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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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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Marginal costs and benefits in building energy retrofitting transaction

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Summary

Since some pioneering studies published during the late eighties, an increasing amount of research has addressed issues related to the economic and financial valuation of buildings' energy retrofitting transactions over the span of the last two decades. Nevertheless, conflicting results emerge: some hypotheses turn out to be feasible, while others do not, depending on several variables such as investment costs, energy supply costs and energy price trend. Moreover, the supposed price premium for green buildings is still unclear and ambiguous.
According to the economic theory, a way to assume decisions related to feasibility issues relies on the comparison between marginal costs and benefits. A couple of recent studies discussed about marginal costs and benefits in building energy retrofitting transactions, arguing that marginal costs are found to be steeply increasing with raising the thermal standards of buildings. Nonetheless, due to the paucity of systematic studies and consistent data, the topic deserves further investigations.
This essay aims to expose and discuss results obtained in a research conducted on public housing settlements. Analysing several energy retrofitting measures, marginal costs are found to assume a near-parabolic shape: it is, firstly, mildly decreasing and then sharply increasing. Moreover, marginal costs are compared with marginal benefits, in order to highlight feasible intervention options.

Keywords: Building energy-efficiency; marginal cost; Life cycle costing; Cost-optimum approach.

1. Introduction

Buildings are estimated to be responsible for a very high percentage of energy consumption, as they represent 32% of total final energy consumption in most IEA Countries, and human activities in the buildings cause the 40% of the primary energy consumption [1]. This suggests a growing attention within the construction sectors regarding the building's role in exploiting renewable energy and so, in reducing climate changes. The European Commission is always remarking the need of improving building energy performance, as unsatisfactory results have been achieved so far [2].
Energy use in the Italian residential sector accounted for 20% of the total final energy consumption (TFC) in 2007 but from 1990 to 2005 the same sector showed the greatest improvements in terms of energy-efficiency [3]. This reduction was mainly due to domestic efficient lamp bulbs, followed by

thermal insulation and more efficient air-conditioning systems. Energy savings for the period 2005 – 2012 amount roughly at 3.79 Mtoe/y, and more 5.16 are expected by 2016.
Approximately 62% of the edifices in Italy were built before the 1970s [4] and so before the first Italian Regulations about energy saving in the buildings were enacted. The residential building sector's contribution to the national targets is estimated at 3.67 Mtoe/y, considering the application of new standards for buildings concerning cooling and heating, thermal account, tax deduction and white certificates.
Several energy measures can be used in the buildings in order to reduce energy consumptions, in particular:

- Measures for the improvement of the energy performance of the building through the envelope (insulation, heat-insulating door and window frames, building shapes, etc.) [5];
- Use of renewables (ground source heat pumps, solar panels, photovoltaics, etc.) [6];
- Measures for reducing the heating and cooling loads (passive heating and cooling techniques, uses of bioclimatic architecture, etc.) [7];
- Actions for the improvement of indoor comfort conditions (use of mechanical ventilation combined with heat recovery, efficient use of multi-functional equipment, improvement of boilers and air-conditioning, etc.) [8];
- Use of building energy management and monitoring systems [9];
- Use of energy-efficient appliances and compact fluorescent lighting [10].

Those solutions turn out to be almost irreversible, so many efforts are spent to assess their economic feasibility in relation to the energy improvements that these measures ensure. From the perusal of the literature, it is possible to see how those proposed measures could be assessed through different approaches, which take account of financial, environmental and social factors in order to reach the most feasible solution.
Some methods which have been widely used are the Life Cycle Costing (LCC), the Discounted cash flow analysis (DCF) and the multi – criteria approaches (MCA). Kneifel [11] determines the simultaneous impacts of energy-efficient design on life-cycle costs, life-cycle carbon emissions, and energy use in an integrated building design context for commercial buildings across different climate zones. Life cycle approach has been used [12] in order to investigate the impacts of pressure duct designs on factors influencing central residential HVAC energy consumption. The study used a life cycle cost analysis to simulate the net life cycle impacts of lower pressure duct designs in dwellings. For the building retrofitting investments, LCC can be applied to estimate the overall cost of the alternatives during the life-cycle of the building and evaluate the cost-effectiveness; moreover, LCC can be used to define the optimal thickness of the insulation material in a building envelope [13] and so getting the optimum cost-effectiveness solution.
An alternative approach to the LCC is represented by Discounted Cash Flow analysis (DCF). DCF has been extensively used when valuating economic feasibility of energy-efficiency actions. One of the most popular indicators is the payback period, which, for a project, is the time in which the initial cash outflow is expected to be recovered from the cash inflows generated by the project. The simple payback period was used to assess the economic feasibility of different energy-efficiency works [14] and a discounted payback period was implemented to show the payoff of a renewable energy applied in the residential sector [15]. Furthermore, the net present value is a widely recognized indicator of economic performance and feasibility of different retrofitting actions [16, 17], in the residential and commercial sector [18, 19]. Moreover, it is used to quantify the increase of the market value of the building generated by the application of energy-efficiency measures. The net present value in the financial approach could be the measure of the energy savings and the added value due to energy performance [20].

