**A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfilment of the Degree of Master of Science**

# Critical Analysis of the Tunnelling Through Effect: Assessment of the Theory in Case of Residential Buildings of Hungary



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**July, 2011**

**Budapest**

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(3) For bibliographic and reference purposes this thesis should be referred to as:

Ozden, E. 2011. *Critical Analysis of the Thunnelling Through Effect: Assessment of the Theory in Case of Residential Buildings of Hungary.* Master of Science thesis, Central European University, Budapest.

**Author's declaration**

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Eren OZDEN

**CENTRAL EUROPEAN UNIVERSITY**

**ABSTRACT OF THESIS** submitted by:
Eren OZDEN
for the degree of Master of Science and entitled: Critical Analysis of the Tunnelling Through Effect: Assessment of the Theory in Case of Residential Buildings of Hungary

Month and Year of submission: July, 2011.

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The research constitutes of the theoretical assessment and practicality analysis of the ‘tunnelling through effect’ which is a theory serving to achieve a higher energy standard in buildings with the same or even lower economic costs than with conventional methods. The theory promises an answer to the problem of large initial costs of high efficiency measures in buildings to acquire high energy efficiency levels with no additional burden.

The practicality potential of the theory is analysed with the study of selected renovation projects in buildings with great diversity from all around Europe. The study of the empirical data on energy efficiency and its economy adopted from the real case samples. Additionally, the conventional methodology on energy measures and cost is tested with the comparison of the obtained results based on the empirical data from real case studies.

As a result, direct correlation is observed between the energy savings and costs of energy measures in the residential renovations in Europe in parallel to the conventional understanding on efficiency implementations. Nevertheless, different patterns of the marginal costs are found according to building type and features of the selected subordinate groups in the study. The developed countries displayed a wide distribution of marginal cost in relation to energy efficiency although the cost stays low for different energy saving levels in transition economies and buildings constructed after 1960.

In the light of the literature review and results gathered by the analyses performed, the research confirms the practicality potential of the theory of the tunnelling through effect. In lack of a better tool for practice, the efforts have focused to analyse the energy efficiency improvements and the features of the buildings to determine the practicality of the theory in real life.



**Keywords:** energy efficiency, buildings, Hungary, the tunnelling through effect, cost

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## Acknowledgements

Here I would like to thank to people who helped to accomplish this research work.

The first and most sincere gratitude of mine goes to my research supervisor, Professor Diana Urge-Vorsatz, who lighted my way in doing research at many times and shared her wisdom that made me learn a lot.

Moreover, I would like to thank all other professors and the staff of Department of Environmental Science and Policy. I am sure that every single component of the excitingly interesting, yet highly challenging programs and courses has contributed to the accomplishment of my work.

Also I am grateful to those who directly contributed in my research: Sergio Tirado-Herrero who supported me in every stages of my work from the beginning to the end with his expertise and rich comments; Ksenia Petrichenko who helped me with literature and did not hesitate to share her knowledge and experience on the field; Agnes Toth who helped me in the composition and organization of the research with a great devotion and effort ; Eszter Timar who showed a great patience in the development of the chapters and contributed to finalize the structure of the work; and many other people who assisted me during the research and formation of my research.

Lastly, I want to thank my family, my group mates and my closest friend who provided their encouragement, friendliness and support up to the final moment of my work. Their assistance formed the main motivation of this work which made it possible to realize.

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# 1. Introduction

## 1.1. Background information on energy efficiency opportunities in buildings

Energy is the most essential input to sustain fundamental activities of society , in addition to other substantial elements for survival. It is highly attached to modern technologies to fulfil basic needs in daily life (Harvey 2010). The International Energy Agency (IEA) describes an upward trend for the world energy demand, with a growth of 2.4% every year in the first decade of the 21st century (IEA 2010). The energy need is developing rapidly in parallel to the lifestyle change and widespread energy tools (Metz 2010). In regard to the growing hunger of the energy system, supply of resources has been a more costly and challenging task, almost impossible in sustainable ways. Population growth and economic development in contrast to degrading resources are the major actors to support the pattern in the current system (Cornillie and Fankhauser 2004). Furthermore, the energy sector, which is responsible for following the demand curve, is mostly dependent on fossil fuel based energy resources and generates approximately two thirds of total greenhouse gas (GHG) emission, which is the primary anthropogenic source of climate change and global warming (IPCC 2007).

Considering these facts, the energy system needs to be switched to a sustainable base. The efficiency measures carry the biggest potential in this goal to diminish energy consumption to the lowest possible level (Lombard P.L et al. 2008). The adopted measures will contribute to closing the gap between the demand and sustainable energy supply while playing an active role in the mitigation of the impacts of climate change (Ürge-Vorsatz, and Koeppel 2007).

The buildings hold a substantial position in the energy system with regards to the biggest share in total final energy consumption among all energy end-use sectors and hold the biggest potential for energy savings with no or minimum investment (Meier et al. 1983 , Weizsäcker 1997). However, the high initial cost of efficiency measures constitutes a great challenge, resulting in the unwillingness to practice high energy savings. The cumulative economic costs overshadow the savings, particularly in the conservative structure in transition economies and developing countries (Lovins et al. 1989). Additionally, the risk of late introduction of energy saving measures is critical with respect to the loss of opportunities in energy improvements (Perkins 2003). Therefore, scientific information on theoretical and technological improvements consisting of more efficient and simple ways holds a great deal of importance to overcome the cost barrier and put measures into effect on a great scale in the near future.

The 'tunnelling through effect' is a hypothesis based on the design, engineering and economic components aiming to achieve high energy saving levels with the same or lower costs than conventional models (Hawken et al. 1999). Multiple benefit principles generated by the integrative design and coordination of the energy measures with currently existing needs of the framework (replacement of the heating, ventilation and air conditioning systems (HVAC) at the end of their life time) are the two substantial factors which bring the theory into action (Lovins 2007). Various different strategies including the tunnelling through effect, integrative design and others functions for the enhancement of buildings in the energy, environment and social aspects within the framework of 'whole building design'.



In presence of the opportunities created by innovative approaches, highly developed countries have already started to research and develop the solutions for the building sector while developing countries and transition economies have focused their efforts on creating a potential for the change by the determination of their national figures. At the dawn of a new age of the energy systems together with the state of art solutions, the building sector of Hungary provides an ideal scene where the national and sector figures confirm the great necessity for energy efficiency improvements. Hungary could benefit from good practices and lessons by pioneer implementations in developed countries while being prepared for the transition of the building stock following the formation of the required national potential.

This thesis research is designed to identify the tunnelling through effect and demonstrate the potential of the theory of the tunnelling through effect to practice state-of-art efficiency measures in Europe with a particular focus on Hungary. The cost and energy efficiency information on the renovation projects aiming to increase energy savings in residential buildings is collected through several implementation programs and research studies. Following that, a database is created on the received information to designate the distribution of the efficiency improvement and economic costs in practice. Finally, the findings are assessed to develop a better understanding of the opportunities to enhance the number and the scope of energy efficiency improvements in real life cases.

## 1.2. Aim, Research Question, Hypothesis and Objectives

The aim of the dissertation is to discuss the 'tunnelling through effect' in real life practices and analyse its presence in the improvement of energy efficiency in the residential buildings of Hungary. This aim will be fulfilled by means of overcoming monetary barriers and carrying buildings to a higher efficiency standard with no or lower economic payoff in comparison to conventional methods. The research is designed to describe the level of contribution of the tunnelling through effect in energy savings in buildings through the assessment of related theoretical concepts and the estimation of their success potential with the analysis of implementation examples in the residential building stock of Hungary. With this regard, the main research question is:

**What is the practicality potential of the tunnelling through effect?**

To answer the defined research questions above, the hypothesis of the research is:

**The tunnelling through effect significantly contributes to the application of energy measures in residential buildings in Hungary through higher cumulative resource savings with no extra marginal costs.**

To reach the defined aim and answer the research question above, the study will be derived along the following objectives:

1. To identify the tunnelling through effect and the related concepts.
2. To estimate the present state of residential buildings in Hungary from the perspective of energy efficiency.
3. To estimate the practicality potential of the theory by the analysis of selected residential buildings within Europe.
4. To estimate direct and indirect revenues of the tunnelling through effect in Hungary.

## 1.3. Structure of the research

The research consists of six sections in total. In the first chapter, the scope of the study is explained following the introductory information provided about the studied concept above. The aim of the dissertation is shared and the objectives clarified in light of research question information describing the background of the study.

The second chapter illustrates background information in literature about energy efficiency in buildings and the key concepts related to tunnelling through effect and its implementation areas. The key parameters are defined with the aid of theoretical information and technical knowledge collected from previous studies. Following, the substantial parameters of the conceptual ideas are described and existing applications of the concept in the building sector is employed.

The third section elaborates the research design and data collection methods including the description of qualitative and quantitative methods used in analysis of the theory. First, empirical data collected within previous scientific research and project studies is included in the analysis by means of graphical and statistic tools. The tunnelling through effect is examined through the applied projects and its role in the implementation success is discussed. The difference between the component level and real life cases is interrogated to discuss the contribution of a whole-system design implied in examples. Second, theoretical information about the concept in literature is examined in the interviews conducted with experts by means of deterministic questions. The concept theory is explained and selected experts and administrators make a related evaluation on the energy efficiency in buildings and discussed theory.

The fourth section includes the results obtained at the end of analysis. The findings are inscribed in detail with the help of graphical content to enhance understanding on the results.

The fifth section comprises of discussion on the theoretical information and on the findings as a result of conducted analysis by empirical methods. The theory of the tunnelling through effect is assessed in light of the both findings. Thus the barriers and opportunities about the integration of theory are determined. Furthermore, the scope of contribution of energy efficiency on the efforts made in the economic revenues towards the climate change mitigation, social concerns and risks are discussed in order.

The sixth section presents the conclusion and recommendations of the study. It is finalised by the presentation of the theoretical and analysis part of the research together with the last remarks and suggestions for further studies.

# 2. Literature Review

## 2.1. Building stock and energy efficiency in Hungary

### 2.1.1. National structure of energy use

Hungary owns a few national energy resources in oil, gas and coal, which are being used in full capacity and bordering on a decrease in the coming years. Half of the energy demand is met by energy import in Hungary whereas imported oil and gas provide the supply up to 80% of the market (IEA 2006a). According to the national figures, Hungary demonstrates a strong tendency towards energy dependency in future in the absence of investments on alternative energy resources such as solar, wind and nuclear (Figure 1). The major energy supplier for electricity production is nuclear energy with the one-third of the sector energy need in Hungary (IEA 2006a).

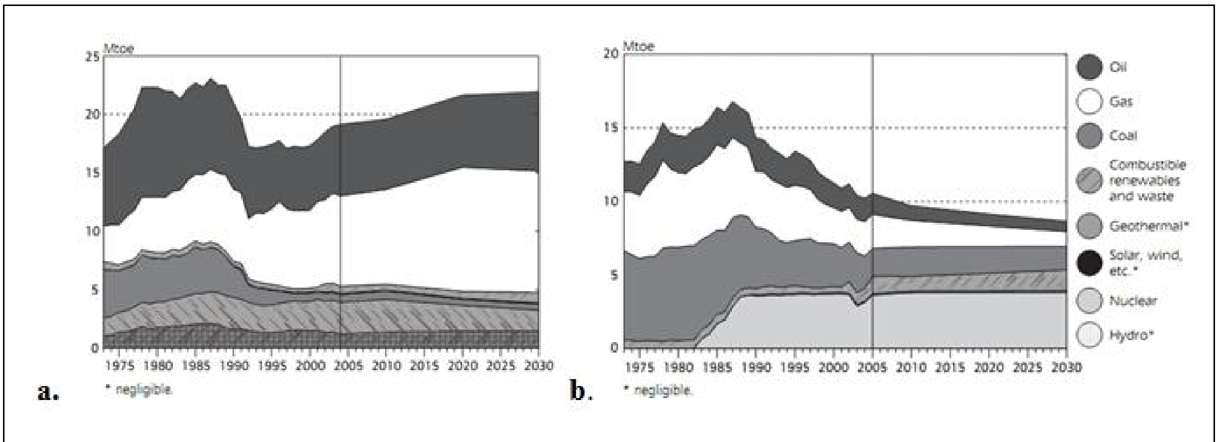


**Figure 1.** Total Primary Energy Consumption (a) and Production (b) in Hungary from1973 to 2030

**Source**: IEA 2006b.

The energy system of Hungary was developed in the communist state regime, where the parameters about efficiency and energy costs were neglected and the investments were mainly focused on the energy access (IEA 2006c). Therefore, at present, the country preserves its place in the lines by current high energy saving potential on account of poor efficiency condition and high dependency rate within Europe. Gas and oil are the two largest resources among primary energy supplies while the one-third of fuel oil was replaced by gas through the EU accession period (EC 2011). On the demand side, the households and related services have the largest final energy consumption following by the transport and industry[1] (Figure 2).

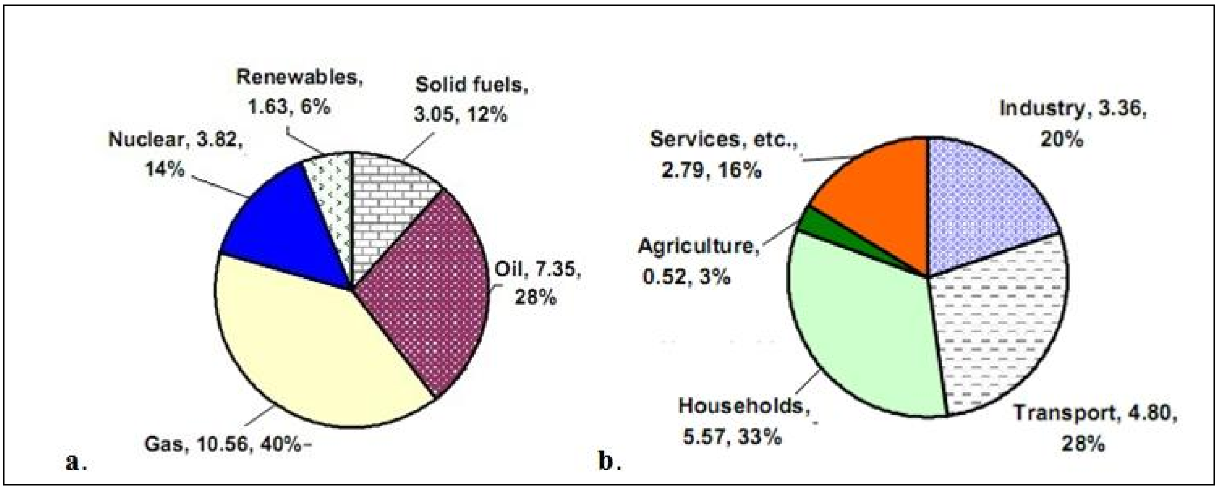


**Figure 2.** Primary Energy Supplies (a) and Final Energy Consumption by Sectors (b) in 2004, Hungary in Mtoe[2].

**Source**: EC 2010.

### 2.1.2. Building stock of Hungary

The buildings of Hungary has been undergone a radical change similarly to other materials with the regime change in terms of status, energy systems, functions and habitants.

In the 1990s, the Hungarian state held the ownership of more than half of the residential building stock, while 90% of the houses passed to the owner-occupation in the market-based economy during the following ten years (IEA 2006a). At present, residential buildings could be roughly categorized under three titles as single family houses, traditional multi storey buildings[3]

[1] The detailed figure of the energy consumption by the sectors are prensented in Table 4 in Appendixes.

[2] Conversion rates of energy units are presented in Figure 27 in Appendixes.

[3] Panel buildings are built of a prefabricated structure with monotype construction elements to create large multi-family residential facilities.

and panel blocks of flats with the percentage of 66%, 20% and 14% in respect (IEA 2006a). The average flat size is 75$m^2$ within the country, while this number decreases in more concentrated residential areas, for example 63 $m^2$ in Budapest (Ball 2005).

The majority of the buildings in the market was built before 1980s with low quality materials and still endure their framework in spite of degraded functional attributes (Fülöp 2007). Therefore the transformation[4] or renovation of the buildings has been kept in low scale where 24% of the flats are built before 1960 in low energy standards with no latter refurbishment (IEA 2006a). Only one-quarter of the existing residential building stock are equipped with a proper energy efficient equipment (Ball 2005). Within Budapest, 90% of apartments require a refurbishment in a wide range while one-third of the buildings are in need of full restoration or demolition (IEA 2006a). Accordingly, one third of the building stock does not meet the official comfort standards where the half is missing one or more essential amenity such as sewage system link (Ball 2005).

### 2.1.3. Energy use in the building sector of Hungary

The buildings are known to have the biggest share in energy consumption among all sectors (Harwey 2010). The building sector consumes approximately two-fifths of the final energy and half of the electricity generated in total (Price *et. al.* 2006, Metz 2010). The share of the buildings in energy consumption shows a wide variety from 20 % up to 90% in line with the development level and other conditions (UNEP 2009). Additionally, buildings are responsible for one fifth of the greenhouse gas emissions (GHG) by direct and indirect means through sector related activities such as electricity production and heating systems (IEA 2010).

[4] Transformation refers to the replacement of the old stock with new buildings.

In a different pattern than EU, Hungarian buildings cover alone half of the energy demand since the decrease of industry after the change of regime (IEA 2006c). Figure 3 demonstrates the weight of the sectors in energy use from 1990 to 2008 in Hungary. After 1990, the industry loses nearly one third of energy consumption and the building sector became the outweigh sector in final energy consumption.

