SBE16 HAMBURG

STRATEGIES
STAKEHOLDERS
SUCCESS FACTORS

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Conference Proceedings

Sustainable Built Environment Conference 2016 in Hamburg

Strategies, Stakeholders, Success factors

7th - 11th March 2016

KIT Karlsruhe Institute of Technology

Hochschule für angewandte Wissenschaften München

HCU HafenCity Universität Hamburg

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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 / Excursions
10.30-11.00 a.m.		Coffee	Coffee	Coffee	Excursions
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 / Excursions
12.30-2.00 p.m.		Lunch	Lunch	Final Session / Lunch	
2.00-3.30 p.m.	Excursions / Pre-Registration	Scientific and special sessions / Day of Municipalities	Scientific and special sessions / Housing Industry Day	Final Session / Excursions / Day of Architecture, Planning & Engineering	PhD Session
3.30-4.00 p.m.	Excursions / Pre-Registration	Coffee	Coffee	Excursions / Coffee	
4.00-5.30 p.m.	Excursions / Pre-Registration	Scientific and special sessions / Day of Municipalities	Scientific and special sessions / Housing Industry Day	Excursions / 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

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Organised by

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Imprint

Conference organisers

ZEBAU – Centre for Energy, Construction, Architecture and the Environment GmbH

www.zebau.de

In cooperation with

Supported by

Edited by: ZEBAU – Centre for Energy, Construction, Architecture and the Environment GmbH, Große Elbstraße 146, 22767 Hamburg, Germany

This book was prepared from the input files supplied by the authors.

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2016

Printed on 100% recycled paper.
Druckerei in St. Pauli, Große Freiheit 70, 22767 Hamburg, Germany

ISBN 978-3-00-052213-0
DOI: 10.5445/IR/1000051699

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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 delivereyd 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 0. 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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The full paper proceedings with ISBN and DOI can be downloaded on http://digbib.ubka.uni-karlsruhe.de/volltexte/1000051699

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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 it 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.

