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Smart metering as a tool to improve the energy performance of Greek buildings

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SID: 3302120011

SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Energy Systems

NOVEMBER 2014

THESSALONIKI – GREECE

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Abstract

This dissertation was written in the context of the MSc in Energy Systems of the International Hellenic University. As a main objective, the dissertation deals with the effectiveness of smart metering on the energy performance of residential buildings. It examines the conditions under which it can be applied and the expected benefits, not bypassing eventual problems that may occur by using this technology. Finally, it investigates the circumstances that need to prevail so that it can be applied with success in the Greek building stock, contributing to the improvement of the overall energy efficiency.

For the purpose of this thesis much research has been initially conducted on the existing literature and several projects curried out by the E.U., providing an overview of the savings achieved by the smart meter systems and a brief description of the typology of the buildings that these systems were implemented.

In order to find the potential of the smart meter systems to control and reduce the energy needs of the residential building stock in Greece, evaluation estimation was carried out for the scenario of evaluation installing 1.000.000 smart meters in residential buildings all over Greece, both in apartment buildings and in detached houses, hence examining 2 different scenarios. Other interventions on the buildings' envelope were also taken into consideration, as they are the most widely used measures to achieve greater energy savings. A major parameter that was taken into consideration to determine the value of the savings' calculation, were the oil and the natural gas prices, as well as their projected future development. The study is also extended to other evaluation scenarios, trying to cover a wide range of possible cases and is supplemented by a financial and a parametric analysis in order to evaluate the economic feasibility of such a system.

The analysis conducted, confirmed the potential of the smart meter systems as a tool to provide savings in the residential sector of Greece. However, the economics of the system appeared for some scenarios profitable, whilst for others not, at least for the current situation in Greece.

Lelaki Angeliki

12 October 2014

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For the completion of this dissertation, the contribution of some people was very important and I would like at this point to thank them.

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In addition, many thanks should be given to Dr. Georgios Koutitas of the International Hellenic University, for all the knowledge he imparted me about smart meters and their applications, in relative courses, during my undergratuating and postgraduating years. This knowledge formed the basis but also a motive for the selection and conduction of this dissertation.

I cannot but thank my lifetime support team, the people who helped me begin it all, my family. An extra special thanks to my parents Dimitris and Stella for giving me the opportunity to do this master program and for believing in me, as well as to my sister Katerina who once again stood by my side.

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1 Introduction

1.1 Background

The rapid growth of economic activity, industrialization and consumption induces changes in the environment, with most important the global climate change which is constantly accelerating. The vast majority of emissions of polluting gases into the atmosphere come from the human factor and especially burning of gasoline and other petroleum derivatives for transportation needs. The remaining emissions are caused by electricity generation to meet the daily needs of a city’s residents. These facts have caused many considerations among the countries and many policies have arisen, focusing on security of energy supply, sustainability and environmental conservation. Goals such as reducing the ecological footprint combined with savings of resources and the needs of the population can be achieved with the use of renewable energy sources for electricity production.

Nowadays, according to the International Energy Association (IEA) [1], over 80% of the energy supply globally is produced by NON-renewable energy sources such as coal and oil.

In the developed world, a large growth in energy consumption appears in the building sector. Buildings constitute one of the dominant energy consuming sectors as they account for about 40% -more than one third- of the total primary energy consumption [1]. Therefore, a road towards the energy efficiency of the buildings is indispensable. Both residential and commercial buildings demand huge amounts of energy for uses like heating, air-conditioning, domestic hot water preparation (residential mainly), lighting and electric and electronic applications. Specifically, a 33% of all energy in the European Union is used for transport, the 26% is used by industry and a percentage equal to 41% of all energy in the European Union is used by buildings [2]. As a result, the Directive 2002/91/EC was adopted in 2002, in order to decrease the fossil fuel energy consumption. The directive was amended in 2010 with the new 2010/31/EC directive. This directive defines a nearly zero energy building (NZEB) as “a building that has a very high energy performance and even the very low amount of energy required should be covered to a very significant extent by energy form RES”. In the context of effort for sustainable development, significant reductions can be achieved in energy consumption and CO_2 emissions through bioclimatic design and energy technologies in the built environment. In Greece, it is technically possible to reduce energy consumption in buildings by at least 30% of today's total consumption (CRES) [3].

Smart meters are innovative systems, which by use of modern information and communications systems, permit functional penetration of renewable energy sources and a rational control of energy consumption in a building, even in whole urban neighborhoods.

All the above prove the sententiousness of energy efficiency and the use of a smart metering system, especially in the residential sector where a vast amount of energy is consumed.

1.2 Problem definition

As mentioned above, building energy performance needs to be significantly improved in order to reduce overall energy demand and carbon dioxide emissions in line with the cost-effective potential and Europe's GHG emissions objectives.

The residential building stock represents 75% of the European buildings, where 64% are single family houses and the rest 36% are apartment blocks. Non-residential buildings, such as offices, wholesale and retail shops, educational premises, hospitals and hotels comprise 25% of the European buildings [4]. The household sector accounts for a 29% of final energy consumption (transport excluded), so it becomes one of the largest consumers of energy in the EEA. Between 1985 and 1998, the household energy consumption was nearly constant, but the growing number of households increased energy use by 4%. This energy consumption decreased slightly in northern countries and increased in southern Europe, in Austria and Ireland [5].

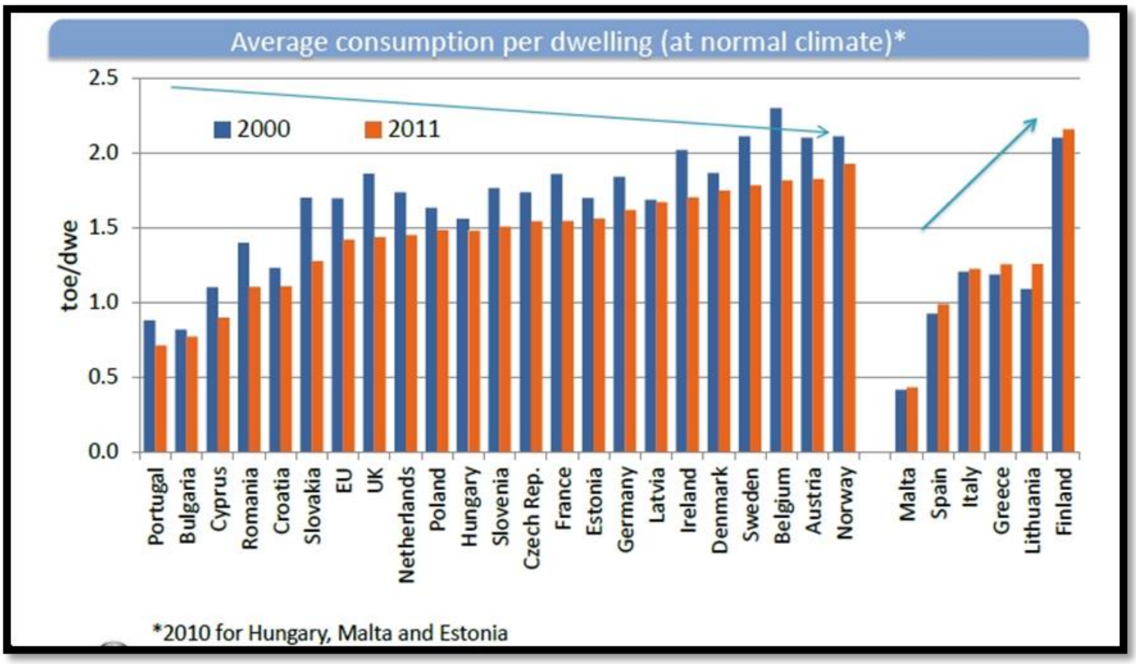


Figure 1: Average consumption per dwelling, [5]

During the period 1990-2009, the energy efficiency of households rose by 24% in EU-27 countries by an annual average rate of 1,4%, driven by space heating technologies, the spreading of more efficient buildings and modernized electrical appliances. During this period, the final residential energy consumption grew by about 8%, at an annual average rate of 0,4%. Electricity consumption increased much faster at an annual growth rate of 1,7%. Over the years 2005-2009 energy efficiency increased annually by 5%, or 1,3% [6].

Although considerable improvements in energy efficiency have been attained in lighting and home appliances, the electricity consumption in the average EU-25 household has been heightening by an annual rate of 2% over the last 10 years. Some of the reasons for such growth in the residential electricity consumption are related with a higher degree of basic comfort and level of amenities (particularly in the new EU member countries) and also with the diffusive utilization of relatively new types of loads whose penetration and use has experienced a very significant growth in recent years. The International Energy Agency (IEA) estimated that, even with a continuation of all existing appliance policy measures, the appliance electricity consumption will grow by 13% from 2000 to 2010, and by 25% by 2020 [7].

For example, the fastest growing electricity demand, according to IEA, is projected to be standby power consumption or the consumption of electricity by appliances that are turned “off” or, that are in a low power consumption mode. 15% of total appliance electricity consumption in Europe, by 2030, could be due to stand-by functionality. This also represents the largest potential saving as it is currently unregulated (there are no relative policies) and efforts to introduce measures to reduce this wasteful consumption are only just beginning (last decade) [7].

