 0,37 | 0,14 | 0,108 | 3924,13 | 218,11 | 1666,44 | 1493,96 | € 7.302,64 | € 2.277,00 |
| 21 | 0,38 | 0,14 | 0,112 | 4041,85 | 224,65 | 1716,43 | 1538,78 | € 7.521,72 | € 2.212,55 |
| 22 | 0,40 | 0,14 | 0,115 | 4163,11 | 231,39 | 1767,92 | 1584,94 | € 7.747,37 | € 2.149,93 |
| 23 | 0,41 | 0,15 | 0,118 | 4288,00 | 238,33 | 1820,96 | 1632,49 | € 7.979,79 | € 2.089,09 |
| 24 | 0,42 | 0,15 | 0,122 | 4416,64 | 245,48 | 1875,59 | 1681,47 | € 8.219,18 | € 2.029,96 |
| 25 | 0,43 | 0,16 | 0,126 | 4549,14 | 252,85 | 1931,86 | 1731,91 | € 8.465,76 | € 1.972,51 |
| 26 | 0,45 | 0,16 | 0,129 | 4685,62 | 260,43 | 1989,81 | 1783,87 | € 8.719,73 | € 1.916,68 |
| 27 | 0,46 | 0,17 | 0,133 | 4826,18 | 268,25 | 2049,51 | 1837,38 | € 8.981,32 | € 1.862,44 |
| 28 | 0,47 | 0,17 | 0,137 | 4970,97 | 276,30 | 2110,99 | 1892,50 | € 9.250,76 | € 1.809,73 |
| 29 | 0,49 | 0,18 | 0,141 | 5120,10 | 284,58 | 2174,32 | 1949,28 | € 9.528,29 | € 1.758,51 |
| 30 | 0,50 | 0,18 | 0,146 | 5273,70 | 293,12 | 2239,55 | 2007,76 | € 9.814,13 | € 1.708,74 |
| TOTAL | | | | € 106.467,88 | € 5.917,67 | € 45.213,12 | € 40.533,52 | € 198.132,19 | € 80.152,99 |

SUMMARY - TOTAL COST

| Reference | Cost | | | | NPV |
|---|---|---|---|---|---|
| Year | Investment | Energy | Maintenance | Total | Total |
| 0 | € 25.331,00 | € - | € - | € 25.331,00 | |
| 1 | € - | € 4.164,59 | € 1.058,00 | € 5.222,59 | € 4.926,97 |
| 2 | € - | € 4.288,53 | € 1.058,00 | € 5.347,53 | € 4.759,28 |
| 3 | € - | € 4.418,22 | € 1.058,00 | € 5.476,22 | € 4.597,94 |
| 4 | € - | € 4.550,76 | € 1.058,00 | € 5.608,76 | € 4.442,66 |
| 5 | € - | € 4.687,28 | € 1.058,00 | € 5.745,28 | € 4.293,21 |
| 6 | € - | € 4.827,90 | € 1.058,00 | € 5.885,90 | € 4.149,33 |
| 7 | € - | € 4.972,74 | € 1.058,00 | € 6.030,74 | € 4.010,79 |
| 8 | € - | € 5.121,92 | € 1.058,00 | € 6.179,92 | € 3.877,36 |
| 9 | € - | € 5.275,58 | € 1.058,00 | € 6.333,58 | € 3.748,84 |
| 10 | € - | € 5.433,85 | € 1.058,00 | € 6.491,85 | € 3.625,01 |
| 11 | € - | € 5.596,86 | € 1.058,00 | € 6.654,86 | € 3.505,70 |
| 12 | € - | € 5.764,77 | € 1.058,00 | € 6.822,77 | € 3.390,71 |
| 13 | € - | € 5.937,71 | € 1.058,00 | € 6.995,71 | € 3.279,86 |
| 14 | € - | € 6.115,84 | € 1.058,00 | € 7.173,84 | € 3.173,00 |
| 15 | € 3.067,00 | € 6.299,32 | € 1.058,00 | € 10.424,32 | € 4.349,70 |
| 16 | € - | € 6.488,30 | € 1.058,00 | € 7.546,30 | € 2.970,57 |
| 17 | € - | € 6.682,95 | € 1.058,00 | € 7.740,95 | € 2.874,71 |
| 18 | € - | € 6.883,44 | € 1.058,00 | € 7.941,44 | € 2.782,23 |
| 19 | € - | € 7.089,94 | € 1.058,00 | € 8.147,94 | € 2.693,00 |
| 20 | € 10.072,00 | € 7.302,64 | € 1.058,00 | € 18.432,64 | € 5.747,38 |
| 21 | € - | € 7.521,72 | € 1.058,00 | € 8.579,72 | € 2.523,77 |
| 22 | € - | € 7.747,37 | € 1.058,00 | € 8.805,37 | € 2.443,53 |
| 23 | € - | € 7.979,79 | € 1.058,00 | € 9.037,79 | € 2.366,07 |
| 24 | € - | € 8.219,18 | € 1.058,00 | € 9.277,18 | € 2.291,27 |
| 25 | € - | € 8.465,76 | € 1.058,00 | € 9.523,76 | € 2.219,02 |
| 26 | € - | € 8.719,73 | € 1.058,00 | € 9.777,73 | € 2.149,24 |
| 27 | € - | € 8.981,32 | € 1.058,00 | € 10.039,32 | € 2.081,83 |
| 28 | € - | € 9.250,76 | € 1.058,00 | € 10.308,76 | € 2.016,70 |
| 29 | € - | € 9.528,29 | € 1.058,00 | € 10.586,29 | € 1.953,77 |
| 30 | -€ 5.036,00 | € 9.814,13 | € 1.058,00 | € 5.836,13 | € 1.016,13 |
| TOTAL | € 33.434,00 | € 198.132,19 | € 31.740,00 | € 263.306,19 | |
| NPV | € 28.874,43 | € 80.152,99 | € 14.563,19 | € 123.590,61 | € 123.590,61 |
| | € 233,61 | € 648,48 | € 117,83 | € 999,92 | € 999,92 |