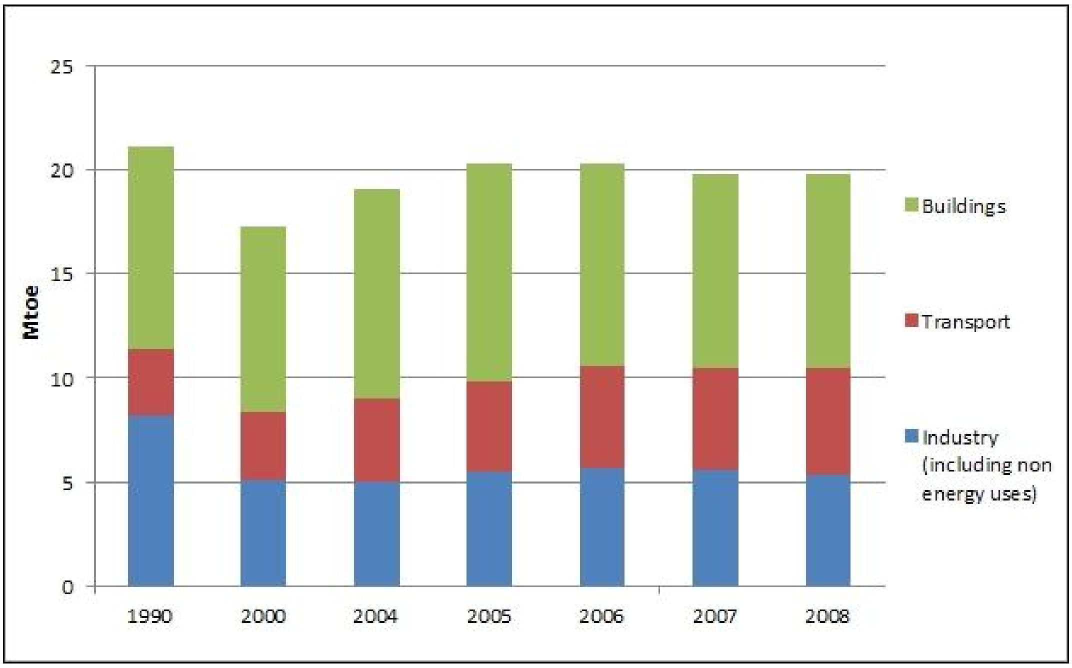


**Figure 3.** Final energy consumption in sectors from 1990 to 2008 in Hungary.

**Source**: constructed based on Enerdata 2010.

In detail, residential buildings are responsible of the major energy demand and GHG emissions with three-quarters of the total. This figure could rise up to 90% in relation to the factors such as energy efficiency, building type, climatic conditions and other related factors (IPCC 2007). Models project an approximate 40% increase in the building sector for the coming twenty years and emphasize the importance of taking measures with no delay (IEA 2010).

The building stock in Hungary has been experiencing an energy crisis in parallel to other transition economies in a very complex structure together with various risks and opportunities

(Ürge-Vorsatz 2010). The chinese word for 'crisis' which is made up of two components signifying danger and opportunity must be remembered at this point[5]. The new buildings have been upgrading with the design and construction parameters according to high energy efficiency standards while the existing building stock has been respectively improving by retrofits in a wide range of energy performance. The residential buildings of Hungary are responsible for the major part of energy consumption with the highest energy end-use for space heating (Ürge-Vorsatz 2010). There is a great potential to achieve energy efficiency improvements with a comprehensive deep renovation programme for the old buildings currently holding the highest energy intensity within their heating/cooling and water boiling equipments (Ürge-Vorsatz 2010). Energy savings in buildings carry a significant importance in terms of both direct economic profits and supply of unused energy. Therefore, the energy savings could be accepted as a distinguished primary energy source (negajoule[6]) which has the largest capacity in energy system than any other energy production mechanism (Commission of the European Communities 2006).

In this regard, the largest and most critical obstacle on the way to retrieving high energy efficiency in Hungary is the outweighed initial costs, particularly for the deep renovation of residential buildings (Perkins 2003). The cost of the state-of-art measures is up to five times higher than less efficient traditional options due to underdeveloped market conditions, missing practical experiences, but most importantly because of absence of conceptual thinking (Waide 2006). Therefore, projects with large energy savings only happen in low penetration rate and a large share of the buildings could not perform the transition to high efficiency levels to meet the low or zero energy building standards (Szönyi 2010).



[5] The visual of the character could be seen in Figure 29 in Appendixes.

[6] Negajoule is a term referring to energy savings in relation to the energy intensity; the quantity of negajoule in Europe is demonstrated in Figure 30 in Appendixes.

### 2.1.4. Energy efficiency potential in buildings

Ürge-Vorsatz and Novikova (2008) argues that the residential sector comprises a great potential on energy efficiency and mitigation of GHG emissions with the simple lower-cost solutions in the first place among all sectors. To fulfil these opportunities, economic requirements which could be summarized as unavoidable high initial investments and long term payback periods constitute the biggest barrier (Hirst *et al.*1986, Lovins *et al.* 1989, Von Weizsacker et al. 1997).

In order to achieve the desired improvements in terms of energy efficiency, the technologies for low-energy buildings and passive energy systems are ready to be implied in the new building constructions and renovation of the existing building stock (Novikova 2008). In the residential sector, the wide energy consumptions in heating and cooling activities comes up to 87% of the total energy consumption and mitigation of GHG emissions in the same manner (Novikova and Ürge-Vorsatz 2007).

Therefore, the residential building sector carries a great risk through the loss of energy savings and mitigation of GHG emissions. Groot *et al.* (2001) demonstrates the primary cause of the lock-in effect, which refers to lost opportunities in presence of savings lower than available achievable efficiency level, is the misinformation and economic concerns. Considering the recovery time of the locked savings in the components is until the end of their lifetime, the risk of missing the opportunity window is very serious and requires larger efforts to be avoided (Mulder 2005, Metz 2007).

Beside the monetary factors related to energy savings, there are co-benefits including environmental revenues, and financial savings and social gains are provided by efficiency enhancement. The importance of co-benefits is acknowledged and demonstrated in literature by several studies, for instance Hirst *et al. (*1986), Jakob (2006), Leaman and Boardass (1999), Metz *et al.* (2007) and Aunan *et al.* (2000) etc. The improvement of occupants' health as a result of extended air quality, higher structural endurance of buildings by the use of high quality material, promoted job market, improvement of the social welfare by the reallocation of the economic resources to investment and damage reduction in surrounding environment are some of the benefits demonstrated as a result of efficiency improvement (Leaman and Boardass 1999, Metz *et al.* 2007). The high labour force embedded in new constructions and deep renovations carry a great importance on the side of buildings' energy conservation (Jochem and Madlener 2003, Ürge-Vorsatz 2010). Furthermore, residential buildings hold one-third of the total GHG mitigation function with the biggest and most critical potential for the low cost mitigation options since missing the chance will be too costly (IPCC 2006, Levine *et al.* 2007).

## 2.2. Fundamentals of energy efficiency in buildings

### 2.2.1. Design and engineering principles in buildings

#### *2.2.1.1. Whole-system design in building sector*

In presence of the economic adversity commonly shared by the building sector, whole system design provides the concept of integrative design with the theory of the tunnelling through effect which promises the most effective technique to overcome the cost barrier with the possibility to enhance predetermined goals to a higher level. Several studies in literature mainly support to adopt this new system thinking (see Meier *et al.* 1983, Hawken 1994, Lovins *et al. 2010,* Von Weizsacker *et al.* 1997, Reed 2009).

### 2.2.1.2. *Integrative design concept in buildings*

The integrative design[7] concept is described as "the process to form an integral whole and to function, operate, or move in unison" in lexical manner (Webster's New International Dictionary, 2nd edition, 1951). Nevertheless, investigating the purpose, the components, the functioning mechanism and the scope of the integrative design holds a great value, particularly in terms of the potential of practice, while considering this most discussed concept of the design and engineering of buildings in the last decade.

Reed *et al.* (2009) illustrate the integrative design as a term deeply attached to the synergistic relations with the argument of "a key purpose of integrative design processes is to find and drive synergy". With the help of this definition, the essential element in the integrative design could be interpreted as the use of whole building design principles and improvement of the system capacity with a formed synergy between the energy measure instruments.

The concept of integrative design deal with the connections of individual parts and sub-systems with a wider understanding of boundaries in focus of the whole system because of one's nature (Baggs 2011).To seek the potential beneficial relationships between the discrete measures of the energy system in building and to conduct an unlimited search for the different paths of efficiency are essential to meet the maximum integration level in the designed energy systems of buildings (Harvey 2006). Hence, getting out of the custom logic boundaries and adopt an open ended strategy embracing the out of the box[8] thinking is a must while dealing with system improvements in the scope of integrative design.

[7] It is also called as integrat**ed** design in different literatures talking about the same concept.

[8] A think tank referring to avoid common knowledge and methods and wide open the doors of the mind for creativity

Figure 4 demonstrates the components of the integrative design process and sets forth the substantial differences with the conventional methodology. The complexity of the integrative design involves the theoretical logic coming from the concepts of sustainability and interconnectivity' which are necessary to follow the right path on energy measures.

| Integrated Design Process | | Conventional Design Process |
|---|---|---|
| Inclusive from the outset | vs | Involves team members only when essential |
| Front-loaded — time and energy invested early | vs | Less time, energy, and collaboration exhibited in early stages |
| Decisions influenced by broad team | vs | More decisions made by fewer people |
| Iterative process | vs | Linear process |
| Whole-systems thinking | vs | Systems often considered in isolation |
| Allows for full optimization | vs | Limited to constrained optimization |
| Seeks synergies | vs | Diminished opportunity for synergies |
| Life-cycle costing | vs | Emphasis on up-front costs |
| Process continues through post-occupancy | vs | Typically finished when construction is complete |

**Figure 4.** The comparison of integrative design process with the conventional one

**Source**: Perkins 2011.

The integrative design requires a diversified team of experts with developed analytical skills, the will of occupant to try new ideas pushing the limits and very strong belief of the all included parties (Lovins 2010). Looking in the three steady steps of the integrative design could be helpful to understand the extents of the theory. Baggs (2011) illustrates the three principles of integrative design as:

1. Everybody equates to all consultants representing the key areas of design.
2. Early in the process means as early as possible - even before the site is selected if possible
3. Every issue requires developing an understanding of the essential patterns to address 'whole systems'.

In regards to the stated factors and conditions, integrative design could be defined as a state of art concept which is argued as a myth by some of the expert on the field. However, beside the philosophical discussions and theoretical studies on the concept of the integrative design, many projects from all around the world have been already putted the energy measures in practice according the principles of the theory. The most ambitious projects on energy efficiency measures in buildings of Europe are ran by German and Austrian low energy building institutions, although a great diversity of organizations exist all around the world. Among developed countries, some of the leading organizations and groups who argue the involvement of the integrative design criteria in their projects are: the Passive House Institute from Darmstad, Germany, the Austrian Passive House Group from Vienna Austria, the Energie Insistute from Dornbirn, Austria, the Passive House Center from Gotland, Sweden, the Rocky Mountain Institute from Colorado, USA, the Ecospecifier Pty Ltd from Cannon Hill, Australia, the Metro Vancouver from Burnaby, Canada, the International Council for Building from Rotterdam, the Netherlands, International Initiative for a Sustainable Built Environment from Ontario, Canada, the Association for the Conservation of Energy from London, England and the American Council for an Energy-Efficient Economy from Washington, USA. Thus, the question of existence of the integrative design concept in buildings becomes invalid and leaves its place to the question of the possible potential of the concept in energy renovations to reach the optimum level of energy savings in regards with the costs.



### 2.2.2. Energy efficiency levels in buildings

The buildings are categorized in various ways according their total energy consumption and the energy efficiency standards. Although there is no official agreement on this term, the term 'passive house' which refers to the low-energy demanding buildings, was defined by the

Passive House Institute located in Darmstadt, Germany, in 1997 and since then it is mostly used and accepted on the global level.

The Passive House Institute (PHI) entitles residential buildings as the passive house if the building energy performance meets the predetermined level energy consumption and criteria for adjustment of inner climate and primary energy consumption (15 kWh for active heating and cooling systems and 120 kWh for heat, hot water supply and household electricity), while keeping the interior living conditions with an accurate comfort level (Feist 2007). The Passive House Institute also provides a certificate to the buildings meeting the predetermined standards according their definition of low energy building. The parameters to receive a passive house certificate are determined by PHI in Table 1.

**Table 1.** The passive house certification criteria

| | |
|---|---|
| **Specific Space Heat Demand or ………..….:**<br>**Heating Load…………………………..…...:** | **max. 15 kWh/($m^2$a)**<br>**max. 10 W/$m^2$** |
| **Pressurization Test Result $n_{50}$……….......…:** | **max 0.6 $h^{-1}$** |
| **Entire specific Primary Energy Demand….:** | **max. 120 kWh/($m^2$a) (incl. domestic electricity)** |

**Source:** Feist 2007

The conceptual parameter of the Passive House Planning Package is demonstrated in Figure 5. The limit of 15 kWh/($m^2$.a) in the description of passive house is based on the economics in concern to fix the cost curve on the optimum point for both energy savings and prices calculated in combination of both energy costs and construction costs. The drop in construction costs near the 10 kWh/($m^2$.a) level in specific energy demand for space heating is in relation on the cost savings originated by the simplification of large heating/cooling systems in building where the improved insulation performance of the building is enough to meet the deficit and keep the indoor temperature within the comfortable range .

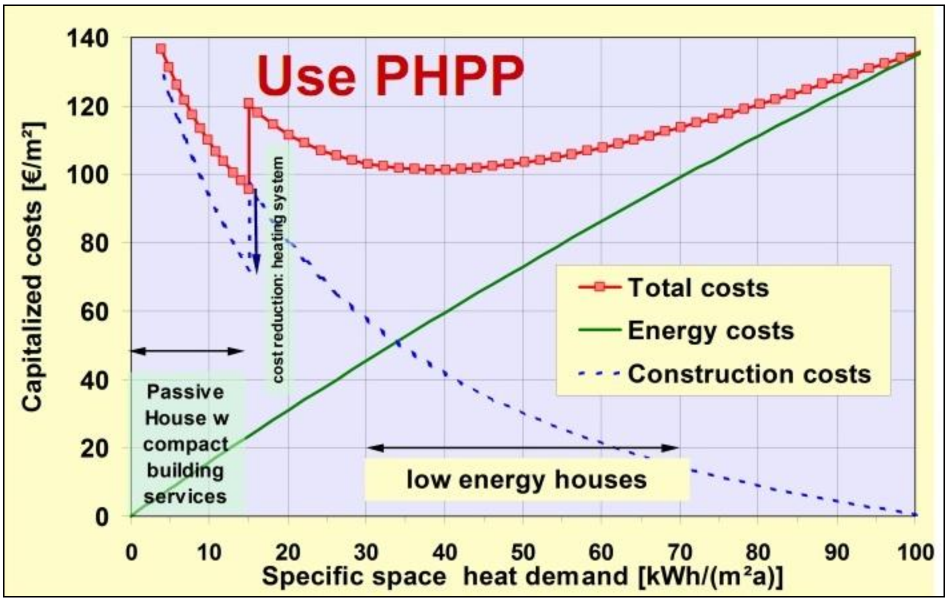


**Figure 5.** Passive House Planning Package (PHPP) in the high efficiency standards

**Source**: Feist 2011.

Furthermore, new notions such as nearly zero-energy buildings and zero energy buildings were introduced in the market with the goal of creating self sufficient energy systems in buildings with incorporation of renewable energy resources (BPIE 2010). Nevertheless, considering the fact that these concepts are developed on the basis of the passive house concept and do not provide any influential contribution on the demand side, the baseline in the energy savings is accepted as the passive house standard.

### 2.2.3. Economics of energy efficiency in buildings

The conversion of buildings to a higher energy standard is easier to practice in new buildings because of low construction and design cost, whereas current buildings require a significantly higher threshold[9] for system change and re-built (Feiler and Ürge Vorsatz 2010).

[9] The detailed figures about the individual measures with the saved energy, annual investment cost, cost of conserved energy and simple payback time is demonstrated in Table 5 in Appendixes.

Each of the applied energy saving measures brings a cost to the system and the combination of these individual measures[10] in a compatible mode forms energy efficiency packages. Energy measures are paired up in packages with different combinations to show a variety of options with different energy saving performances which could be used to determine the most effective solution for the different energy systems (Figure 6) (Boermans *et al.* 2011).

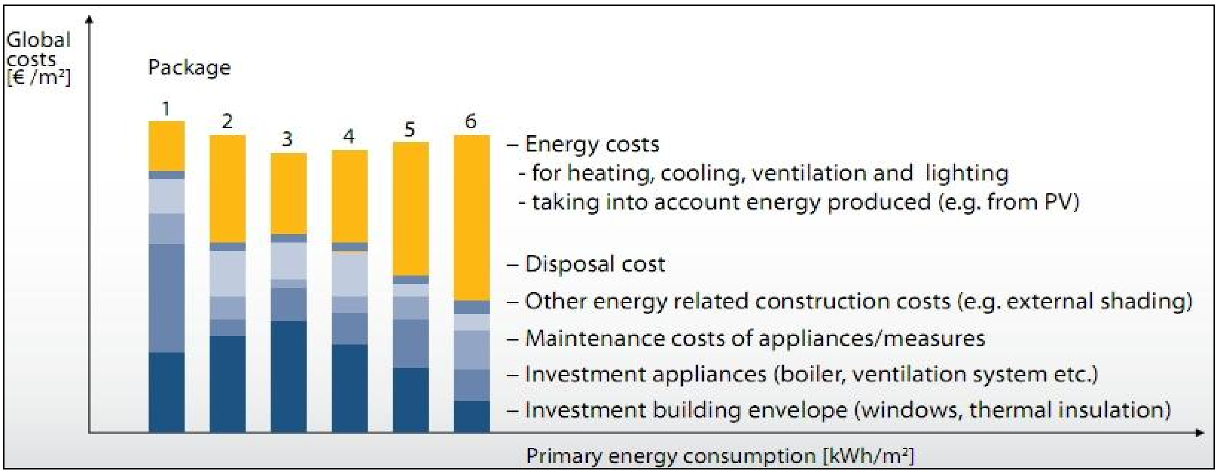


**Figure 6.** Cost calculations for different retrofit packages

**Source**: BPIE 2010.

The optimum point on the cost curve, in other words "cost-optimal energy performance", determines the most profitable moment in the energy system in terms of global costs[11] (BPIE 2010). The marginal cost refers to the price and savings of the last measure in a package and was used to follow the impact of each next action on the whole system while marginal costs and marginal savings are equal to each other at the optimum economic point.

However, in a point for high energy savings beyond the optimum point, such as low energy house, the marginal cost curve demonstrates an upward trend while the marginal cost is on the



[10] The individual measures could be described as thermal insulation, low energy windows, solar thermal systems, a condensing boiler etc.

[11] The calculation is demonstrated in the Figure b in Appendixes.

negative side but total costs keeps on zero level until it covers the cost difference to the starting point (Figure 7) (BPIE 2010).