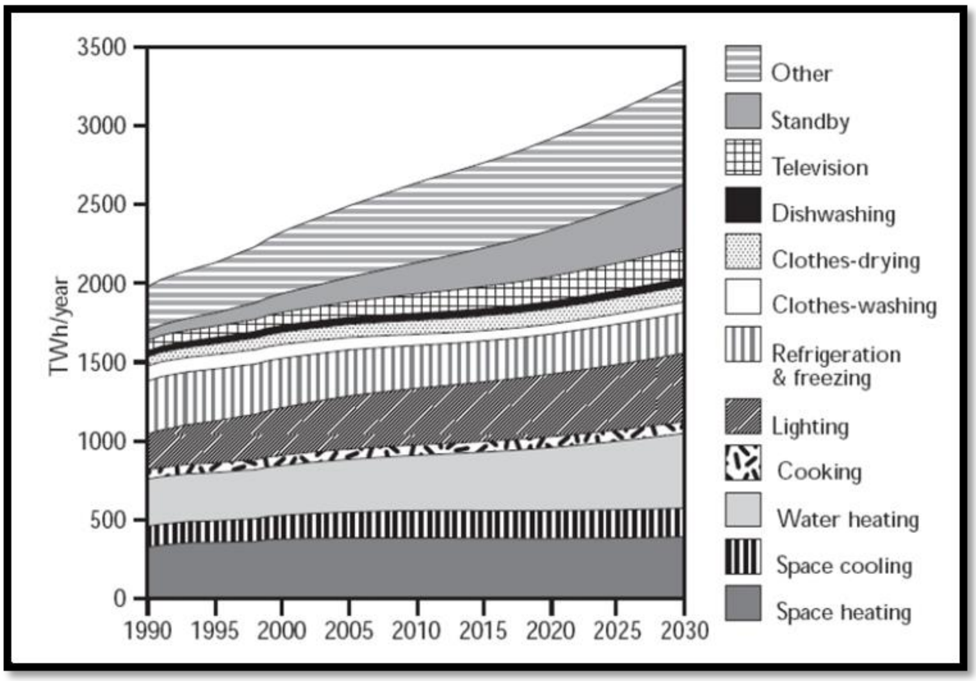


Figure 2: Projected IEA residential electricity consumption by end-use with current policies [7]

All this progress brings into light the significance of controlling the electricity consumption in residential buildings. Individuals have to create an environmental friendly energy profile in order to face effectively the growing demand of energy. Renewable energy sources and pathetic systems in the building design are not adequate to solve the problem if the consumers do not change their behavior. The combination of all these will bring the optimal solution [7].

1.3 Aim of thesis

A number of different studies has shown that IT and entertainment loads, including standby mode, are a key contributor to the power demand. Basically, in all types of loads there is wide range of performance levels, including new emerging technologies, in the models available in the market.

Available technology, associated with responsible consumer behavior, can reduce wasteful consumption. The potential electricity savings that exist in the residential sector in Europe, and which can already be implemented by existing means, like the use of BAT (best available technology), efficient appliances or the elimination/mitigation of standby consumption, can reach up to 48% savings. Specific policy recommendations to promote market transformation and behavioral changes in the equipment selection and operation have been identified [7].

Consequently, there has to be a mean of monitoring and controlling the electricity consumption inside a household. This system has to be easily understood by and handy to every consumer and the user should have the ability to intervene in real time in order to make changes at the time of the consumption.

This dissertation deals with the effectiveness of smart metering on the energy performance of residential buildings. It examines the conditions under which it can be applied and the expected benefits, not bypassing eventual problems that may occur by using this technology. Finally, it investigates the circumstances that need to prevail so that it can be applied with success in the Greek building stock, contributing to the improvement of the overall energy efficiency.

1.4 Structure of thesis

The content of this dissertation is structured in 9 chapters which are presented below.

The first chapter is the introductory chapter in which a brief background is presented along with the problem definition, the aim and the structure of the thesis.

Chapter two contains a theoretical background regarding the smart meters and the demand response mechanism. The description of the system and the basic operating principles are also presented in this chapter.

In the third chapter, a review of the existing literature is performed and especially of studies and realized projects with the same or similar content with the subject of this thesis. This literature provides both a basis and a measure of comparison for the results that will be obtained in the end.

Chapter four identifies the methodological approach that will be adopted during the study and the steps that will be followed in order to be completed.

In the next chapter, best cases exams are described. These exams concern integrated projects throughout Europe, relative to the subject of the study as well as the undertaken results of their implementation.

Chapter six presents the description of the Greek building stock with energy, economic and social parameters and how the principles of smart meters can be implemented in this category of buildings.

Chapter seven contains the feasibility analysis. Evaluation tools like Payback Period, Net Present Value and Internal Rate of Return are used in this chapter in order to assess the economic feasibility of the systems.

In chapter eight a parametric analysis is conducted, examining the influence of the initial cost of the project and the conventional energy prices, on the economic feasibility of applicable system.

The results of the evaluations are presented and discussed in chapter seven.

Finally, chapter nine includes a summary of the thesis and the final conclusions of the study.

2 Overview

This chapter describes concepts central to this thesis. At first, it deals with the importance of the electricity consumption to the energy savings of the buildings. Furthermore, a brief review of the definition and the benefits of smart meters are given and the energy management of the building as well as the demand response mechanism is represented.

2.1 Buildings Automation

Throughout the EU, there has been a move towards smarter electricity networks, where increased control over electricity generation and consumption has been achieved with improvements in new technologies such as Advanced Metering Infrastructure (AMI). Residential smart metering is part of this and is seen as a necessary pre-requisite for the realization of EU policy goals for increased renewable energy penetration, residential demand side management opportunities and improvements in energy efficiency, for achieving ambitious 20/20/20 targets.

Buildings’ energy performance depends not only on thermal but also on electrical factors like:

- the presence of electrical or thermal energy generation from Renewable Energy Sources (RES) and Combined Heat and Power (CHP) systems;

- the presence of Building Automation Control Systems (BACS) and Technical Building Management (TBM) systems.

A recently issued directive of this group is the 2012/27/EU, which refers to automation as a tool to attain the cited objectives through the implementation of demand response (DR) policies, and the wide spread application of smart meters which is considered a cost-saving measure for energy gains and savings. A key contribution to worldwide energy efficiency is the European Standard EN 15232 (“Energy performance of buildings – Impact of Building Automation, Controls and Building Management”). This standard describes methods for evaluating the influence of building automation and technical building management on the energy consumption of buildings.

Indeed, a potential for energy savings resides in the use, control and interaction of appliances and domestic devices, in order to reach their full efficiency during normal operation, also thanks to the recourse to specific software systems that orchestrate all energy facilities in the house [8].

2.2 Smart meters

2.2.1 Definition and location of smart meters

There is no single definition of smart metering, however all smart metering systems include an electronic box and a communication link. Basically a smart electronic meter counts how much energy is used at a certain time and passes this information to the relevant service. This information can be shared in the end- use appliances thus the user knows at any time how much energy is used and what is the cost.

Figure 3:Smart meters [9]

Smart metering has the following characteristics:

- Measures energy usage at regular intervals
- Stores data on energy use to communicate with the utility that manages the system data (utility meter data management)
- Performs automatic processing, transportation, management and use of measured data
- Provides automatic handling of measurements
- Utilizes bidirectional data communication with service management (utility meter data management)

- Supports services that improve the efficiency of energy consumption and energy systems (production, transmission, distribution)

Smart meters can provide meaningful and timely information on the electricity rates and personal information on the consumption of electricity by means of the competent bodies and systems, including energy consumers. They also have the opportunity to provide information and evidence which triggered the operation of the equipment based on the needs that each consumer has indicated. Smart meters do not only include automatic reading.

The development and siting of smart meters is still in an early stage in many countries. Many initiatives and projects, however, have recently begun to accelerate their development in some countries, such as Italy where smart meters have penetrated almost 100%. With the European Union directives on energy efficiency, it seems that in coming years the development of smart meters will be enforced in several European countries.

In most countries there are no appropriate standards for the operation of smart meters. The requirements of smart metering systems have an increased cost and make development, support and implementation of these applications and market services very expensive.

The frequency and duration of the intervals of the measurement will depend on the cost of supply of electricity and the cost of system design. The requirements for charging the measurements derive from the tariffs applied between the consumer and the relevant provider of electricity. The measurement service is not required to know the applicable tariff. It is adequate that the meter counts both consumption and production of power in real time, in order to calculate the relative cost that will appear on the bill. In the Nordic countries the measurements are obtained hourly and in other countries every 15 or 30 minutes. The metering data can be stored for days or weeks before being transferred to the data management system of the utility. The data must be reliable and accurate. Lost or false data can lead to increased costs, but this can be avoided with a transactional communication mechanism, where smart meters provide consumption data to both the suitable service and the consumer.

Apart from well-established applications, regarding the received data-measurements (e.g. storage for days or weeks before being transferred), it is useful to detect errors of the meter for data corruption and errors when installing the meter. Compensation of large-scale power outages or power quality is included in the bill.

The contact details of the meter shall be the optimal so that the accuracy of the data from the meter may not be reduced due to problems in communication. The most serious errors in data accuracy depends mainly on how often measurements are taken and to a lesser degree on the transmittance [10].

2.2.2 Benefits of smart meters

Smart meters have many advantages, some of which are the lower metering cost, energy savings for user, greater reliability in supplies and variable pricing schemes to attract customers and detect any false measurement. Advantages are also provided for distributed generation (DG). The smart meter can be used in order to measure separately the electricity supplied by distributed generation in the network infrastructure and smart metering with direct communication can be used to perform remote control in decentralized production (for example, a virtual power plant).

Smart meters are useful in many areas. The benefits derive from the examination and comparison of the old meter in relation to the smart meter, as shown in the following figure.