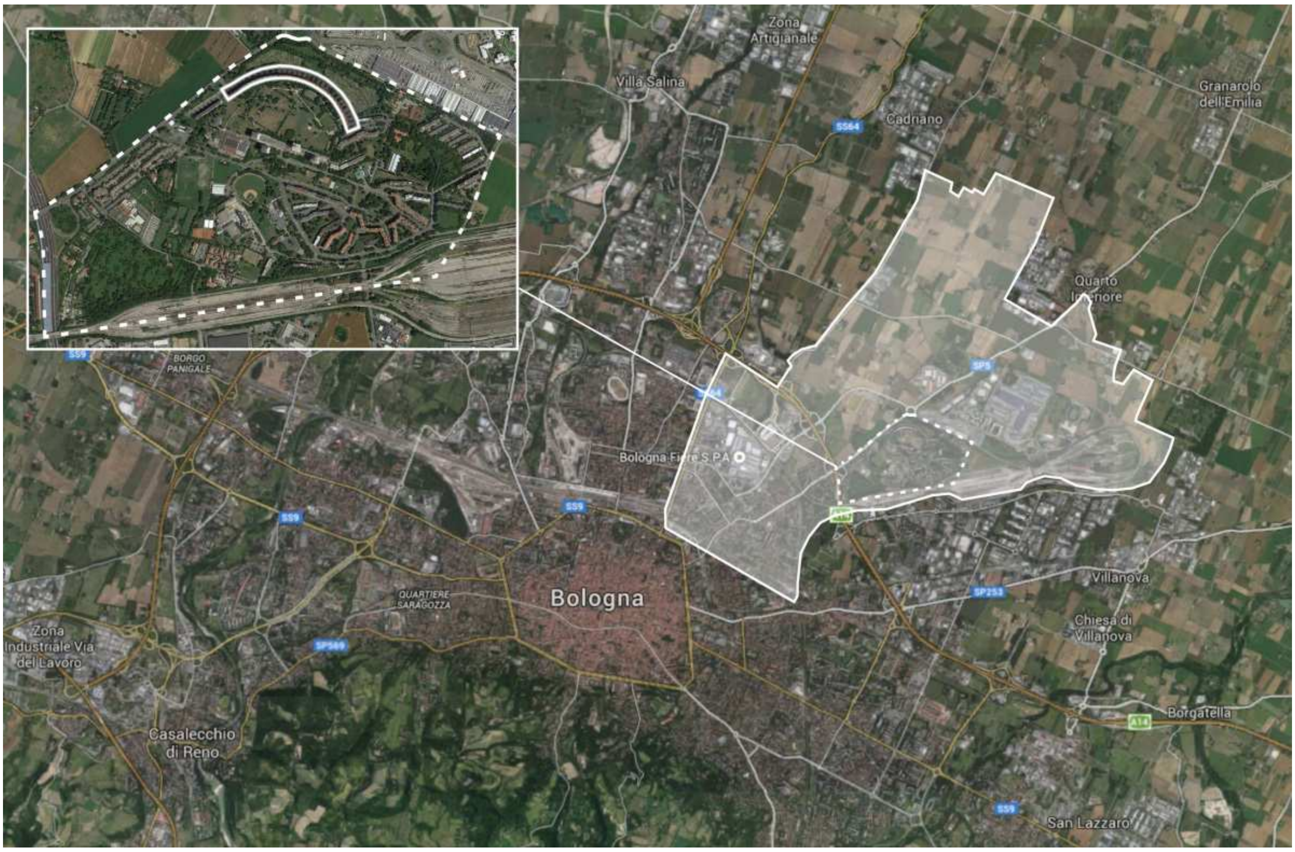

Fig. 1 The city of Bologna with San Donato district (continuous line), Pilastro neighborhood (dotted line) and case study building (continuous line, top left box)

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-

cades (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).

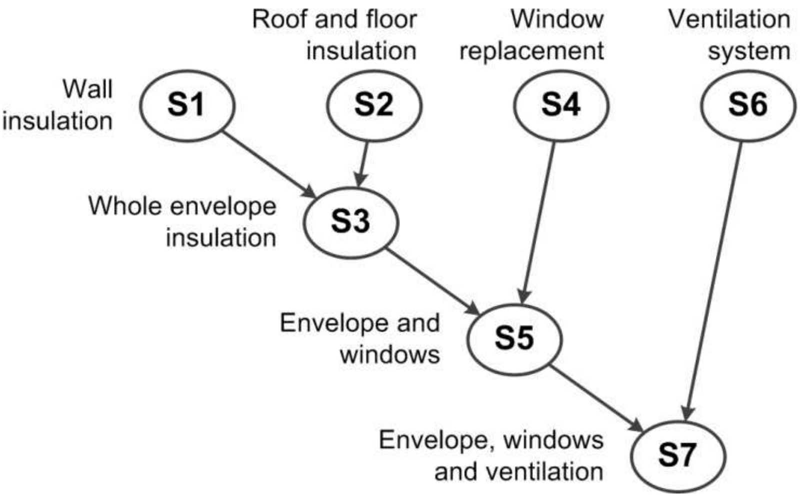

Fig. 2 Scenario’s tree

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 implementing 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).

