



## Conference Proceedings

# Sustainable Built Environment Conference 2016 in Hamburg

## Strategies, Stakeholders, Success factors

7<sup>th</sup> - 11<sup>th</sup> March 2016

# Program Overview

	Monday 7.3.2016	Tuesday 8.3.2016	Wednesday 9.3.2016	Thursday 10.3.2016	Friday 11.3.2016
8.00-9.00 a.m.		Registration	Registration	Registration	
9.00-10.30 a.m.		Opening Keynotes	Scientific sessions Housing Industry Day	Scientific sessions Day of Architecture, Planning & Engineering	PhD Session
10.30-11.00 a.m.		Coffee	Coffee	Coffee	
11.00 a.m.-12.30 p.m.		Scientific sessions Day of Municipalities	Keynote Session UN Climate Change Conference	Scientific sessions Day of Architecture, Planning & Engineering	PhD Session
12.30-2.00 p.m.		Lunch	Lunch	Lunch	
2.00-3.30 p.m.	Excursions	Scientific and special sessions Day of Municipalities	Scientific and special sessions Housing Industry Day	Final Session Excursions	PhD Session
3.30-4.00 p.m.		Coffee	Coffee	Coffee	
4.00-5.30 p.m.		Scientific and special sessions Day of Municipalities	Scientific and special sessions Housing Industry Day	Day of Architecture, Planning & Engineering	
5.30-7.00 p.m.	Warm-up and exhibition opening	Welcome and Networking-Reception for all participants (Handelskammer)	Get Together and Award Ceremony (Holcim Study Award)		
					Scientific Session Session in German language PhD Session

# SBE16 Hamburg

## International Conference on Sustainable Built Environment Strategies – Stakeholders – Success factors

7<sup>th</sup> - 11<sup>th</sup> March 2016

### Conference Proceedings

Organised by



## Imprint

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## Table of content

SBE16 Hamburg – a brief introduction .....	10
The program committee of the SBE16 Hamburg welcomes you! .....	12
Scientific committee .....	14
Exhibitors .....	15
List of authors.....	16
Program overview .....	19
<b>Full paper</b>	
<b>Ses 1.1   International experience</b>	
Sustainability profile of urban planning in Algiers .....	1134
Learning from Ethiopia – A discussion on sustainable building.....	796
Resilient Community Centers for Nepal Earthquake Victims .....	1002
Green Buildings: A Concept aligning the interests of Stakeholders (Developers / Clients and End-users) in Estate Development Projects in Abuja - F.C.T (Federal Capital Territory), Nigeria ...	622
Solar collectors in a prefabricated housing estate: lessons learnt after four years of operation ..	1060
BuildNow! – Research and Training .....	184
<b>Ses 1.2   Energy supply for urban areas</b>	
Buildings as active components in smart grids .....	168
Renewable Energy and Thermal Comfort in Buildings as Smart Grid Components.....	982
Effects of energy efficiency measures in district-heated buildings on energy systems .....	448
The aspect of space in future energy systems.....	1226
Development of a simple approach for applying LCA analysis to compare decentralized energy supply options for urban areas.....	370
<b>Ses 1.3   Valuation and selection of construction products</b>	
Environmental product declaration (EPD) for sustainable construction – new challenges .....	516
LCA, EPD and Labels – How to Select Green Building Products?.....	776
Ecolabelling of Building materials in Russian Federation: condition and prospects .....	420
European LCA data network – open public online database and data format of ÖKOBAUDAT as a starting point? .....	526
<b>Ses 2.1   Net zero and plus energy buildings</b>	
Design for minimum life cycle energy and emissions (minLC <sub>ee</sub> ) building .....	302
Potential and Risk for Zero-Energy-Buildings under Defined Urban Densities .....	942
Design phase calculation of greenhouse gas emissions for a Zero emission residential pilot building .....	312
Graphical User Interface for Plus Energy Multi-family houses .....	612
Life cycle approach as a method for optimizing building services systems in extremely low energy buildings.....	806
<b>Ses 2.2   Education I</b>	
Environmental and Social Concerns in Architectural Education: Experience of School of Architecture, Tianjin University .....	496
Where do architectural design ideas come from? A sustainability and bioclimatic-oriented teaching experience.....	1332
Teaching Sustainability & Strategies of Reuse: Critically Examining Sustainable Design Parameters and Methods of Evaluation .....	1216
Creating Awareness for Sustainable Construction through Practice-Oriented Teaching in Architectural Education in Eastern Africa.....	276
Integrating Climate Responsive Principles into the Design Process: Educating the Architect of Tomorrow.....	736
<b>Ses 3.1   Building integrated solutions and new technologies</b>	
benefit E, Strategies for building integrated solaractive systems .....	128

Green Roof Integrated Photovoltaics: Technology and Application on a high-rise settlement in Hamburg, Germany .....	632
On your roofs – get set – Green! .....	902
Assessment of sensing performance of wireless illuminance sensors in built environment.....	110
Effects of a building-integrated photovoltaic system on a high-rise estate in Hamburg, Germany .....	428
Functional building surfaces - Self-sufficient facade module .....	592
<b>Ses 3.2   Education II</b>	
Integrating Urban Ecodesign in French engineering curricula: an example at École des Ponts ParisTech .....	746
Sustainable Housing Design. Integrating technical and housing quality aspects of sustainable architecture in civil engineering education. ....	1154
Learning by Doing.....	786
Conceptual Design and Development of a Study Program in the Field of Climate Protection Management .....	246
Sustainable Real Estate Education: Competencies and Didactics for a Transdisciplinary Master's Program.....	1184
<b>Ses 3.3   Infrastructures and constructed assets</b>	
Evaluation of Sustainable Infrastructure – Using the Southern Quay of the Island of Heligoland as a Case Study .....	556
Life cycle assessment of small road bridges: Implications from using biobased building materials ..	816
Assessing the Sustainability Performance of Sports Facilities – Methodology and Case Studies .....	92
Environmental performance of urban transit modes: a Life Cycle Assessment of the Bus Rapid Transit .....	506
<b>Ses 4.1   Urban design and mobility</b>	
Promoting Sustainable transport – Reviewing the case of pioneer cities .....	962
Shenzhen's New Energy Vehicles and charging infrastructure – policies, instruments and development .....	1040
Commercial areas achieving the zero emission goal using the potentials of electric mobility: The eCar-Park Sindelfingen .....	238
Assessment of Walking Experience in Kitakyushu, Japan.....	120
<b>Ses 4.2   Timber structures and biobased products</b>	
Timber Building Details for a Leaner Design Process .....	1286
Carbon storage and CO <sub>2</sub> substitution in new buildings.....	200
The linkage of environmental requirements with the selling of building plots – an example....	1266
Biocomposites for architectural applications based on the second generation of natural annual renewable resources .....	138
<b>Ses 4.3   Standardisation, regulation, innovation</b>	
A Comparison of How Sustainability and Green Building Standards are being adopted into Building Construction Codes within the United States and the EU .....	42
Sustainability elements in the Danish Building Regulations.....	1124
Building for the Gap. Innovative engineering for housing applications in Africa. ....	148
Research on Innovation Development for Residential Real Estate Investment Projects.....	992
<b>Ses 6.1   Development of urban districts I</b>	
Decision Support Environment – assisting the transformation of built environment towards sustainability .....	286
Sustainable neighbourhood in Saint-Petersburg .....	1164
Planning of ecologically and economic optimized district refurbishments.....	932
A holistic Methodology for District Retrofitting projects management through an Integrated Decision Support Tool.....	62
Supporting urban district development by accompanying sustainability assessment .....	1104



**Ses 6.2 | Sustainable assessment systems – further development and application**

Towards Unified Sustainable Buildings Rating System Categories through Assessing Buildings' Life Cycle Sustainable Requirements .....	1296
Development of the LCAByg tool: influence of user requirements and context .....	380
Development of a cost-effective sustainability assessment method for small residential buildings in Germany: Results of pilot case studies .....	352
Certification of Sustainability: Results from Practice .....	210
User-friendliness of current building environmental impact assessment tools: an architect's perspective .....	1306

**Ses 6.3 | Portfoliomanagement & improvement of building stock**

Implementation of Sustainability Success Factors in Processes of Portfolio Management .....	680
Improving energy performance: many small interventions or selective deep renovations?.....	690
Guiding the building stock to a post-carbon future.....	642
Single family home stocks in transition – implications for urban resource efficiency.....	1050
Monitoring of Energy-Saving Processes in Residential Building Stocks .....	856