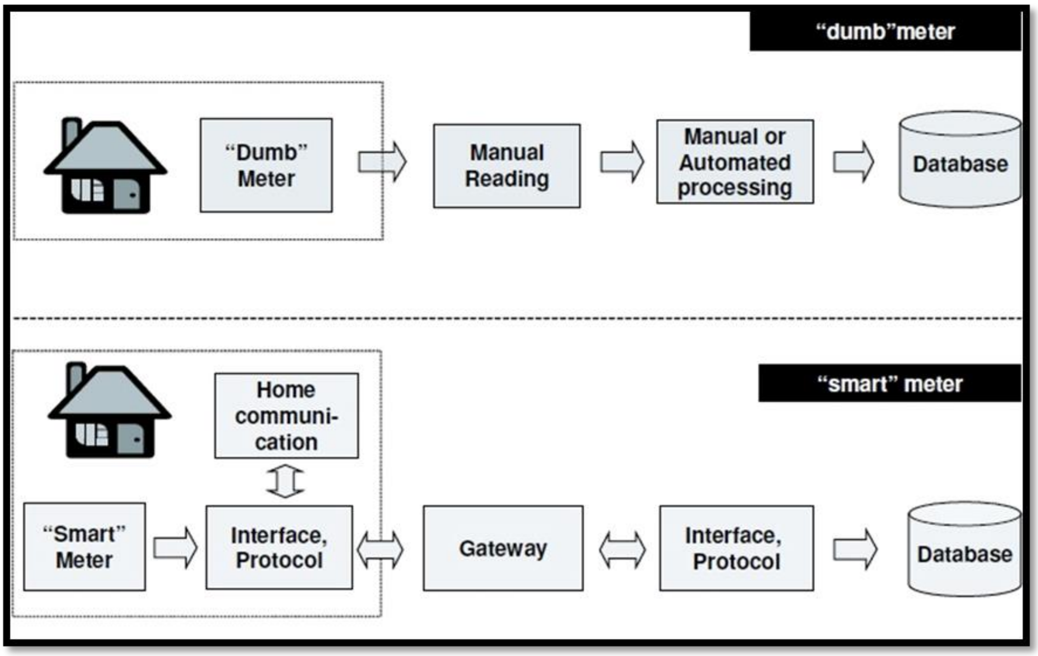


Figure 4: Differences between conventional and smart meters [11]

The Demand Response (DR) of energy users is not a common mechanism, but it will be using the system of smart metering. Smart meters can reduce or even discontinue the use of energy according to the market developments (Restriction of the use of electricity can be achieved by cutting off the electricity when the flow exceeds a certain maximum value during a certain time and restoring it, when this flow is reduced). When all residential and small businesses in a country will be able to adjust their energy use during a period of high prices or reduced availability, this will improve the reliability of supply and strengthen market transactions on energy conservation, awareness and efficiency. These long-term benefits of smart meters can also contribute to the achievement of energy policy objectives of government bodies.

In the short term, users benefit from smart meters, after having the opportunity to examine at any time the amount of energy they consume. Adjusting their handling habits, consumers can reduce their energy costs.

The measuring company initially faces the challenge of replacing old meters with smart meters. By installing smart meters, a different type of operation for data collection and communication is required, because smart meters introduce high quantity flows of information frequently, processes and systems that must be adapted and prepared accordingly. The data collection procedure will not depend on the users who are at home, but it will be a continuous, automated process, which simplifies the daily operation of the company measurements.

When the energy use is monitored by smart meters, network services will receive a more accurate and realistic picture of the energy consumption in their area/ building/ floor according to the application scale. This means that it can examine suspect areas where energy use is higher than expected and so the smart meters will provide to the network operators a tool to detect non- rational use. In times of electricity shortage, the network administrator shall be able to restrict the use of electricity. By gathering all these data, the network operator will be able to provide electricity flows more accurately and use this knowledge in network design and maintenance. Automating the data collection process, with numerous and more recent data at a higher frequency, higher demands enter the systems. This, of course, will have an impact on the market since any contract with users should be changed.

For the supplier, the smart meter provides the opportunity to offer new and special services to their customers. Also, regarding the billing process, actual consumption data can be used, simplifying the current process of advances and the recalculation [11].

2.2.3 Energy management of a building with smart meters

Energy management is becoming increasingly important in homes and businesses, due to environmental factors, and the high cost of electricity. Many homes and businesses are now choosing to manage their consumption, using devices that control the consumption of energy and can help to identify areas where savings and reductions are feasible.

In combination with the pressure of cost reduction comes the pressure for companies to become more transparent about their efforts to reduce their carbon footprint. Thus, more and more consumers today, realize how important it is to manage and maintain the consumption so as to economically invest in them.

Generally, smart meters are divided into two types. In the first category are those that measure the energy consumption and manage the energy of the entire building or compartment (clamp sensors) and are linked to the main table. The second category includes the plug sensors, sensors mounted in sockets and they switch off electrical appliances when they are not in use. The user is able to remotely instruct the sensor to activate or deactivate a device.

2.2.3.1 Clamp sensors

Clamp sensors measure the current in the cable. The device is simply placed around a cable in a single line meter or consumer unit. The device is self-powered and requires no maintenance [12].

Figure 5: Clamp sensors [13]

The clamp sensors exhibit real time power consumption per hour / day / month and the contribution of each consumer to reduce carbon emissions. The above data is provided with a visual display. Watching the consumption through this display, the ability of regulating the consumption and managing the energy produced is provided to serve various objectives, such as reducing costs. This display can be also used to monitor the production of electricity from photovoltaic systems installed at home and to monitor the balance between solar output and consumption at home. This will increase awareness of energy conservation and will encourage users to take action to reduce electricity consumption and emissions of CO_2.

Figure 6: Clamp sensor [14]

The transmitter collects data of electricity consumption through the clamp sensor as shown in the figure. After pairing the transmitter to the screen recording and monitoring, the system begins to operate and monitor the electric power consumption and/or production in real time.

Smart plug strip

The consumer electronics, office equipment and other devices consume electricity a 15-20% of all residential and commercial buildings in the United States [15]. Much of this energy is consumed when devices operate at low power, the rest being actually consumed when the devices are not in use. One way to reduce this unnecessary consumption of electricity is the smart plug strip.

With automatic deactivation of plugged in devices when not in use, the smart plug strip can provide energy savings in homes and offices. The applications of smart plug strips include residential, workstations, home entertainment systems and so on. Estimates of how much energy can be saved with smart plug strips vary and depend largely on the type and the devices that are connected to them and how these devices are connected.

Figure 7: Smart Plug Strip [15]

The smart plug strips resemble a typical power strip but they incorporate the latest technologies to disconnect automatically the operation of the devices that are not in use.

According to Aníbal de Almeida and Paula Fonseca of Coimbra University in Portugal, the European-wide residential energy monitoring must focus on electronic loads (entertainment, information and communication technologies, plus stand-by consumption) and lighting, as well as air conditioning in Southern European countries. Particular attention should be given to the stand-by consumption as in accordance with the next figure it covers the majority of the total consumption of every device [16].

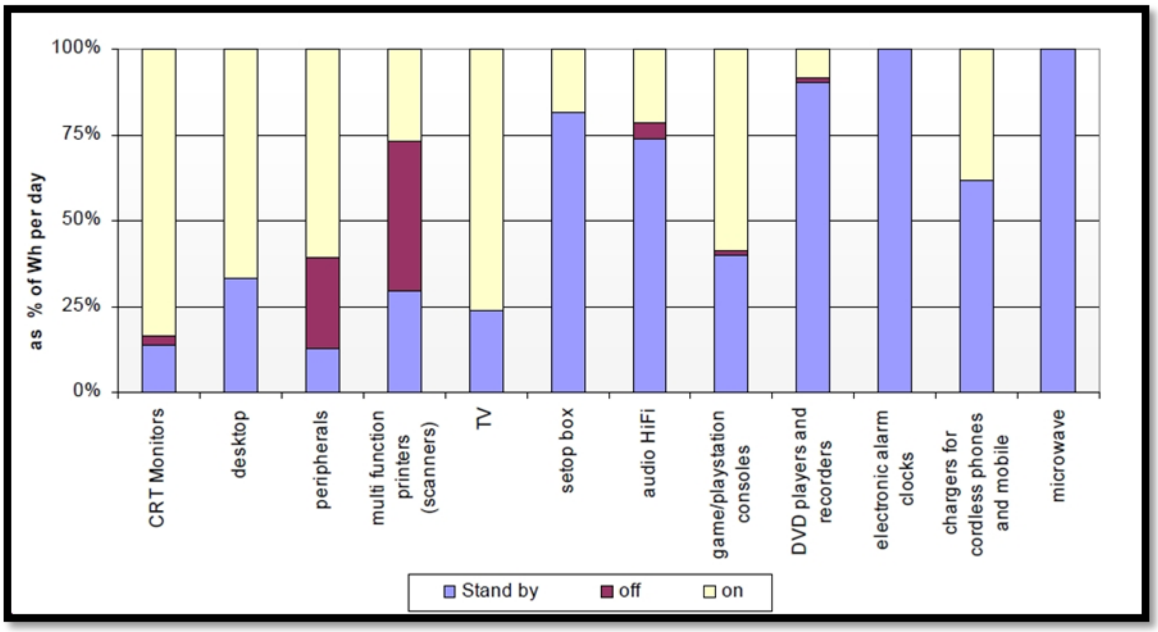


Figure 8: Stand by, off and on mode electricity consumption as % of their total consumption [16]

This chart is a good example for the need and offer of smart plug strips on the reduction of electricity consumption.

