

International Energy Agency

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

## Executive Summary for Policy Makers

October 2017





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### **Authors**

University of Minho – Civil Engineering Department, Guimarães, Portugal

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

Marco Ferreira, [marcoferreira@civil.uminho.pt](mailto:marcoferreira@civil.uminho.pt)

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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 29 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

## The IEA Energy in Buildings and Communities Programme

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

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

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

## The Executive Committee

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

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

- Annex 24: Heat, Air and Moisture Transfer in Envelopes (\*)
- Annex 25: Real time HVAC Simulation (\*)
- Annex 26: Energy Efficient Ventilation of Large Enclosures (\*)
- Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (\*)
- Annex 28: Low Energy Cooling Systems (\*)
- Annex 29: Daylight in Buildings (\*)
- Annex 30: Bringing Simulation to Application (\*)
- Annex 31: Energy-Related Environmental Impact of Buildings (\*)
- Annex 32: Integral Building Envelope Performance Assessment (\*)
- Annex 33: Advanced Local Energy Planning (\*)
- Annex 34: Computer-Aided Evaluation of HVAC System Performance (\*)
- Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (\*)
- Annex 36: Retrofitting of Educational Buildings (\*)
- Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (\*)
- Annex 38: Solar Sustainable Housing (\*)
- Annex 39: High Performance Insulation Systems (\*)
- Annex 40: Building Commissioning to Improve Energy Performance (\*)
- Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (\*)
- Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (\*)
- Annex 43: Testing and Validation of Building Energy Simulation Tools (\*)
- Annex 44: Integrating Environmentally Responsive Elements in Buildings (\*)
- Annex 45: Energy Efficient Electric Lighting for Buildings (\*)
- Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (\*)
- Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (\*)
- Annex 48: Heat Pumping and Reversible Air Conditioning (\*)
- Annex 49: Low Exergy Systems for High Performance Buildings and Communities (\*)
- Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (\*)
- Annex 51: Energy Efficient Communities (\*)
- Annex 52: Towards Net Zero Energy Solar Buildings (\*)
- Annex 53: Total Energy Use in Buildings: Analysis & 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 (RAP-RETRO) (\*)
- Annex 56: Cost-effective Energy & CO<sub>2</sub> Emissions Optimization in Building Renovation
- Annex 57: Evaluation of Embodied Energy & CO<sub>2</sub> Equivalent 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: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles
- Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems
- Annex 66: Definition and Simulation of Occupant Behavior in Buildings
- Annex 67: Energy Flexible Buildings
- Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings
- Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
- Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
- Annex 71: Building Energy Performance Assessment Based on In-situ Measurements
- Annex 72: Assessing Life Cycle related Environmental Impacts Caused by Buildings
- Annex 73: Towards Net Zero Energy Public Communities
- Annex 74: Energy Endeavour
- Annex 75: Cost-effective building renovation at district level combining energy efficiency and renewables
- Working Group - Energy Efficiency in Educational Buildings (\*)
- Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (\*)
- Working Group - Annex 36 Extension: The Energy Concept Adviser (\*)
- Working Group - Survey on HVAC Energy Calculation Methodologies for Non-residential Buildings

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# Introduction

Energy is crucial to the wellbeing and development of nowadays society and will remain important for the foreseeable future. Significant changes are ongoing and further major changes can be expected in the near future with respect to the type and quantity of energy consumed.

Among the various policy objectives that shape energy policy, the following can be highlighted:

- minimizing any adverse effects on the climate and on the environment;
- providing energy access to all;
- securing energy supply;
- reducing dependence on energy imports;
- looking for new energy sources, routes and suppliers that offer local economic benefits;
- reducing local environmental pollution;
- driving job creation;
- achieving low energy costs for society.

Key strategic elements to reach such objectives are in particular the gradual transformation of the energy systems from fossil fuels to renewable energy, the increase of the efficiency of the energy systems, the reduction of energy use by consumers, the creation of fully integrated energy markets and the removal of unnecessary regulatory or technical barriers.

Existing buildings present a tremendous potential, not only to reduce energy use and emissions, but also on other areas of the political agenda. In many developed countries, the renovation of the existing building stock is a relevant part of the actions to deal with climate change mitigation and to move towards a sustainable relation with our planet (European Commission, 2011). Building renovation that increases the energy performance of a building or that increases

the share of renewable energy in its energy use, reduces carbon emissions and the emissions of local air pollutants. By renovating a building instead of replacing it with a newly constructed building, the depletion of resources is reduced and the amount of waste is minimized.