**Ses 6.4 | Stakeholder perspectives and actions I**

Documenting sustainable business practices of housing companies: Sector-specific supplement to the German Sustainability Code (Deutscher Nachhaltigkeitskodex, DNK) .....	400
How Future-proof Is Your Campus? Sustainability in the Real Estate Management of Research Organizations .....	660
Capturing sustainable housing characteristics through Electronic Building Files: The Australian Experience .....	190
Embodied impacts in stakeholder decision-making in the construction sector .....	458
Emerging Envelopes: Design Education for adaptive and sustainable Facades .....	468

**Ses 7.1 | Development of urban districts II**

Enabling energy sufficiency as a sustainable development concept in shrinking urban districts: the case of Wuppertal-Vohwinkel .....	478
Local initiatives for motivating Danish house-owners for energy improvements .....	826
Institutional conditions for sustainable private sector-led urban development projects: A conceptual model.....	726
„degewo Zukunftshaus“: Concepts for sustainable energetic rehabilitation of buildings.....	296

**Ses 7.2 | LCA-application and further development**

Building life cycle assessment: investigation of influential parameters in a helpful decision tool ..	158
Effects of different reference study periods of timber and mineral buildings on material input and global warming potential.....	438
Innovative building technologies and technical equipment towards sustainable construction – a comparative LCA and LCC assessment.....	716
Application of a parametric LCA tool in students' design projects.....	72

**Ses 7.3 | Public sector – activities and experiences**

Faithfulness in small things? .....	582
Sustainable Public Procurement of construction works – a literature review and future requirements.....	1174
Exemplary Results of the Implementation of the Assessment System BNB in the Public Sector...566	
Monitoring of the new building of the Ministry for Urban Development and Environment in Hamburg .....	866
Developing Abu Dhabi's Sustainability Energy Index .....	332

**Ses 7.4 | Stakeholder perspectives and actions II**

Stakeholders Awareness of Green Building and Sustainable Development Issues in Abuja, Nigeria.....	1068
Sustainability survey amongst architects in the German state of Baden Wurttemberg on the adaptation level of sustainability aspects in the real estate sector .....	1144

Risk Management for Construction Green Building in Kuwait .....	1030
Success Criteria for Green Building Projects in the Nigeria's Construction industry: "The Stakeholders' perception" .....	1094
Evaluation of risks associated with bonds and guarantees in construction projects .....	546
Determining Characteristics in Developing Economies that Influence Sustainable Construction...	330
<b>Ses 8.1   Urban development under specific conditions</b>	
The Future of Urban Development in Egypt under the Impact of Water, Fossil Fuel Energy and Climate Change Barriers, Green Infrastructure and Renewable Energy as Sustainable Urban Development Approaches .....	1246
A Case Study of Rainfall Water Harvesting Effects on Runoff for Guzelyurt, Northern Cyprus....	34
Evaluation of green roof hydrologic performance for rainwater runoff management in Hamburg .....	536
Asphalt Solar Collectors contribution to the Urban Heat Island Effect under Hot Arid Climate Conditions .....	82
Assessment of Land Use/Cover Change and Urban Expansion in Tehran, Iran, by using GIS and remote sensing.....	100
<b>Ses 8.2   Construction products and processes</b>	
Hempcrete from cradle to grave: the role of carbonation in the material sustainability .....	650
Thermal mass behaviour of concrete panels incorporating phase change materials .....	1276
The effect of water dosage on the properties of wet spray cellulose insulation .....	1236
Increase in Efficiency and Quality Control of Construction Processes through Off-Site Fabrication .....	706
Characterization of Fly Ash/Metakaolin-based Geopolymer Lightweight Concrete Reinforced Wood Particles .....	220
<b>Ses 8.3   Design stages – importance and contribution</b>	
Strategies Analysis on Simulation Application of Sustainable Strategies Development in the Conceptual Design .....	1084
Optimizing Low Carbon Retrofit Strategies in Residential Buildings from the point of Carbon Emission and Cost-effective .....	922
Impact of the Project Initialization Phase on the Achievement of Sustainable Quality in Building Projects in China .....	670
WECOBIS: The Challenge of Planning with Ecological Construction Material .....	1326
Naturalism in Architecture .....	876
Pre-Design Steps for Regeneration of Urban Texture .....	952
Integration of building performance simulation tools in an interdisciplinary architectural practice .....	756
<b>Ses 8.4   Cooling, ventilation and air conditioning</b>	
Façade design for night cooling by natural ventilation in different climate zones .....	572
Ventilative Cooling Potential .....	1316
Occupant discomfort due to background passive ventilation .....	862
Energy-plus primary school Hohen Neuendorf: Measurement based evaluation of a hybrid ventilation system .....	488
The geocooling, bioclimatic solution to conventional air – conditioning for existing residential buildingconditioning .....	1256
A Design for Improved Natural Ventilation in Housing Development in Thailand.....	52
<b>Ses 9.1   Urban planning and energy</b>	
Optimization of energy planning strategies in municipalities: Are community energy profiles the key to a higher implementation rate of renewable energies? .....	912
Strategic Urban Energy Planning – Vienna 2050.....	1078
Networking Intelligent Cities for Energy Efficiency – The Green Digital Charter Process and Tools .....	886
Designing and retrofitting the urban structure with daylight.....	322



Modelling approach for the thermal response of a residential building equipped with a CHP unit in an urban area .....	846
Global Sequential Sensitivity Analysis for Building Energy Simulation of Residential Quarters ...	602
Climatic Zones in Poland and the Demand for Heating in a Typical Residential Building.....	228
<b>Ses 9.2   Cost and value – the economic point of view</b>	
Investment vs. subsequent costs – the significance of occupancy costs in real estate life-cycle ...	766
Marginal costs and benefits in building energy retrofitting transaction .....	836
Buildings energy retrofit: dealing with uncertainty .....	174
Risk and scenario-based approach assessing sustainability .....	1020
Drivers for change: Strengthening the role of valuation professionals in market transition – insights from the RenoValue research project.....	410
<b>Ses 9.3   Collaboration and user involvement</b>	
Diversification of construction projects by implementing collaboration and information sharing tools .....	390
Cooperative Housing Models in Zurich. Or: Can sustainable, affordable and socially-mixed housing be realised together?.....	266
30 years after – case study of ‘Ökologische Gemeinschaftswohnanlage Nofels’ (ecological housing cooperative Nofels).....	24
Rehabilitation of Public and Semi-Public Space of Housing Estates: the Case of Lubartow ....	972
Improving energy retrofit strategies with definitions of human interaction parameters in residential building.....	696
<b>Ses 9.4   Resource efficiency and recycling</b>	
Resource saving potentials through increase recycling in the building sector – sensitivity studies on current and future construction activity .....	1010
Constructions suitable for recycling .....	256
Sustainable Urbanism: Research-based collaboration of intercultural and transdisciplinary student teams towards resource-efficient solutions for challenges of current urban planning on exemplary neighbourhoods in Hamburg .....	1206
Sustainable re-use of a building in the case of cultural industries: ‘salt galata’ on voyvoda streer in Istanbul .....	1196
Developing the Brighton Waste House: from zero waste on site to re-use of waste.....	342
Development of a Raw Material Model for Urban Systems – A Contribution to Support Material Flow Analysis and Resource Management.....	362
Sustainability assessment tool for building materials .....	1114
<b>Full paper of Special Sessions</b>	
PLANNING FOR ENERGY EFFICIENT CITIES –	
How to achieve the sustainable Energy Smart City – The PLEEC Final Conference .....	1344
EPD and use of external data for building calculation in Denmark.....	1348
European LCA data network – open public online database and data format of ÖKOBAUDAT as a starting point? .....	1350
Implementing European harmonised EPD .....	1352
Materials environmental performance data for building level assessments – a UK perspective.....	1354
The Experience – Rules and verification processes .....	1356
The Experience of data import and export as EPD program operator .....	314
Towards a European Data Network for Construction Product EPDs.....	316
Assessment of daylight conditions in the office room equipped with reflective louver system ....	318
Energy efficiency of experimental BIPV façade in high temperatures.....	320
Temperature distribution in the mineral wool insulation component enhanced by PCM external covering.....	322

## SBE16 Hamburg – a brief introduction

„SBE16 Hamburg“ is an international scientific conference on sustainable building that is part of the Sustainable Built Environment Conferences series 2016/2017. The series is run by the International Council for Research and Innovation in Building and Construction (CIB), the International Initiative for a Sustainable Built Environment (iiSBE), the Sustainable Building and Climate Initiative (SBCI) of the United Nations Environment Programme (UNEP), and the International Federation of Consulting Engineers (FIDIC).