ENERGY COST

| | Electricity | Natural gas | Wood pellets | Heating | Cooling | DHW | Lighting | Energy Cost | Energy NPV |
|---|---|---|---|---|---|---|---|---|---|
| Year | €/kWh | €/kWh | €/kWh | € annual | € annual | € annual | € annual | € annual | € annual |

SUMMARY - TOTAL COST

| 1 | Cost | | | | NPV |
|---|---|---|---|---|---|
| Year | Investment | Energy | Maintenance | Total | Total |

COST

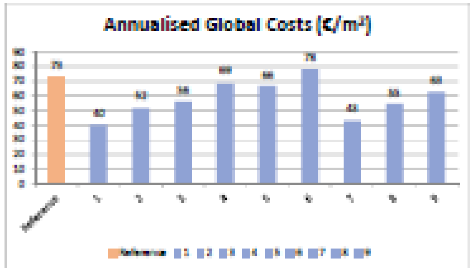
GLOBAL COST AND ANNUALITY COST

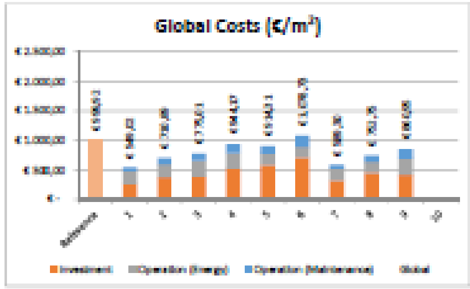
| Table 22 | | | | | |
|---|---|---|---|---|---|
| NPV Costs | Investment | Operation (Energy) | Operation (Maintenance) | Global | Annualised Global costs* |
| | €/m² | €/m² | €/m² | €/m² | €/m² |
| Reference | € 233,61 | € 648,48 | € 117,83 | € 999,92 | 73 |
| 1 | € 262,07 | € 219,79 | € 67,15 | € 549,02 | 40 |
| 2 | € 387,00 | € 213,31 | € 110,58 | € 710,89 | 52 |
| 3 | € 397,25 | € 267,38 | € 110,38 | € 775,01 | 56 |
| 4 | € 523,17 | € 267,16 | € 153,84 | € 944,17 | 69 |
| 5 | € 590,36 | € 185,19 | € 138,76 | € 914,31 | 66 |
| 6 | € 716,27 | € 180,27 | € 182,19 | € 1.078,73 | 78 |
| 7 | € 326,23 | € 201,37 | € 61,70 | € 589,30 | 43 |
| 8 | € 452,15 | € 195,47 | € 105,13 | € 752,75 | 55 |
| 9 | € 425,95 | € 274,75 | € 160,26 | € 860,96 | 62 |
| | | | | | |