Decision-making in retrofitting has been implemented with multi-objective optimization models (MCA) for retrofitting buildings, including a non - linear function which allows to find a different way to approach at the retrofitting options [21] and showing that an optimal solution does not exist.
Over the span of the past decade, several studies and papers introduced the cost – effective solutions in buildings retrofit. The Commission Cost-Optimality Delegated Regulation [22] establishes a comparative framework methodology to determine a cost-optimal level of minimum energy performance of buildings and building elements and a guidance document [23] on how to implement the methodology at a national level was then published in 2012.
A different cost approach has been used in marginal terms. A marginal cost approach in order to value thermal renovation of existing homes has been implemented in a series of Swiss case studies [24]: the marginal costs of energy-efficiency investments have been quantified for each increment of refurbishment's standards commencing from a baseline. The approach also introduces different scenarios, considering the lifetime of the components and allowing comparison of thermal renovation actions without using the pre-restoration energy consumption. Another method with marginal costs has been employed with the aims of finding the optimum measures of different energy-efficient elements [25] using the marginal difference between the savings and the cost of implementing those measures to renovate building fabric elements.
In this paper, we adopt an approach which includes both marginal cost and cost-optimum analysis applied to different retrofitting scenarios. The aim of the paper is to understand if the purpose of retrofitting is to achieve maximum reduction in consumption or seek a balance between investment costs and energy savings achieved with energy retrofitting measures. This essay aims to expose and discuss results obtained in a research conducted on public housing settlements, located in the metropolitan area of Milan, in the north of Italy. Moreover, different life cycle costs combined with the benefits will be used to assess the impact of some options for energy-efficient and renewable on a building over its service life.

2. Research method

In economics, marginal cost in the short run is the change in the total cost resulting from the production of one additional unit. That is the cost of producing one more unit of a good or service [26]. In the short run, marginal cost is equal to the additional amount of a variable factor that the firm should employ to increase production, multiplied by how much the company must spend in order to get an extra unit of variable factor. At each level of production and the time period being considered, marginal costs include all costs that vary with the level of production, called variable costs, whereas other costs that do not change with production are considered fixed. The marginal cost first decreases and then increases with the quantity produced, very sharply and that is due to the principle of diminishing marginal productivity.
In this paper, we analyse the marginal cost and its dynamics as it has been rarely examined for retrofitting methods, and it helps to understand how much an efficiency measure costs. Moreover, it helps to understand how much energy-efficiency can be reached through, e.g. additional insulation, defining the marginal cost of energy-efficiency, which is the difference in the investment cost due to one added step (or scenario, in our case) of retrofitting works.
The formula is:

$$Mce = \frac{Investment\ costs_n - \ Investment\ costs_{n-1}}{DEnergy_n - DEnergy_{n-1}}$$

Where the investment costs are the sum of money needed to implement the retrofitting measures, while DEnergy is the energy demand during different scenarios (n) of the building.