2.2.4 Demand Response

2.2.4.1 Definition of Demand Response

According to the Federal Energy Regulatory Commission of the U.S. the definition of "demand response" is:

"Changes in the use of electricity by consumers, via their consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to lead to reduced use of electricity during periods of high demand or when system reliability is at risk".

The aim of Demand Response is to incur changes in consumer habits in extreme days and specific hours where energy demand is high or when there is energy availability. This is based on demand management mechanisms. The adoption of Demand Response in consumer behavior offers the possibility of energy efficiency and energy conservation. For example, some programs of Demand Response in U.S.A. reduced electricity consumption at least by 10% [17, 18].

The consumer prioritizes loads of the building (home, office) putting on priority the device whose function is more important. The term loads includes air conditioning, lighting and various machines / devices. The "smart" management system of loads knows the cost of kWh and is in contact with the administrator. Thus, the production company or energy regulation system based on consumer preferences and trade prices can decide to switch to “off load” at crucial times. In the case where the building or a larger area is equipped with the alternative electricity from renewable sources (e.g. wind, solar), when the load is cut, these mechanisms are put into operation. However there is also the case when the demand is greater when the output is correspondingly increased. Thus, it is "a shift of peak demand to give as smooth and advantageous as possible in terms of production costs of the demand curve". Therefore, consumers are able to change their behavior and adjust their demand in relation to time. This treatment increases the chances of having backup power for unexpected situations. As stated by the U.S. Department of Energy (DOE): «it concerns a reducing demand at peak hours or even at a threat to the stability of the system» [19].

This mechanism gives the operator direct knowledge of the needs of the system, the producer the ability to meet demand and the consumer optimal management of operating costs for example transferring the demand during peak hours to the hours that the system is not so highly loaded. Energy efficiency by consumers can be achieved in two ways. Whether knowing their energy profile and reducing consumption at times of high demand or using energy saving devices.

A key component of the Demand Response is the direct load control (DLC) that allows the administrator remote control to the consumer, to turn on and off specific appliances during periods of peak demand. This is used especially during summer where several machines (e.g. air conditioners or heaters) are in a continuous operation [17,19,20].

2.2.4.2 Demand side management

The Demand side management for efficient use of energy is achieved by managing loads of consumers. It seeks to change the profile of the consumer in terms of energy consumption and use of energy saving devices and the greatest possible normalization of demand curves. This means that the generators and networks will have fewer losses, which means money saving. If consumers do not pay a fixed price, but know and actually pay each time the actual cost of the energy they consume, then they would have the incentive and ability to adapt their consumption profile based on energy demand of peak or off-peak hours [20, 21].

3 Literature review

Various studies have been carried out so as to monitor the electricity consumption in the residential building stock. The legal framework has been updated in order to meet and cover the new needs and the design of the buildings is changed for the same purpose. In this chapter the concepts identified in the introductory chapter are further developed and a number of relevant studies that have been carried out will be presented and analyzed.

3.1 Legal Framework

In the last decades various support policies have been put into effect for promoting the energy efficiency of the building stock, in order to reduce energy consumption and diminish the CO_2 emissions to the environment.

The building sector is one of the main protagonists in environmental problems because of the exploitation of nonrenewable resources, the use of soil and the energy consumption during the whole life cycle of a building. The negative effects on the environment include both resource consumption and pollution; in the building sector, the latter factor causes the largest impact. In 2000, it was estimated that 45% of the energy produced in Europe was used in the building sector and 50% of air pollution was caused by this sector. The European Energy Performance of Buildings Directive 2002/91/EC (EPBD) [22] aims to promote the reduction of carbon dioxide emissions, according to the limits established in the Kyoto Protocol. In order to reach this target, the EPBD foresees a substantial contribution to the energy performance (EP) of buildings, and requires the Member States to provide regulations to comply with [23].

Directive 2006/32/EC on Energy End-Use Efficiency and Energy Services mandates the installation of smart meters according to a pre-defined agenda for various sectors including electricity and gas distribution. Thus, smart meters are expected to be installed in the coming years in most, if not all, European countries [24].

Following this direction, in 2007, the European Standard EN 15232 [25] was issued to devise terminology, rules and methods for the estimation of the impact of Building Automation Control (BAC) and Technical Building Management (TBM) Systems on energy performance and energy use in buildings. The standard EN 15232, today in its second edition, gives a list of BACS and TBM functions that can affect the energy performance of buildings (omitting however other important functions able to improve domestic or electrical safety [26]), and introduces four different efficiency classes for buildings according to BACS and TBM systems installation.

According to the European Performance in Building Directive (EPBD) 2010/31/EU [27], all EU Member States have defined methodologies for the calculation of the energy performance of buildings on the basis of a general framework. An analysis of the progress toward implementation in European Countries of the EPBD can be found in [28].

It is important to underline, how the current edition of the EPBD, differently from the old version (Directive 2002/91/EC [22]), gives greater importance to automation, control and monitoring systems. In particular, the new EPBD encourages the use of active control systems and intelligent metering systems for energy saving purposes whenever a building is constructed or undergoes major renovation in line with Directive 2009/72/EC [29].

Moreover, the ‘climate and energy package’ enacted by the European Union (EU) in June 2009 sets a series of demanding climate and energy targets to be met by 2020, known as the “20-20-20”. A recently directive of this group is the 2012/27/EU [30] on energy efficiency that establishes a common framework of measures for the advancement of energy efficiency within the Union in order to obtain the success of the above-mentioned target on energy efficiency and to prepare for farther energy efficiency progress beyond that date. It explicitly refers to automation as a tool to attain the cited objectives through the implementation of demand response (DR) policies, and the wide spread application of smart meters is considered a cost-saving measure for energy gains and savings [31].

3.2 Buildings Management

According to Rebekka Volk, Julian Stengel and Frank Schultmann [32], Building Information Model (BIM) is determined by international standards as “shared digital representation of physical and functional characteristics of any built object […] which forms a reliable basis for decisions” [33]. BIM represents real buildings virtually over the whole life cycle (LC) as semantically enriched, consistent, digital building models. BIM is perceived with object-oriented software and consists of parametric objects displaying building components. BIM in a narrow sense includes only the digital building model itself in the sense of a central information management hub or storage and its model creation issues. Commercial BIM platforms donate complete data management, component libraries and general functionalities. Extensive differentiations of BIM are 3D (spatial model with quantity takeoff), 4D (plus construction scheduling) and 5D (plus cost calculation) BIM.

Alternative BIM creation procedures for new and existing buildings are illustrated in figure 9. For new buildings, BIM is created in a procedure over several LC stages, beginning with a brief design to production (case I) and part of the project delivery. As BIM sometimes is not used by all AEC/FM stakeholders in the building LC yet, some create detached BIM only for a sole scope. In existing buildings, BIM can be either modernized (case II) or created again (case III). In Europe, more than 80% of dwellings have been built before 1990 and have not mainly had a building documentation in BIM format. Consequently, if executed in practice, manual and costly reverse engineering procedures (case III) help recapturing building information.

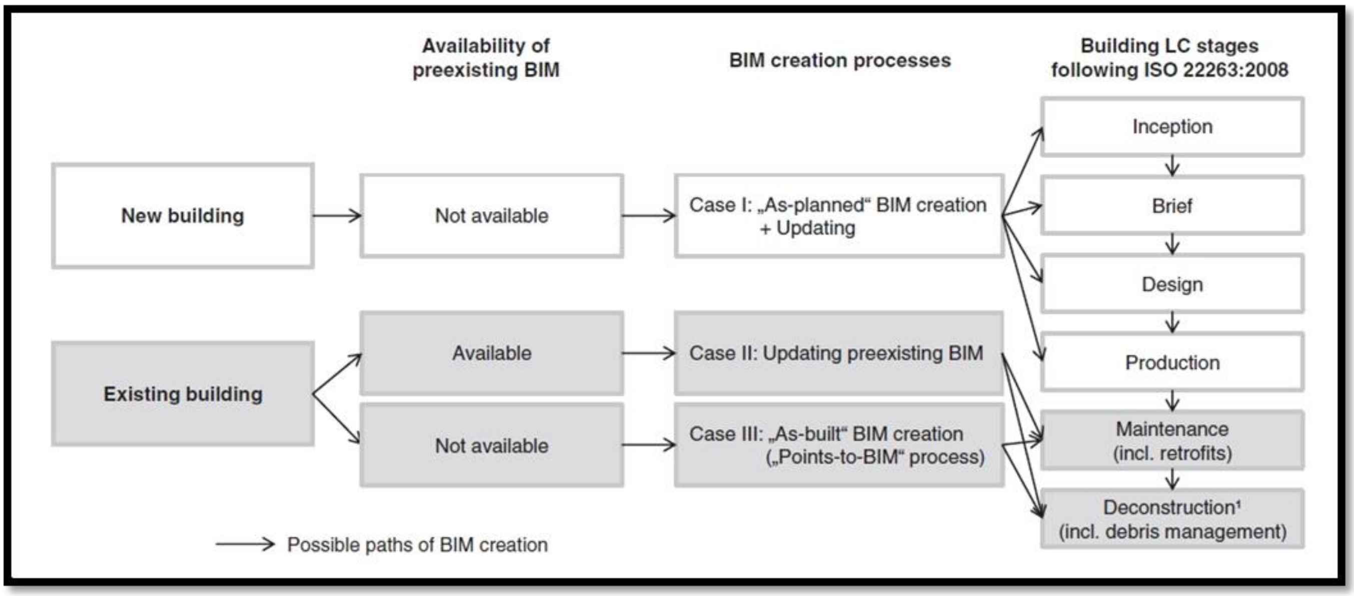


Figure 9: BIM model creation processes in new or existing buildings depending on available, preexisting BIM and LC stages with their related requirements [32]

Fu Xiao Cheng Fan [34] indicates that modern building automation system (BAS) provides us with a terrific quantity of data on real building operation. Buildings are becoming not only energy-intensive, but also information-intensive. Data mining (DM) is a rising strong technique with sizeable potential to find out hidden knowledge in large data sets. The use of DM for resolving the large data sets in BAS intends to improve building operational performance. After data preparation, clustering analysis is implemented to identify the conventional power consumption patterns of the building. Then, association rule mining is affiliated to reveal the associations among power consumptions of major components in each cluster. DM techniques are precious for knowledge discovery in this database; however, deep knowledge is still necessary to practice the knowledge discovered to succeed in better building operational performance.