*

Within the Annex 56 calculations and to allow the comparison between the National case study and other participating countries, the NPV of each renovation package was transformed into annuity value by using the following formula:

$\frac{(NPV \times r)}{(1-(1+r)^{-n})}$, r = discount rate (6%); n = life cycle (30 years)




COST

IMPACT: GWP impact and total primary energy

Exterior walls painting

Fill adapting to each case

In Table 23, the unitary impacts for each material and energy involved in the renovation packages must be provided. Tables 24 to 34 calculate the GWP and total CEDTotal for each renovation package. For that, each material and energy used in the packages must be included.

| Values from Impact DATABASE | SimaPro results for each of the renovation materials (including manufacturing and transport) | | |
|---|---|---|---|
| | Table 23 | | |
| t | GWP | $CED_{NRE}$ | $CED_{total}$ |
| | $[kgCO_{2eq}/(m^2y)]$ | $[kWh/(m^2y)]$ | $[kWh/(m^2y)]$ |
| Exterior walls painting | 0,0007382248 | 0,004011601 | 0,004313471 |
| Repairing and painting windows wood frames | 0,0007382248 | 0,004011601 | 0,004313471 |
| Black agglomerated cork | 0,00031014 | 0,001880080 | 0,003800673 |
| XPS | 0,002801715 | 0,007438875 | 0,007528701 |
| Rockwool | 0,000291262 | 0,001416811 | 0,001481052 |
| EPS | 0,001116505 | 0,007870371 | 0,007945891 |
| ETICS (without the insulation) | 3,27143E-05 | 0,000115517 | 0,000130226 |
| PVC window | 0,000899189 | 0,004483242 | 0,00464488 |
| Wood window | 0,000407149 | 0,002194298 | 0,004413083 |
| Aluminium Window | 0,002537293 | 0,010998135 | 0,012203287 |
| glass (single) | 0,000280484 | 0,000601172 | 0,000968725 |
| glass (double) | 0,000380014 | 0,001526507 | 0,001802225 |
| Windows sills (aluminium) | 0,002349191 | 0,008443739 | 0,010204546 |
| PVC membrane under floor cork insulation | 0,000799808 | 0,006981947 | 0,007122773 |
| | | | |
| BITS | GWP | $CED_{NRE}$ | $CED_{total}$ |
| | $[kgCO_{2eq}/(m^2y)]$ | $[kWh/(m^2y)]$ | $[kWh/(m^2y)]$ |
| Gas Boiler | 0,101941775 | 0,47420149 | 0,5130739 |
| Heat Pump | 0,42810572 | 0,57750049 | 0,6098433 |
| Biomass Boiler | 0,70748652 | 2,44810584 | 3,5951302 |
| Electric heaters | 0 | 0 | 0 |
| Radiators | 0 | 0 | 0 |
| Fan coils | 0 | 0 | 0 |
| Electric water heater | 0 | 0 | 0 |
| Solar Thermal | 0,35868283 | 1,57489143 | 1,79631914 |
| Photovoltaic | 0,10483882 | 0,47094751 | 0,55048452 |
| | | | |
| | | | |
| Energy | GWP | $CED_{NRE}$ | $CED_{total}$ |
| | $[kgCO_{2eq}/(m^2y)]$ | $[kWh/(m^2y)]$ | $[kWh/(m^2y)]$ |
| HVAC | 0 | 0 | 0 |
| MVHR | 0 | 0 | 0 |
| Electricity | 0,6912 | 2,73500157 | 3,22440157 |
| Natural gas | 0,26172 | 1,22820181 | 1,24050581 |
| wood pellets | 0,045 | 0,24230018 | 1,33757018 |

| Grid conversion factors | |
|---|---|
| Electricity | 2,28 |
| Natural gas | 1,12 |
| Wood pellets | 1,12 |
| Oil | 1,12 |
| Electricity RSN | 0 |
| District heating | 0 |