A second issue will be shown later regarding life cycle costs of the different scenarios. The life cycle costing (LCC) is a widely recognized method, as described in the paragraph 1.
The approach is based on the logic that economically optimal retrofitting measures minimize the sum of construction and running expenses over the building lifetime. The annual stream of costs is then discounted to present values and compared with the investment costs.

$$LCC = C_{inv} + \sum_{t=0}^{n} Ci_{inv}\left[\left(\frac{r}{q^t - 1}\right)\cdot\frac{1}{q^t}\right] + \sum_{t=0}^{n}\frac{C_{Ener}}{r-g}\left[\left(1-\frac{(1+g)^t}{(1+r)^t}\right)\right] + \sum_{t=0}^{n}\frac{C_{man}}{r-g}\left[1-\left(\frac{(1+g)^t}{(1+r)^t}\right)\right]$$

in which Cinv is the investment cost, and the sinking fund formula has been used to build up a sum of money to replace the systems after their usable life, Ce are the operating costs, Cman are the maintenance and cleaning costs, g is the growth rate, r is the discount rate and q is 1+ r. This formula will be applied with the aim of performing a cost optimal level calculation. The discussions of the results will follow the application of the models.

3. Case studies

The following three case studies described below are examples of multi–family social housings. The building # 1, constructed in 1986, develops into an L shape plant, it is a 5-storey building with two basement floors for car parking. The property is 3,212 m2. The building has reinforced concrete structure and 8 apartments per floor, of about 68 m2 each. The building is in good overall condition and has had experienced, over the years, some maintenance works. The annual energy demand is 109 kWh/m2 for heating and hot-water and 40 for electricity. The building #2 is a 4-storey construction built during the 50ies with commercial spaces on the ground floor and the three floors above are residential. There is a total of 18 apartments of about 56 m2. The building has not undergone much maintenance during its life. The building's annual energy consumption is 145 kWh/m2 for heating and hot-water and 40 for electricity. The property is 1,924 m2. The building #3 is fairly recent (90ies) and, therefore, is representative of a part of the Italian residential stock. It is a 6-storey building, with 54 apartments, which have an average size of 82 m2. The ground floor has a commercial space, and the basement houses garages. The whole building has an area of 4,914 m2. The building's annual energy consumption is 114 kWh/m2 for heating and hot-water and for 41 for electricity. The three case studies have been deeply analysed in a European research focus on existing social housing in Europe, improving measures for their energy-efficiency and using renewable energy in order to participate in the reduction of greenhouse effect gas emission [27].

Fig. 1. The three different case studies

4. Retrofit different scenarios

Thermal improvement potential of existing buildings located in the metropolitan area of Milan, and particularly in its suburban areas, has been investigated by a number of studies [28].
As far as the case study is concerned, to improve energy performance in comparison to the building as is, five retrofit scenarios were defined for each building, keeping the shape and the square meter of dwellings or commercial areas as constraints. The first three scenarios concern a better insulation of external and internal walls (1_S), of the roof and the floors in the basement (2_S), while the third scenario (3_S) focuses on the replacement of windows, by installing double-glazing with low-emission coating and thermal break frame, doors and thermostatic valves and efficient lighting system. The fourth scenario (4_S) introduces the BEMS, control system services with measures for the thermal bridges and air infiltration reductions. The last scenario (5_S) combines the previous measures with photovoltaic plants and MEV (Mechanical Extract Ventilation). Not all of these scenarios are fully applied to the three case studies: the dissimilar ages and levels of maintenance have led to different intensities of intervention in each building. So, in 1_S, for example, insulation of walls was completely added to some buildings, while in other buildings this happened just in part of it. The 5_S only combines the integration of photovoltaic panels and MEV in every building.

5. Method, assumptions and estimates

A marginal cost calculation was performed in order to understand the level of the economic impact and its intensity, in terms of cost, of the actions that make up different scenarios. The marginal cost has been calculated as explained in paragraph 2. A second issue will be shown later regarding life cycle costs of the different scenarios. The LCC has been used to support the cost-optimal analysis methodology, which has been developed by the European Commission as a tool to support decision makers about which energy-efficiency measures lead to minimum energy performance requirement achieving cost-optimal levels [29].
According to this approach, an intervention or a set of measures is efficient when the cost is lower than the sum of benefit that you will get along the expected lifespan of the measures. Future costs and savings are discounted in order to get their net present value. The cost-optimal analysis involves the identification of several scenarios, which take into account different level of energy-efficiency and, therefore, costs. The option with the smallest cost will provide the minimum level of requirements at the optimal cost. If options have the same cost, the package with the lowest energy use should normally be selected.
When applied to existing building, this approach may also consider the cost and the savings which do not have an economic value (e.g. improving internal comfort or maintenance needs) and a possible market value added to the revamped property.