A.I. Dounis and C. Caraiscos [35] presented a review of control systems for energy management and comfort in buildings. Firstly, they defined the problem as a whole, where energy, comfort and control are involved. The development of intelligent control systems in the framework of computational intelligence has set the basis for improving the efficiency of control systems in buildings. New ways of designing human-centric systems arose from the development of the scientific field of computational intelligence. Application of such systems to buildings results in the so-called ‘‘intelligent buildings”. Living space climate regulation is a multivariate problem having no unique solution, particularly in solar buildings. More specifically, the goals of an intelligent management system for energy and comfort are as follows:

- High comfort level: Learn the comfort zone from the user’s preference, and guarantee a high comfort level (thermal, air quality and illuminance) and good dynamic performance.

- Energy savings: Combine the comfort conditions control with an energy saving strategy.
- Air quality control: Provide CO_2-based demand-controlled ventilation (DCV) systems.

Satisfaction of the above requirements demands control of the following actuators/effectors:

- Shading systems, to control incoming solar radiation and natural light, as well as to reduce glare.
- Windows opening for natural ventilation or mechanical ventilation systems, to regulate natural airflow and indoor air change, thus affecting thermal comfort and indoor air quality.
- Electric lighting systems.
- Auxiliary heating/cooling systems.

The concept of an Intelligent Agent (IA) has been introduced recently in the area of computer science. It has been used extensively in the field of Artificial Intelligence and is closely related to the subject of distributed problem solving.

An IA consists of a virtual entity (software) that mainly has the following properties:

(a) It has the ability to communicate and interact with its environment.

(b) It is able to perceive the local environment.

(c) It is guided by basic ‘‘objectives’’.

(d) It has feedback behaviors.

The design of a multi-agent control system consists roughly of three steps:

1. Structuring: Decompose the whole problem into a set of independent partial problems.
2. Solving individual sub-problems: Solve the partial problems by designing controllers–agents that know how to solve the partial problems.
3. Combining individual solutions: Combine the set of implemented agents into a coherent whole by properly coordinating their activities.

According to Mario J. Kofler et. al.,[36] the consideration of facilities and their energy behavior is undoubtedly necessary for an energy efficient smart home. When exact energy behavior of installed equipment is known, an intelligent system operating on behalf of the user can control the residential home energy efficiently while still respecting user comfort. This article proposed the representation of home facilities and their energy demand or supply as OWL ontology. The so called Semantic Web, of which OWL is one of the most popular languages, for example facilitates the operation of autonomous software agents on behalf of users, assisting them with their tasks. They propose to utilize the Web Ontology Language for a smart home system controlled by a population of agents, thus building the basis for an intelligent pervasive system. Its structure makes all knowledge easily available to the smart home system and considerably supports the control processes with its inherent logic.

To operate successfully, the system has to be aware of a multitude of different energy parameters and facilities as well as providers in order to make energy efficient decisions on behalf of the user, thus aiding in the realization of an eco-friendly operation of the smart home.

3.3 Relevant efforts

E. Riva Sanseverino et. al., [31] evaluated the impact of building automation control (BAC) and technical building management (TBM) systems on residential buildings. This effort indicates how the monitoring, control and automation functions assumed by the European Standard EN 15232 can sufficiently affect the energy performance of a typical Italian medium scale single-family test building and, thereafter, its energy performance class. It also investigates the economic impact of automation and control systems and the number of years required to cover the initial investment (payback period).
The electric consumption of the house was calculated using a simulation tool with statistical approach. The BAC factors method, proposed by EN 15232, is used in order to estimate the effectiveness of the homonym system on the building energy performance. The energy performance class of the under study building accounts only the primary consumption for heating and hot water production. Lighting and cooling are neglected.
Several probability functions cover the relationship between the demand of residential customers and the psychological and behavioral factors that are typical of the inhabitants of the household. It is important to underline that also the automation level of a building [37] and the presence of central or local displays for providing information on energy usage [38] can affect the occupants behavior.
The daily power profiles of the electric loads are simulated according to the Monte Carlo approach and are influenced by:

- the number of inhabitants of the house;
- the period of the year (winter or summer season);
- the different working cycles of some devices (electric oven, dishwasher, washing machine, etc.)

The widespread in the market of BAC systems is one of the most important reasons for their very high purchase and installation costs. The introduction of BAC systems (reduction of the primary energy consumptions for heating, cooling, ventilation and lighting) caused energy savings that improved the house from class D to class A.
The economic analysis is performed considering a period of 10-30 years, taking into account an annuity factor equal to 2% and an annual increase of electricity and natural gas cost equal to 4%/year.

A survey in Northern Ireland, by Will Gans et. al., [39] estimated the effect of real-time usage information on residential electricity consumption. In 2002, the utility substituted conventional meters with modernized meters that allow the consumer to watch usage in real-time. This research ended up in an 11-17% reduction of electricity consumption and an important decrease of CO_2 emissions. The results would have been even better if this whole effort was combined with the Demand Response mechanism. The meters are calculated to cost 37-43 € to buy and install, plus an operating cost of 25-30 € for the life of every meter which is assumed to be 10 years. The Northern Ireland Energy (NIE) initially planned to install 75.000 keypad meters, but now having installed over 250.000, would seem to be evidence of some derived benefit to the utility. However, in order for all these to be realized, the inhabitants must be willing to make behavioral changes to save on their energy bill when they have the opportunity to do so.

Martin Anda and Justin Temmen [40] explain how a large urban electricity meter substitution program can manage a reduction in peak demand and overall energy consumption through the use of advanced metering infrastructure (AMI), in Western Australia. Experience with consumption-driven grid issues has shown that end-users, to a degree, can engage with behavior changes such as:

- Adoption of AMI for bi-directional communication of data at fine-time intervals for accurate consumption metering;
- Modification of consumption in response to a signal to do so (such as through the implementation of In-Home Displays (IHDs)), with the desired response of applying energy conservation measures, and changing levels of consumption;
- Adoption of a demand response system, Direct Load Control (DLC) to automatically reduce non-critical elements of consumption;
- Adoption of energy efficient appliances, at time of replacement, to reduce ambient or characteristic demand.

With the aid of feedback mechanisms, behavior change programs (such as modifying habits that waste energy) can result in an activated consumer who reduces consumption. In order to measure success the following targets were set and achieved:

- Peak demand reduction (peak lopping) of 20% from the households participating in the Behavior Change Programs (BCPs).
- Peak demand shifting (load shifting) to decrease energy consumption during ‘super peak’ by 10% in BCP participating households.
- Average total energy use reduction of 10% in BCP participating households

A research of Ben Gilberta and Joshua Graff Zivin [41] points out that in U.S.A., residential energy consumers, reduced consumption by 0,6–1% in the week after receiving the first bill using the smart metering system. The response magnitudes are larger among larger users, but the percentage responses are almost the same across quintiles of average use. Most interestingly, reductions continued through the peak hours of the day, providing the first evidence to our knowledge that information signals (as opposed to direct time-of-use pricing) can reduce peak electricity demand. Summertime cooling is a key driver of this peak demand reduction, suggesting that thermostat adjustments are a low cost response to the billing information signal.

Simon Kaufmann et. al., [42] argue that implementing smart metering is an important field for energy policy to successfully meet energy efficiency targets. They modeled how important is the customer value for a positive effect of implementing smart metering systems. The study ends up that Swiss consumer realized positively the smart metering effects and is willing to pay for them. However, consumers have different preferences, for example risk-averse, tech-minded, price sensitive, safety oriented so researchers recommend designing different energy policies for different customers such as residential and industrial in order to achieve their different goals. Also, in order for the smart meters to be accepted, they must be easily understood and handled and the consumers must have visible benefits from them. Finally, the more the users that decide to adopt this way of life, the earlier the amortization of the venture. The abovementioned complement the research of Tuan Anh Nguyen and Marco Aiello from Netherlands [43] who claim that the user unawareness adds 1/3 to the energy performance of the building, whereas A. Pfeiffer et al., [44] claim that in order to tap the potential in the residential buildings sector, there is an urgent need for immediate action at various levels (e.g. through financial incentive systems, consumer information campaigns).

On the other hand, a research in United Kingdom by Tom Hargreaves, Michael Nye and Jacquelin Burgess [45] supports that even if they used smart meters for better efficiency, the results were not so encouraging. That is because, initially, a decrease in consumption of unnecessary consumption was noted but nothing more since there were no broader policies or measures for savings.

4 Methodological Approach

The main objective, of this study, is to understand how effective smart metering can be on the improvement of the energy performance of, mainly existing, residential buildings. It will also examine the conditions under which it can be applied and the expected benefits, not bypassing eventual problems that may occur by using this technology. Finally, it investigates the circumstances that need to prevail so that it can be applied with success in the Greek building stock, contributing to the improvement of the overall energy efficiency. The potential of this venture will be identified based on a literature survey and an analytical procedure in order to end up in comparative results. The four basic steps of this methodology refer to a climate analysis, a typological building description, a statistical analysis of the residential building stock, an estimation of the energy savings due to the introduction of smart meters and a feasibility and parametric analysis of the data occurred in order to end up in rational results.