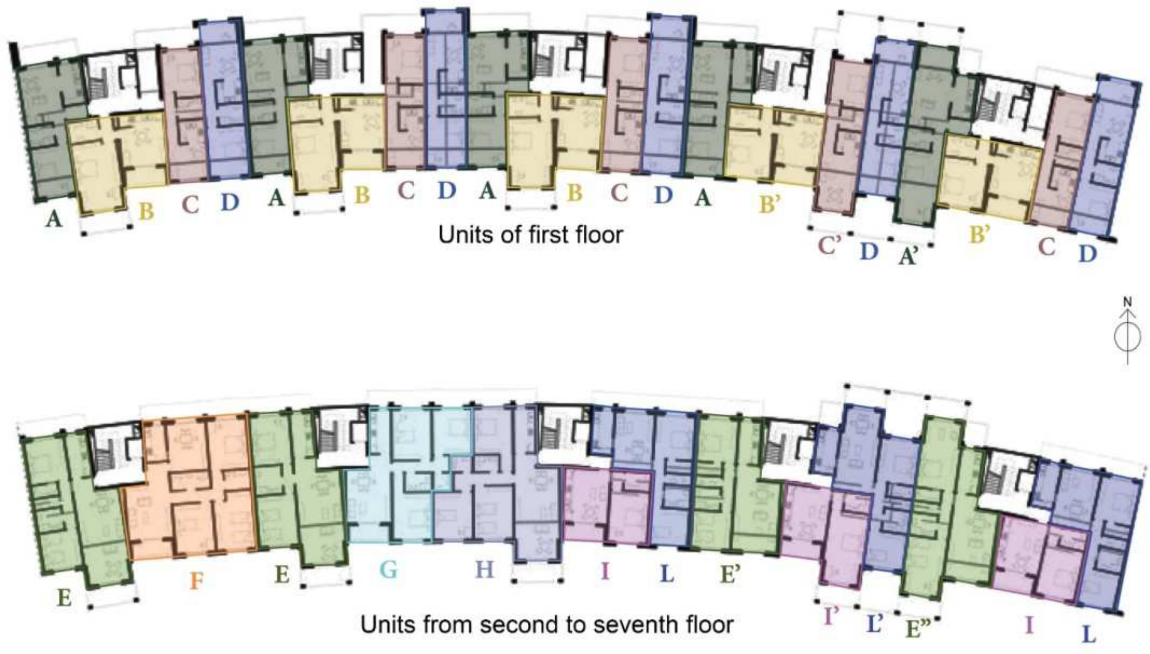

Fig. 3 Plans of the case study, adapted from Copiello and Bonifaci [10], p. 80

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 *m2*	Unit investment *Euros/m2*	Total investment *Euros*	Energy requirement *kWh/m2 y*	Energy saving *kWh/m2 y*
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

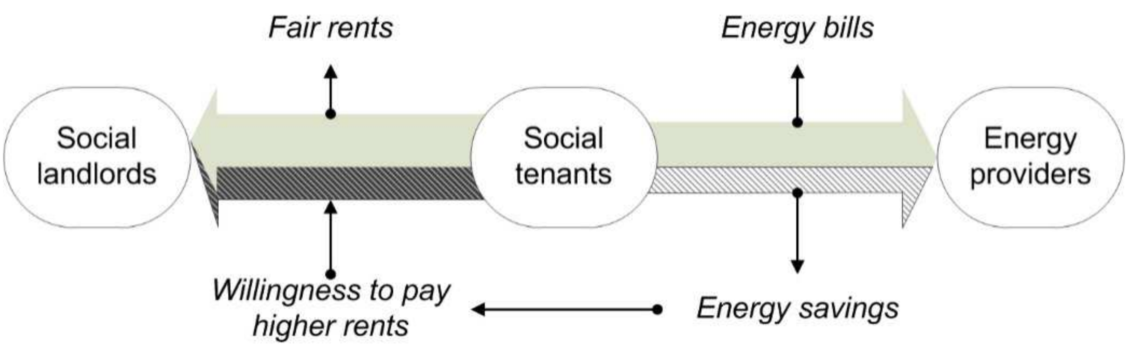

Fig. 4 Allocation of burdens and benefits among the stakeholders

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).