Regardless of this significant potential, it has been hard to fully exploit it (BPIE, 2011). The methodology developed within the context of this project to enable cost-effective building renovation towards a nearly zero energy and emissions objective, intends to highlight the full scope of benefits, direct and indirect, resulting from the renovation process and to evaluate how they can be taken into account in decision-making processes, helping policy makers in the development of energy related policies.

The methodology (graphically shown in Figure 1) allows the assessment and evaluation of energy related renovation options, including:

- a comprehensive evaluation and assessment of cost-effective reductions of primary energy use and carbon emissions within energy related building renovation, comprising also lifecycle impacts like embodied energy;
- the evaluation of cost-effective combinations of energy efficiency measures and measures to increase renewable energy use;
- highlighting the relevance of the additional benefits (co-benefits) achieved in the renovation process.



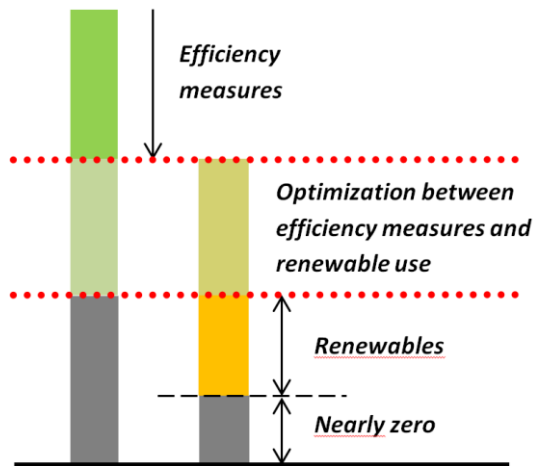


Figure 1 – Concept for an optimized combination of energy efficiency measures and renewable energy measures in building renovation with a nearly-zero energy and emissions target (Geier S., Ott W.).

## Change of mindset towards building renovation

In building renovation, lack of information, limited access to capital to face the high investment costs and long pay-back times of these investments, are the most commonly cited reasons hampering the wide use of energy conservation and renewable energy deployment measures. Additionally, in many cases, those who pay for the energy renovation are not those who benefit from it, leading to a situation known as split-incentives situation. Therefore, energy renovation projects often run into barriers that hold up the projects. It is then an obligation that owners, technical consultants and policy makers find solutions to overcome these barriers.

Up to now, strategies to improve the energy performance in the building sector were largely focused on tapping and developing

efficiency potentials of new buildings and more specifically on improving the building envelope. However, in face of the above mentioned barriers, such an approach is not responding effectively to the numerous technical, functional and economic constraints of existing buildings.

Given the major challenge of mitigating climate change and the important share of carbon emissions caused by energy consumption in existing buildings, reducing carbon emissions within building renovations is an important objective and probably the most important one. Up to now, standards for building renovation have focused mainly on the reduction of energy use through energy efficiency measures, which also contribute to the reduction of carbon emissions. However, given the barriers building renovation has to face, it is interesting to compare the effects of renovation packages consisting of measures to increase energy efficiency and those considering measures to increase the share of renewable energy sources used and to put them into perspective comparing energy and carbon emissions reductions achieved.

In fact, considering the goal of reducing carbon emissions, measures promoting the use of renewable energy can be as effective as efficiency measures and sometimes be obtained in a more cost-effective way. In existing buildings, the most cost-effective renovation solution is often a combination of energy efficiency measures and measures that promote the use of renewable energy. Hence, it is relevant to understand how far it is possible to go with efficiency measures (initially often less expensive measures) and from which point the use of renewables becomes more economical considering the local context.

Each one of these types of measures will be also responsible for a certain amount of embodied energy related to the materials added to the envelope or to the technical systems. Indeed, the more the building

energy demand is minimized, the more the embodied energy in the materials added (eg. envelope insulation), becomes more relevant. Similarly, renewable energy systems, such as ground source heat pumps, often have more embodied energy than conventional heating systems. It is known that as the energy performance of buildings increases, the embodied energy in the materials used in building renovation becomes more important, but its relevance is still not well-known.