The conference series follows a ten-year tradition. Held in three-year intervals in different cities around the world, the conference series has established itself as one of the major events in this field. Following the World Conference in Barcelona in 2014, 20 regional conferences will take place in 2016 to prepare for the next World Conference in Hong Kong in 2017 and bring together thousands of players in the field of sustainable construction.

The title of SBE16 Hamburg, the regional conference in Germany, is „**Strategies, Stakeholders, Success factors – Strategien, Akteure, Erfolgsfaktoren**.“ With this title SBE16 Hamburg exemplifies what the general framework for sustainable construction must consist of and which procedures, influences, interactions and stakeholders, in fact, need to be part of a successful implementation. It focuses geographically on Germany, Scandinavia, Poland, the Baltic States and Russia, and is aimed at scientists, architects, city planners and engineers, politicians, stakeholders, the real estate industry, and municipalities.

The **Scientific Advisory Board** of SBE16 Hamburg is composed of more than 80 international and recognized scientists and experts who evaluate independently and anonymously all submissions to the conference and thus ensure the scientific quality of the event. Presiding over the Scientific Advisory Board are Professor Thomas Lützkendorf (Karlsruhe Institute of Technology), Professor Peter O. Brown (HafenCity University Hamburg), and Professor Natalie Eßig (University of Applied Sciences Munich).

The **multi-faceted program** provides congress participants with the opportunity for intensive exchanges and knowledge gain and thereby also fosters experiences. The aim is to bring together scientists, planners and representatives from politics and business to discuss science, policy and practice with one another, thus contributing to a targeted and effective exchange of knowledge.

SBE16 Hamburg consists of various components: a combination of scientific knowledge, research results, and examples of practical implementation and innovation. The conference planners have made this possible by building into the agenda a diverse lecture program, ample opportunities for communication and networking, and a varied menu of excursions.

The lecture program consists of plenary, scientific contributions, and, for German-speaking participants, **subject-specific theme days**.

In the **plenary** opening by the event organizers, speeches and greetings will be given by representatives of the main sponsors of SBE16 Hamburg as well as German and international representatives of the political and scientific arenas. The national political representatives include Federal Minister for the Environment, Nature Conservation and Nuclear Safety, Dr. Barbara Hendricks and the Second Mayor of the Free and Hanseatic City of Hamburg, Katharina Fegebank. Nils Larsson (iiSBE) and Prof. Dr. Lützkendorf (KIT) will cover the significance of this conference series. Keynotes will be delivered by Professor Mojib Latif of GEOMAR Kiel and Hans-Dieter

Hegner from the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety.

A program of outstanding speakers will accentuate once again the results of the **UN Climate Change Conference in Paris COP 21** and highlight key issues and challenges during the second plenary session on Wednesday morning. Nils Larsson (iiSBE) will convey his impressions of his participation at the Paris conference. He will be followed by Stefan Schurig (World Future Council) on the impact on future cities and Dr. Harry Lehmann (German Federal Environment Agency) on the consequences of the UN climate summit for the construction and property industry.

The **scientific sessions** will take place over the three main days of the event (Tuesday to Thursday) with parallel sessions consisting of 10-minute presentations by national and international researchers, whose submissions were reviewed and selected by the SBE15 Hamburg Scientific Advisory Board. Around 150 papers from 34 countries will be presented, and each presentation will be followed by a brief discussion. In addition, contributions in the form of posters will be introduced in short talks at the end of some sessions.

The opportunity to **network and talk** with others is an essential part of SBE16 Hamburg. An accompanying exhibition of industrial partners, 'chat breaks,' and various evening events and excursions offer participants the chance to discuss scientific findings and link them with practice.

The **exhibition** takes place in the foyer of the HafenCity University, which forms the spatial intersection of all other activities of SBE16 Hamburg. Designed as a communication area, the space allows visitors to learn about the innovations of the supporting partners.

Within the program framework, on Monday, Wednesday and Friday the interplay of lectures and discussions will be rounded by several **excursions**. Through these conferences participants will be able to witness examples of sustainable building in practice. The program includes excursions to a variety of interesting locations and construction projects, such as the urban development project HafenCity Hamburg, where the event venue - HafenCity University (HCU) - is located.

**SBE16 Hamburg thematic focuses:**

- Strategies and frameworks for sustainable construction and sustainable urban development
- Innovative concepts and case studies in sustainable neighborhood and urban development
- Project development and sustainability
- Application of sustainability tools and methods in the construction and property industry
- Research on innovative materials and products
- Expression of sustainability in education and training

## The program committee of the SBE16 Hamburg welcomes you!



Prof. Dr.-Ing. habil. Thomas Lützkendorf,  
Karlsruhe Institute of Technology (KIT), Head of the Scientific Committee

Prof. Dr. Natalie Eßig, Munich University of Applied Sciences (MUAS)  
Prof. Peter O. Braun, HafenCity University Hamburg (HCU)

Both the planning, construction and operation of buildings in accordance with the principles of sustainable development, and the further development of the building stock and infrastructures to improve the quality of the built environment require the active involvement of all relevant stakeholders. Being dedicated to these topics, SBE16 Hamburg has a scientific program that is specifically addressed, among others, to representatives from research and education and to the staff of municipal administration, housing companies, and real estate and portfolio management companies. The discussions of how aspects of sustainability can be integrated in the processes of planning and decision making, of which strategies and solutions are available, and of how success can be measured are the thematic continuation of the SB 13 Munich Conference. It is not only the provision of calculation and evaluation methods, of design principles and design tools or of new structural and technical solutions that decides on the success of sustainable construction. As a matter of fact, the respective approaches need to be in demand, to be applied successfully, and to offer clear advantages to the environment, society, and industry. SBE16 Hamburg tries to overcome the traditional separation between science and practice. Contributions on the further development of methodical approaches are complemented by presentations of practical examples and analyses of experiences.

The international sustainable building conference series, within which Hamburg is the host city, has developed its range of subjects and has clearly expanded its focus to comprise all aspects of the design of a sustainable built environment. SBE16 Hamburg caters to this development by offering a program emphasizing a sustainable development in neighborhoods and urban districts. This focus is supported by discussions of issues related to the interaction between buildings and the grid. In addition, SBE16 Hamburg deals with the further development of national and company-owned building stock to achieve the objectives of climate protection and with the sustainable planning, construction and operation of civil engineering structures and constructed assets.

We are pleased that we will be able to benefit from many contributions by young researchers and PhD students. Whereas it becomes clear that the issue of sustainability is rather widespread in research and practice, future generations of specialist and executive staff may profit from some sessions dedicated to the integration of aspects of sustainability into the further education of planners, real estate agents, and specialists for property evaluation.

The conference is the perfect platform for scientific exchange between national and international participants. The results of inter- and transdisciplinary research projects with partners from several countries are presented in various contributions, and international experience is communicated.

We are very grateful to the members of the International Scientific Committee who have ensured the scientific quality of the conference by participating in the preparation and holding of SBE16 through reviewing papers and taking over organizational tasks.

We wish all guests and participants successful days and interesting encounters while being in Hamburg.