The first step of this methodology concerns the analysis of the Greek residential building stock, as well as the study of the typical Greek building. More specifically, the energy behavior of the building stock will be presented and a categorization of the buildings in seven classes according to different parameters will follow.

Subsequently, integrated projects of smart metering installation and their results all over Europe will be examined, as well as the climatic characteristics of each understudy location are being described in order to make the suitable comparisons with the situation in Greece.

Afterwards Evaluation tools like Payback Period, Net Present Value and Internal Rate of Return are used in order to assess the economic feasibility of the systems.

Consequently, an outcome assessment will be presented in order to understand how advantageous it will be to implement such a project, under what circumstances and which is the best way to be adopted by the Greek population.

4.1 Categorization of the Greek building stock

A new regulation framework, based on the European Directive of the Energy Performance of Buildings, which aims in the CO_2 emissions reduction caused by the building sector, has already been implemented in Greece. Aware that 71% of the Greek building stock was constructed years before the operation of the first Thermal Insulation Regulation (TIR) and given the fact that 83% of these buildings consist of residential buildings, indicates the large potential in energy conservation on the existing building stock [46]. Moreover, Greece is one of the most energy depended countries in EU-27 with an average dependency of 69,9% and a rather constant performance over the past 3 years. These buildings are lacking adequate thermal insulation and HVAC equipment, and are fundamental candidates for a large scale energy renovation program. However, in order to amplify the productiveness of such programs, economically and energy efficiently, the buildings stock's features have to be analyzed in order to ensure that the most suitable and efficient energy saving measures, with respect to the building's architectural, structural and operational characteristics will be implemented.

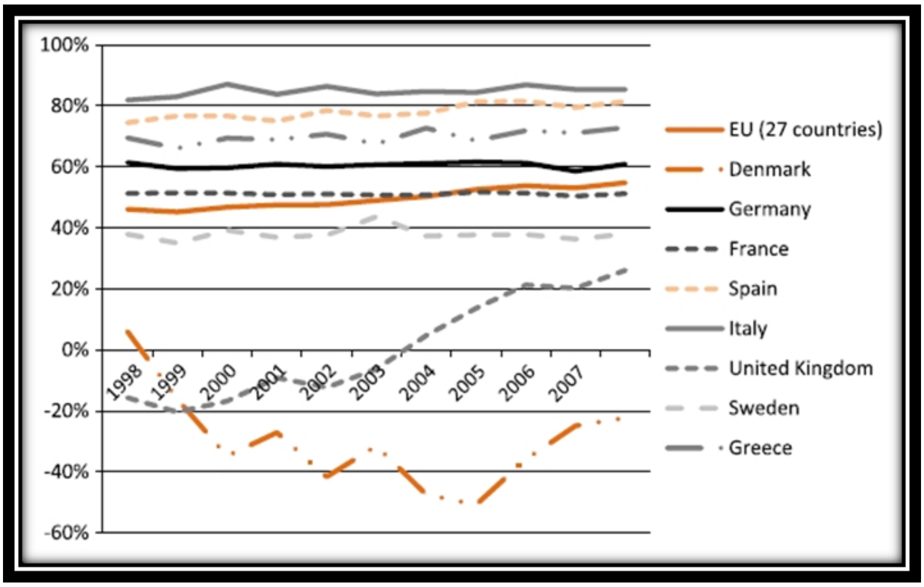


Figure 10: Energy dependency in % in EU-27 and various Member States, Source: Eurostat (2010)

In order to achieve this, a basic classification of Greek buildings has to be determined, taking into account their typology and their year of construction. This classification derived from the analysis of statistical data provided by the Hellenic Statistical Authority (EL. STAT.).

For the abovementioned classification, the importance of the age criterion is particularly significant, since automatically reveals further information about the building's typology, the materials, elements and equipment used and the construction practices applied, which are strongly connected to the building's energy behavior. In Switzerland, for example, there is a categorization for buildings regarding those built before 1920, during 1921–1980 and after 1981. Similar categorization schemes are met in countries like England, Italy and Denmark. Furthermore, Gustavsson and Joelsson also used a classification based on the year of construction related to the life cycle primary energy analysis of residential buildings. Balaras et al. distinguish between single and multi-family buildings and use a generalized categorization scheme according to their year of construction [46].

Apart from this kind of classification procedure, Zhang supports that the estimation of the residential energy consumption is another sophisticated procedure, mainly due to the lack of survey data. Up to now, several authors tried to investigate the energy consumption and demand of the residential sector in Greece, focusing mainly on heating and electricity demand. In addition to this, Balaras et al. studied the energy behavior and possible retrofit scenarios in various Greek residential buildings using the EPIQR meth-

odology. Papadopoulos et al. completely examined 90 buildings in Northern Greece for a 6-year period, in order to define the most appropriate energy saving measurements considering their economic viability. Moreover, Santamouris et al. collected data from 1110 households in Athens in 2004, in order to specify the relation between social and economic characteristics and the energy behavior of the residential sector [46].
The classification of the building stock, according to Ifigeneia Theodoridou et al., [46] is based on the year of construction, the technical, historical, political and social proceedings. The Greek residential building stock is now categorized in seven classes which are briefly described.

- "Class A (1919–1945): based on German and French architectural influences, leading to the so-called "Neoclassic" trend. A new legislative frame was introduced in order to cover the highly increased demand for housing because of Greek-Turkish war (1922) and industrialization. After 1922, with the appearance of elevators the height of the buildings is larger, the number of the floors is increased and the entrance becomes unified. Small balconies, overhangs and openings remained in the facades.

- Class B1 (1946–1960): The prevalence of new building materials and methods and the drastic urbanization afterWW2led to a steeply increasing need for accommodation in the urban areas and therefore to the construction of MF – buildings influenced by the Bauhaus style (massive use of concrete). A new regulation led to a massive MF – building construction sheltering many people by spreading the costs to multiple co-owners. Furthermore the General Construction Regulation (GCR) of 1955 defined the form of the cities with the continuous building system for the densely populated center, the detached type for the suburbs and the semi-detached and stand-alone buildings for rural communities

- Class B2 (1961–1980): Modernism became a dominant influence, apartments became bigger, oil-fired central heating systems became the standard installation and building elements like aluminum openings are met. Gradually the boost of population in the city centers led to their rapid expansion. This occurrence was observed firstly in Athens and Thessaloniki and afterwards in other Greek cities. The introduction of the thermal insulation regulation in 1979 and its actual implementation after 1981, allows us to classify Greek buildings accordingly. It is a turning point, as this thermal insulation regulation was, until September 2010, the only legal contrivance for the improvement of the energy behavior of Greek buildings.

- Class C (1981–1990): Important for the buildings' typology, was the formal introduction of Pilotis in 1985, where the 1st floor was no longer attached to the ground. The Pilotis, i.e., the free space in the ground floor usually 3m high, was mainly used as parking area for MF buildings. The vertical and horizontal structural elements were mostly uninsulated, leading to great thermal losses (Fig. 10).

This building form was used since the 1970s and became vastly popular after 1985, along with the revised Greek Seismic Code of 1954 that came into force.

Figure 11: Typical MF building with Pilotis floor used as parking area [46]

- Class D (1991–2010): The typological features remained to a great extent similar to those of the previous period. Furthermore, the New Greek Seismic Codes of 2000 followed by several revisions affected the construction materials, their width and the buildings’ envelope in general.

- Class E (2010–today): Since October 2010 the implementation of KENAK has set a new legal framework, which is expected to influence the new constructions significantly, as it imposes new, tighter energy standards. The actual impact of this procedure is however not yet apparent.”

4.2 Available statistical data

The available statistical data for the Greek building stock in general are derived from the Hellenic Statistical Authority (El.Stat.) [47], the Organization for Economic Cooperation and Development (OECD) and the International Energy Agency (IEA).

4.2.1 Data concerning the period till 2001

- ✓ Buildings according to the year of construction: The large boost in the building sector during the period 1945-1980 indicates that the majority of the buildings (71%) are uninsulated.

- ✓ Buildings according to their typology-usage: El.Stat., provides data by classifying buildings according to their usage, namely dwellings, churches/monasteries, hotels, factories/ laboratories, educational buildings, shops/offices, parking blocks, hospitals, and others. The elaboration of these data shows that 70,7% of the rural building stock comprises mixed and exclusive residential uses, whereas in urban areas this percentage rises up to 83,5%. This fact leads us to the conclusion that the urban as well as the rural built-up environment is being architecturally characterized by the MF – buildings. Hence, MF – buildings, the so called 'Polykatoikia" (Greek: polys =multiple and katoikia = dwelling) are the main component of Greek city centers, determining their energy behavior, their typology and aesthetic identity. Polykatoikies are met everywhere; in the city centers, in the suburbs, in old and new districts and, without any doubt, in future. In both Thessaloniki and Athens approximately 80% of the buildings have an absolute residential use, whereas 90% of the mixed use is located in Polykatoikies dominated by apartments. It becomes obvious that the typology of Polykatoikia is the central element in Greek cities. Furthermore, according to official data mixed use buildings with dominating office usage in the Municipality of Athens and Thessaloniki do not exceed 8%. Therefore, Polykatoikia can be a pliable building model in the hands of experienced architects and adjust to various usage needs. However, the Greek reality is that in multi-family buildings, the apartment owners are often more than 10, leading to a mosaic of opinions, rarely converging, according to individual believes and interests.