In the case of existing buildings, it can be observed that opportunities to significantly improve their energy performance are missed too often despite their cost-effectiveness if a life cycle cost approach is assumed. Often, this is because of the high initial costs involved but also because of lack of know-how and awareness regarding life cycle cost-effectiveness. Also, traditional approaches disregard benefits of building renovation measures beyond energy and costs. It is therefore relevant to explore and illustrate the range of cost-effective renovation measures to increase efficiency and deployment of renewable energy to achieve the best building performance (less energy use, less carbon emissions, higher overall added value achieved with the renovation) at the lowest effort (less investment, less life cycle costs, less intervention on the building, less users' disturbance).

To investigate related questions within the framework of the Annex 56 project, an adequate methodology for energy and carbon emissions optimization in building renovation was developed (Ott, W. et al., 2017). The methodology intends to become a basis for extending and further developing the existing standards to be used by interested private entities and agencies for their renovation decisions as well as by governmental agencies for the definition of their renovation strategies, regulations and their implementation.

## Annex 56 proposal for a new approach

The need for a drastic reduction of carbon emissions in the building sector, associated with the specific constraints of the existing buildings, require changes in the approach to mitigating climate change in this sector. Thus, a new methodology is proposed to be used in the decision making process for energy related building renovation, allowing to optimize energy consumption, carbon emissions and overall added value of the renovation process in a cost-effective way.

The approach to the large-scale renovation of the existing building stock relies on three major issues to be addressed:

- Buildings are in general long lasting structures and their renovation implies large investments and the development of long-term strategies considering a life-cycle approach;
- Carbon emissions need to be considered in standards and target setting at least at the same level as energy (Bolliger, R. and Ott, W., 2017)
- Energy and carbon optimized building renovation usually have several side effects often yielding substantial additional benefits, which can be as important as energy cost savings (like increased user comfort, fewer problems with building physics, etc.). These co-benefits have to be identified and combined with the impacts of carbon emissions and energy reduction measures in the decision making process (Almeida, M., Ferreira, M., Rodrigues, A., 2017)

### **i. Life-cycle approach**

Defining targets only for new buildings and acting only on new buildings is not enough to achieve the established long term carbon emissions reduction targets (in line with the recent Paris Agreement) mainly because of the low rate of replacement of the existing building stock.

Improving a building's energy performance and switching to renewable energy, is not just a contribution to mitigating climate change and to save resources, but often also saves costs. The analysis of the cost-effectiveness of a certain measure or renovation package of measures is done using a cost/benefit analysis using several possible methods. The simplest method is the simple payback method calculation, where the payback period is the length of time required to recover the cost of an investment and the longer these periods are, the less attractive such investments are. The simple payback does not take into account any benefits or costs that occur after the initial investment has been recovered and therefore there's a tendency for the cheapest solutions to become the most attractive ones. This simplified analysis leads to the missed opportunity of improving the buildings' energy performance in a more effective way, although it is frequently used in standards and national regulations.

On the other hand, the life cycle costs analysis may include the total lifespan of the building or the period for which the renovation is being planned. Costs and benefits of each alternative are analysed along their life time and expressed in annualized costs or net present value (NPV). It includes the investment costs, energy costs, operation and maintenance costs and any residual value of the building at the end of the period considered in the analysis. Life cycle costs (LCC) analysis is an adequate approach because it accounts for all cash outflows and inflows over the period under analysis and it

also discounts the value of the money to adjust the cash to its present value.

### **ii. Carbon emissions in standards and targets**

There is, in general, a large potential for cost-effective building renovations that reduce both carbon emissions and non-renewable primary energy use. Both energy efficiency measures and measures to promote the use of renewable energy sources contribute to these objectives. Renewable energy measures often have the potential to reduce carbon emissions more strongly and at fewer costs than energy efficiency measures. This underlines the importance of taking into account renewable energy measures in future policy making.

Nevertheless, important reasons justify keeping carrying out energy efficiency measures. Among these reasons are the ones assuring thermal comfort and other co-benefits that can result from those measures such as the reduction of problems related to building physics (such as humidity and mould) or aesthetics improvements. Besides that, as some natural resources are scarce, it makes furthermore sense to reduce the energy consumption of buildings, even if by using these resources the buildings immediately reach nearly zero carbon emissions and non-renewable primary energy use.