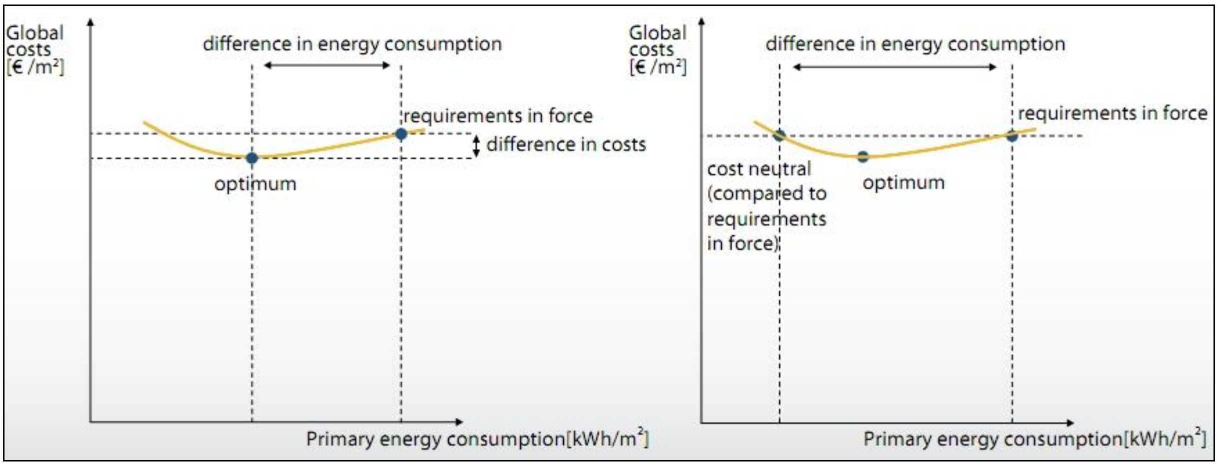


**Figure 7.** The cost curve in demonstration of the cost-optimum and cost neutrality in energy performance

**Source**: BPIE 2010.

Buildings Performance Institute Europe (2010) argues that economic concerns should be prioritized in the application of innovative design solutions in the purpose of meeting 'minimum performance requirements' at first. Accordingly, different preferences could be introduced in energy improvement packages to meet the efficiency level close to low energy standards. Additionally, the costs emerged in maintenance purposes with no energy improvements have to be kept separately from cumulative system energy cost since allocation of the maintenance cost into the initial cost of the specific unit in need of the maintenance will be the best choice (BPIE 2010).

Hawken *et al.* (1999) illustrates the graphical presentation of the marginal cost of efficiency improvements in relation to the cumulative energy savings which could contribute to demonstrating the economics of energy efficiency in order to avoid the possible confusion originated from the complex pattern and calculations of global costs and to improve the understanding of behavioural patterns in advance energy savings (Figure 8).

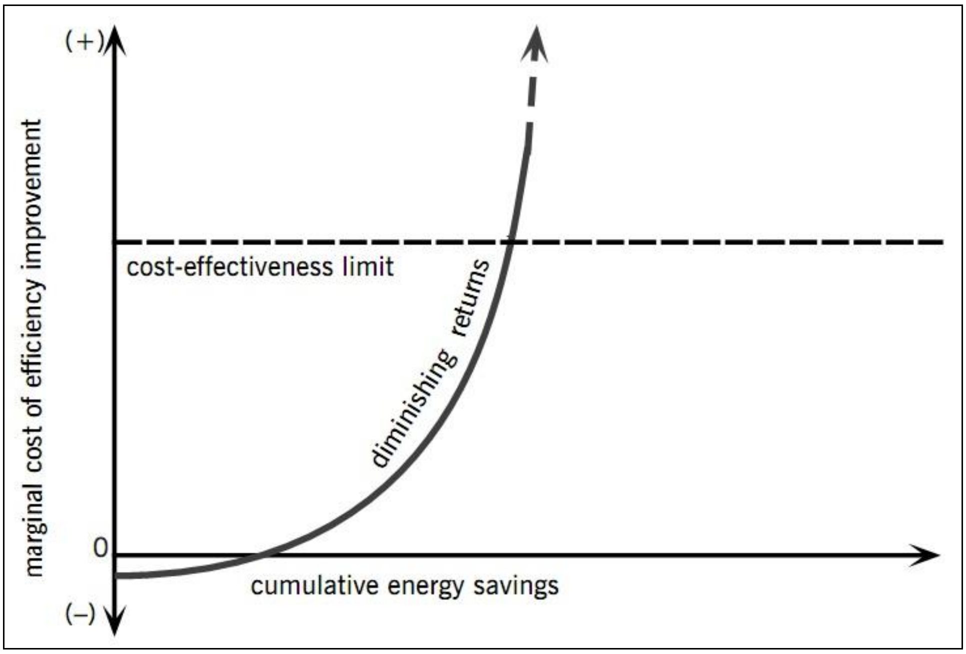


**Figure 8.** The marginal cost of efficiency improvement in relation to cumulative energy savings

**Source**: Hawken P. *et al.* 1999

In Figure 6, the theory advocates the marginal cost increase for each additional energy savings until the cost-effectiveness limit, where the upward curve become too steeply and cumulative energy savings do not meet the equivalent costs.

### *2.2.3.1. The conventional method on the economics of energy measures*

The conventional method on the economics of energy efficiency measures has been suggesting the calculation of the renovation projects' price through the cumulated cost of each individual expenditure. The straightforward logic is followed and accepted as each individual energy measure brings a potential of efficiency enhancement and a cost value added to the project. A hypothetical illustration about the theory is shown in Figure 9 to improve the understanding behind the methodology.

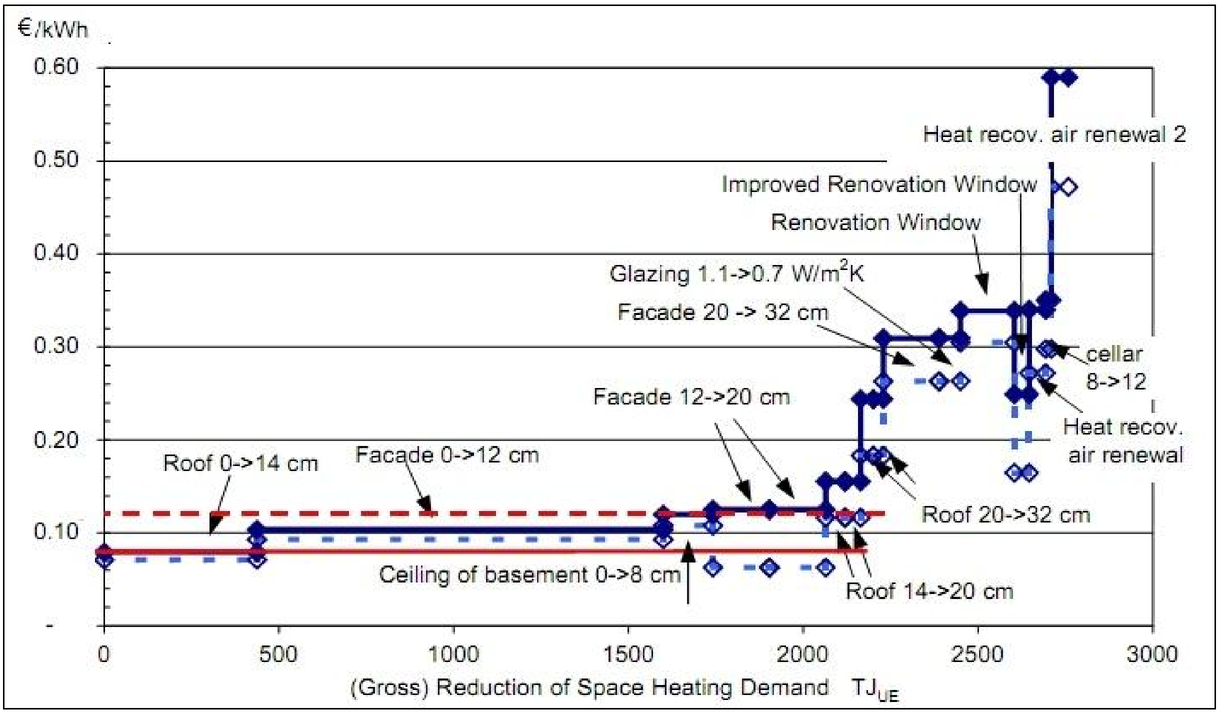


**Figure 9.** Marginal cost curve in terms of cost-effectiveness and energy savings

**Source**: Jakob 2006

Figure 9 presents a representative marginal cost demonstrating the relation between the units' performance and cost relationship and the general economic trend of energy efficiency renovation project. The energy measures are included with simulated performance factors of the expenditures (e.g. roof, facade, ceiling, glazing and heat recovery systems). Each individual measure on efficiency enhancement owns a reduction potential on the space heating need of the energy system and increases the implementation price in parallel. The contributions of the energy efficiency measures on efficiency are calculated step by step in all implementation parts. Therefore, the cost curve shows a stair form where the energy measures could be added or removed from the designed system at any stage. Accordingly, the enhancement practice continues until meeting with the budgetary limits, while the priority of implementation is generally given to the most cost-effective parameters.

## 2.2.4. The theory of the tunnelling through effect

The tunnelling through effect is the theory developed with the aim of meeting big energy savings with no initial cost while creating an additional return of savings by considerable cut-offs in operational costs. Baggs (2011) briefly described the tunnelling through effect as "finding actual lowest first cause in energy systems" where various factors and concepts lie behind this definition.

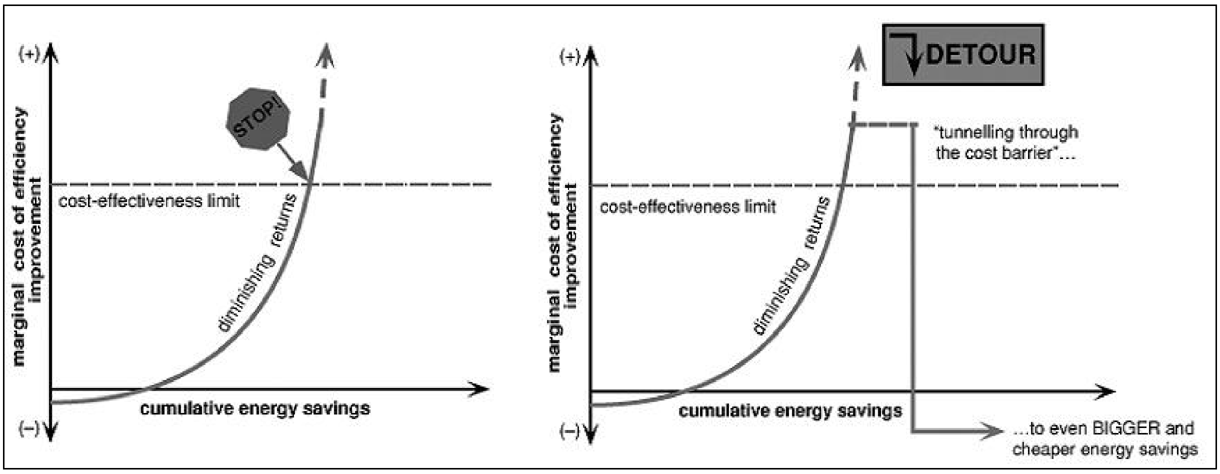


**Figure 10.** The tunnelling through effect

**Source:** Lovins 2010

The illustration of the tunnelling through effect is presented in Figure 10. The first graph demonstrates the incremental rise of the marginal cost of efficiency improvements in relation to high cumulative energy savings up to cost-effectiveness limit as explained under the section about cost optimality. The latter graph shows a representative point where the cost curve makes a detour[12] from a point beyond the cost-effectiveness' limit to down below the zero level. At this point, the marginal cost passes again to the negative side of the marginal cost axis collaterally to the starting point in a lower level. The line of the detour is drawn at random although the message of the 'bigger' and cheaper energy savings is conveyed clearly. However,

[12] A term in traffic which refers to take a roundabout course.

the point of detour starts in an unfavourable extreme point, where the high slope of the marginal cost curve makes it impossible to reach that live in concern of economic feasibility in real life cases. Lovins (2007) points to the functioning mechanism of the tunnelling through effect in real life examples, where the cost curve cuts straight through the "mountainous" form in the graph to the targeted high energy saving level with a marginal cost on the negative side throughout.

The tunnelling through effect is deeply associated with the integrative design approach and whole system design in origin and refers to reach possible higher energy savings with the same or lower economic costs than starting point (RMI 2010). The design of an energy system as a whole with an integrated approach carries a big importance, while energy efficiency measures are implemented in a package which sustains single expenditures attached to each other and holding multiple benefits (Harvey 2006). The design is optimized to keep its role with the intent to serve the whole system in optimum level (Lovins 2010). Nevertheless, the serious challenges to preserve the assertive goal of keeping marginal costs in the same or lower level must be noted.

The tunnelling through effect also includes the system optimization with the direct benefits achieved through minimizing or eliminating traditional elements designed inefficiently such as excess capacity. The upfront savings originated by the measures implemented on the system elements with over energy consumption covers the initial costs to reach further efficiency levels (Baggs 2011). The practices in the implementation projects present the possibility of energy efficiency improvements up to four times than the conventional methods, mostly with the replacement of oversize HVAC equipment (Hawken *et. al.* 1999). The course of the research is based on the system optimization principle of the tunnelling through effect since the possible multiple benefits ensured by the system synergy principles still requires development for the assessment of the concept in the implemented examples. The tunnelling through effect, in theory, allows the extension of energy savings for the existing building stock in a cost-effective manner down to the low and zero energy buildings standards.

# 3. Methodology

## 3.1. Research design

The research design provides a description of the conducted study together with the data collection and analysis methods to address the research question. The quantitative methods are chosen as the primary and only tool to examine the research hypothesis on the ground of the nature of the research area. The considerable entity of the numerical data used in the background of energy efficiency measures in buildings and their economic aspects leads the direction of the research towards empirical studies. Additionally, the essential quantitative parameters embedded in the description of the theory of the tunnelling through effect emphasize the accuracy of this decision.

Considering the absence of a long-standing background, the principles of the theory are still in progress of evolution and the implications on the field bring new sights to the issue as it can be expected from the nature of science. Under the certain circumstances, the design of the research is based on the empirical data to provide findings for and against the theory. Hence, the examination of the theory is designed to involve calculation of the parameters with the collection of numeric data on energy use and prices in parallel to the tools used in the literature.

The real case implementations are used in the example group with regards to the essentials of the tunnelling through effect referring to integration of the measures and synergy of whole system while any theoretical or experimental model different than the real life cases will not be able to fulfil this standard. Additionally, the purpose to designate the scale of energy efficiency improvement in buildings makes only the existing residential building stock available for the research. The renovation projects in the existing building stock provide the best medium of research in the scope of the thesis. The projects meet the appropriate backdrop in the existing buildings with the possibility to coordinate energy measures in implementation of the direct benefits originated by the tunnelling through effect.

It has been acknowledged that the theory could be also analysed for new buildings with the implementation of the same design and component packages in same featured buildings and calculate the energy performances with the comparison of old and new stated energy consumption for each building. However, the fact that each building and each measure comes with a unique energy profile should be kept in mind. The difference could be related to the distinguished building characteristics such as type, age, position, envelop, climate, heating/cooling unit or occupant[13]. Nevertheless, the use of existing buildings in research brings an added value due to the significant share and potential of the existing building stock in the energy market in comparison to the limited potential and small share of new buildings in whole (Fülöp 2007).

The energy efficiency level of the existing building is designated by the energy efficiency improvement rate dependent on the proportion of the 'annual heat requirement'[14] in achieved after the performed renovation compared to the primary energy requirement (total demand on heating installation, domestic hot water, household electricity and auxiliary electricity). The price of the renovation is designated as the structure building costs only including the construction and building services while the costs of site development, relevant structures and

[13] Even if the efforts made to keep the identical formation and features, the difference would be unavoidable due to the conditions related to human factor in operation.

[14] The term of annual heat requirement refers to the saved energy per floor area in a year.

additional costs are not included in the calculation with the concern of irrelevancy of these implementations with the efficiency improvement.

In a significantly limited number of the cases, the datasets are received with only construction costs. In these cases, the building cost is accepted to be equal to 80% of the construction cost. The conversion equivalent (CE) is estimated by the proportion of the construction costs and building costs from the projects in the developed dataset.

Accordingly, the assessment of the theory was performed based on the collected data in energy efficiency and cost with the intention to test the presence of the tunnelling through effect. The database including the information and figures on the energy efficiency and price was created to meet the objectives of the thesis work through the energy renovation projects. Furthermore, the created database brought the opportunity to examine the conventional methodology formulated on the economics of the energy efficiency based on the component level calculations.

## 3.2. Data collection methods

In regard to the aim of the research which was identified as to discuss the practicality potential of the theory by analysing its presence in the energy efficiency improvement practices in the building sector of Hungary, the boundaries of the study were identified as the residential buildings in Europe with the focal point in Hungary. Accordingly, the energy efficiency and the prices of renovation projects was set as the outline of the database where the data was collected from the renovation projects conducted within Europe, with a special emphasis on the cases in Hungary.

The database was formed on the basis of the data received from the Center for Climate Change and Sustainable Energy Policy (3CSEP) through personal communications. The results are obtained through the developed database on the basis of the data collected within the 'Employment Impacts of a Large Employment Impacts of a Large-Scale Deep Building Energy Retrofit Programme'. Following, the database was enlarged with the data from the online glossaries of the leading institutions (Austria PHDB , PHI, Energie Insistute) in practice of advance retrofits in Europe. The database is built on the datasets collected from 110 specific energy renovation projects conducted all around Europe. The dataset covers renovation case studies with a wide variety in terms of building type, development level, construction year and countries. The approximated price for the improvement of a residential building to the different efficiency levels is calculated and provided by Energy and Climate Protection Building Complex Program (KÉK) conducted in national level in Hungary according to the conventional theory in the calculation of the efficiency price (Tamas 2011). The renovation projects in the dataset are categorized according their scope and conceptual context in a broad variety such as energy refurbishment, retrofit, passive house retrofit, the passive house renovation or the low energy renovation with passive house components.

## 3.3. Data analysis methods

The database is made of the energy efficiency and prices was collected from different resources and was categorized according to country, building type, development category and the year of construction.

The data belonging to each of the energy renovation project is demonstrated on the scatter plot to observe the distribution of the data, to perform statistical analysis for the whole sample group and sub-categories, to represent and determine the cost effectiveness in the best manner. The examples are grouped individually under 4 different sub-groups according the renovation projects and the feature of the building. The constructed graphs are categorized under the sub-groups as follows:

**I.**

**1-** Multiple and single family buildings in Europe according to countries without conversion equivalent.
**2-** Multiple and single family buildings in Europe according to countries with conversion equivalent.