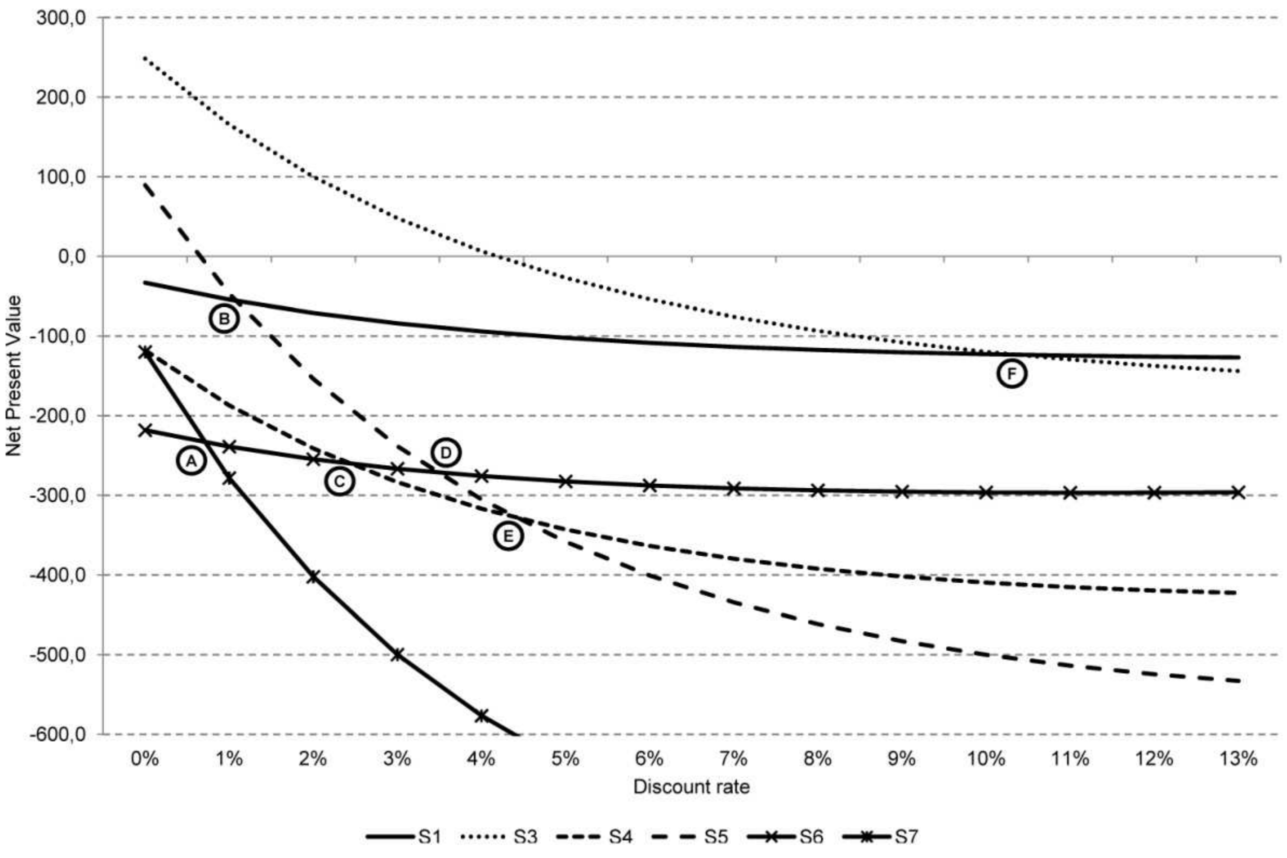

Fig. 5 Reversal points in NPV curves

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.

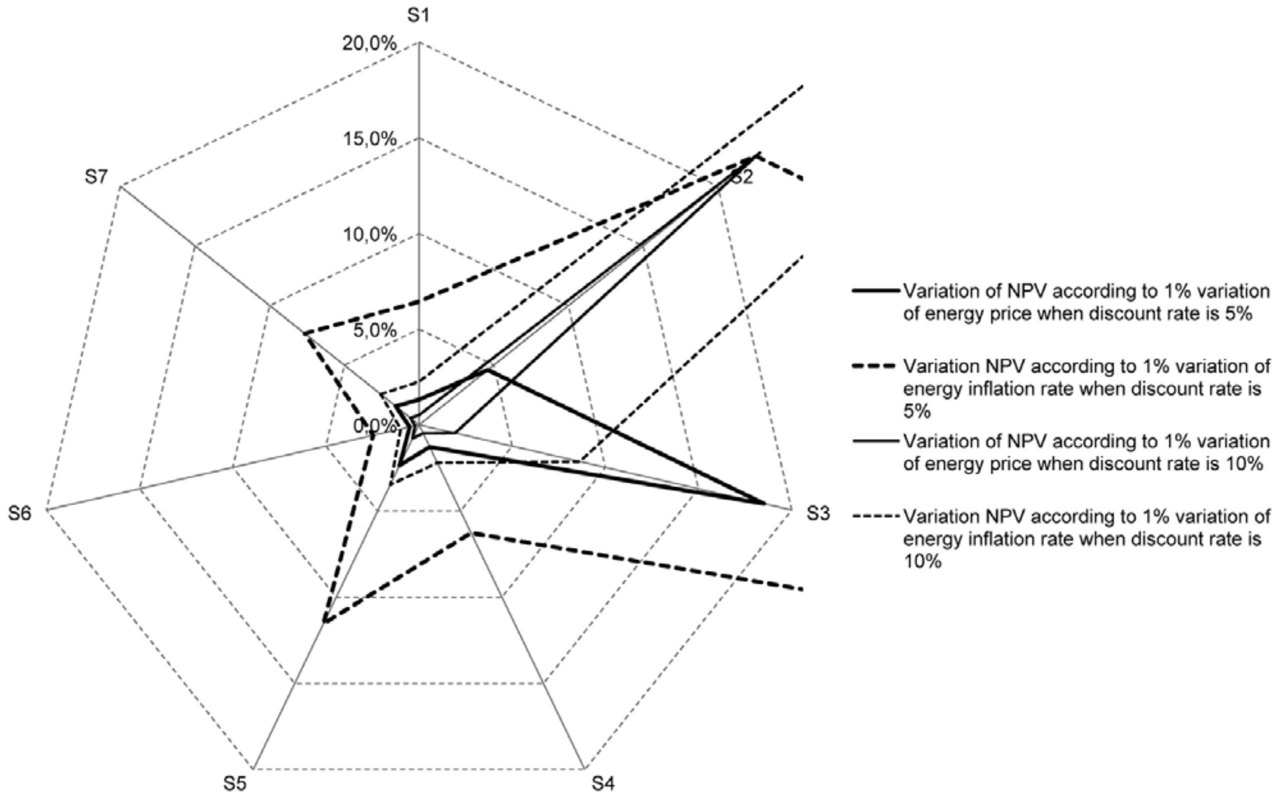

Fig. 6 Sensitivity analysis

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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