### **iii. Co-benefits**

The renovation of the existing building stock, improving significantly its energy performance, can deliver a broad range of additional benefits (co-benefits) to the inhabitants of the buildings and to society. However, the evaluation of the benefits from energy related renovation programmes and policies focusses mainly on energy savings, leading to the underestimation of the positive impacts of building renovation, which may

lead to sub-optimal investment decisions and policy design.

While co-benefits could basically act as a driver for building renovation, the problem is that they are not perceived adequately by the users benefitting from them or by the investors taking the renovation decisions. The problem also extends to specialists supporting investment decisions: energy specialists tend to focus solely on energy-related effects such as primary energy consumption and costs, and professionals from other fields, such as health professionals, are unlikely to be consulted in the context of building renovations. This means that information to increase the perception of co-benefits, as well as interdisciplinary cooperation, is needed to fully take into account the extent of the non-energy benefits and to let them influence investment decisions and policy design.

Co-benefits of energy efficiency investments in the built environment can act as a supporting instrument to reach policy goals in several areas.

## Recommendations for policymakers

The work developed within this project allowed to formulate a set of recommendations that should be considered by policy makers in the definition and design of new policy programs and regulations. These recommendations focus on three major vectors that are expected to be addressed by policy makers:

- Strategic thinking in the development of energy policies;
- Standard setting;
- Incentives.

The main goal is to create awareness about various aspects of building renovation which are so far often not adequately taken into account, allowing for a better definition of upcoming standards, rules and regulations. A change of mind-set is proposed.

### Recommendation # 1:

#### Introduce carbon emissions targets in addition to energy targets

It is advisable to introduce a target to reach nearly zero carbon emissions in existing buildings undergoing a major renovation, complementing existing energy efficiency requirements. If this is not cost-effective because, for example, the heating system would not have to be replaced in the near future, exceptions can be made or subsidies can be allocated for these cases considering the co-benefits from a macroeconomic perspective. For buildings connected to a district heating system, it is possible to reach the goal of nearly zero carbon emissions collectively by changing the energy source of the district heating system. In such cases, it is advisable to develop the most favourable strategy in cooperation with building owners.

### Recommendation # 2:

#### Shift to technical systems based on renewable energy

It is adequate to make a switch to renewable energy mandatory when a heating system is replaced, similarly to energy improvements of the building envelope. Exemptions may still be granted from such a rule if the building owner can show that such a measure would not be cost-effective from a life-cycle perspective or subsidies can be allocated for these cases considering the co-benefits from a macroeconomic perspective. Exemptions could also be made if a building is connected to a district heating system which either already has a high share of renewable energy

or for which a plan exists to switch to renewable energy.

### Recommendation # 3:

#### **Create incentives to support a shift to renewable energy**

Usually, renewable energy systems have higher investment costs than conventional heating systems. Even if such systems are often cost-effective from a life cycle perspective, it is recommended to design incentives or other financial mechanisms to support this shift.

### Recommendation # 4:

#### **Promote the combination of energy efficiency measures with renewable energy**

It is recommendable that standards and other policy measures, for example subsidies, create incentives to combine renovation measures on the building envelope with a replacement of the heating system, in order to make sure that reductions in energy use and emissions are achieved most efficiently. Exceptions could be made for buildings connected to a district heating system, which already has a high share of renewable energy or for which a switch of the district heating system to renewable energy sources is already planned.

### Recommendation # 5:

#### **Shift from cost-optimality to cost-effectiveness**

It is recommendable that standards do not limit themselves to make an energy performance level mandatory up to the cost-optimal level but to make also further measures mandatory as long as they are cost-effective with respect to a reference case.

Depending on the original condition of the building, improving all elements of the building envelope often means going beyond the cost optimal level (since in a comprehensive package of measures the improvement of certain elements may not be cost-effective). However, in these circumstances, the packages of measures can remain cost-effective when compared to the reference case and the improvement of all elements of the building envelope is usually the way to maximize the added value achieved with the co-benefits.