**II.**

**3-** Multiple and single family buildings in Europe according to building type.

**III.**

**4-** Multiple and single family buildings in Europe according to construction year.
**5-** Multiple family buildings in Europe according to construction year.
**6-** Single family buildings in Europe according to construction year.

**IV.**

**7-** Multiple and single family buildings in highly developed countries according to countries.
**8-** Multiple and single family buildings in less developed countries according to countries.
**9-** Multiple and single family buildings in Europe according to development level.

**V.**

**10-** Multiple and single family buildings in Hungary according to building type.
**11-** Multiple and single family buildings in Hungary according to construction year
**12-** Multiple and single family buildings in Germany according to building type.
**13-** Multiple and single family buildings in Germany according to construction year
**14-** Multiple and single family buildings in Austria according to building type.
**15-** Multiple and single family buildings in Austria according to construction year

In the Table 2, the distribution of the datasets is explained in table format to ease understanding and more easily, of emphasize the crossing points of the sub-groups and criteria for the implemented of sample group.

**Table 2.** The cross points for the different sub-groups of the renovation projects in Europe.

| Criteria / Sub-Groups | Countries | Development Level | Construction Year | Building Type |
|---|---|---|---|---|
| Multiple and Single Family Buildings | • Europe (without conv. eq.)<br>• Europe (with conv. eq.)<br>• Highly developed countries<br>• Less developed countries | • Europe | • Europe<br>• Hungary<br>• Germany<br>• Austria | • Europe<br>• Hungary<br>• Germany<br>• Austria |
| Multiple Family Buildings | | | • Europe | |
| Single Family Buildings | | | • Europe | |

### 3.3.1. Conditioning the cost value in relation to development level

In the analysis of the data, a normalization equivalent is introduced to avoid the large differences in the price values of the countries where the gap on the graph could be related to many aspects, such as construction costs, material preferences, employment cost rate or market development. Large difference is observed between the highly developed and less developed countries while the implementation of the equivalent co-efficient will contribute to sustaining the coherence of the datasets and provide the best graphical demonstration of the data through the graphs.

Instead of adopting an external value, it has been preferred to designate the conditional equivalent through the collected dataset on the basis of the average economic costs of highly developed and less developed countries[15]. At this point, the purchasing power parity (PPP) was taken into account as an adequate measure commonly used by international financial organizations to measure exchange rates between the countries according to their relative price level indexes. Figure 11 demonstrates the distribution of the countries in Europe according to their approximated PPP in 2010 with EU27[16] at 100 PPP. A significant difference in regional distribution is observed between Northern-Western Europe and Central-Eastern Europe at the 90 PPP level the. Accordingly, this PPP level is adopted to determine the development level of the countries and the member states are distributed with the entitlement as highly developed and less developed countries (Table 3). Therefore, the renovation projects are categorized in parallel to this classification according the country where they are implemented (Tirado-Herrero 2011).



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[15] The list of the countries distribution is presented in Appendixes.

[16] EU27 refers to the member states of the European Union

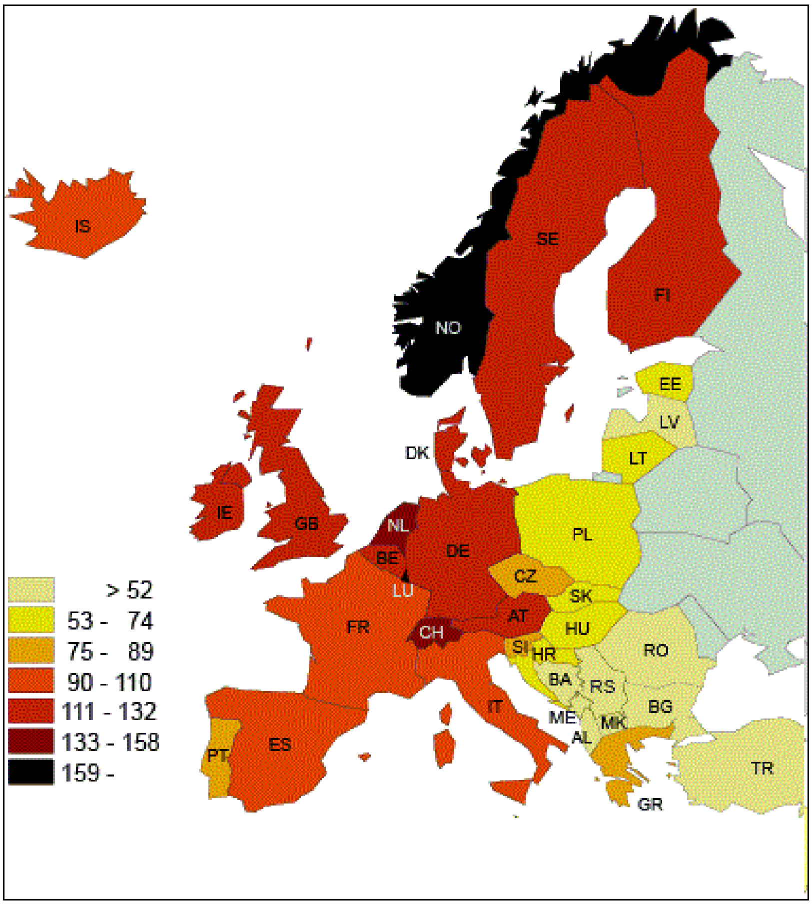


**Figure 11.** The colored scheme of the countries in Europe for the estimated PPP in 2010

**Source**: Statistics Norway 2011.

**Table 3.** The development categories of the EU countries where the renovation projects are implemented

| Highly Developed Countries | Less Developed Countries |
|---|---|
| 1. Austria | 1. Bulgaria |
| 2. Belgium | 2. Hungary |
| 3. Denmark | 3. Latvia |
| 4. France | 4. Lihuania |
| 5. Germany | 5. Slovenia |
| 6. The Netherlands | |
| 7. Sweden | |
| 8. Switzerland | |



The equivalent of normalization is found as 3,57 as the result of the performed calculations. The general graphs in scale of Europe are prepared in both original and converted data in order to provide the original figures and the best illustration of cost-effectiveness of energy efficiency in status quo. The rest of the results prepared for the sub-groups are demonstrated with the converted equivalent data to provide a clear understanding on the current situation in Europe.

# 4. Results

This chapter is reserved to demonstrate the graphical findings created at the end of the dataset analyses. The detailed information about the graphs is provided with the assessment under the section 5.2.

## 4.1. Residential buildings in Europe

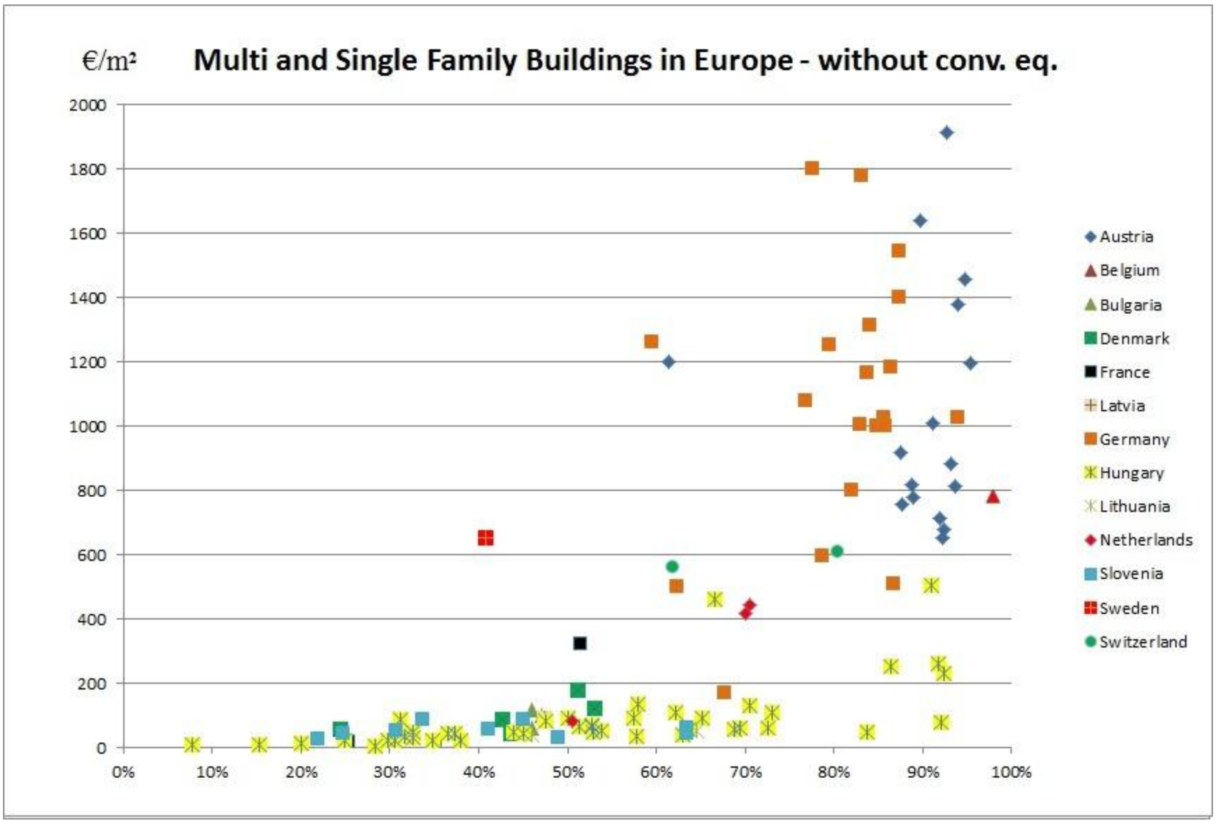


**Figure 12.** The cost-effectiveness of the energy effieciency retrofits in residential buildings in relation to countries in Europe without the ‘conversion equivalent’ (CE).

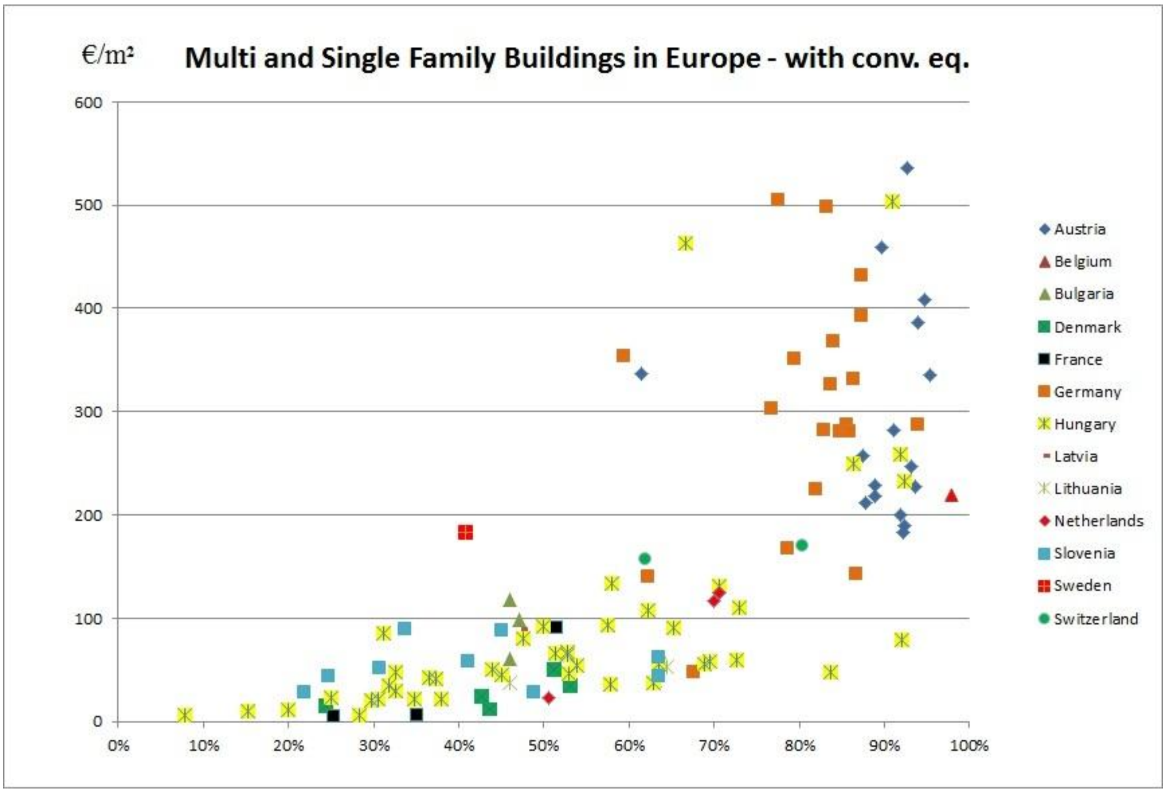


**Figure 13.** The cost-effectiveness of the energy efficiency retrofits in residential buildings in relation to countries in Europe with the conversion equivalent

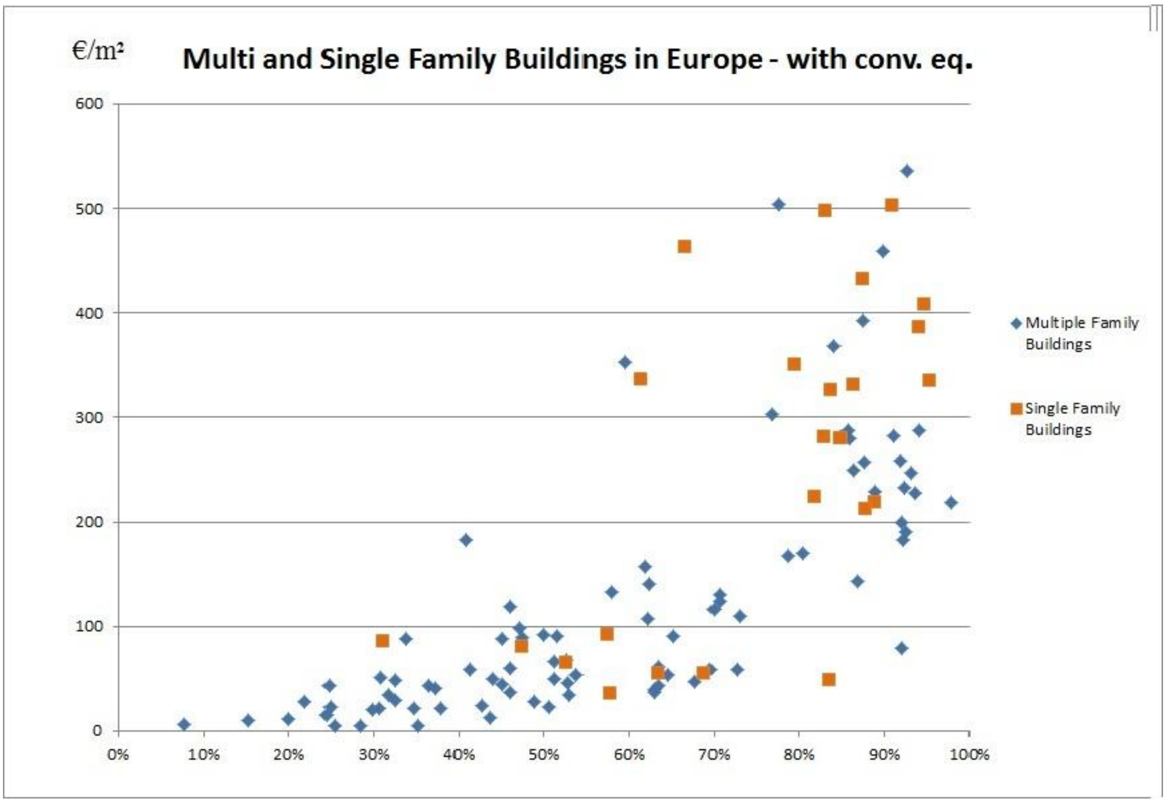


**Figure 14.** The cost-effectiveness of the energy efficiency retrofits in residential buildings in relation to multiple and single family buildings in Europe with the CE.

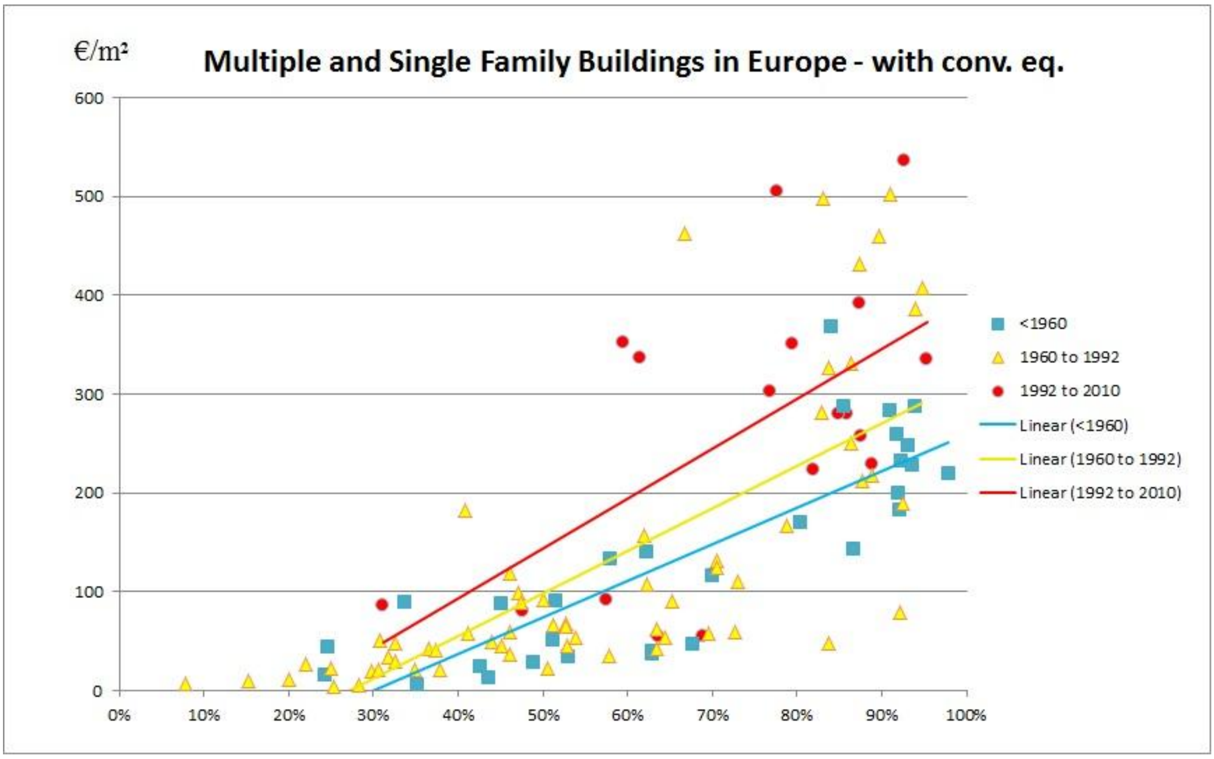


**Figure 15** The cost-effectiveness of the energy efficiency retrofits in residential buildings in Europe in relation to construction year in Europe with the CE.