Reference PACKAGE

| Table 24 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Element | MATERIAL | Life time (y) | Thickness (m) | Quantity (m²) | Density ρ (kg/m³) | Nº replacem. (in 30 years) | Quantity (kg) | Quantity (kg) | GWP $[kgCO_{2eq}/(m^2y)]$ | $CED_{total}$ $[kWh/(m^2y)]$ |
| 1 Maintenance | Exterior walls painting | 10 | 0,000 | 96,550 | 1,650 | 3 | 59,740 | 477,923 | 0,043984 | 0,257688 |
| Maintenance | Repairing and painting windows wood frames | 10 | 0,000 | 23,310 | 1,650 | 3 | 14,423 | 115,385 | 0,010619 | 0,062213 |
| Roof | 140mm Rockwool | | | | | | 0,000 | 0,000 | 0,000000 | 0,000000 |
| Floor | 80mm Rockwool | | | | | | 0,000 | 0,000 | 0,000000 | 0,000000 |
| Wall | ETICS_10mm EPS | | | | | | 0,000 | 0,000 | 0,000000 | 0,000000 |
| Extras | Windows sills | | | | | | 0,000 | 0,000 | 0,000000 | 0,000000 |
| | | | | | | Partial | | | 0,054602 | 0,319902 |
| BITS | | Life time (y) | Thickness (m) | Quantity (m²) | Density ρ (kg/m³) | Nº replacem. (in 30 years) | Quantity (kg) | Quantity (kg) | GWP $[kgCO_{2eq}/(m^2y)]$ | $CED_{total}$ $[kWh/(m^2y)]$ |
| BITS | electric heater | 20 | | 2,000 | | 2 | 4,000 | | 0,407767 | 2,052296 |
| BITS | HVAC | | | | | | 0,000 | | 0,000000 | 0,000000 |
| | | | | | | Partial | | | 0,407767 | 2,052296 |
| ENERGY | | | | | | | Use kWh/m² *y | Needs kWh/m² *y | GWP $[kgCO_{2eq}/(m^2y)]$ | $CED_{total}$ $[kWh/(m^2y)]$ |
| | Heating energy | | | | | Electricity | 84,920 | 84,920 | 58,697 | 273,816 |
| | Cooling energy | | | | | Electricity | 4,720 | 16,520 | 3,262 | 15,219 |
| | DHW energy | | | | | Electricity | 36,063 | 28,850 | 24,926 | 116,280 |
| | Lighting energy | | | | | Electricity | 32,330 | 32,330 | 22,346 | 104,245 |
| | RES* | | | | | Electricity | 0,000 | 0,000 | 0,000 | 0,000 |
| | | | | | | Partial | | | 109,232064 | 509,560241 |
| TOTAL | | | | | | | | | 109,694433 | 511,932438 |

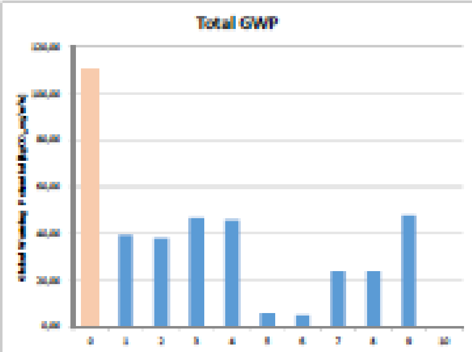
* In reality the production of RES does not have an impact, but to ease the calculations it was included in the chart