*Thomas Lützkendorf, Natalie Eßig, Peter Braun*



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## List of authors

Abbe, Owen .....	1354	Chien, Szu-Cheng.....	110
Abd El Fattah, Ahmed.....	1296	Cicek, Burhan.....	72
Aje, Olaniyi.....	546	Copiello, Sergio.....	174, 836
Akintug, Bertug .....	34	Cronhjort, Yrsa.....	1286
Alavi, Ali .....	100	Czarnigowska, Agata.....	972, 1060
Albiez, Marius.....	1104	Dahlquist, Erik.....	1344
Albus, Jutta .....	706	Dahman Meyersson, Sarah.....	756
Alho, Carlos.....	1114	Dahy, Hanaa .....	138
Al-Qawasmi, Jamal.....	1296	Daugélienė, Ala.....	992
Alsalmi, Huda.....	332	Davidse, Bart Jan.....	902
AlSanad, Shaikha .....	1030	de Bortoli, Anne .....	506, 746
Amorrortu, Ander Romero .....	62	de Lima Vasconcelos, Silvia.....	1114
Amundsen, Harald .....	312	Deilmann, Clemens.....	1010
Andes, Lisa .....	660	Deliberador, Marcella.....	1332
Andresen, Inger.....	312	Dewancker, Bart.....	120
Anthrakidis, Anette.....	246	Diakite, Aicha .....	322
Apanaviciene, Rasa.....	992	Dickhaut, Wolfgang.....	34, 536, 902, 1040
Arrigoni, Alessandro .....	650	Diefenbach, Nikolaus .....	856
Ashour, Anan.....	468	Dietrich, Udo .....	736,942, 1206
Asif, Muhammad .....	1296	Dietz, Sebastian.....	488
Babsail, Mohammad .....	1296	Dissel, Peter.....	148
Bajere, Paul Abayomi.....	1068	Donath, Dirk .....	148, 796
Baker-Brown, Duncan.....	342	Dotelli, Giovanni.....	650
Balarabe, Hadiza .....	622	Drebes, Christoph .....	128
Balaras, Constantinos A.....	42	Duus, Kristian.....	866
Balouktsi, Maria .....	458, 1104	Ebert, Marcel.....	72
Bannier, Florence.....	1286	Elewa, Ahmed .....	1246
Baron, Nicole.....	796	Elrefeie, Hussameldeen Bahgat.....	876
Bauer, Martin.....	982	Erlandsson, Martin.....	816
Beckmann, Bertram.....	246	Eßig, Natalie.....	62, 92, 352
Berezowska Azzag, Ewa .....	1134	Farrelly, Dermot.....	756
Bhattarai, Deepak.....	1002	Féraillé, Adélaïde .....	506, 746
Bi, Xiaojian .....	1084	Fernandes, Luciana .....	572
Birgisdóttir, Harpa .....	380, 1124	Fertner, Christian .....	1344
Blum, Andreas.....	886, 1050	Fischer, Gernot.....	716
Bohara, Alok K. ....	1002	Flamme, Sabine .....	256
Boje Groth, Niels.....	1344	Flayyih, Mustafa.....	846
Borkowski, Esther .....	556	Foliente, Greg .....	458
Bornholdt, Hanna.....	902	Friedrich, Matthias .....	572
Borowczyński, Artur.....	1362	Friedrich, Thomas .....	680
Bosch, Georg .....	556	Friis, Freja .....	826
Bougain, Aude.....	670	Gabrielli, Laura.....	174, 836
Brockmann, Tanja .....	526, 1350	Gampfer, Susanne .....	276
Bychkova, Mariya.....	1164	Geier, Sonja .....	1286
Campillo, Javier.....	1344	Giannousopoulou, Maria-Ioanna.....	736
Celik, Bilge Gokhan .....	330	Gidado, Salisu Dalibi.....	1094
Chan, Yiu Wing .....	110	Giffinger, Rudolf .....	1344
Chebel Labaki, Lucila .....	572	Gomes da Silva, Vanessa.....	1332
Chen, Hsiao-Hui.....	942	Gomes, Vanessa.....	302

Good, Clara Stina .....	312	König, Holger .....	200
Görner, Klaus .....	846	Kopfmüller, Juergen .....	1104
Gottschalk, Wiebke .....	400	Kotelnikova, Natalia .....	746
Graf, Roberta .....	932	Kowwaltowski, Doris .....	1332
Gram-Hanssen, Kirsten .....	826	Krause, Karina .....	438, 1266
Gramm, Rafael .....	670	Krauß, Norbert .....	1050
Graubner, Carl-Alexander .....	370	Kristjansdottir, Torhildur Fjola .....	312, 806
Gröne, Marie-Christine .....	478	Kullman, Mikael .....	1344
Große, Juliane .....	1344	Kumo, Hassan Ali .....	1094
Grudzińska, Magdalena .....	228	Kuperjans, Isabel .....	246
Gruhler, Karin .....	1010	Kusche, Oliver .....	1360
Gruthoff, Stefan .....	184	Lasshof, Benjamin .....	766
Gumpp, Rainer .....	72	Lattke, Frank .....	1286
Gustavsson, Leif .....	448	Lauer, Johannes .....	1040
Haas, Stefan .....	1326	Lauring, Michael .....	1154
Hafner, Annette .....	438, 1266	Lawrence, Thomas .....	42
Hager, Karsten .....	238	Lehmann, Burkhard .....	1358
Haile, Asgedom .....	148	Leurent, Fabien .....	506, 746
Haindlmaier, Gudrun .....	1344	Liebold, Bert .....	592
Hammer, Renate .....	1078, 1316	Lima, Bruno .....	302
Hartenberger, Ursula .....	410	Lindauer, Manuel .....	602
Haselberger, Julia .....	1344	Lindner, Sara .....	352
Heim, Dariusz .....	1362, 1364, 1374	Linne, Katrin .....	592
Heinrich, Matthias .....	362	Lippe, Heiner .....	184
Henriquez, Andrea .....	736	Liu, Conghong .....	922, 1084
Heurkens, Erwin .....	726	Liu, Li .....	922
Høeg, Mathias .....	1348	Liu, Shida .....	496
Hofstadler, Christian .....	1174	Loeser, Jonas Karl .....	1144
Hollberg, Alexander .....	72	Loga, Tobias .....	856
Holzer, Peter .....	1078, 1316	Lopez Hurtado, Pablo .....	1236
Horn, Rafael .....	932	Lorenz, David .....	410
Isa, Rasheed Babatunde .....	1068	Lützkendorf, Thomas .....	190, 410, 458, 660, 1104
Jäger, Michael .....	932	Machniewicz, Anna .....	1374
Jahani, Elham .....	34	Magdolen, Simone .....	92
Jakutyte-Walangitang, Daiva .....	286	Mai Auduga, Jamilu Bala .....	622
Jäppelt, Ulrich .....	556	Makhlouf, Said .....	1256
Jensen, Jesper Ole .....	826	Markham, James R. .....	1002
Kaempf-Dern, Annette .....	1184	Martinsen, Milena .....	1050
Karimian, Bahram .....	100	McCormack, Sarah .....	1276
Keiser, Jan .....	168	Means, Janice K. .....	42
Khoja, Ahmed .....	62, 82	Meex, Elke .....	1306
Khoshnood, Sahar .....	952	Mehdipour, Zahra .....	696
Kietzmann, Anita .....	1358	Miller, Wendy .....	190
Kinnane, Oliver .....	892, 1276	Mitterer, Christoph .....	670
Kirmayr, Thomas .....	670	Mittermeier, Paul .....	62
Kluczka, Sven .....	246	Mohamadi, Hossien .....	100
Knapen, Elke .....	1306	Mortensen, Lone H. .....	1124
Knera, Dominika .....	1364	Mötzl, Hildegund .....	1356
Knies, Jürgen .....	1226	Mu, Yu-Yangguang .....	496
Knoop, Martine .....	322	Müller, Birgit .....	1114
Koch, Annkatrin .....	612	Nakashima, Yuki .....	120

Neitzel, Michael.....	400	Schwede, Dirk.....	670
Nguyen Le, Truong.....	448	Secmen, Serengul.....	1196
Niall, Dervilla.....	1276	Seiler, Lisa.....	766
Nieboer, Nico.....	690	Shittu, Usman Abdulwahab.....	1068
Nishida, Hirofumi.....	120	Siangprasert, Wannaporn.....	52
Nuzir, Fritz Akhmad.....	120	Sick, Friedrich.....	168, 296, 488
Ogunlana, Stephen.....	546	Silva, Maristela.....	302
Ogunsemi, Deji.....	546	Sinning, Heidi.....	266
Oke, Ayodeji.....	546	Sinnott, Derek.....	892
Ollig, Monika.....	642	Snarski, Joshua W.....	330
Osman, Dalia Abdel Moneim.....	962	Sölkner, Petra.....	716
Ostanska, Anna.....	972, 1060	Soong, Boon Hee.....	110
Pannier, Marie-Lise.....	158	Spaun, Sebastian.....	716
Pantze, Anna.....	816	Srir, Mohamed.....	1134
Papadopoulos, Antonia.....	330	Staab, Fabian.....	370
Passer, Alexander.....	716	Stein, Britta.....	856
Pelosato, Renato.....	650	Steuri, Bettina.....	428, 632
Penaloza, Diego.....	816	Stollenwerk, Dominik.....	246
Peters, Terri.....	1216	Stone, Mark C.....	1002
Peters-Anders, Jan.....	286	Stoy, Christian.....	766, 1020
Petersen, Jens-Phillip.....	912	Strohmayer, Florian.....	1344
Peuportier, Bruno.....	158	Strunk, Sarah Ok Kyu.....	1020
Pottgiesser, Uta.....	468	Sum, Yee Loon.....	110
Pousette, Anna.....	816	Sun, Lu.....	496
Preuner, Philipp.....	1206	Tayebi, Safiye.....	100
Ramapuputla, Matau Andronica.....	390	Tønnesen, Jens.....	806
Rasmussen, Freja.....	380	Tseng, King Jet.....	110
Raynaud, Christine.....	1236	Turner, William J.N.....	892
Reuther, Iris Marie.....	582, 786	Unholzer, Matthias.....	660
Richter, Michael.....	536, 902	Unterrainer, Walter.....	24
Rid, Wolfgang.....	238	Vandenbossche, Virginie.....	1236
Riediger, Nicole.....	168	Verbeeck, Griet.....	1306
Rietz, Andreas.....	566	Verseckiené, Rimanté.....	992
Roether, Katja.....	1184	Vignola, Gionatan.....	428, 632
Rohde, Catharina.....	256	von Grabe, Jörn.....	82
Rouilly, Antoine.....	1236	Wall, Johannes.....	1174
Russell, Mark D.....	1002	Wankanapon, Pimonmart.....	52
Ruth, Jürgen.....	72, 592	Weißmann, Claudia.....	370
Saade, Marcella.....	302	Wellershoff, Frank.....	572
Salisu Gidado, Dalibi.....	622	Welsch, Merten.....	210
Sarmin, Siti Noorbaini.....	220	Wenzler, Ivo.....	286
Schadow, Thomas.....	556	West, Roger.....	1276
Schäfer, Sabrina.....	438, 1266	Wurzbacher, Steffen.....	128
Schalbart, Patrick.....	158	Yang, Hongwei.....	922
Schlipf, Sonja.....	1206	Yang, Wei.....	496
Schmid, Manfred.....	238	Zeidler, Olaf.....	1114
Schmincke, Eva.....	516, 1352	Zermout, Ratiba.....	1256
Schmitz, Gerhard.....	866	Zhang, Yifan.....	496
Schmitz, Thomas.....	776	Zhuk, Petr.....	420
Schuberth, Jens.....	642	Zwerenz, Stefan.....	1358
Schütz, Stephan.....	72		