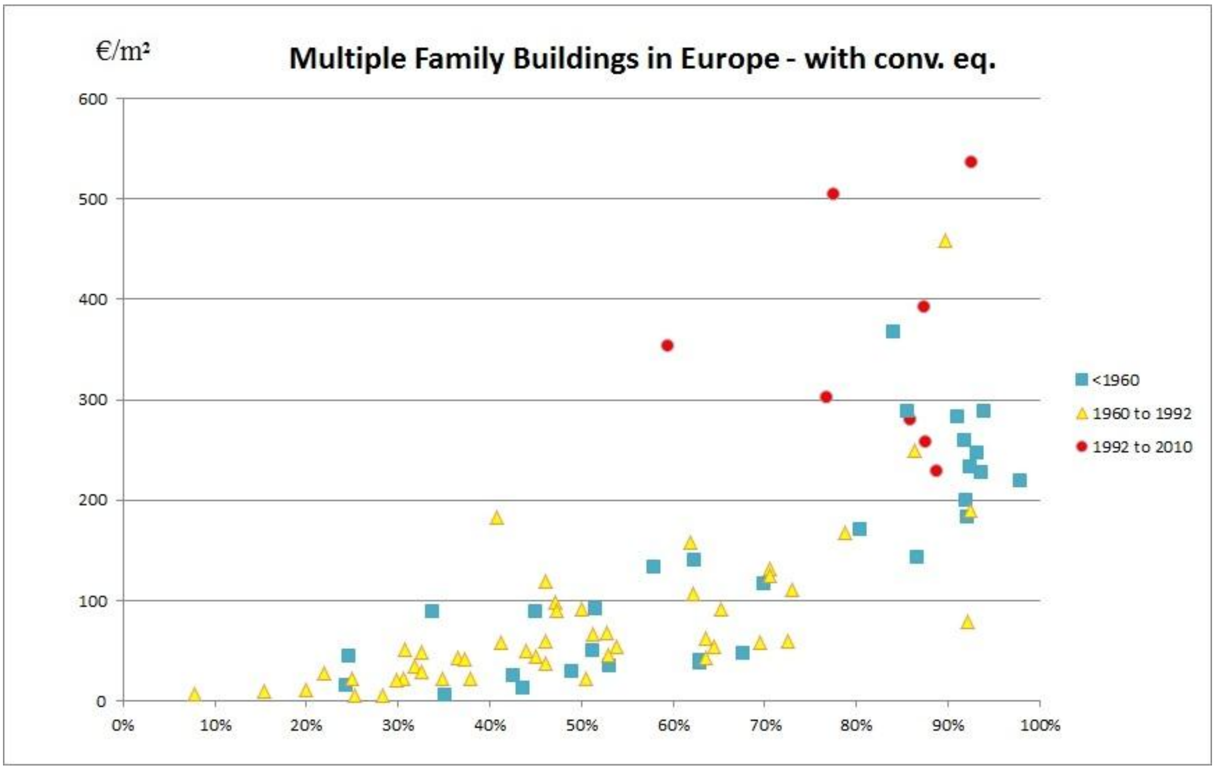


**Figure 16** The cost-effectiveness of the energy efficiency retrofits in multiple family buildings in relation to construction year in Europe with the CE

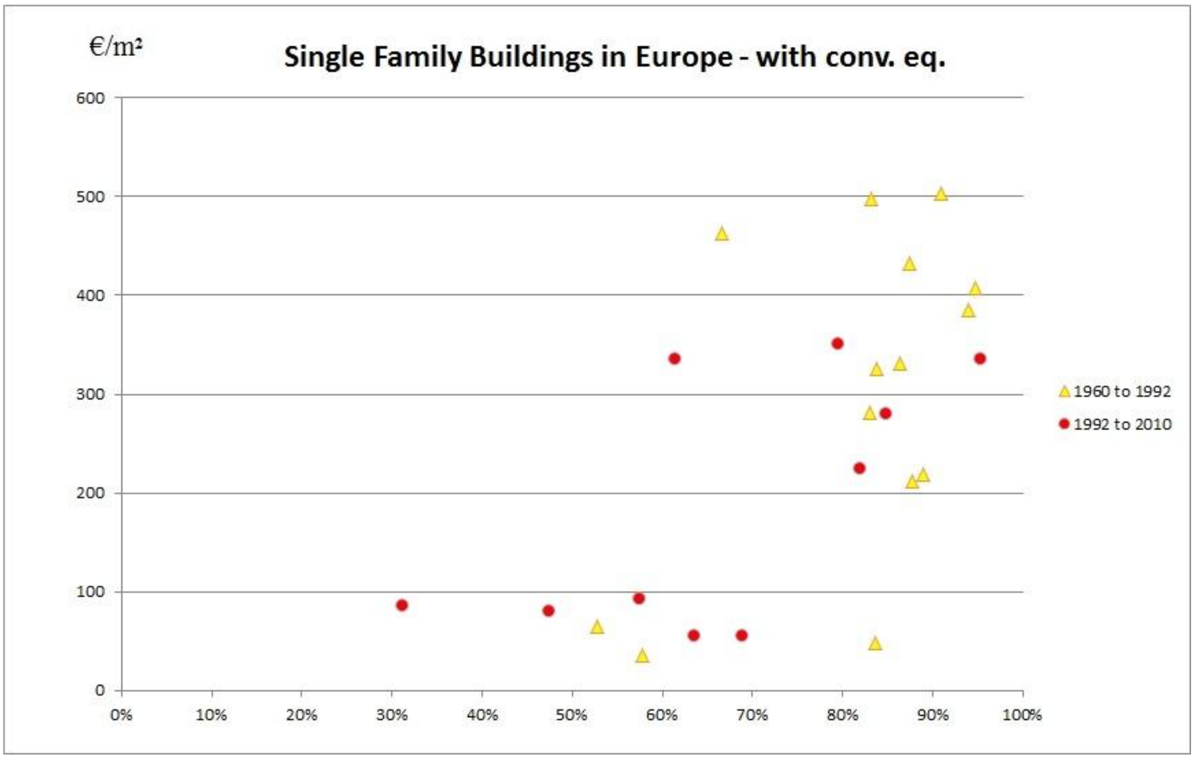


**Figure 17** The cost-effectiveness of the energy efficiency retrofits in single family buildings in relation to construction year in Europe with the CE.

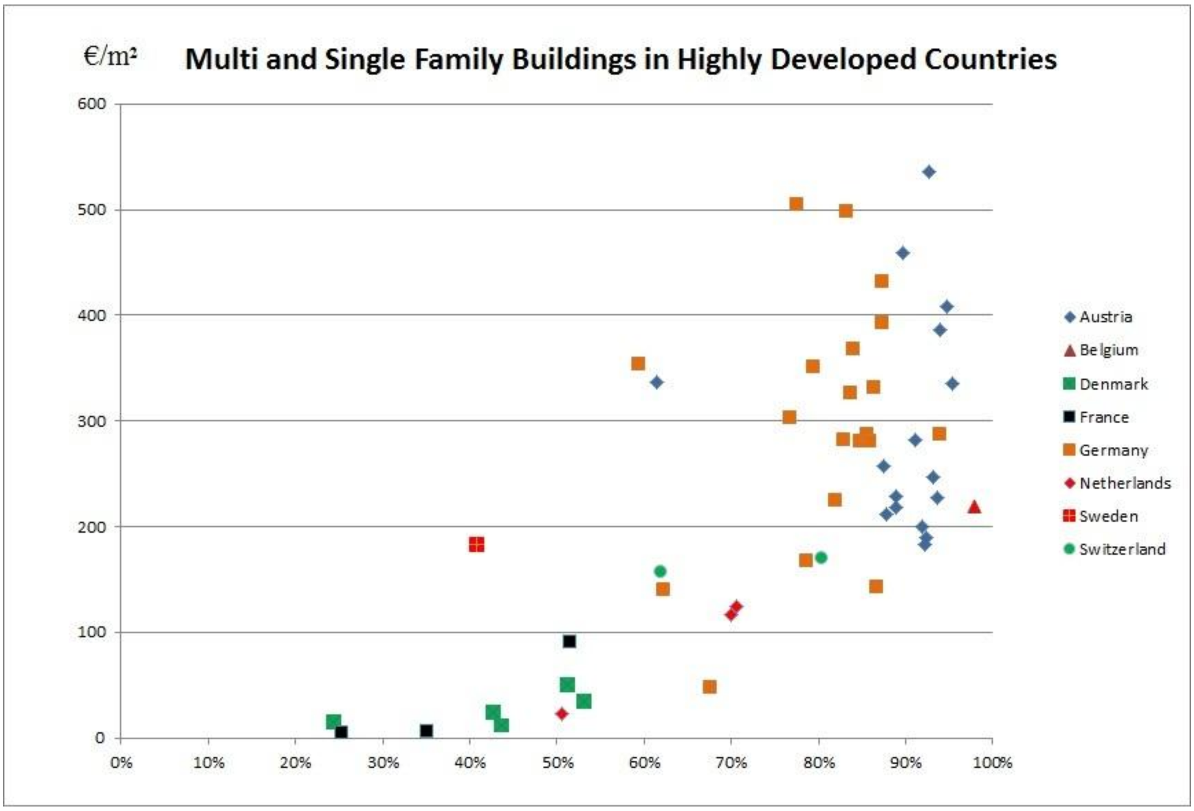


**Figure 18** The cost-effectiveness of the energy efficiency retrofits in residential buildings in relation to multiple and single family in Highly Developed Countries with the CE.

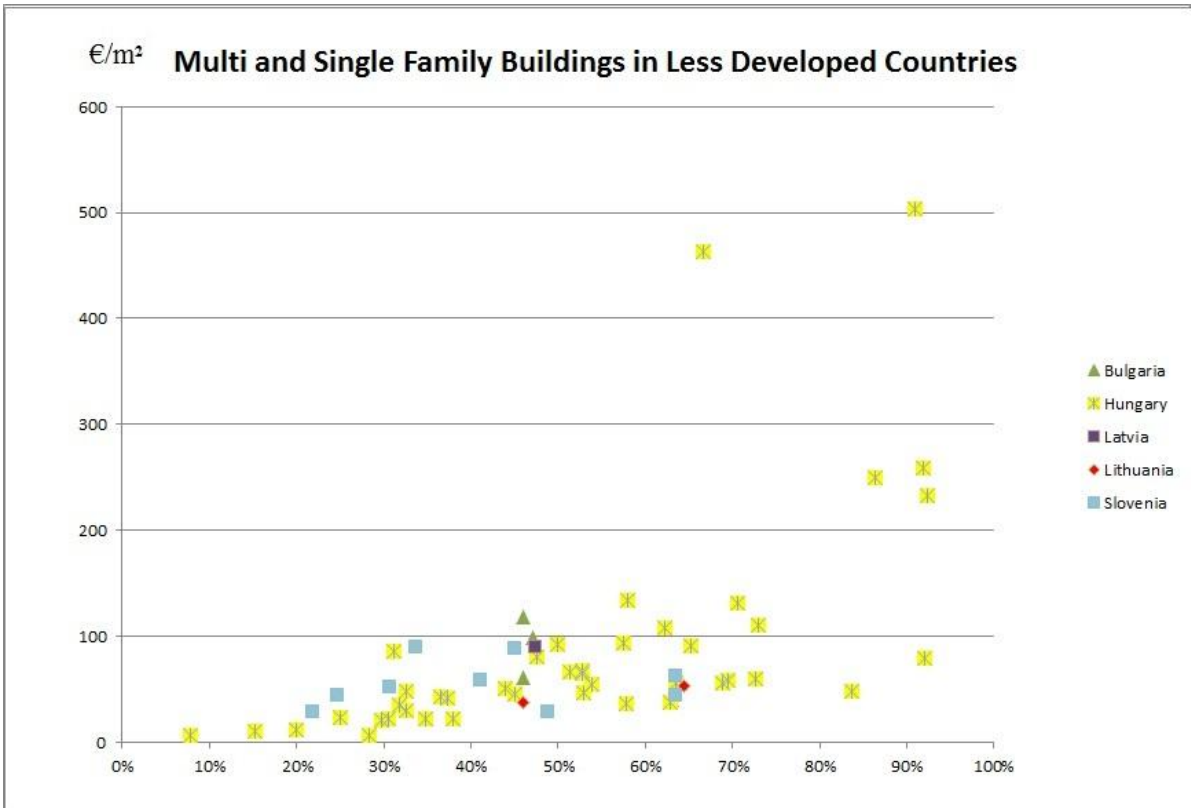


**Figure 19** The cost-effectiveness of the energy efficiency retrofits in residential buildings in relation to multiple and single family in Less Developed Countries with the CE.

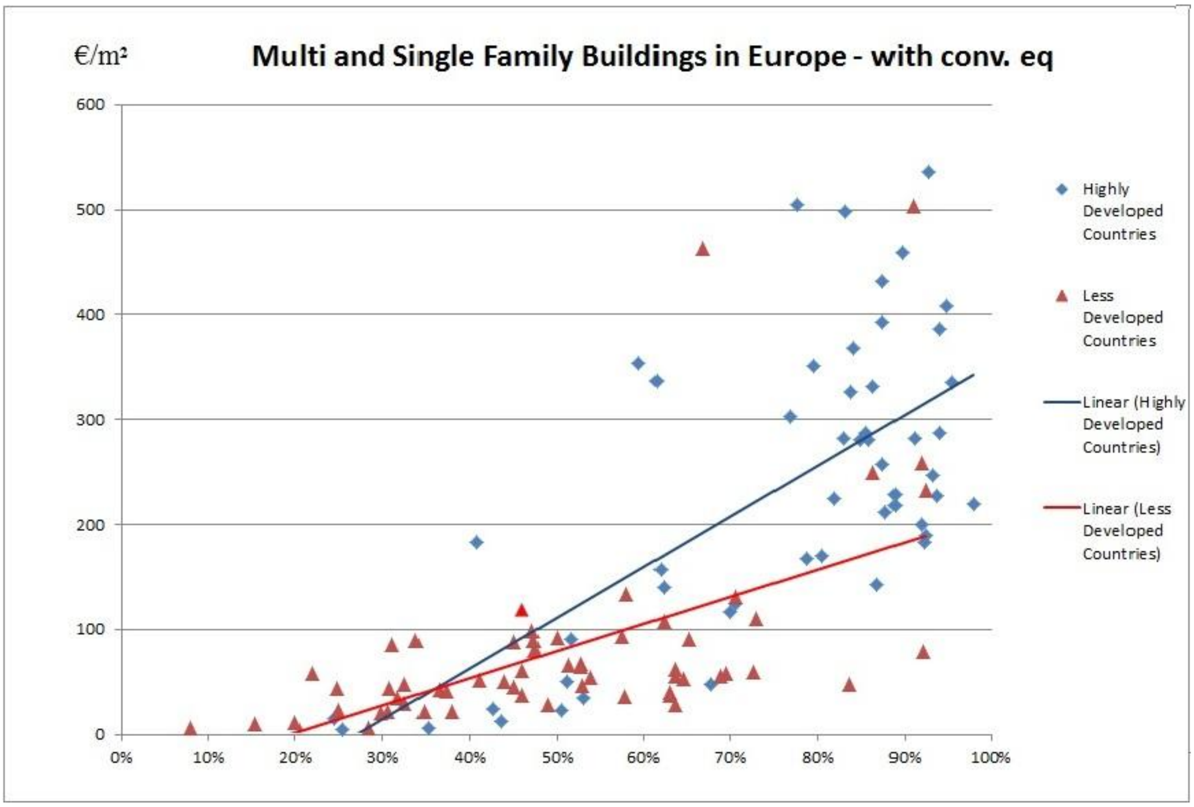


**Figure 20** The cost-effectiveness of the energy efficiency retrofits in residential buildings in relation to development level in Europe with the CE.

## 4.2. Residential buildings in Hungary

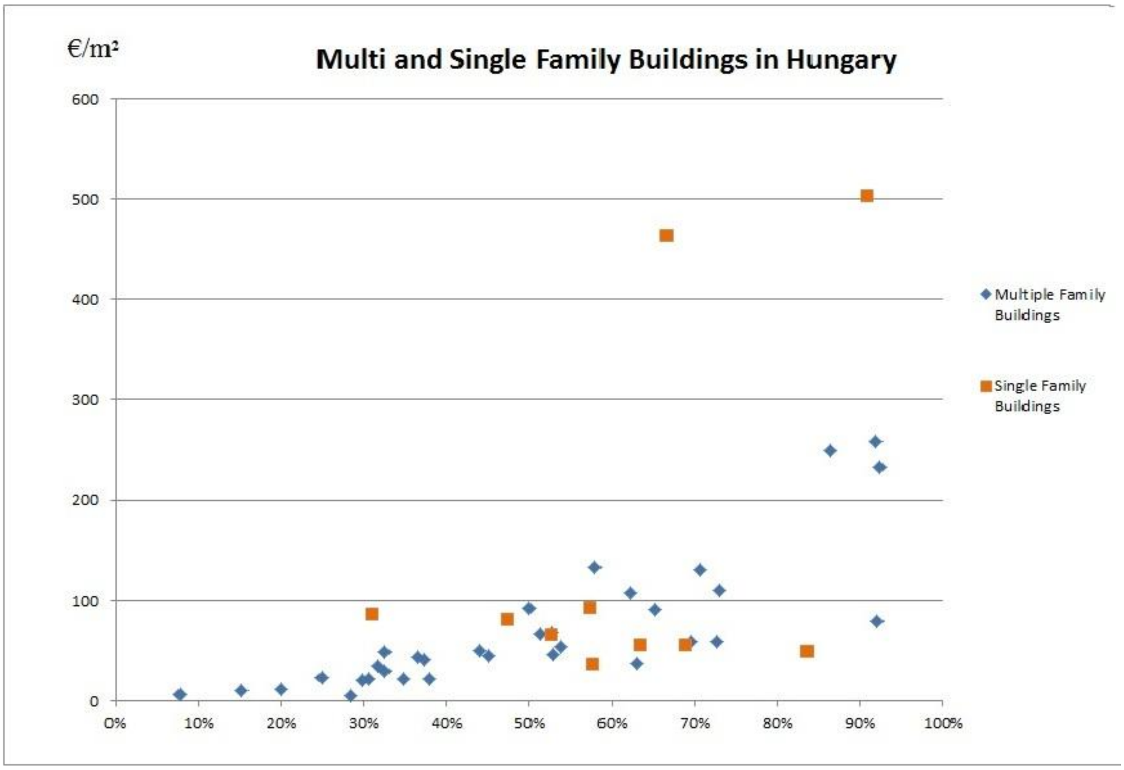


**Figure 21** The cost-effectiveness of the energy efficiency retrofits in residential buildings in relation to multiple and single family buildings in Hungary.