5.1 Investment costs

All the scenarios previously outlined have been applied to the different buildings, which features are outlined in paragraph 3. Investment costs have been calculated through a cost estimate, a brief bill of quantities, and all costs have been considered together with design cost, security costs, materials, labour costs, equipment and scaffolding, construction services (Table 1).

5.2 Other economic inputs

In order to estimate energy consumption and savings a package has been used. The Termo here used is a software performing a steady-state simulation, allowing to calculate the primary energy need for heating and domestic hot-water production, as well as electricity consumption by means

of a procedure which relies on standards UNI TS 11300:2014, part 1 and 2 and UNI TS part 3 and 4 (based on UNI EN ISO 13790). In order to translate the estimated energy savings in monetary terms, we assume a unit energy price of 0.85 euros/kWh for gas and a unit energy price of 0.25 euros/kWh for electricity [30], an energy inflation rate of 3.5% per annum for electricity, and 3% for gas. The discount rate in this simulation is set at 5%. All the data introduced in the model are reflecting prices, costs and rates of the second semester of 2015. These data will be used in order to implement the life cycle cost of the different scenarios.
The LCC has been performed within a period of 20 years.

Table 1. Scenarios, investment costs and energy requirements for case study #1

Scenarios and energy-efficiency measures	Cost of investment Euro	Energy requirements kWh/m2 y	Energy savings kWh/m2 y	Unit cost of investment Euro/m2
0_S - Building as is	-	142.1	-	-
1_S - Building thermal coating: exterior wall insulation made by rock wool panels	89,500	102.3	39.8	32.7
2_S - Building thermal coating: insulation of floor and roof made by rock wool panels	186,600	73.6	68.5	68.3
3_S - Windows replacement: double glazing with low-emission coating and thermal break frame, thermostatic valves	207,500	63.3	78.8	76.0
4_S - Introduction of BEMS, control system services, thermal bridges reductions	345,700	54.8	85.3	126.6
5_S - New ventilation system	645,700	43.7	98.4	336.5

Table 2. Scenarios, investment costs and energy requirements for case study #2

Scenarios and energy-efficiency measures	Cost of investment Euro	Energy requirements kWh/m2 y	Energy savings kWh/m2 y	Unit cost of investment Euro/m2
0_S - Building as is	-	184.6	-	-
1_S - Building thermal coating: exterior wall insulation made by rock wool panels	26,700	92.3	92.3	24.92
2_S - Building thermal coating: insulation of floor and roof made by rock wool panels	35,900	85.6	99.0	33.4
3_S - Windows replacement: double glazing with low-emission coating and thermal break frame, thermostatic valves	100,800	62.2	122.2	94.0
4_S - Introduction of BEMS, control system services, thermal bridges reductions	189,400	51.3	133.3	176.6
5_S - New ventilation system	305,750	45.0	139.6	285.2

Table 3. Scenarios, investment costs and energy requirements for case study #3

Scenarios and energy-efficiency measures	Cost of investment Euro	Energy requirements kWh/m2 y	Energy savings kWh/m2 y	Unit cost of investment Euro/m2
0_S - Building as is	-	154.6	-	-
1_S - Building thermal coating: exterior wall insulation made by rock wool panels	239,000	85.7	68.9	57.33
2_S - Building thermal coating: insulation of floor and roof made by rock wool panels	390,800	57.5	97.1	93.5
3_S - Windows replacement: double glazing with low-emission coating and thermal break frame, thermostatic valves	465,300	51.8	122.2	111.4
4_S - Introduction of BEMS, control system services, thermal bridges reductions	799,300	43.4	111.2	191.3
5_S - New ventilation system	1,126,000	36.9	117.7	269.5

6. Results and discussion

For each scenario, marginal costs and LCCs have been calculated, which results are displayed in Fig. 2 and 3. The marginal costs in Fig. 2 show the traditional shape usually depicted in economic theory: in the first part, the cost increases very slowly or with a mild decrease in value, and then it shows a step-wise increase due to the principle of diminishing marginal productivity.
In 1_S, for all case studies, albeit with limited capital, the efficient energy level fully compensates the investments. In contrast, in 4_S or 5_S, to get even a small improvement of the building's energy performance, it is necessary to invest considerable sums of money. The nonlinear relationship between energy retrofitting costs and higher energy standards is well-known in the construction market: an increase of, let's say, 10% of the costs of investment do not match a decrease in energy consumption of equal proportion.