## Buildings energy retrofit: dealing with uncertainty



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### Summary

Over the span of the past decade, the interest in issues related to building energy efficiency has been ever growing. Consequently, an increasing amount of studies has focused on the economic viability of energy retrofit measures. Despite all these research efforts, the results are still uncertain and conflicting. Nonetheless, such studies have brought out the main variables affecting the economic feasibility of interventions improving building energy performance: savings-investment ratio, cost-effectiveness of energy supply, energy price trends.

The aim of this paper is to investigate the relevance of an often disregarded aspect: the rate of time preference as an expression of households' behaviours, that is to say, the discount rate adopted within several valuation approaches, which are based on discounted cash flow. A case study analysis is performed on a refurbishment project. It concerns a public housing estate, built during the seventies, located in the suburbs of Bologna. A number of retrofit alternatives are examined, by resorting to different judgement criteria, particularly the Net Present Value.

It is shown that uncertain results may occur repeatedly, more frequently than literature has evidenced. Moreover, unclear outcomes closely correlate to the discount rate level, which may lead to conflicting options; therefore, it is hard to unequivocally identify the alternative characterized by the highest NPV.

**Keywords:** Building energy efficiency; uncertainty; property investment valuation; Discounted Cash Flow; discount rate.

### 1. Introduction

In the Italian context, the building performance issue entered into the political debate during the mid-seventies. As a consequence of the Oil Shock, the Law 373/1976 provided a first set of rules to reduce energy consumptions of residential buildings, focusing particularly on the standards required to be met by the building envelope and the heating installation. Subsequently, a major update of the legal system in this matter came into being fifteen years later, with Law 10/1991, which has enforced the so-called first national energy plan. Latest developments have been fostered by the EU energy policy: two main steps have been accomplished by Directives 2002/91/EC and 2010/31/EU, which have been acknowledged in the national territory by Legislative Decree 192/2005 and Law 90/2013, respectively.

Despite the aforementioned efforts, energy efficiency still represents a trend issue within the building sector. Indeed, according to Eurostat [1], residential and tertiary buildings account for about 40%



of energy consumptions and around 36% of greenhouse-gas emissions. Moreover, the European Commission [2, 3] has repeatedly stressed the remarkable unexpressed potential to improve the building performance, in view of the unsatisfactory results achieved so far.

While growing the interest in building energy efficiency within the political and academic debate, as well as in the industry sector, an increasing amount of studies has focused on the economic viability of energy retrofit measures. Despite that, the results are still uncertain and conflicting. However, such studies have brought out the main variables affecting the economic feasibility of interventions improving building energy performance: savings-investment ratio, cost-effectiveness of energy supply, energy price trends.

The aim of this study is to investigate the relevance of an often disregarded aspect: the rate of time preference as an expression of households' behaviours, that is to say, the discount rate adopted within several valuation approaches, which are based on discounted cash flow. Our purpose is to discuss a kind of paradox. The discount rate is commonly estimated in order to take into account uncertainty; nonetheless, the self-same estimation of the discount rate may be a source of additional uncertainty.

## 2. Literature review

Uncertainty represents a long since well-known issue within the construction and real estate sectors, due to a peculiar production process, which is likely to be more complex and less standardized than other industries [4], hence characterized by fragmentation and discontinuity [5]. A part of recent literature recognized that uncertainty is a main challenge when dealing with retrofit interventions aimed to improve building energy performance [6], because of fluctuating processes involving climate change, government policies, consumers' preferences and technological innovation [7]. Besides, investment in building energy efficiency turns out to be almost irreversible, and this awareness puts more pressure on dealing with an uncertain future [8].

A number of studies found many key variables highly affecting feasibility and success of energy efficiency measures applied in the building sector. The building age is among these variables, although sometimes with a non-linear relationship between energy consumption and construction period [9]. Other relevant variables include savings-investment ratio [10], cost-effectiveness of energy supply [11] and the forthcoming trend of energy supply price [12]. It should be taken into account that the aforementioned parameters exhibit multiple interactions, so as contributing to further increase uncertainty. Meanwhile, surveys conducted during the past years led to argue that stakeholders might perceive investment in energy efficiency as too uncertain, due to high construction or refurbishment costs, ambiguous saving forecasts, unclear maintenance costs and increase of building value still hard to predict [13]. Therefore, households may prefer to delay investment decisions. In other terms, it might be worth to postpone rather than immediately investing in energy efficiency, being the investment characterized by a high option value to waiting [14].

When constructing or retrofitting a building, uncertainty may affect construction as well as running costs, hence planning and design activities have begun to include risk management systems and methods in a life cycle perspective [4, 15]. Appraisal tools based on Discounted Cash Flow (DCF) are set up to handle uncertainty and risk in various ways. Among others, a well-known and widely adopted technique since early pioneering studies [16] relates to the discount rate estimation.

The sum of a base and an additional rate is part of the theoretical background upon which the Capital Asset Pricing Model (CAPM) relies. Indeed, the rationale of CAPM lies in the assumption that the expected return of an investment is expressed by the sum of a risk-free rate and a risk-premium rate, the latter in turn multiplied by a beta parameter, which is estimated in order to cope with the degree of exposure to the non-diversifiable market risk [17]. Accordingly, the model has been recently used to perform quantitative economic analyses in the field of building energy retrofit, wherein conditions of uncertainty entail the need to decide whether to invest immediately or to



postpone the decision [6]. Moreover, on the wave of a highly debated issue, relating to the so-called energy efficiency gap [18], CAPM was adopted in the past to appraise the appropriate rate when discounting energy-efficient investments [19, 20].

### 3. Case study: Overview of Virgolone building within Pilastro district in Bologna

The Pilastro neighbourhood is part of a district named after San Donato, located northeast from the city centre of Bologna (Fig. 1). It is a high-density settlement, mainly composed of public housing. Relying on a council housing plan designed in 1962, construction works started a couple of years later and were carried out by the local public housing authority.