- ✓ Buildings according to their number of floors: The height of buildings is a very important feature in order to determine the density, the approximate envelope surface, the typology and the available vertical and horizontal areas, green roofs, walls, etc. The majority of buildings overall consists of single-floor buildings, regardless their use. This tendency is lower in urban areas.

- ✓ Buildings and construction materials: Accordingly, in 66% of the urban buildings the main construction material is reinforced concrete, used for the load bearing structure according to the Greek anti-seismic regulations. The walls are as a rule double brick walls. In rural areas, brick and stone walls are met more frequently, as the buildings are lower and the anti-seismic requirements are not as strict, whilst stone is in many cases a material in local abundance. Furthermore, some settlements feature landmark protected architecture, which presupposes the use of traditional building materials like stone.

4.2.2 Data concerning the period after 2001

During the last decade, the phenomenon is even more intense in the area of Attica (Athens and surrounding areas) and in the northern part of the country, in Central Macedonia (Thessaloniki and surrounding areas). It is also clear that in the period 2007–2010 occurred the largest drop in the number of building permits issued throughout the last decade.

A survey of Agis Papadopoulos et al., shows what affects the energy behavior of the apartments and whether there is any relation between the age and the income of the inhabitants and the structure and quality of the building. As regards the occupancy, policies concerning energy conservation measurements should be designed according to the real buildings' usage and the status of occupation. Attention should be laid upon all legal barriers, which may prevent owners from not implementing energy renovation measurements. Moreover, the occupants' income and the quality of the building's envelope and systems should be taken into consideration when designing measurements and developing economic and other support policies and tools. Furthermore, clear definitions for building energy standards should be made, referring to specific categories of buildings, providing the respective support tools. Otherwise, there is the risk of prescribing standardized interventions for all typologies, without taking important parameters of differentiation into account, resulting therefore in less than optimum results [48].

4.2.2.1 Social and economic characteristics

A parameter with strong influence on energy saving policies is the low level of awareness as regards the environmental, economic and energy efficiency benefits. Energy conservation and sustainability are still not strongly endorsed by the Greek society. The fear of still unknown technologies and the ignorance of energy conservation's benefits along with restricted financial incentives, are acting as a barrier for the broad implementation of such measures.

Furthermore, related research shows that the lower the income, the worse the indoor conditions, especially during the cooling period [48]. Moreover, private investments in order to upgrade the energy behavior of the buildings become under these circumstances rather unlikely to be implemented. Based on this fact, the recently announced measures concerning energy conservation in residential buildings, aiming particularly to support low income owners, seem to be reasonable. They include subsidies, low interest loans and tax deductions for retrospective thermal insulation, installation of solar thermal collectors, as well as replacement of windows and balcony doors, boilers and burners [48].

Last but not least, a very important aspect is the tenure status. Greece has a very large tenure quota, which mainly refers to apartments. In particular, ownership status in large MF – buildings, such as the Greek Polykatoikia, can influence the implementation of saving measures to great extents. As already described earlier issues concerning multiple ownerships and respective disagreements on matters of energy saving measures are often the reason for their slow implementation as well as their rejection.

5 A discussion of good examples

In this chapter, integrated projects of smart metering installation and their results throughout Europe are presented. The countries are not randomly selected. Each of them are of particular interest in issues of importing smart meters in everyday life, their rational use, the adoption of appropriate behavior by the users and finally their acceptance or not and their possible extension. These countries have made significant progress at the application of this project. In each understudy location, we examine the climatic conditions and the building types in order to make the relevant comparisons with the Greek world.

5.1 The Irish case

5.1.1 Climatic characteristics of Ireland

The climate of Ireland can be described as moist, mild and changeable with plenteous rainfall and a lack of extreme temperatures. This type of climate is called temperate oceanic climate. The country is generally characterized by warm summers and mild winters. It is much warmer than other areas on the same latitude, because it lies in the northeastern Atlantic Ocean, so it is warmed by the North Atlantic the whole year.

Because of the North Atlantic Current, the coastline of Ireland remains ice-free during the winter—whereas the Sea of Okhotsk and the Labrador Sea which are at the similar latitude do not. The weather in Ireland is not extreme at all, without tornadoes and similar weather features.

May and June are the sunniest month in Ireland. Sunshine lasts between 5 and 6½ hours daily over most of the country, during these months. The southeastern area gets the most sunshine for about 7 hours per day in early summer. December is the bleariest month with a daily sunshine ranging from 1 hour in the north area to almost 2 hours in the southeast area. During the whole year, most of the areas get an average of between 3¼ and 3¾ hours of sunshine per day. The Irish sky is completely cloudy roughly half of the time.

Rainfall is the most ordinary form of precipitation on the island, although some parts of the west coast receive approximately 4 times more rain than the east coast. Rainfall in Ireland comes mainly from the Atlantic Ocean, traveling in a north-east direction over the island, bringing cloud and rain.

Severe cold weather is unusual here with the majority of winter precipitation coming in the form of rain. Although mountains and hills of the country are covered up by snow for almost 30 days annually, at the lower lying regions of the island does not snow at all. Nevertheless, in recent winters, there has been a considerable growth in extended "cold snaps", in which heavy snow falls across Ireland for many weeks, often causing disorganization to services and traffic across Ireland. Therefore, there have been risen calls to prepare the country for such circumstances, including the distribution of grit, salt, and other snow-treatable minerals. In late 2011, the Irish Government set up "Winter-Ready", in order for the country to be prepared [49].

5.1.2 Building typology of Irish buildings

In Ireland, [50] 70% of the existing housing stock was built prior to 1991, 88% of which was built prior to 1980 when minimum insulation standards were implemented. These energy inefficient houses fall well below the current building regulations requirements and offer the good potential for energy savings from retrofitting. Most residential buildings (43%) in Ireland are single family and semi-detached and terrace houses which combined make up the largest proportion of the 1,46 million dwellings. 72% of them are rurally located [51]. Their average floor area is 80 m^2.

5.1.3 Smart meters in Ireland

Fintan McLoughlin et. al., [52] examined the influence of the implementation of smart metering on dwelling and occupant characteristics on domestic electricity consumption patterns of 4.200 dwellings at half hourly intervals, in Ireland. They made a linear regression model with four parameters: total electricity consumption, maximum demand, load factor and time of use (ToU) of maximum electricity demand. The factors that influence the total domestic electricity consumption are the dwelling type, number of bedrooms, head of household (HoH) age, household composition, social class, water heating and cooking type. The appliances with the greatest impact are tumble dryers, dishwashers and electric cookers and the one that showed the greatest potential for shifting demand away from peak time use was the dishwasher. The survey shows that the smaller the size and the fewer the number of the inhabitants, the lower the total electricity consumption. It was calculated that by shifting 10% of installed dishwasher demand away from peak times, could result in a saving of 29 MW of peak time electricity generation capacity. This indicates how significant is the energy profile of every user in correspondence with peak hours and suggests the introduction of smart appliances for the sector.

As expected, apartments had significantly lower total electricity consumption than all other dwelling types, a result of their smaller size and less number of occupants. For each additional bedroom, total electricity consumption on average increased by 349 kWh over the six month period. On a per capita basis, total electricity consumption for the residential sector accounted for 948 kWh over the six month period. This suggests that planning laws in favor of smaller dwellings or a property tax to encourage older lone HoH's (whose children have vacated the family home) to downsize, would reduce overall electricity demand for the sector.

Electricity consumption for younger HoH's was significantly lower when compared to the other two age categories, 36–55 and 56 plus. This could be attributed to middle aged HoH's having more children living at home (thus having a higher number of occupants) and increased occupancy patterns (i.e. dwelling occupants at home for longer periods of the day). This is also apparent when looking at household composition: adults living with children consume considerably more electricity than those living alone or with other adults. Social class was used as a proxy in the absence of reliable data on household income. This suggests that Higher Professionals are inclined to consume more electricity than Lower Professionals with the former tending to live in larger dwellings and have a greater number of electrical appliances, suggesting a possible income effect.

An indicator variable was also used to measure potential household electricity savings by asking those surveyed to quantify how much they believed they could cut their electricity consumption by changing their behavior. The variable showed strong positive correlation with increasing electricity savings (i.e. respondents with higher electricity consumption believed they could make greater electricity savings than those who consumed less). This suggests that larger electricity consumers are wasteful (i.e. leave lights on in unoccupied rooms) and hence believe they can cut back on their electricity use. In contrast, those who consume less may believe that they are efficient in their use of electricity and cannot make further substantial cuts.

It is important to note that the analysis above is independent of lighting, which is a significant contributor to electricity consumption. Lighting demand could not be distinguished from the survey as the number of fittings was not recorded. Similarly, electrical appliance refrigerator was not recorded as part of the survey.

As mentioned in the literature review, another survey in Northern Ireland, by Will Gans et. al., [39] estimated the effect of real-time usage information on residential electricity consumption. In 2002, the utility replaced prepayment meters with advanced meters that allow the consumer to track usage in real-time. This research ended up in an 11-17% reduction of electricity consumption and an important decrease of CO_2 emissions. The results would have been even better if this whole effort was combined with the Demand Response mechanism. The meters are calculated to cost 37-43 € to buy and install, plus an operating cost of 25-30 € for the life of every meter which is assumed to be 10 years. The Northern Ireland Energy (NIE) initially planned to install 75.000 keypad meters, but now has over 250.000 installed, and that would seem to be evidence of some derived benefit to the utility. However, in order for all these to happen, the inhabitants must be willing to make behavioral changes to save on their energy bill when they have the opportunity to do so.