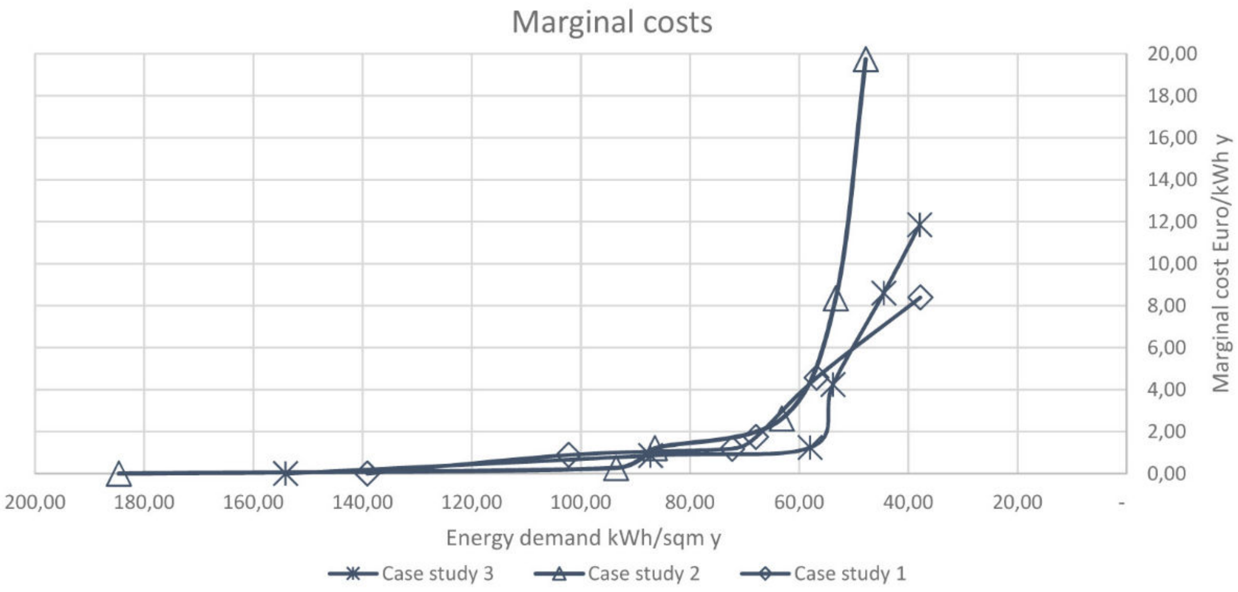

Fig. 2 Marginal costs for multiple family houses

The marginal cost curves of the first and the third building, which are relatively modern properties, do not increase as sharply as does that of the second building in 4_S and 5_S. In practice, the marginal increase in investment costs leads to an increase, albeit less effective compared to the first scenarios, of achievable energy savings. The building #2, which is a 50's construction of a very poor maintenance level, shows a curve that despite substantial measures of energy retrofits, increases very rapidly, and it is almost vertical in its last part: subsequent works do not improve building energy standard. Old buildings in poor maintenance conditions, even if actions include the combination of efficient energy measures, the use of renewable energy and technologies for the control of energy consumption, do not get proportional improvements in energy performance, and surely cannot reach the standards of passive houses. The decision makers or the investors should find the optimal scenario, and that point in the curves of marginal costs is represented by the one preceding the rapid growth of cost. In case study #2 and #3, this point corresponds to the package of measures that characterize 3_S and 4_S, while in the building #1 costs increase rapidly after 2_S.