### Recommendation # 6:

#### **Make use of opportunities when renovations are made “anyway”**

It makes sense that standards for achieving improvements in energy performance focus on the situation when one or more building elements are in need of renovation anyway.

An understanding of the current status of the building stock is essential to clearly define the strategy and timing for building renovation.

### Recommendation # 7:

#### **Take into account the complexity of building renovation in standards, targets, policies and strategies, introducing flexibility into regulations**

To achieve a large reduction in energy use and carbon emissions in existing buildings most effectively, it is important that standards, targets and policies take into account the complexity of building renovation while seeking for cost-effective solutions. Flexibility is needed to give renovation strategies a chance to enable the transformation of the building stock towards low energy use and a nearly zero emissions level. This includes the flexibility to reach these targets step by step over time.

## Recommendation # 8:

### Promote quality and accuracy in design and execution

No matter what renovation measures are chosen, good design and good execution are decisive for the added value of the building, to ensure the expected co-benefits from the related renovation measures. Therefore, promoting the quality in design and execution of building renovation is crucial for their success and acceptance.

## Recommendation # 9:

### Assure a minimum level of energy efficiency

Depending on the original condition of the building and its context, cost optimal packages of renovation measures only considering investment and operational costs are often not very ambitious regarding energy performance, mainly due to certain specific measures that are not cost-effective.

To maximize the co-benefits resulting from energy related renovation measures, all main elements of the building envelope should be improved to a minimum energy performance level in accordance with the local climate requirements. In most cases, this improvement represents just a small increase in the global costs when compared to the cost optimal solution and still remains cost-effective when compared to the reference case which includes an “anyway renovation”. A far-reaching solution maximizes the co-benefits achieved with the intervention and consequently the added value of the building.

## Recommendation # 10:

### Whole building renovation is preferable instead of maximizing the energy performance of just one or few individual elements

In the existing building stock, buildings often have several building elements with low efficiency performance. A higher impact is achieved if several building elements are involved in the building renovation process than just act on a single building element alone.

However, it is advisable to choose a high efficiency level as target if the energy performance of an element of the building envelope is improved since it is much cheaper to achieve a high insulation standard for a certain building element in one step rather than to insulate first to some degree and to increase the energy performance at a later stage. Often, measures that reach high efficiency levels are at the same level of cost-effectiveness as the low efficiency measures.

Additionally, energy efficiency measures are the source of many co-benefits, particularly those improving building quality, such as the reduction of problems with building physics, increase of useful building areas and improved safety against intrusion, and the resident's comfort and physical wellbeing, such as increased thermal and acoustic comfort, increased use of day lighting and better indoor air quality. To maximize the co-benefits from energy related building renovation, it is more relevant to improve as many elements of the building envelope as possible, than to significantly improve just few of them.

## Recommendation # 11:

### Take into account the challenges of integrating renewable energy

At the building level, measures for the use of renewable energy sources usually have as co-benefits the reduction of the exposure to energy price fluctuations. Residents with systems based on renewables (with the exception of systems based on wood pellets) are more comfortable regarding future variations on the energy prices because they

are less dependent on energy from the market.

Some renewable energy systems present specific challenges regarding their integration into existing buildings. Some of these systems (e.g. photovoltaic or solar thermal) present a challenge for their integration into the architectural characteristics of the existing buildings, while others (e.g. geothermal heat pumps) present technical or financial challenges to be implemented. On the other hand, some of these systems (e.g. air/air or air/water heat pumps or wood pellets boilers) are much easier to implement than most energy efficiency measures and may allow reducing the depth of the interventions on the building envelope.

renovation. The relationship between them should be improved, in terms of laws and regulations, so that these two players can be more coordinated towards the motivations and benefits of building renovation.

## Recommendation # 12:

### **Consider energy related building renovation as an opportunity to increase building (stock) value**

The economic value of the existing building stock is an important asset whose value can be potentiated in an optimized way. By saving future energy costs, energy related building renovations increase the value of the renovated buildings. The co-benefits further contribute to improving the building value.

## Recommendation # 13:

### **Assure inclusion of tenants in building renovation processes**

In rented buildings, tenants should be involved in the renovation process, so that they can feel more engaged in that process and consider the renovation as positive and understand the long-term environmental benefits.

Quite often, the relation between housing companies and residents is critical for the acceptance of the latter towards building



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