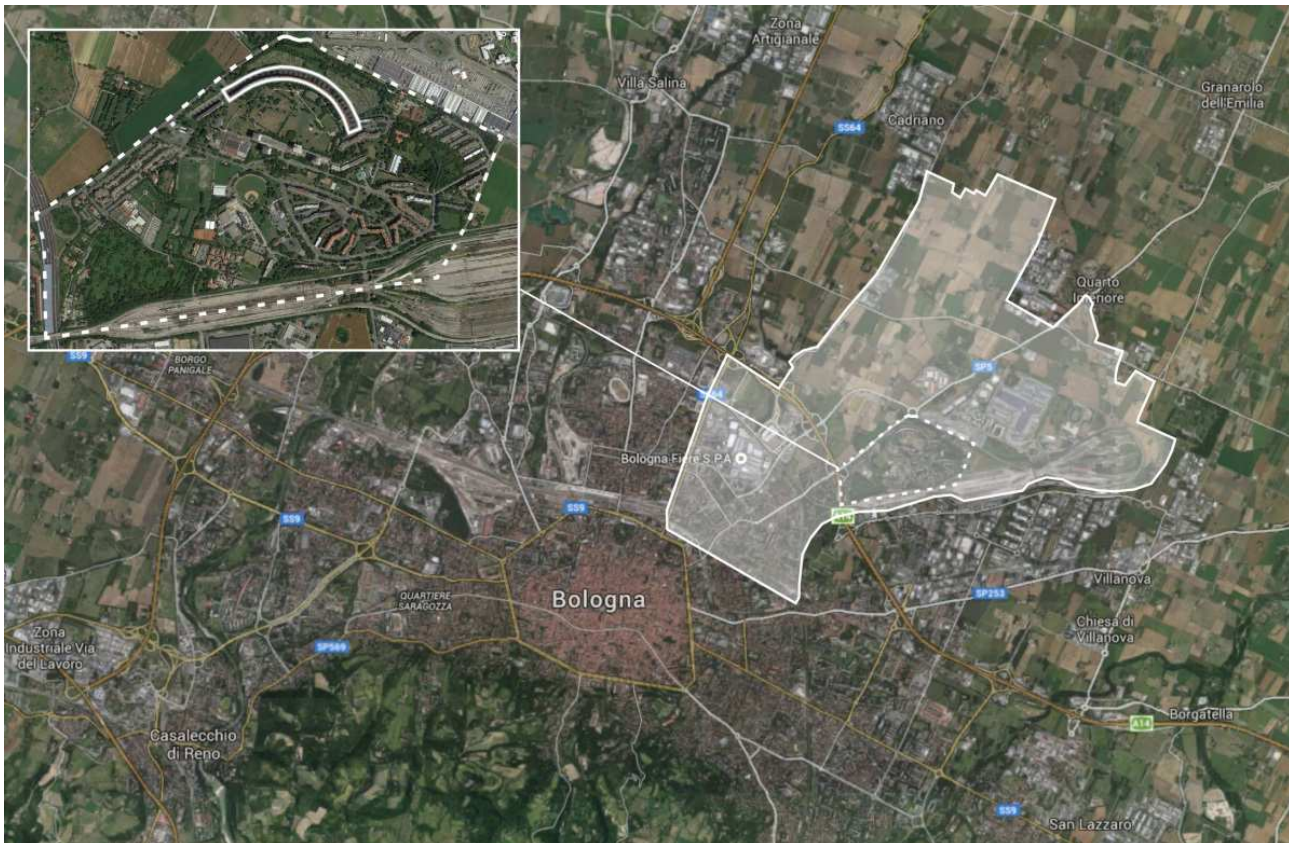


Fig. 1 The city of Bologna with San Donato district (continuous line), Pilastro neighborhood (dotted line) and case study building (continuous line, top left box)

A plan amendment approved in 1975 led to the erection of a peculiar eight-storeyed building, seven hundred meters long. Due to its semi-rounded shape (Fig. 1, top left box), the building is colloquially referred to as “Virgolone”, a slang term which means “big comma”. Construction work lasted from 1975 to 1977. The building was cast-in-place through tunnel form construction technique. It led to erect a reinforced concrete building structure, relying on the systematic repetition of load-bearing partition walls and flat slabs.

### 4. Retrofit scenarios

Thermal improvement potential of social housing settlement located in the city of Bologna, and particularly in its suburban areas, has been investigated by a number of studies [10, 21].

As far as the case study is concerned, to improve energy performance in comparison to the building as is, seven retrofit scenarios were defined, keeping the structure and arrangement of dwellings as constraints. The first three scenarios concern a better insulation of walls (S1), of horizontal dispersant surfaces such as the ceiling below the roof and the floor above the ground-level ar-

acades (S2), as well as of the whole building envelope (S3). The goal is pursued by means of 14 thickness rock wool panels placed on the exterior. The fourth scenario (S4) focuses on the replacement of windows, by installing double-glazing with low-emission coating and thermal break frame. The fifth scenario (S5) combines the building coating, as in the previous S3 scenario, with window replacement, as in the previous S4 scenario. A new ventilation system, leading to a more satisfactory air exchange rate, is adopted in the sixth scenario (S6). Finally, a further scenario (S7) merges the interventions pertaining to whole building envelope insulation, to the replacement of the windows with double glazing and to the improvement of the ventilation system, as in previous S3, S4 and S6 scenarios. The above description explains that the scenarios lend themselves to be connected in chains, which are suitable to be represented by a kind of tree (Fig. 2).

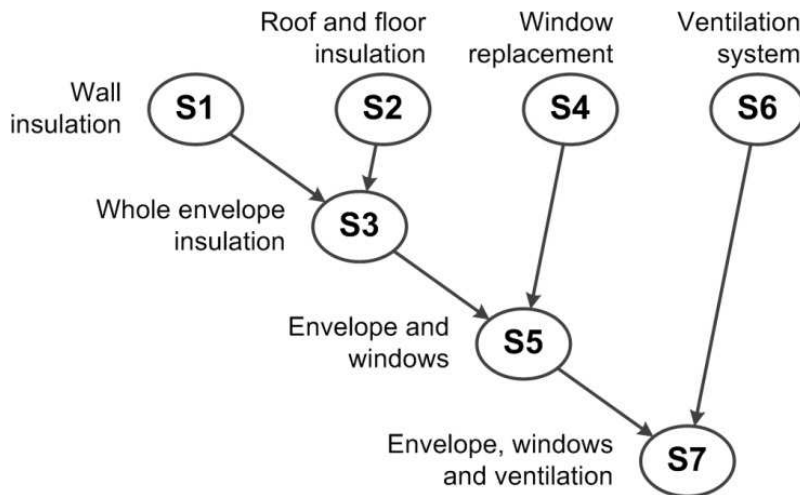


Fig. 2 Scenario's tree

## 5. Method, assumptions and estimates

To analyse the feasibility of the outlined scenarios, the Discounted Cash Flow approach (DCF) is adopted here. DCF is a widely recognized method, whose introduction into real estate appraisal and property investment valuation dates back to pioneering studies carried out during the mid-sixties and the early seventies [22, 23]. According to the International Valuation Standards, DCF is “A financial modelling technique based on explicit assumptions regarding the prospective income of a business or property” (p. 300) [24].

With regard to analysed cash flows, literature about uncertainty within the building sector distinguishes between internal and external factors affecting projects [13]. The internal ones relate to aspects considered during scheduling and design stages, so under direct control of the participants. As far as the case study is concerned, investment costs depend on decisions of stakeholders about gross floor area of intervention and intensity of retrofit measures; hence, they are classified among internal factors and examined in next paragraph 5.1. External factors are those beyond the project scope, since their source is correlated with the prices of goods and services exchanged within international markets. Within the case study, energy savings are considered mainly an external factor, because they depend on occupant behaviours as well as on the price of energy supply, and they are discussed in following paragraph 5.2.

### 5.1 Investment costs

All the scenarios previously outlined in section 4 have been applied to a residential block, to which belong thirty flats (Fig. 3). The overall gross floor area under analysis amounts to 1,651 square meters. Investment costs have been estimated through concise sheets relying on the structure of a bill of quantities. Estimates have been performed regardless of savings achievable by imple-

menting the scenarios jointly with other periodic maintenance activities. Costs to supply and installation of the foreseen improvements have been considered together to design costs and expenses due to rental of construction site goods and services, such as equipment and scaffolding (Table 1).