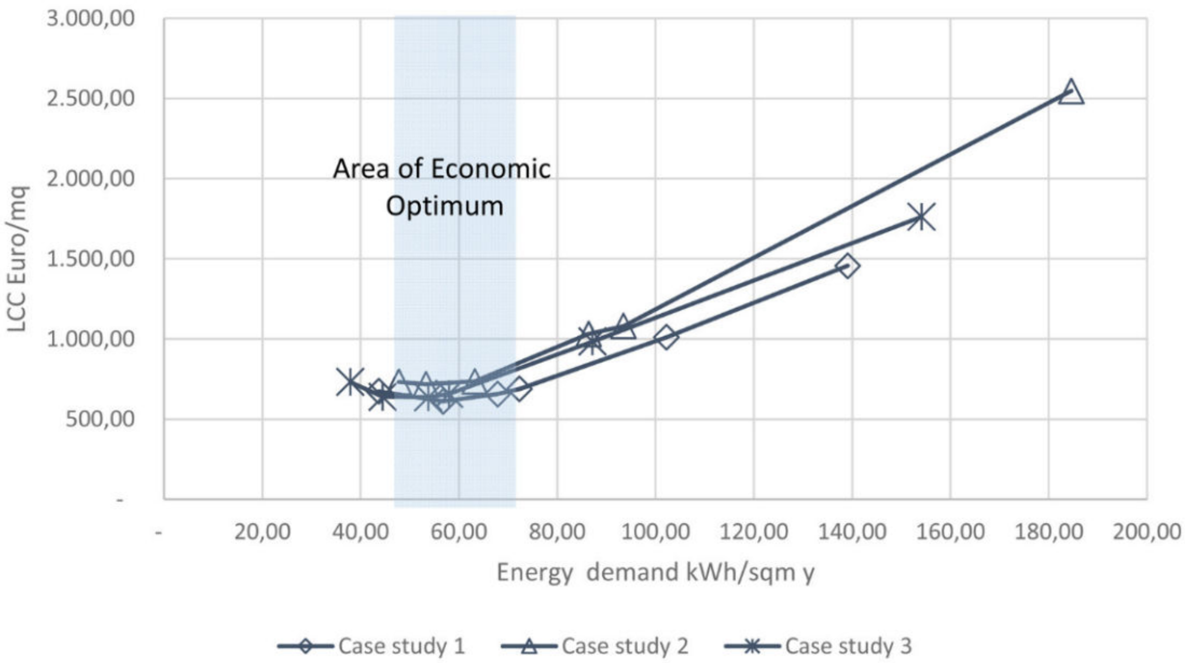

Fig. 3 Cost-optimum options

In order to detect the optimal scenario, in addition to an analysis which includes only the initial costs, a cost–optimal approach has been adopted, which includes the calculation of the life cycle costs for a period of 20 years. The results of the analysis are represented in Fig. 3. The concepts of cost efficiency and cost–optimality are related but different as a cost–effective action is when the cost of its implementation is lower than the present value of the expected benefits. The cost-optimal result is the retrofit action that minimizes the total costs. In Fig. 3 the range of economic optimum, for all case studies, is obtained when the overall cost gets its minimum at the level of the energy requirements of approximately 55 kWh/m2 years. Such energy consumption values are very similar in all case studies, although in the building #2 and #3 these could be reached through the actions of 4_S, while in building #3 those measures concern 5_S. The life cycle costs increase when energy demand is around 30-40 kWh/m2 year due to the high investment costs. The analysis of the two models does not fit together: however, it should be stressed that the first model based on marginal costs does not consider the costs that will be incurred in the future. The LCC approach considers the whole life cycle of the property, or as in this case, the costs that occur in a given period of analysis.

7. Conclusions

The analysis performed suggests that methods as Marginal costs and Life Cycle Cost might help to find the best scenario or combination of measures to improve the energy performance of the building. In existing buildings, the cost-optimal solution is not necessarily the one that leads to the lowest energy consumption. Often these actions have a high investment cost, and the marginal cost grows very quickly, not having, as a counterpart, equal reduction in energy consumption. And moreover, it is difficult to justify renovation to the highest standards if the costs rise exponentially while the amount of energy saved grows slightly. Sometimes it is technically not possible to reach that standard in existing buildings as the thermal insulations, for example, could not fit the physical form of the building, or the shape of the roof, or the terrace. The roof overhanging a wall could be too small to accommodate layers of insulation so a complete substitution of the roof could be required, with obvious additional costs [31]. Another issue arises when investment costs over – exceed the owner/investor budget constraints or he/she is not willing to pay that sum of money today and cash the benefits in the future. The payback period could be simply too long, so there is not financial profitability in investing in energy-efficient measures. The scenario with the higher energy saving, for economic and technical reasons, might not be the best option.
Future research could analyse the market value of those buildings which have been renovated, in terms of possible value recouped in comparison to the investment costs to value the green premium. This analysis could help to find different options of economic optimum solutions, which could diverge from the ones identified here.

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