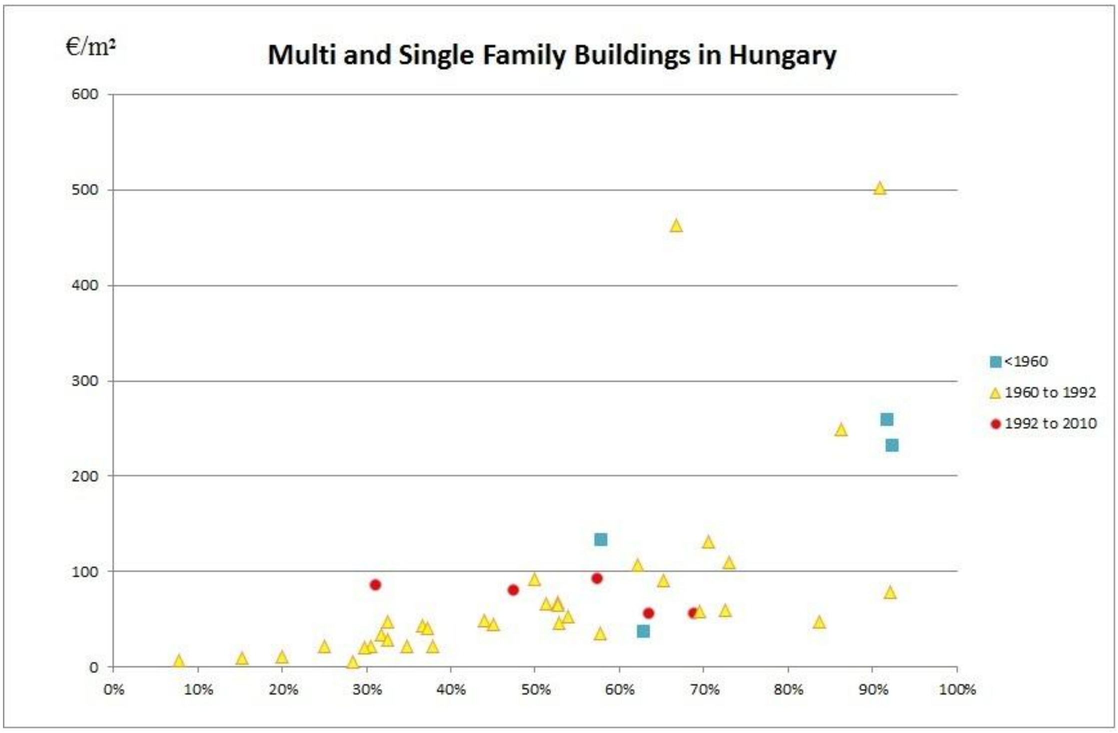


**Figure 22** The cost-effectiveness of the energy efficiency retrofits in single family buildings in relation to construction year in Hungary.

## 4.3. Residential buildings in Germany

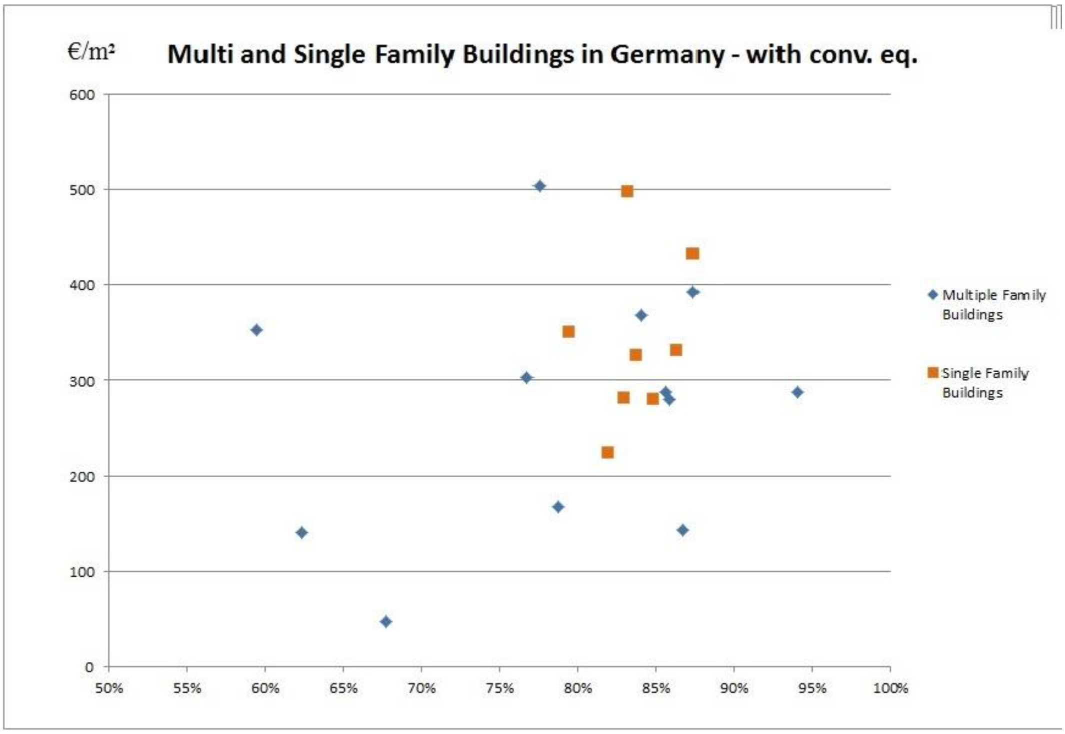


**Figure 23** The cost-effectiveness of the energy efficiency retrofits in residential buildings in relation to multiple and single family buildings in Germany with the CE.

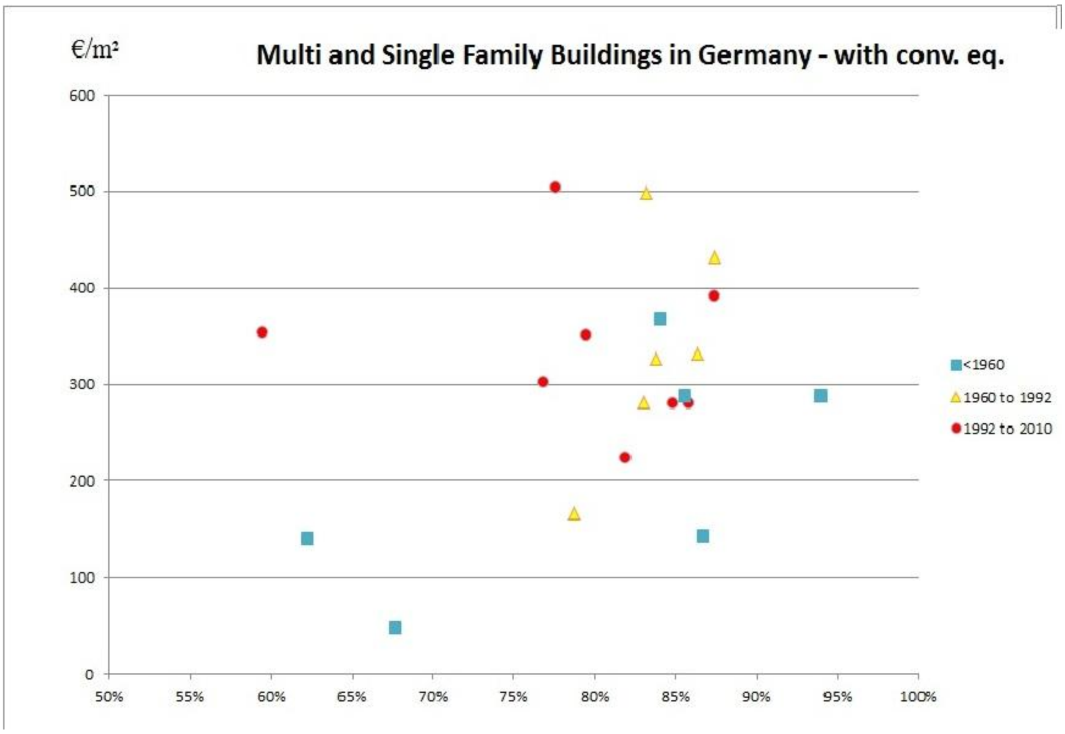


**Figure 24** The cost-effectiveness of the energy efficiency retrofits in single family buildings in relation to construction year in Germany with the CE.

## 4.4. Residential buildings in Austria

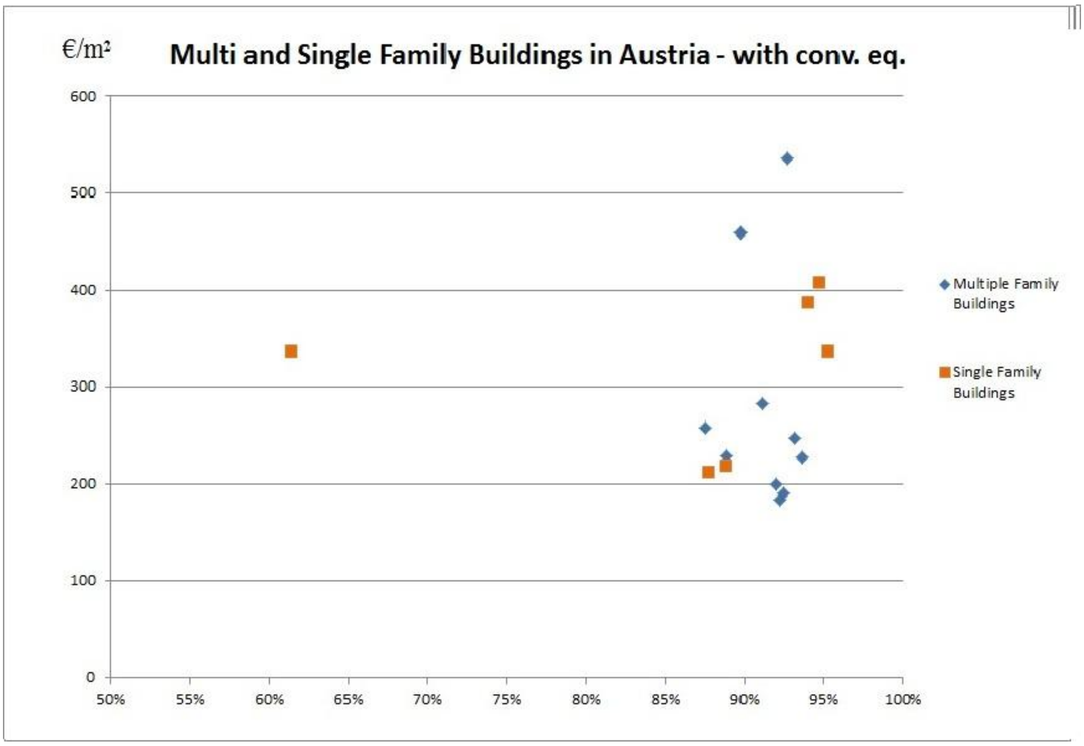


**Figure 25** The cost-effectiveness of the energy efficiency retrofits in residential buildings in relation to multiple and single family buildings in Austria with the CE.

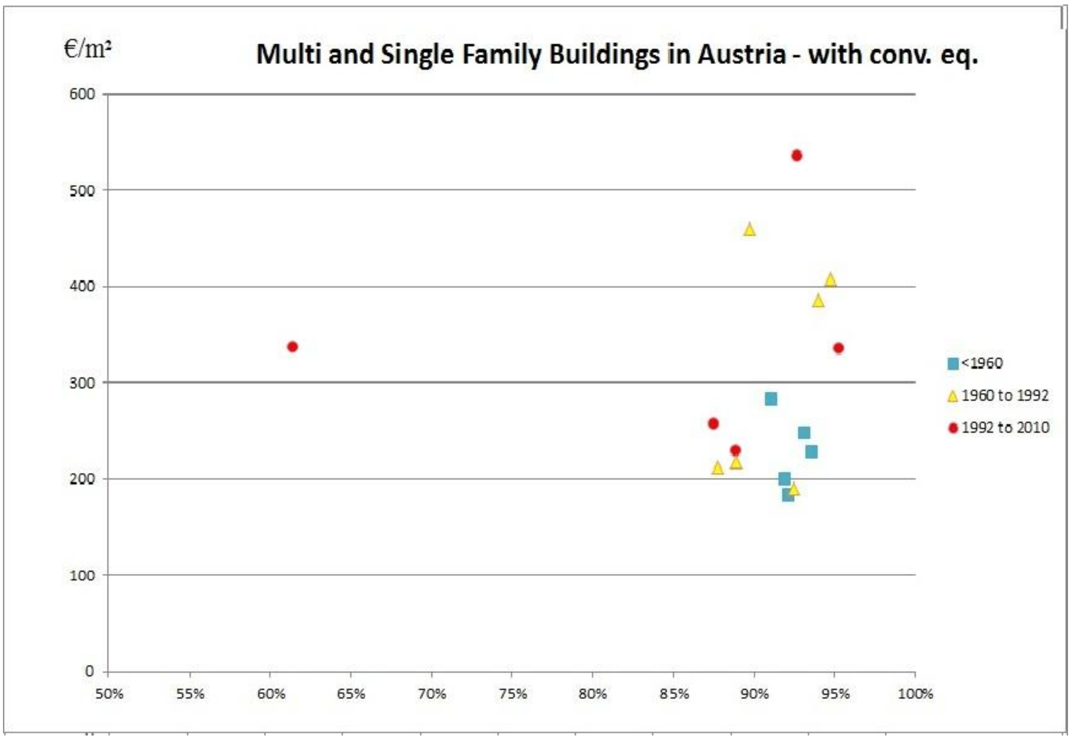


**Figure 26** The cost-effectiveness of the energy efficiency retrofits in single family buildings in relation to construction year in Austria with the CE.

# 5. Discussion

## 5.1. Assessment of the theoretical aspects of the tunnelling through effect

The theory of the tunnelling through effect is demonstrated in chapter 2 in detail, together with the presentation of the background information of the underlying concepts of the design and economics of efficiency improvements in buildings. The two substantial components of the theory, which are the establishment of a synergistic effect in integrative design and the coordination of the marginal costs of efficiency measures in buildings, are essential in understanding the tunnelling through effect from all aspects and require to be addressed explicitly (Harvey 2006, Lovins 2007 ). Therefore, related parameters on these two issues will be discussed prior to getting into the assessment of the theory of the tunnelling through effect.

### 5.1.1. Discussion of the integrated design concept

The definition of the integrated design is based on, but not limited to the design of the system in a way to create a synergistic relation between the utilities and receiving larger energy savings through the implied efficiency measures. The roots of the integrative concept in buildings embrace the basics of architectural design where formation and functioning mechanisms (e.g. rock formations, a bee hive or an ant nest) are inspired by the elements in nature and are supposed to function in full harmony and congruity (Lovins 2010). The processes carry on with observation and imitation of the nature in terms of achieving the same efficiency level in the anthropogenic systems. As it is known, nature does not waste any resource and does function in full system efficiency. Although perfect system efficiency is acknowledged as an impossible level to achieve in man designed systems, the discussions have been going on to reach the highest possible efficiency level (Baggs 2011). In the scene of constantly on-going researches, the efforts to enhance the present conditions in human-made systems rightfully consider the most fundamental living space of humans, namely their homes.

However the first publications on the design concepts underlying the efficiency in buildings have been presented only in the last two decades, where the largest contributions to the field have been made just at the beginning of this millennium. The late timing of the concept discovery and slow evolvement of the practices could give us an idea about the complexity of conceptual efficiency improvements in buildings. Although the context of simplifying the system and interconnections is considered to be an easy task to perform, the implementation of the design related parameters is another level of challenge. Especially the interdependent texture of the complex systems plays an active role in this newly discovered field, as opposed to the individually achieved technical improvements in utilities.

Integrative design composes a synergic interaction between the utilities leading to larger energy savings. At this level, the equipment in relation with the energy demand in buildings is designed to act as a whole to meet the common purpose of maximum energy efficiency rather than having divided roles under the function of energy system (Harvey 2006). Additionally, the concept states that the fulfilment of the interaction of the measures is only possible in pursuit of the essential principles of the synergistic mentality (Baggs 2011). These three principles are: firstly investing time and energy in early stages of the project with the full optimization of the building services systems, secondly calculating costs for the whole life-cycle period since the profits will be made throughout the utilities service time, and thirdly thinking of the system as a whole while allowing the involvement of all parties (Reed *et al.* 2011). In evaluation of the principles in detail, both encouraging and critical factors have been seen.

First, the whole-system thinking has to be applied all through the project starting from the earliest phases. At the initial level, the project keeps the influence potential at the highest level with the lowest costs. However, the latter interventions bring larger difficulties because of the lower effectiveness potential and end up with the loss of possible energy and economic savings in the system[17] (Meyer *et al.* 1992). Accordingly the integrative design has to be embedded in the renovations projects necessarily before the implementation phase, but preferably even before programming the related parameters; for example the project site or details of the measures. The synergistic relation between the equipment could be implemented in the large scale only from the earlier stages of the project without meeting any substantial technical and economic restrictions. Therefore the opportunity to influence the outcome of the project rapidly declines with time, while the implementation costs of the change increase similarly towards the end of the project. Although these criteria are very effective for the new building constructions, it meets with serious obstacles in the renovations projects of existing buildings. The situation in the already designed and implemented energy systems in buildings widely restricts integration opportunities for the utilities.