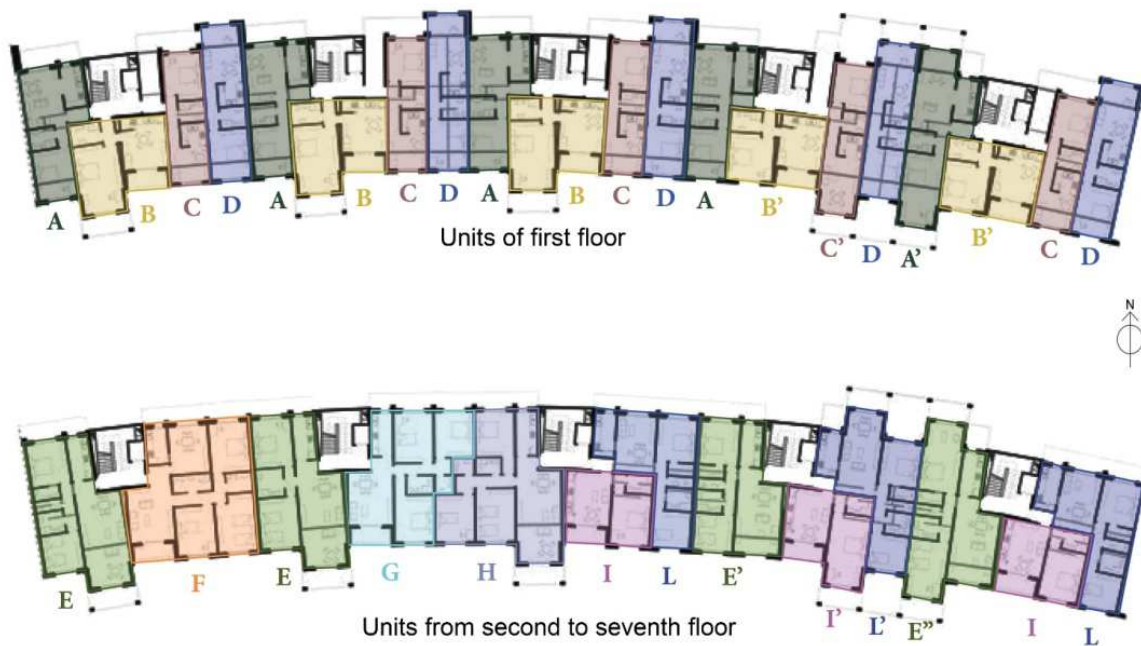


Fig. 3 Plans of the case study, adapted from Copiello and Bonifaci [10], p. 80

## 5.2 Energy savings

Not only predictable energy consumption, but also data concerning the current energy consumption has been gathered by means of thermal simulation (Table 1), knowing that this could lead to partly biased results. Resorting to simulation models is very usual within building energy analysis, but it is also a source of supplementary uncertainty during scheduling and design stages [13], due to the remarkable amount of parameters to consider and assess [25]. In particular, the accuracy of the model adopted by simulation tools, besides to the building operation practices, is identified as a main factor subject to a margin of error in energy consumption estimates [26].

The software Termolog here used [27] is a package performing a steady-state simulation, allowing to calculate the primary energy need for heating and domestic hot-water production, by means of a procedure which relies on the standard UNI TS 11300 (based on UNI EN ISO 13790) and CEN-Umbrella standards [28]. Not having the opportunity to perform systematic on-site investigations, outcomes of thermal simulation have been compared with consumptions recorded in energy bills on a sampling basis. It has been experienced a rather narrow variance, which is limited to less than 5%.

In order to translate the estimated energy savings in monetary terms, we assume a unit energy price of 0.9 euros/kWh and an energy inflation rate of 4.5% per annum; both the values are consistent with the estimates expounded by a recent study [10].

## 5.3 Allocation of burdens and benefits among the stakeholders

In Italy, fair rents in public housing and social housing sectors are mainly tenant's income based; nonetheless, the rules governing protected tenancies allow to cover capital expenditures, as established by the legal system of other Western European countries [29]. Besides, social tenants pay energy bills to gas, electricity and water providers. We assume that energy saving allows the tenants to be willing to pay higher rents, although this is a still debated issue in the literature [30, 31]. Because these savings are due to capital improvements on the whole building or on the



dwellings, the social landlord - namely the local public housing company - is entitled to cover investment costs by imposing higher rents, hence by capturing the tenants' willingness to pay (Fig. 4).

Table 1: Scenarios, investment costs and energy requirement

Scenarios and energy efficiency measures	Gross floor area <i>m</i> <sup>2</sup>	Unit investment <i>Euros/m</i> <sup>2</sup>	Total investment <i>Euros</i>	Energy requirement <i>kWh/m</i> <sup>2</sup> <i>y</i>	Energy saving <i>kWh/m</i> <sup>2</sup> <i>y</i>
S0 - Building as is	1,651	0	0	162.6	0
S1 - Building coating: exterior wall insulation made by rock wool panels of 14 cm thickness	1,651	102	168,073	147.3	15.3
S2 - Building coating: insulation of floor and roof made by rock wool panels of 14 cm thickness	1,651	53	87,047	118.3	44.3
S3 - Building coating: insulation of whole building envelope made by rock wool panels of 14 cm thickness	1,651	155	255,121	105.5	57.1
S4 - Windows replacement: double glazing with low-emission coating and thermal break frame	1,651	338	558,675	112.6	50.0
S5 - Building coating as in S3 scenario and window replacement as in S4 scenario	1,651	459	757,928	66.5	96.1
S6 - New ventilation system	1,651	219	361,060	146.4	16.2
S7 - Building coating as in S3 scenario, window replacement as in S4 scenario, new ventilation system as in S6 scenario	1,651	678	1,118,988	49.3	113.3

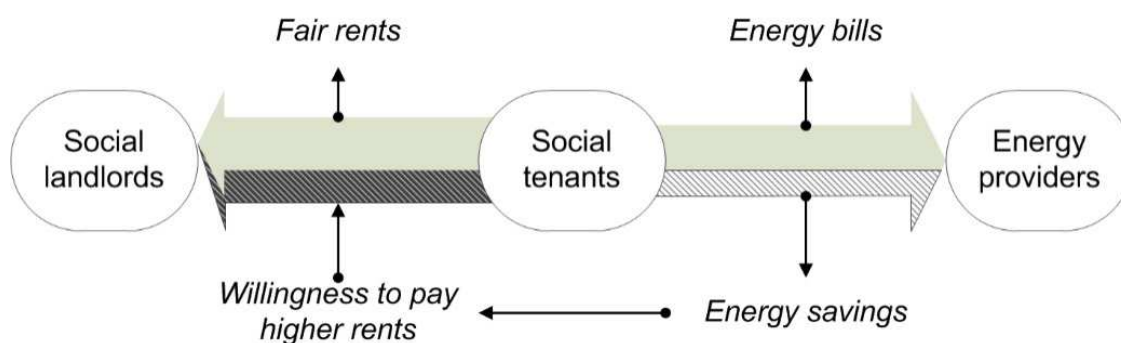


Fig. 4 Allocation of burdens and benefits among the stakeholders

## 6. Results and discussion

For each scenario, several NPVs have been calculated, by varying the discount rate within the range from zero to 15%. Discount rates adopted by the previously referenced literature are consistent with this range. The study performed by Kumbaroğlu and Madlener [12] suggested a typical value range from 2.25 to 5%, another research developed a sensitivity analysis assuming an expected rate of return ranging from 3.5 to 4% [32], while Nikolaidis et al. [33] appraised net present values and payback periods with discount rates from 4% to 8%. From the perspective of a

household or a public housing company, an ordinary discount rate might lie between 3% and 5% [10], and the same lower level is consistent with the yield rate characterizing the venture philanthropy approach adopted in some recent social housing transactions [30]. Higher discount rate values may be appropriate in order to represent those consumers whose behaviour is driven by a higher rate of time preference [34], or otherwise by upper levels of opportunity cost of capital [35]. A first point worthy to be discussed here concerns the feasibility of hypothesized scenarios. Just the scenario S2 is likely to be economically viable, since the NPV remains positive unless the discount rate is more than 10%. The scenario S3 may be described as characterized by limited viability, because NPV turns out to be positive only when the discount rate is lower than 5%. The scenario S5 is economically viable under the unrealistic condition of a null discount rate, while the NPV swiftly falls below zero if the rate increases. All other scenarios are far from being viable, as witnessed by constantly negative NPVs.

A simple graphic representation brings out the most interesting result: discount rate is set as the independent variable, while NPV is the dependent one (Fig. 5). NPV curves of the seven scenarios show multiple intersections. A total of six reversal points are identified: the first two are recorded for a discount rate close to 1% (points A and B), three other for a discount rate within the range from 2 to 5% (point C, D and E), and the last one for a 10% discount rate (point F).