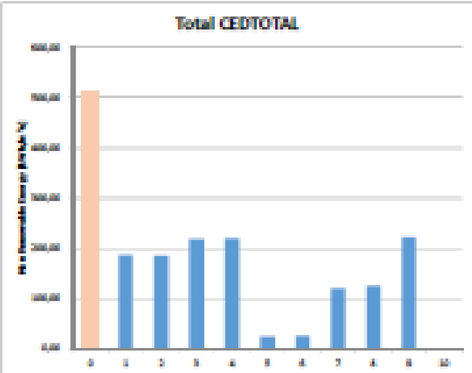
1 PACKAGE

| Table 25 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Element | MATERIAL | Life time (y) | Thickness (m) | Quantity (m²) | Density ρ (kg/m³) | Nº replacem. (in 30 years) | Quantity (kg) | Quantity (kg) | GWP $[kgCO_{2eq}/(m^2y)]$ | $CED_{total}$ $[kWh/(m^2y)]$ |
| Maintenance | Paint (exterior walls) | 10 | 0,000 | 96,550 | 1,650 | 3 | 59,740 | 477,923 | 0,043984 | 0,257688 |
| Maintenance | Repairing and painting windows wood frames (8L/m²) | 10 | 0,000 | 23,310 | 1,650 | 3 | 14,423 | 115,385 | 0,010619 | 0,062213 |
| Roof | 140mm Rockwool | 30 | 0,140 | 80,000 | 100,000 | 1 | 1.120,000 | 1.120,000 | 0,326214 | 1,658778 |
| Floor | 80mm Rockwool | 30 | 0,080 | 80,000 | 100,000 | 1 | 640,000 | 640,000 | 0,186408 | 0,947873 |
| Wall | ETICS_10mm EPS | 30 | 0,100 | 96,550 | 18,000 | 1 | 164,140 | 173,790 | 0,183263 | 1,304238 |
| Extras | Windows sills | 30 | 0,030 | 3,000 | 2.700,000 | 1 | 243,000 | 243,000 | 0,546553 | 2,479705 |
| | | | | | | Partial | | | 1,297040 | 6,710496 |
| BITS | | Life time (y) | Thickness (m) | Quantity (m²) | Density ρ (kg/m³) | Nº replacem. (in 30 years) | Quantity (kg) | Quantity (kg) | GWP $[kgCO_{2eq}/(m^2y)]$ | $CED_{total}$ $[kWh/(m^2y)]$ |
| BITS | Gas Boiler | 20 | | 2,000 | | 2 | 4,000 | | 0,407767 | 2,052296 |
| BITS | HVAC | 20 | | 1,000 | | 2 | 2,000 | | 0,000000 | 0,000000 |
| | | | | | | Partial | | | 0,407767 | 2,052296 |
| ENERGY | | | | | | | Use kWh/m² *y | Needs kWh/m² *y | GWP $[kgCO_{2eq}/(m^2y)]$ | $CED_{total}$ $[kWh/(m^2y)]$ |
| | Heating energy | | | | | Natural gas | 27,581 | 25,650 | 7,218 | 34,215 |
| | Cooling energy | | | | | Electricity | 0,000 | 0,000 | 0,000 | 0,000 |

IMPACT

| | Total GWP [kgCO2eq/m²y] | Total CEDTOTAL [kWh/m²y] |
|---|---|---|
| [illegible] | 109,894408 | 511,882 |
| 1 | 39,388658 | 185,707 |
| 2 | 38,060598 | 185,127 |
| 3 | 46,549688 | 217,817 |
| 4 | 45,745629 | 218,899 |
| 5 | 5,882743 | 23,898 |
| 6 | 5,022163 | 23,489 |
| 7 | 23,829152 | 119,448 |
| 8 | 23,898567 | 124,879 |
| 9 | 47,891107 | 221,487 |
| 10 | 0,000000 | 0,000 |