Second, the cost calculations in the renovation projects have to be carried out with an extra attention to fully meeting all angles related to the defined active time and on-going expenses during the life time of the energy services. Therefore the period for calculating cost has to be defined in the right scale to enable following the same track in theoretical design and afterwards in practice. The cost calculations are mainly dependent on the acknowledged evolution time period. This time period is mostly limited in terms of the implementation period. However whole-system thinking requires a more adequate comprehension considering costs and profits through the life cycle of the service utilities and to set system boundaries accordingly. In this regard, thinking of the whole life-cycle period involving the period for the design, implementation and practice of the service utility will develop the understanding of the initial costs and operational expenses. Such a comprehension of the utilities provides the long



[17] A graphical illustration of the  on the interpretation of design in the project is presented in Figure 31.

term costs and revenues for the whole-system rather than individual components limited only to the implementation phase. Hence, this strategy broadens the selection criteria in projects and makes it possible to get a true comprehension on the measures with high initial costs. In practice, the illusion of ‘cheapest is the best’ could be falsified and is able to provide a true comparison for the solutions. The high performance measures often come with higher initial costs but could be more profitable when the operational costs are considered in terms of the service utility and low maintenance rates.  In contrast, implementation of conventional techniques displays initially lower individual costs but gets less beneficial in terms of higher total costs and a lower performance rate.

Third, the limitations in terms of the budget, time and special attributes of the building are not considered in relation to the investment of the resources as needed in the early stages of the projects. Most of the real case projects come with strongly embedded time and budget constraints, and accordingly exceeding the allocated time or budget comes with the risk of disregarding efficiency measures altogether.  These resources are related to the factors incorporated into the concept according to perfect world conditions, thus they bring serious difficulties to the implementation in real cases. Additionally, the involvement of the parties in all phases could be impossible because of the personal attitude of the professionals towards opening their field of expertise to the discussion of an inexperienced group, or even simpler reasons, such as the time limitation of experts. However, if enough motivation is found to eliminate these barriers towards the participation of all designers, practitioners and tenants, the results of the discussions on a commonly shared ground will serve to upgrade the implementation performance with regards to the shared opinions and concerns of each party involved in the project.

### 5.1.2. Discussion of the economics of energy efficiency in buildings

The economics of energy efficiency in buildings covers the attached economic costs and revenues from the implemented energy measures in buildings. While the economics of new buildings includes only the construction and operation costs, the energy systems in existing buildings show a more complex structure with distinct or combined alternatives of refurbishment of the building services systems, replacement of the current units or installation of additional measures in the existing system.

Assembly of the applied energy measures are considered as a renovation package and the cost of this package is determined by the sum of the cost of utilities introduced in the system. Considering the given priority of the most cost-effective measures, the marginal cost of each additional measure increases through the efficiency upgrades (BPIE 2010). The total expenses inclines to the limit of effectiveness or to the determined budget of project with the improvement of buildings' energy system instalment within the limit value. In light of these facts, two different methods are applied in the assessment of the economics related to the energy measures.

The conventional method on the economics of efficiency measures considers the refurbishment or replacement possibilities while designating the most cost-effective renovation package for the system (Jakob 2006). The methodology carries out the economic cost calculations on the component basis although it includes several important disadvantages with regards to the missed energy and economic savings specific to the building. A prescriptive identification is used in the methodology to designate pre-determined packages of the measures to be implemented in the projects according to the desired level of efficiency. The representative figures are used to determine costs of the selected parameters of refurbishment preferences. The limit of effectiveness for the project is set according to the found cost-effectiveness pattern and creates the baseline of the project capacity. Simple context, wide applicability and satisfying proximity (only in a limited range) of the method promote its utilization as a common tool and provide enough for the method to be acknowledged as the most reasonable method in calculation of the costs. Nevertheless, the designated limit value is based on average values collected beforehand for each of the energy system services and carries a great tolerance factor in total. Additionally, the created sum is not able to merge energy savings accumulated by the synergistic effect between the utilities. Therefore, the calculations driven by this method tend to express lower energy saving potentials in higher costs with a great tolerance rate. Additionally, estimated performance of the utilities causes to projection and implementation of the measures in excess capacity and induces system loss in general scale.

### 5.1.3. Discussion of the theory of the tunnelling through effect

The theory of the tunnelling through effect is developed on the basis of both design and economic parameters (Baggs 2011). In specific, the theory provides an alternative to the conventional method on economics of energy efficiency through the concept of integrative design. Under the required conditions, the theory promises higher efficiency levels than ever possible in the conventional method. The higher level of energy savings is targeted through the involvement of synergistic effects within the system (Harvey 2006). Additionally, the theory commits to overcome the economic barrier in the cost-effectiveness limits by means of direct benefits in coordination of costs of efficiency measures by the replacement of the out-dated system utilities with lower volume and lower cost models (Lovins *et al.* 2010).

The biggest handicap in the tunnelling through effect is the establishment of the integrative design principles in the existing housing stock. The restrictions in the structural composition and design are strongly embedded in building structure and tissue and limit the possible energy measures due to its position. In most cases, the only possible way to perform a large overhand is to remove the utilities altogether and install new equipment, although most of the old building's infrastructure is not strong enough to carry the stress of such pressure and requires the demolition of the whole building.

Additionally, the multiple family building stocks introduce social barriers in terms of innovative solutions. The project requires full approval of the all households, while it involves some informal and educational programs to describe the design and functional principles of the new system. The knowledge barrier has to be recognized at this point considering the difficulties confronted even by experts to understand the stringent but changeable relation between the utilities. Therefore, unexpected limitations could be confronted in the implementation of projects which requires extra measures for the safety of system. For example, in the Solanova Project conducted in Hungary, a smaller sized conventional heating system is introduced in the structure contrary to the calculations that the capacity of a new air heat exchanger system will be able to provide full service for the whole building (Csoknyai 2011). These compromises naturally increase the cost of the project and involve unrequired utilities, which is exactly the opposite of the foundation principles of the theory.

## 5.2. Assessment of the practicality potential of the tunnelling through effect

The practicality of the tunnelling through effect is assessed using the findings in the third chapter. The graphical illustrations of the findings are built on the basis of the performed analysis of the created database. The graphs are demonstrated in an order from general to specific to first understand the big picture of renovation projects in Europe and then assess the situation in specific conditions.

First, the cost-effectiveness graph is prepared for the multiple and single family buildings in Europe and displayed in two different versions with and without the conversion equivalent.

The preference about the demonstration of data with and without the conversion equivalent is made due to the intention to provide both original situation and a better illustration. The initial impression on the original cost-effectiveness is the wide distribution of the cost data about the renovation projects in Europe. The large gap between the cost data after the 70% energy efficiency improvement level is clearly seen in Figure 12. The cost data follows a general pattern up to 200 € until the 70% efficiency level, which is accepted as deep retrofit frontier, while the costs rise up to tenfold beyond this level and reach to 2000 € limit in some specific cases. The general distribution of the cost data beyond the deep retrofit level could be observed around 1000 € which is again tenfold higher than approximate 100 € average for the low-level renovation costs. The most costly projects are observed for the projects located in developed countries. This irrational difference in the cost data could be explained preliminarily with the relation of expenses and a function of national economic differences, diverse priorities and/or private preferences enrolled in the projects. The large gap in the data is eliminated with the conversion equivalent and the cost data is brought to the same scale, where the largest expenses are kept below 600 € (Figure 13). In a detailed look, the specific features of the treated house stock such as a national location, building type, and construction year are analysed to appoint their effect on the costs of retrofits.

The building type is categorized under the groups of multiple and single-family buildings. Both of the building types show a similar behaviour: the costs increase up to five times after the 70% efficiency improvement level. Figure 14 demonstrates the distribution of the cost data according to the building type for the retrofits in Europe. Although the higher expenses are mainly associated with single family buildings, and the less costly efficiency opportunities are identified for multiple family buildings in the literature, for example, Summerfold and McCollum 2009, Lovins 2010, the graphical distribution does not state any significant difference between the building types.

The construction year is categorized under three sub-groups determined according to the year of the construction of buildings. These three groups are: firstly the buildings built in late 19th century to 1960, secondly the buildings build between 1960 and 1992, and thirdly the buildings built between 1992 and 2010. The division for the construction years is selected according to the specific year periods when the structure of buildings differs significantly according to its time. The building construction is effected mainly by the inter war years, industrial technology and modern tools for the periods of before 1960, 1960 – 1992 and 1992 – 2010 respectively. The effect of the construction year on the cost is determined in the positive way, while the expenses get higher as construction date gets closer to the present date. The linear trend lines are added for the comparison of the increase pattern of different construction years and are unrepresentative for any identical cost-effectiveness estimation.

Additionally, the cost data is analysed according to the year of construction specifically for multiple and single-family buildings separately. A similar pattern is determined for both multiple and single-family buildings separately in Figure 16 and 17 with the incline followed by cost through the construction years. For the single-family buildings there are two categories of the construction year: 1960 to 1992 and 1992 to 2010, since there is no example of the retrofit projects in the database for the period before 1960. Since no special effort is made for such an arrangement, the reason of this limitation could be explained with the shorter lifetime of the single-family buildings and historical restrictions for the renovation of buildings older than 50 years.



Forth, the cost data collected on the retrofits is analysed for the countries according to the development level. Price of the retrofits in the group of developed countries show a wide diversity while the majority of the projects found beyond the deep retrofit limit with the 200 € bottom level (Figure 18). These projects show a wide distribution from 200 € and up to 550 €. In contrary, costs of the retrofits in the group of less developed countries concentrate up to a deep retrofit level while the costs are kept below 150 € (Figure 19). The exceptional cases are determined around 250 € which is closer to the bottom level of costs allocated for highly developed countries.

The two specific cases have the cost values around 500 €, which is three times higher than average in less developed countries. These cases show a different pattern from the usual one that could be interpreted in relation with the installed sustainable energy supply technologies such as solar panels or small sized wind turbines. These additional energy systems serving in the supply side are generally not cost-effective and at least double the cost of energy supply systems (Palvölgy 2011). The linear trend lines are drawn for both of the groups of development in Figure 20 to demonstrate the different increase patterns in price. As it is explained previously for the construction year, the lines do not represent any cost-effectiveness performance.

Fifth, the cost data is analysed for three specific countries: Hungary, Germany and Austria. There are two fundamental reasons underlying the made selection. Firstly, the above-mentioned countries compose the largest three datasets that cover more than two-thirds of the whole database. Hungary has the greatest share with nearby 40 % of the database all alone. Secondly, the Hungary holds a great importance due to its position in the core of this research while Germany and Austria carry the leading positions in the sector and are able to give examples of the most successful projects in terms of high efficiency levels in retrofits. A detailed look to Hungary could provide a perspective about the current situation in cost-effectiveness while the examples from Germany and Austria provide a baseline for the case of Hungary and contribute to the efforts to carry cost-effective implementation projects beyond the deep retrofit level.

In Hungary, the cost of retrofits reaches up to 300 € in general while the two examples with the integrated sustainable energy supply systems involve a surplus on top of this level (Figure 21). Both of the multiple and single-family buildings show a similar pattern in prices parallel to the national characteristics. The cost analysis performed on the basis of construction years follows a conventional pattern in a wider distribution (Figure 22).

In Germany, the multiple and single-family buildings are between the 75 % and 90 % efficiency improvement while cost parameters are distributed in a wide area, roughly between 150 and 500 € (Figure 23). The limited efficiency range is related to the definite interest of Passive House Institute oriented within this range (Feist 2007). Despite that, the wide range of the distribution of cost value is not directly related to any identical information. Additionally, the cost data in Figure 24 does not represent any differential patterns on the construction year and shows a homogenous structure (Figure 24).

In Austria, a similar equal distribution of the cost data is observed for the building type and construction year within 85 % and 95 % efficiency levels (Figure 25). Although the cost-effectiveness is limited to a 10 % range only, the prices are spread in a large area in similar to the German retrofits but with a more narrow interval from 200 € to 550 €. (Figure 26).

For the both cases of Germany and Austria, it is seen that retrofitting prices are dependent on some external functions and possible to vary in a large scale for more than two folds at the same efficiency levels. Thus, the price difference in the examples could be possibly explained with various alternatives such as private preferences in design and mentality while the external factors play an important role. The boundaries of project also become important when the intention outreach the goals of efficiency with esthetical preferences. However, the dataset does not provide many cases in sub-groups and require a larger sampling group for further assessment.

## 5.3. Research Limitations

The question of specific conditions and parameters for the successful applications of the tunnelling through effect carry a great importance, although finding an answer to these questions goes far beyond the current objectives of the research. The larger requirements to fulfil such kind of goals have to be acknowledged and need wider resources in terms of time and research opportunities.

The major limitations in the research are related to the lack of sufficient data and resources. First, as a commonly known and accepted weakness in the quantitative methods, the accuracy and reliance of the results is very much dependent on the size of the sample group since the accuracy increases as the number of the cases goes up. The uneven size of different sub-groups introduced a deviation function in the research. Second, in an imperfect world, it is highly possible to face mistakes in the level of implementation, calculation or reporting. To keep the high accuracy in the research, the collection and analysis of the data is performed with the effort to avoid any deviation in the results. However, the various previous steps in data collection such as measurement and reporting is uncovered within the research and accepted as given only with the removal of extreme and unexplainable figures. The deviation of the data has to be acknowledged also in these phases. Furthermore, thinking about the time lag between the implementation of renovations, the inflation rate should be taken into account to demonstrate the results in a high accuracy level, although the current study does not deal due to the construction year is taken into account in the analysis.

# 6. Conclusions and Recommendations

The research is performed to provide a clear understanding on the theory of the tunnelling through effect and demonstrate the practicality potential of the theory for residential retrofits in Europe. First of all, the literature review is provided on the energy efficiency and economics in residential buildings and underlying factors and principles are investigated within the theory. Following that, the renovation projects database is created on the collected information from energy retrofits in residential buildings in Europe with different characteristics such as a building type, development level, construction year and country. Additionally, empirical analysis is performed to demonstrate the status quo in energy retrofits with regards to cost-effectiveness. The results are demonstrated in graphical display to represent the specific parameters and general distribution of the cost data. Furthermore, the assessment of the theoretical aspects and practicality potential of the tunnelling through effect is performed accordingly.

Based on the analysis performed on the dataset, it has been determined that higher energy efficiency improvements increase the cost of the retrofits in residential buildings. However, distinctive distribution patterns have been comprehended from cost data according to both general parameters and specific features of renovation projects. The conventional understanding on the economics of retrofits is proven in only a part of the findings while a wider diversity is seen for the majority of data. For example, the correlation between the building type and cost of retrofits is found insignificant despite the fact that the period of the construction year is found significant in increase of the retrofitting costs as the year gets closer to present time. The development level could not interpreted completely due to the lack of data in different efficiency improvement ranges, while the significant difference in prices has been observed in relation to the achieved efficiency according to the development level of the countries where the retrofits are performed.

The analysis of the research does not prove or disprove the theory of the tunnelling through effect for neither general nor group categories. However, the irregular pattern of the cost data in comparison to conventional theory supports the practicality of the tunnelling through effect for the direct benefits. The conventional methodology and understanding has to be reconsidered according to the findings of the research. Accordingly, the uncovered parameters have to be investigated to discover of the reasons which led the cost out of the regular cost-effectiveness track in traditional understanding.

Furthermore, it could be suggested to focus the research efforts to answer the question of practicality in the holistic concepts considering the promising theoretical studies and different patterns found in specific cases. The limitations of the resources restrict the study from making further assumptions but emphasize the need for a deeper analysis in a further research. Therefore, the need of further investigations on the field should not be underestimated in order to appreciate the promised savings in the best manner.

# References

Austrian Energy Agency (AEA). 2011. Energy country profiles: Hungary, Energy Demand. URL: http://www.enercee.net/hungary/energy-demand.html [consulted on 04 May 2011]

Ball. M. 2005. RICS European housing review 2005. Royal Institution of Chartered Surveyors (RICS). London

Baggs, D. 2011. Integrative design & tunneling through the cost barrier. Ecospecifier. Ecospecifier Pty Ltd: Cannon Hill. URL: http://www.ecospecifier.com.au/knowledge-green/articles/part-1-integrative-design-tunnelling-through-the-cost-barrier.aspx [consulted on 05.04.2011]

Birol, F. 2010. Critical factors changing the future global energy landscape Lecture series for Center for Climate Change and Sustainable Energy Policy, Department of Public Policy. Central European University Budapest, Hungary:

Boermans, T., Bettgenhäuser, K., Hermelink, A. and Schimschar, S. 2011. Cost optimal building performance requirements, Calculation methodology for reporting on national energy performance requirements on the basis of cost optimality within the framework of the EPBD. European Council for an Energy Efficient Economy (ECEEE) : Stockholm.

Buildings Performance Institute Europe (BPIE). 2010. Cost optimality, Discussing methodology and challenges within the recast Energy Performance of Buildings Directive. Brussels. URL:http://dl.dropbox.com/u/4399528/BPIE/BPIE_costoptimality_publication2010.pdf [consulted on 25 April 2011].

Cherry, E. and Petronis, F. 2009. Architectural Programming. Whole Building Design Guide. URL: http://www.wbdg.org/design/dd_archprogramming.php [consulted on 20 April 2011]

Commission of the European Communities. 2006. *Communication from the EuropeanCommission. Action Plan for Energy Efficiency: Realising the Potential*. Brussels.

Cornillie, J. and Fankhauser, S. 2004. The energy intensity of transition countries. .*Energy Economics* 26, 283 – 295.

European Commission (EC). 2010. European Commission, Directorate General for Energy. Hungary: Demand, Supply, Production. URL: http://ec.europa.eu/energy/observatory/eu_27_info/doc/hungary_2010_d2008.pdf [consulted on 15 April 2011]

______________________. 2011. Hungary Energy Mix Fact Sheet. URL: http://ec.europa.eu/energy/energy_policy/doc/factsheets/mix/mix_hu_en.pdf [consulted on 15 April 2011]

Europan Alliance of Companies for Energy efficiency In Buildings (EUROACE). (2005). Energy Efficiency in High-Rise Refurbishment. OECD/EIA. URL: http://www.euroace.org/LinkClick.aspx?fileticket=mF6tS_TYQjM%3D&tabid=122 [consulted on 20 July 2011]

Feiler, J. and Ürge-Vorsatz, D. 2010. Long term (2050) emission reduction goals regarding Hungary [Hosszú távú (2050) kibocsátás csökkentési célok Magyarország vonatkozásában]. Budapest.URL:http://www.nfft.hu/dynamic/Hosszu_tavu_kibocsatas_csokkentesi_celok_Magyarorszag_vonatkozasaban.pdf [consulted on 23 July 2011].

Feist, W. 2007. Passive Houses in Practice. *The Building Physics Calendar*. *Ernst & Sohn*: Berlin. 675-741.