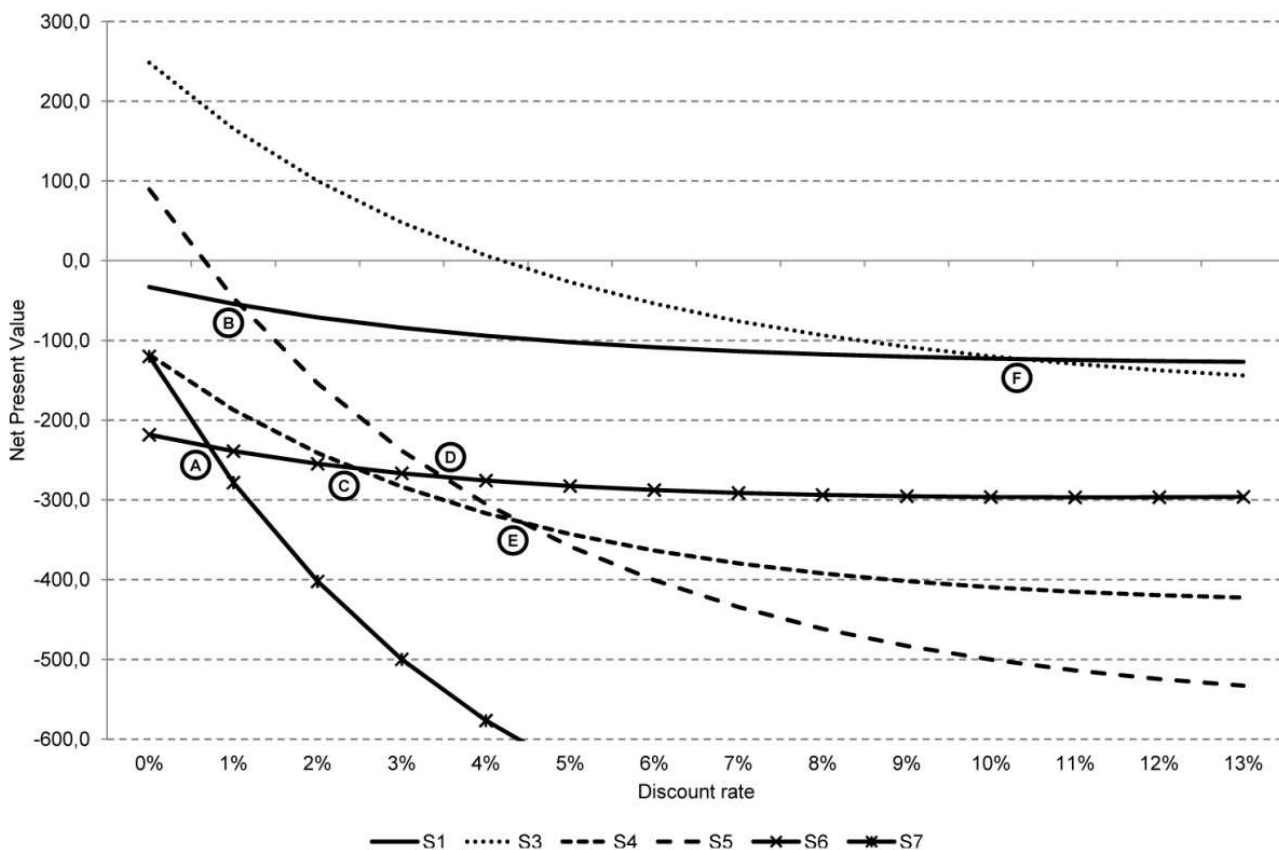


Fig. 5 Reversal points in NPV curves

In the transition from Eq. (1) to Eq. (2) and (3), we experience a major change, since it takes place a complete reversal of the two top alternatives. Despite other minor changes affect the bottom of the rankings, as well as the two other rankings expressed by Eq. (4) and (5), it deserves mention that the top of the rankings may still vary when increasing the discount rate. Indeed, the S3 scenario, which was omitted earlier, shows a reversal point with S1 scenario, corresponding to a 10.5% discount rate.

The diagram in Fig. 5 clearly shows that the NPV curves are characterized by diverging slopes. The reason lies in that the scenarios are at different scales, namely they imply hugely varying savings-to-investment ratios (SIR). Let us consider scenarios S1 and S5. The former is better than the latter when the discount rate is over 1.0% (see point B in Fig. 5), vice versa if the discount rate falls below the same threshold. S5 entails an investment 4.5 times higher than in S1, while the estimated savings are up to 6.3 times higher, but the savings are deferred over time. These are the reasons why the NPV of S5 decreases more swiftly than that of S1.

The achieved results are fairly sensitive to variation in both energy price and inflation rate (Fig. 6). Specifically, assuming a 5% discount rate, in the wake of a 1% decrease in energy price, the NPVs of scenarios S1, S4, S6 and S7 undergo a small reduction of about 1%, while the NPVs of scenarios S2 and S3 are led to a much more intense drop of 4.6 and 18.5%, respectively. A 1% decrease in the energy inflation rate provokes wider swings, up to 22.5% for S2 and 90.7% for S3.

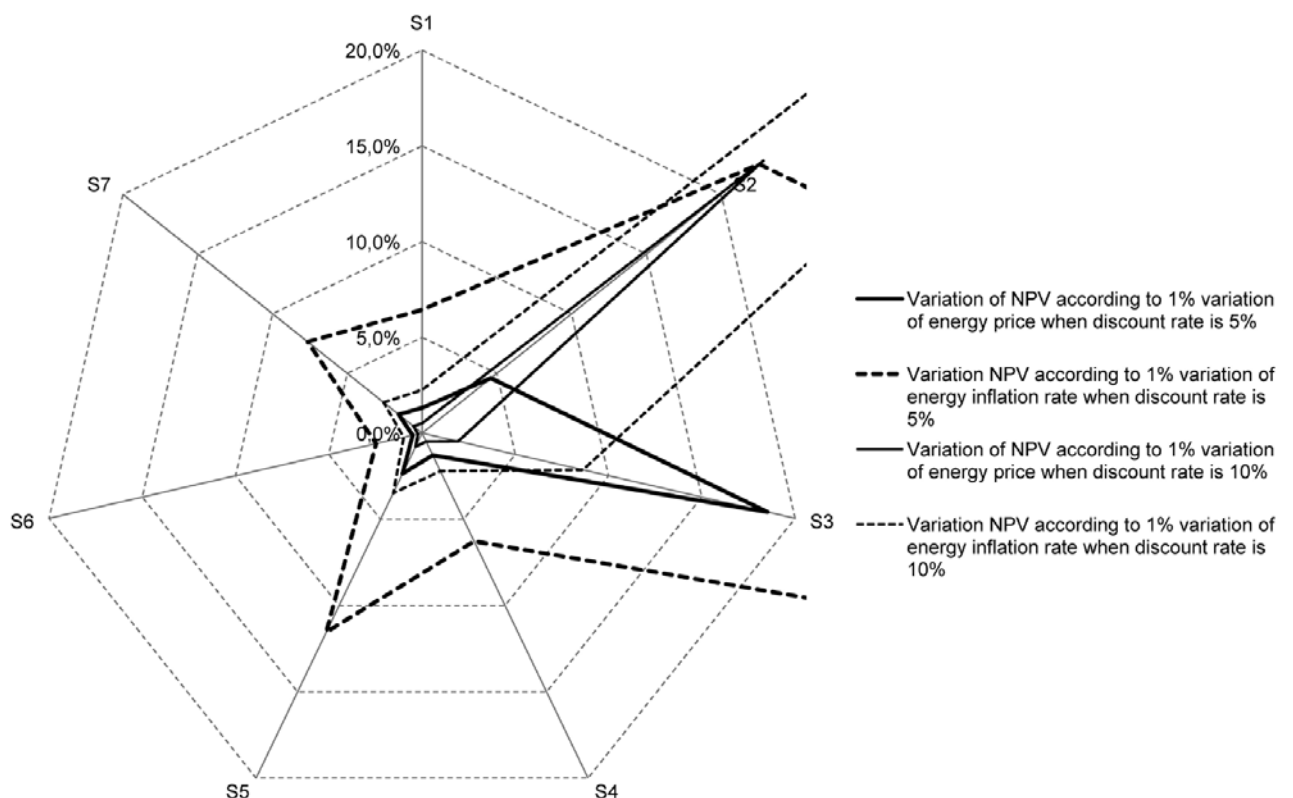


Fig. 6 Sensitivity analysis

## 7. Conclusions

The analysis performed here suggests that methods usually applied to appraise the feasibility of energy-efficient solutions, such as Discounted Cash Flow and Life-Cycle Cost, should be employed carefully. Since the results are highly sensitive to the several essential variables, the feasibility and cost-effectiveness judgment may be biased by the assumptions and estimates upon a couple of key parameters.

Although, in valuation, the discount rate is considered a useful tool to manage uncertainty, we have shown that it may be a source of irresolute results. This issue is especially relevant in the comparison of efficiency solutions applied to the building sector, because the involved measures are prone to be characterized by different scales in both investment and savings. Moreover, this issue is intrinsic to all the valuation methods based upon discounting, hence it affects not only the Discounted Cash Flow approach, but even the Life-Cycle Cost approach as well as the Cost-Optimal Methodology.



Most of the research previously referenced in the literature review section exhibits one-shot results. On the contrary, only few studies arrange the results within confidence ranges, depending on sensitive variables. Aiming to perform a thorough and comprehensive study, the question discussed so far leads to identify the sensitivity analysis as unavoidable. Further developments of our analysis are identified in the opportunity to carry out extensive sensitivity analyses based on the Monte Carlo simulation method, so to treat simultaneously the variation ranges of energy price, energy inflation rate and discount rate and their correlations.

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