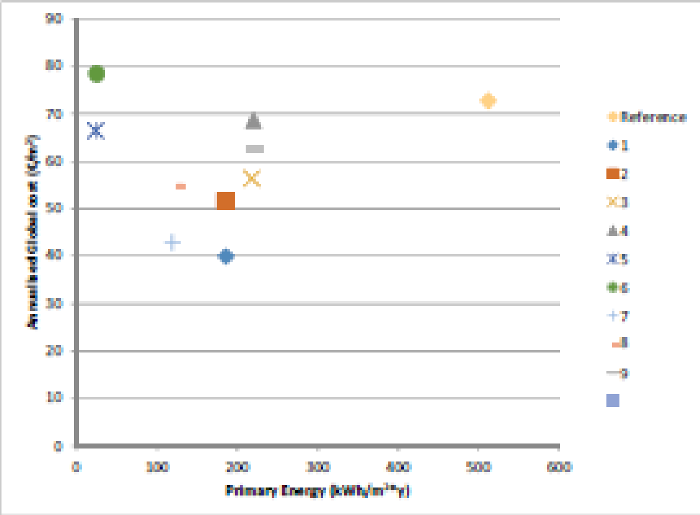


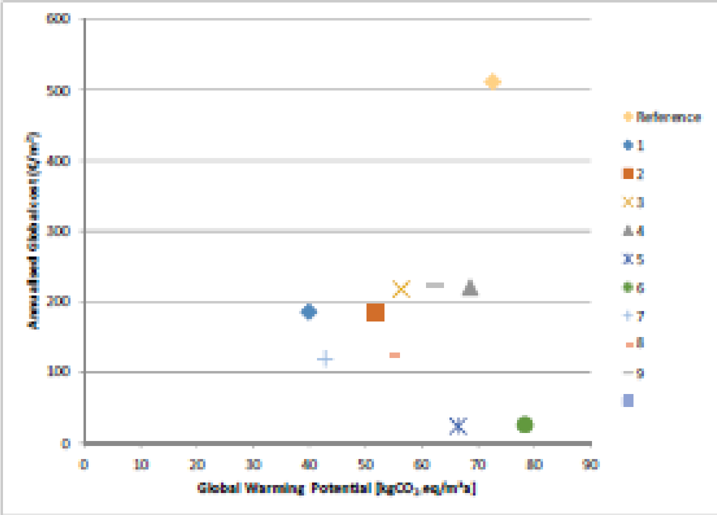




IMPACT

ANNEX 56 CHARTS

| Table 35 | | | |
|---|---|---|---|
| NPV Costs | Annualised Global costs | Primary Energy | GWP |
| | €/m² | kWh/m2 * y | [kgCO2e/(m2y)] |
| Reference | 73 | 512 | 110 |
| 1 | 40 | 186 | 39 |
| 2 | 52 | 185 | 38 |
| 3 | 56 | 218 | 47 |
| 4 | 69 | 220 | 46 |
| 5 | 66 | 24 | 6 |
| 6 | 78 | 25 | 5 |
| 7 | 43 | 119 | 24 |
| 8 | 55 | 124 | 24 |
| 9 | 63 | 222 | 48 |
| | | | |




A56 charts

CO-BENEFIT

**Before filling Table 04, it is advisable to read the explanations below and proceed to the valuation according to the co-benefits matrix.**

Fill adapting in each case.

| Global cost of the cost optimal solution | Eur/m² |
|---|---|
| | 60 |

| Classification | | |
|---|---|---|
| | + | - |
| | ++ | -- |
| | +++ | --- |

Table 04

| Renovation Package code | Wall | Roof | Floor | Windows | BTS | Additional costs (comparing to | Thermal comfort | | Natural lighting | | Air quality | | Building physics | | Internal noise | | External noise | | Ease of use | | Reduced exposure to energy price | | Aesthetics / Architectural | | Useful living area | | Safety (intrusion and accidents) | | Pride / prestige | | Ease of in |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actual | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reference | maintenance | maintenance | _ | maintenance | Multi split + Electric heating | [illegible] | | | | | | | | | | | | | | | | | + | | | | | | ++ | | |
| 1 | EPS 10 cm | RW 14cm | RW 8cm | maintenance | Natural gas boiler | | +++ | | | | + | | ++ | | | - | | | | | + | | + | | | | | | ++ | | |
| 2 | ICB 8cm | ICB 8cm | ICB 8cm | wood U=2,4 | Natural gas boiler | 12 | +++ | | | | + | | ++ | | | - | + | | | | +++ | | + | - | | | + | | ++ | | |
| 3 | EPS 10 cm | RW 14cm | RW 8cm | maintenance | Multi split + Solar thermal backed by electric heating+ST | 16 | +++ | | | | + | | ++ | | | - | | | | | + | | + | | | | | | ++ | | |
| 4 | ICB 8cm | ICB 8cm | ICB 8cm | wood U=2,4 | Multi split + Solar thermal backed by electric heating + ST | 29 | +++ | | | | + | | ++ | | | - | + | | | | +++ | | + | - | | | + | | ++ | | |
| 5 | EPS 10 cm | RW 14cm | RW 8cm | maintenance | Heat Pump + Photovoltaic | 27 | +++ | | | | + | | ++ | | | - | | | | | + | | + | | | | | | ++ | | |
| 6 | ICB 8cm | ICB 8cm | ICB 8cm | wood U=2,4 | Heat Pump + Photovoltaic | 58 | +++ | | | | + | | ++ | | | - | + | | | | +++ | | + | - | | | + | | ++ | | |
| 7 | EPS 10 cm | RW 14cm | RW 8cm | maintenance | Biomass boiler | 5 | +++ | | | | + | | ++ | | | - | | | | | + | | + | | | | | | ++ | | |
| 8 | ICB 8cm | ICB 8cm | ICB 8cm | wood U=2,4 | Biomass boiler | 15 | +++ | | | | + | | ++ | | | - | + | | | | +++ | | + | - | | | + | | ++ | | |
| 9 | EPS 6 cm | XPS 5cm | _ | wood U=3,5 | Multi split + Solar thermal backed by electric heating | 23 | +++ | | | | + | | ++ | | | - | + | | | | ++ | | + | | | | + | | ++ | | |
| 10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