_______. 2011. Passive house: Energy efficient and comfortable. 15th Passive House Conference Presentation: Innsbruck. URL: http://www.cuttingthecarbon.co.uk/uploads/pdfs/UKPHConf%20-%20Wolfgang%20Feist.pdf [consulted on 20 July 2011]

Fülöp, O. 2007. Negajoule 2020 Energy efficiency potential of Hungarian residential buildings. Energia Klub. Budapest.

Groot, H.L.F., Mulder, P. and Soest, D.P. 2001. Subsidizing the Adoption of Energy-Saving Technologies. Analyzing the Impact of Uncertainty, Learning and Maturation. Erasmus University Rotterdam. URL: [http://publishing.eur.nl/ir/repub/asset/813/rm0201.pdf [consulted 12 June 2011]

Harwey, L.D.D. 2010. *Energy and the New Reality 1, Energy Efficiency and the Demand for Energy Services*. London: Earthscan.

Hawken, P.,Lovins, A. Lovins, L.H. 1999 .*Natural Capitalism: Creating the Next Industrial Revolution.* Tunneling Through the Cost Barrier. Little Brown. URL: http://www.natcap.org/images/other/NCchapter6.pdf [consulted on 04 April 2011]

Hirst, E., Clinton, J., Geller, H., Kroner, W. 1986. Energy efficiency in buildings: progress and promise. Washington. D.C: American Council for an Energy-Efficient Economy.

International Energy Agency (IEA). 2006a. *Energy Policies of IEA Countries: Hungary*. OECD/IEA. Paris.

_____________________________. 2006b. *Energy Balances of OECD Countries*. OECD/IEA. Paris.

______________________________. 2006c. *High-Rise Refurbishment. The energy-efficient upgrade of multi-story residences in the European Union*. OECD/IEA. Paris.

_______________________________. 2010. *World energy Outlook*. OECD/IEA. Paris.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Mitigation.* Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Jochem, E. and Madlener, R. 2003. The forgotten benefits of climate change mitigation: Innovation, technological leapfrogging, employment, and sustainable development. Workshop on the Benefits of Climate Policy: Improving Information for Policy Makers. 12-13 December 2002, Paris.

Korytarova, K., Ürge-Vorsatz, D. 2010. Energy savings potential in the Hungarian public buildings for space heating. Presented at IEECB'10: Improving Energy Efficiency in Commercial Buildings. Frankfurt, 13-14 April 2010.

Levine, M., Ürge-Vorsatz, D., Blok, K., Geng, L., Harvey, D., Lang, S., Levermore, G.,Mongameli Mehlwana, A., Mirasgedis, S., Novikova, A., Rilling, J. and Yoshino, H. 2007. Residential and commercial buildings. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Ed. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Lombard, P.L., Ortiz, J., Pout, C. 2008. A review on buildings energy consumption information, *Energy and Buildings*, 40 (3).

Lovins, A. B., Lovins L. H., Krause F. and Bach, W. 1989. *Least-cost energy: solving the CO2 problem*. Andover, Mass.: Brick House.

Lovins, A. B. 2007 Visiting Professorship, Engineering School, Advanced Energy End-Use Efficiency Course. Public Lectures in Advanced Energy Efficiency: 1. Buildings. MAP/Ming. Stanford University: Stanford.

______, A.B. 2010. *Integrative Design: A Disruptive Source of Expanding Returns to Investments in Energy Efficiency*. Rocky Mountain Institute (RMI). URL: http://www.rmi.org/rmi/Library/2010-09_IntegrativeDesign [consulted on 15 June 2011]

Lovins A.B., Michael, B., Michael,K., Lionel,B., Hutch,H., Alok, P., Imran, S. And Zoe, A. 2010. Factor Ten Engineering Design Principles. Rocky Mountain Institute (RMI). URL: http://www.rmi.org/rmi/Library/2010-10_10xEPrinciples [consulted on 15 June 2011]

Meier, A., Wright, J. and Rosenfeld, A.H. 1983. Supplying energy through greater efficiency. The potential for conservation in California's residential sector. Berkeley, Los Angeles, London: University of California Press.

Metz, B. 2009. Controlling Climate Change. European Climate Foundation. Cambridge: Cambridge University Press.

Metz, B., Davidson, O.R. , Bosch, P.R.. Dave, R., Meyer, L.A.. 2007. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Meyer, M., Milgrom, P. and Roberts, J. 1992. Organizational Prospects, Influence Costs and Ownership Changes. *Journal of Economics & Management Strategy*, 1 (1). Massachusets: Massachusets Institute of Technology. URL: http://www.stanford.edu/~milgrom/publishedarticles/Organizational%20Prospects.pdf [consulted on 29 June 2011]

Mulder, P. 2005. The economics of technology diffusion and energy efficiency references. Edward Edgar Publishing Inc., Cheltenham, UK. Novikova, A. 2008. Carbon dioxide mitigation potential in the Hungarian Residential Sector. Dissertation, Department of Environmental Sciences and Policy, Central European University, Budapest

Novikova A. and Ürge-Vorsatz, D. 2007. *Carbon Dioxide Mitigation Potential in the Hungarian Residential Sector*. Budapest : The ministry of Environment and Water of the Republic of Hungary.

Passive House Institute (PHI). 2009. Certification as "Quality Approved Passive House" Criteria for Residential-Use Passive Houses. URL: http://www.passivehouse.us/passiveHouse/PassiveHouseInfo.html. [consulted on 31 May 2011].

Perkins, B. 2011. Roadmap for the integrated design process, part one: summary guide. MetroVancouver:Vancouver.URL:http://cascadiapublic.s3.amazonaws.com/Large%20Cascadia%20Files/RoadmaptotheIDP.pdf [consulted 5 July 2011]

Perkins, R. 2003. Technological "lock-in". International Society for Ecological Economics.

Reed, B., Fedrizzi, S.R., Boecker, J., Horst,S., Keiter, T., Lau, A., Sheffer, M. and Toevs, B. 2009. *The integrative design guide to green building: redefining the practice of sustainability*. New Jersey :Wiley.

Rocky Mountain Institute (RMI). 2010. *Factor Ten Engineering Design Principles Version 1.0*. RMI: Colorado.

Szőnyi, A. M. 2010. Problems concerning the implementation of energy efficient measures in the buildings sector.A comparative study of Sweden and Hungary.Master of Science thesis, Central European University, Budapest.

Summerfold, J. and McCollu, E. 2008. An Integrated Whole Building Diagnostic Approach to Improving California's Existing Multifamily Buildings. ACEEE Summer Study on Energy Efficiency in Buildings, 2 (27). Heschong Mahone Group, Inc. URL: http://eec.ucdavis.edu/ACEEE/2008/data/papers/2_368.pdf [consulted 11 July 2011]

Price, L., Rue du Can, S., Sinton, J., Worrell, E., Nan,Z.,Sathaye, J. and Levine, M. 2006. *Sectoral Trends in Global Energy Use and Greenhouse Gas Emissions*. Ernest Orlando Lawrence Berkeley National Laboratory.

United Nations Environment Programme (UNEP). 2009. *Buildings and Climate change: status, challenges and opportunities*. Nairobi: UNEP.

Von Weizsäcker, E., Lovins, A.B. and Lovins, L. H. 1997. *Factor four: doubling wealth, halving resource use*. London: Earthscan Publications.

Ürge-Vorsatz, D. and Novikova, A. 2008. Potentials and costs of carbon dioxide mitigation in the world's buildings. *Energy Policy*, 36(2): 642-661.

Ürge-Vorsatz, D. and Koeppel, S. 2007. *Assessment of Policy Instruments for Reducing Greenhouse Gas Emissions from Buildings*. Report for the UNEP-Sustainable Buildings and Construction Initiative. Central European University, Budapest.

Ürge-Vorsatz, D. 2010. Employment Impacts of a large-scale Deep Building Energy Retrofit Programme (the case of Hungary). Presentation of the results in the auditorium at Central European University by the Center for Climate Change and Sustainable Energy Poicy (3 CSEP), 8 June, Budapest. URL: http://3csep.ceu.hu/sites/default/files/field_attachment/project/node-6234/employmentimpactstoledopresentation.pdf [consulted 5 April 2011]

Waide, P. 2006. *High-Rise Refurbishment: The energy-efficient upgrade of multi-story residences in the European Union*. IEA Information Paper. International Energy Agency.

## Personal Communications

Csoknyai, Tamas. Budapest University of Technology and Economics (BUTE), Buda, Hungary, Formal Interview, Budapest, Hungary 15 June 2011.

Palvölgy, Tamas. Hungarian Academy of Sciences , Pest, Hungary, Formal Interview, Budapest, Hungary 25 June 2011.

Tirado-Herrero, S. Central European University. Pest, Hungary, Personal Communication, Budapest, Hungary 12 July 2011.

# Appendixes

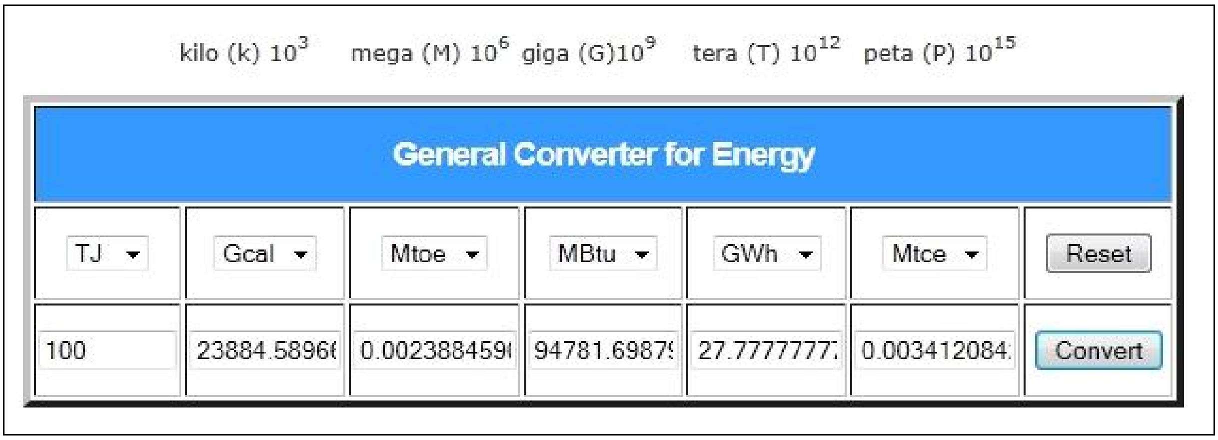


**Figure 27.** Energy unit conversion rates

**Note:** GJ: Giga Joule
MJ: Mega Joule
Mtoe: Million tonnes of oil equivalent
toe: Tonnes of oil equivalent
kWh/ ($m^2$a) = Kilowatt hour per square meters per year

**Source**: IEA energy converter

**Table 4.** Final energy consumption by sector for Hungary, 2008.

| Final Consumption (ktoe) | Solid fuels | Oil products | Gas | Electricit y | Heat | Biomass | Total |
|---|---|---|---|---|---|---|---|
| Industry | 0,57 | 0,21 | 1,18 | 0,82 | 0,36 | 0,18 | 3,32 |
| Transport | - | 4,85 | 2,63 | 0,10 | - | 0,03 | 4,99 |
| Households, Services | 0,24 | 0,32 | 5,45 | 1,98 | 0,89 | 0,48 | 9,36 |
| Non Energy Uses | - | 1,78 | 0,32 | - | - | - | 2,10 |
| Total | 0,81 | 7,16 | 6,96 | 2,90 | 1,25 | 0,69 | 19,76 |

**Source**: constructed based on AEA (2011).

**Table 5.** Energy savings, investment costs and cost of conserved energy in building renovations in Central Eastern Europe

| | U-value before ($W/m^2 °C$) | U-value after ($W/m^2 °C$) | Energy saved [$kWh/m^2a$] | | Annual investment cost [€/$m^2$a] | Cost of conserved energy [€cent/kWh] | Simple payback time [years] |
|---|---|---|---|---|---|---|---|
| Walls | 1.20 | 0.30 | 60.1 | 33.1% | 0.92 | 1.5 | 8.7 |
| Roof | 2.17 | 0.24 | 21.7 | 12.0% | 0.15 | 0.7 | 3.8 |
| Floor | 1.10 | 0.45 | 7.3 | 4.0% | 0.13 | 1.7 | 9.9 |
| Windows | 2.90 | 1.70 | 26.7 | 14.7% | 0.71 | 2.7 | 15.2 |
| Package | 1.63 | 0.59 | 115.8 | 63.8% | 1.91 | 1.6 | 9.3 |
| TRVs | | | 54.5 | 30.0% | 0.19 | 0.3 | 1.6 |
| All of the above combined | | | 135.5 | 74.7% | 2.10 | 1.5 | 8.6 |

**Source**: IEA 2006c

$$C_g(\tau) = C_I + \sum_j \left[ \sum_{i=1}^{\tau} \left( C_{a,i}(j) \times R_d(i) \right) - V_{f,\tau}(j) \right]$$

| | |
|---|---|
| $C_g(\tau)$ | Global costs referring to starting year $\tau_0$ |
| $C_I$ | Initial investment costs |
| $C_{a,I}(j)$ | Annual costs year i for energy-related component j (energy costs, operational costs, periodic or replacement costs, maintenance costs) |
| $R_d(i)$ | Discount rate for year *I* (depending on interest rate) |
| $V_{f,\tau}(j)$ | Final value of component *j* at the end of the calculation period (referred to the starting year $\tau$ *0*). Here also disposal cost (if applicable) can be taken into account. |

**Figure 28.** Formula for the calculation of global cost

**Source**: IEA 2006c


**Figure 29.** Chinese writing for ‘crisis’

**Note**: Although some linguistic experts argue that latter character could be interpreted alternatively as fear, the relation between the opportunity and fear gives more to think.

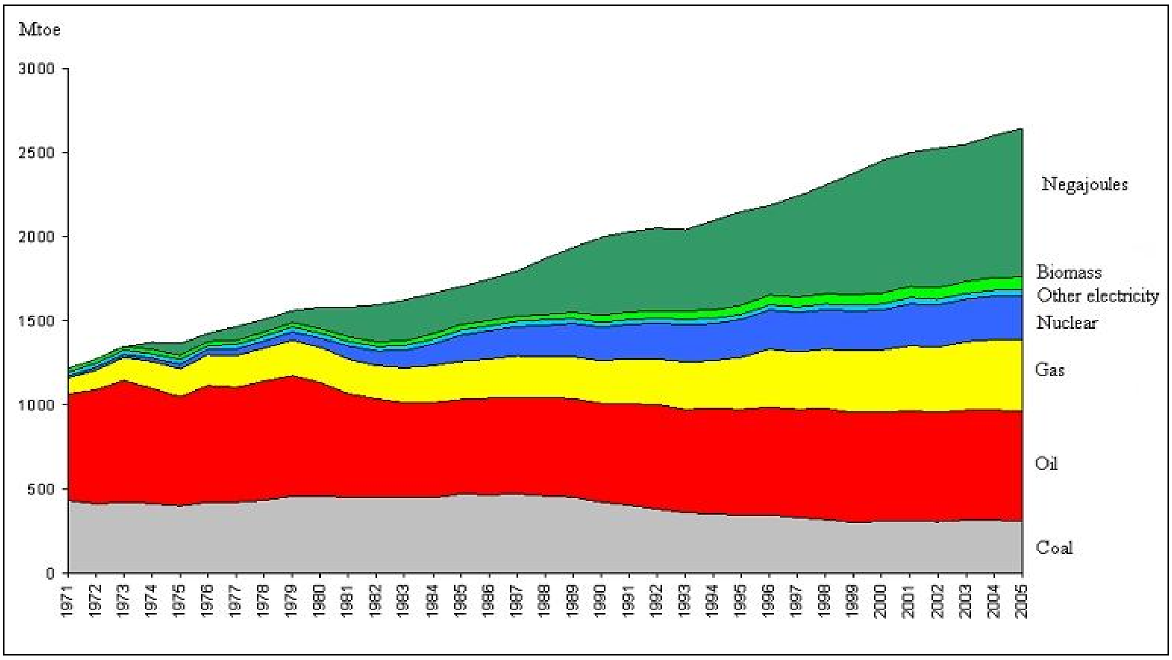


**Figure 30.** Primary energy demand in the European Union

**Source**: Novikova 2008.

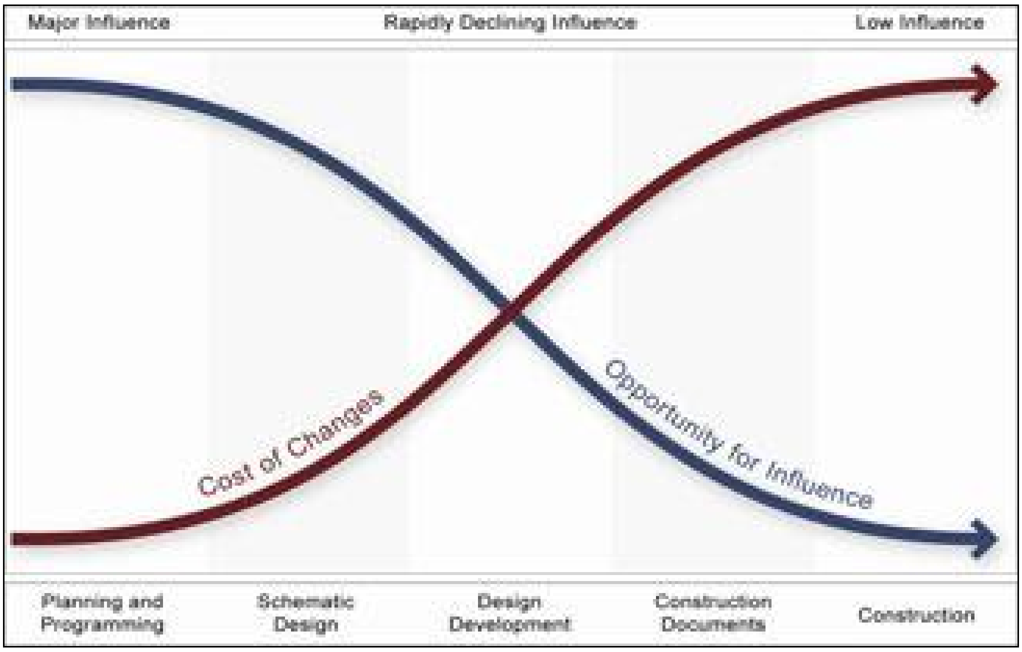


**Figure 31.** Cost and influence level change by time in projects

**Source**: Cherry and Petronis 2009.