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

The matrix relates the co-benefits with specific renovation measures and has been developed based on the literature review, on the analysis of the case studies and on the Annex 56 participants' experience and perception. The relevance of the identified relationship is described with a plus (+) signal for positive impact and a minus (-) for negative impacts and 1 to 3 of the mentioned signals to indicate their relevance (3 - more relevant, 1 - less relevant).

It is important to notice that the indicated relevance is intended to describe the average and most common situation. Nevertheless, the relevance of the co-benefits may be conditioned by several factors leading to significant divergences in relation to the values from the matrix.

In the next lines, some of these factors are highlighted:

- The **physical or technical condition of building prior to the renovation** affects the relevance of the improvements obtained from the implementation of renovation measures and the perception of these benefits by the residents. In fact, the degradation of the building or any of its elements (roof, facade, windows, heating system, etc.) and its original energy performance are decisive for the definition of the benefits from the improvement of its energy performance.
- The **climate conditions of the building site** are decisive for the impact of the renovation measures.
- The **urban context of the building** may be relevant for the co-benefits identification. As an example, the replacement of old single glazed windows by new double or triple glazed windows is normally related with the co-benefit of reducing external noise.
- The **information and knowledge** of the residents about the implemented renovation measures and the reasons for their implementation plays an important role in their capacity to link the co-benefits to the renovation measures. The added value for a building resulting from the co-benefits associated to energy related renovation measures depends on the perception and identification of those benefits by the residents and from their knowledge on the origin of the benefits;
- The co-benefits included in the user wellbeing category such as thermal comfort, natural lighting, air quality and noise have a strong relation with the physical condition of the resident. Factors such as the **age, gender and health** of the residents should be taken into account since these may impact on the relevance of the co-benefits. Older people and small children tend to be more sensitive to thermal comfort and people with respiratory problems tend to be more sensitive to air quality;
- The **financial condition** of the residents is likely to play a role on the relevance of some of the co-benefits. Residents unable to heat their dwellings adequately due to the high energy bill are more likely to identify and appreciate the improvement of thermal comfort from energy related renovation measures than those who had the financial capacity to keep the dwelling warm despite a low thermal performance of the building before the renovation;
- The **occupation profile** of the dwellings affects the perception of the renovation measures by the residents. Those who use the dwelling nearly 24 hours per day are likely to be much more sensitive to the potential co-benefits and highly valuate measures with impact on their wellbeing compared to residents who spend most of the time away from the dwelling;
- **Cultural habits** such as the accommodation to low comfort levels or the constant use of natural ventilation, even during winter, affect the full exploitation of the benefits associated to certain renovation measures and even the acceptance of others.
- **Wrong design and execution** have a strong negative impact on the renovation measures overlapping the benefits.

The described factors are only some examples that intend to highlight that the relevance of the co-benefits has to be evaluated during the process of decision making.

CO-BENEFIT

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