Another study for the Ireland [53] ends up that newer and more expensive homes are more likely to have more energy-saving features, but are also more likely to have more appliances. Indeed, an increase of £100.000 in the value of a home is likely to increase the number of energy-saving features by 3,4%, but is also likely to increase the number of energy-using appliances such that its potential energy use goes up by 5%. A house built in the period since 1997 is likely to have 23% more energy-saving features than a house built before 1900, but it also has the potential to use 4,3% more energy.

Finally for Ireland, another article about e-meter project mentions that Ireland's Commission for Energy Regulation (CER) published the results of its smart metering venture in 10.000 homes and businesses. This project estimated how smart meters influenced electricity consumption, as well as the business case for a national rollout.

CER indicated that Irish customers respond positively to smart meters by decreasing their bills and their electricity consumption.

According to CER, smart meters help reduce electricity costs and improve efficiency, thus providing significant benefits to both utility customers and the nation of Ireland.

Here are some specific benefits seen in this trial from combining smart meter with time-of-use pricing, in-home displays, and related initiatives such as smart bills:

2,5% drop in electricity consumption for residential customers, with peak demand reduction of 8,8%. Ireland's results are lower than the 9,4% average consumption savings seen in other feedback studies.

Limited income customers also benefited. In Ireland, this included customers who receive the Free Electricity Allowance, as well as fuel poor households. This is consistent with results of similar U.S. studies.

Willingness to respond: 82% of residential customers made a change to their electricity use.

In-home displays helped: 91% of residential customers reported that the in-house display unit was especially effective in enabling them to reduce peak consumption.

Smart meter business case: Smart Meters are expected to yield a net benefit to Ireland of up to €282 million over the next 15-20 years. This includes reductions in customer bills, as well as energy efficiency and environmental benefits. In addition, customers will have greater empowerment and choice regarding their energy consumption patterns. Furthermore, smart meter-enabled services such as outage detection and restoration verification will help make the power grid more reliable.

The CER noted that smart meters and smart grids also will help Ireland roll out more wind power and electric vehicles [54].

5.1.4 Conclusions from the application in Ireland

The abovementioned surveys show that several million smart meters operate successfully and are accepted by the users for the last 12 years. This happened because of the positive results achieved by these applications. More specifically, in Ireland, the studies ended up that the smaller the size and the fewer the number of the inhabitants, the lower the total electricity consumption. Another contributory factor to the reduction of the energy consumption is the adopted energy profile by the users, which implies the introduction of smart appliances (11-17% reduction of electricity consumption). The age and the social class play an important role for the energy management.

As a result of the above studies and conclusions, the fact that there are plans to expand these applications and these plans are accepted by the citizens, shows that the experience had a positive effect that is desired to be implemented on a larger scale.

5.2 The Austrian case

5.2.1 Climatic characteristics of Austria

The Austrian weather is influenced by the Alps, which serve as a watershed for Europe's three major kinds of weather systems. The Atlantic maritime climate from the northwest is defined by precipitation, low pressure fronts and mild air from the Gulf Stream. The greatest influence is observed on the northern parts of the Alps, the Danube and the valley the Northern Alpine Foreland. The climate in the continental territories is defined by high pressure systems with dry and cold air in winter and precipitation with low pressure fronts in summer. It influences mainly the east part of Austria. Mediterranean high-pressure systems from the south, with clouds and warm air, affect the weather of the southern slopes of the Alps and that of the Southeastern Alpine Foreland, making them the mildest side of Austria.

The Mediterranean weather systems have a peculiarity called the föhn wind. It is a warm air mass that comes from the African Sahara and moves to the north side rapidly, periodically raising temperatures up to 10 °C (18 °F) in a short period of time. This rapid weather change causes to people irritability, headaches and circulatory problems. During the winter, the rapid increase of temperature that accompanies a föhn can melt the snow in the Alps and incur avalanches.

Given the importance of Alpine skiing for the Austrian tourist industry, in December the weather is observed with important provisions. Invariably, Atlantic maritime weather systems bring snow, and continental weather systems keep it. Nevertheless, a prevalence of dry and cold continental systems or warm Mediterranean ones inevitably put off the beginning of the ski season. In the summer, Mediterranean high-pressure systems bring sunny and warm weather [55].

5.2.2 Building typology of Austrian buildings

The Austrian building stock consists of about 2,05 million buildings (3,9 million dwellings). It is dominated by about 1.56 million one family houses or semidetached houses. This category, called buildings with “one or two dwellings” represents 76 % of all buildings in Austria. Nearly half (47 %) of all Austrian dwellings can be related to this category. About 50 % of the dwellings are in buildings with “three to ten dwellings” and in buildings with “eleven or more dwellings”. The rest of the dwellings belong to the category “for associations” or to the “non-residential buildings” category [56].

Almost 24% of Austrian residential dwellings were built before 1944. The share of dwellings, built from 1945 to 1970, represents 29% of all residential dwellings. Less than one third of all residential dwellings were built between 1971 and 1990. The number of dwellings built in the period 1991-2000 makes up 12% of the total. New dwellings built from 2001 to 2008 represent 6% of total residential dwellings [57].

5.2.3 Smart meters in Austria

Luis Olmos et. al.,[24] insist that smart meters should not be analyzed in an isolated way but together with the implementation of different sets of smart-meter enabled actions that are aimed to increase end consumer energy efficiency and that have an impact on the system as a whole. Regulatory intervention is probably necessary to foster the implementation and acceptance of Demand Response (DR) programs worldwide. The policies that have to be followed in order to achieve this combination are the provision of feedback to consumers on their electricity consumption (FB), different time-varying pricing arrangements including real-time pricing (RTP), critical peak pricing (CPP), peak time rebates (PTR) and time-of-use tariffs (ToU tariffs), as well as the direct control of consumers' load by third parties (DLC). Relevant characteristics of consumers in this regard include the type of uses they make of electricity determining their load level and flexibility of their consumption profile and their attitude toward a change in consumption habits. Relevant system features are related to the variability of electricity prices. Smart meter related sets of actions can be classified into those mainly focused on achieving a reduction in the overall use of electricity (Feedback) and those focused on modifying the pattern of consumption throughout the day (Time Varying Pricing Arrangements). Specific recommendations have been provided for different types of consumer groups using a simple analytical framework. The engagement of consumers in schemes implemented is central to achieving sizable benefits for them and the system as a whole. This would require increasing the frequency, amount, and detail of consumption information provision while making this information easily understandable and accessible. According to their own estimates, electricity savings in this system through the application of advanced feedback achieved a reduction as high as 8% of overall consumption. Furthermore, the application of critical peak prices and simple time-of-use tariffs should also be considered in the short-term. This should result in peak load reductions during normal days amounting to 4-8% of global system residential peak load in Austria. Reductions thereby are proportional to the level of load automation. Peak load reductions in critical days achieved through the application of CPP would range between 10 and 16%. This is expected to result in a significant increase in system reliability and significant long-term savings due to the avoidance of generation and network capacity investments.

5.2.4 Conclusions from the application in Austria

The smart meters application in Austria showed that the only way for this venture to be successful is the adoption of the suitable behavior by the consumers' perspective. Only in this case the benefits will be sizeable. To achieve this, two conditions are necessary. First of all is the consumers' willingness to participate, and secondly an understandable and accessible system. These two are sufficient to note a reduction from 8 to 16%.

5.3 The Italian case

5.3.1 Climatic characteristics of Italy

Italy is characterized by a diversity of climate systems. The hinterland northern areas of Italy (such as Turin, Milan, and Bologna) are defined by a relatively cold, mid-latitude version of the Humid subtropical climate, while the coastal areas of Liguria and the peninsula south of Florence generally fit the Mediterranean climate profile.

The north and the south side have a considerable difference in temperature during the winter. For example, in some winter days it can be −2 °C (28 °F) and snowing in Milan, while it is 8 °C (46,4 °F) in Rome and 20 °C (68 °F) in Palermo. There are no extreme temperature differences in the summer.

The east coast of the Italian peninsula is not as moist as the western coast, but is often colder in the winter. The east coast at the north side of Pescara is occasionally affected by the cold bora winds in spring and winter, but the wind is less powerful there than around Trieste. During these frosty spells from E–NE cities like Rimini, Ancona, Pescara and the whole east part of the Apennines hillside can be affected by true "blizzards".

On the coast from Ravenna to Venice and Trieste, snowfall is more seldom: during cool spells from the eastern part, the chill can be severe but with radiant skies; while during the snowfalls that influence the Northern part of Italy, the Adriatic coast can experience a gentler Sirocco wind which liquefies snow—the gentle effects of this wind often vanish a few kilometers inside the lowlands, and sometimes the coast from Venice to Gradosees is snowy while it rains in Trieste, Ravenna and the Po River mouths. Scarcely, Trieste city may experience snowstorms with north-eastern winds; in the colder winters, the Venice Lagoon may be curdled, and in the coldest ones even enough for one to walk on the ice sheet.

Summer is often more steady, although the northern districts often have downfalls in the afternoon and night hours and some rainy and grey days. So, while the south of Florence is usually sunny and dry in the summer, in the north it inclines to be more cloudy and humid. Autumn and spring weather can be very variable, with warm and sunny weeks, suddenly interrupted by cold spells or followed by cloudy and rainy weeks.

In the north precipitation is more equally allocated during the year, although the summer is commonly gently moister. Between November and March the Po valley is foggy, specifically in the central zone (Piacenza, Pavia, Mantua and Cremona), while the number of days with low temperatures, below 0 °C (32 °F) is ordinarily from 60 to 90 a year, with peaks of 100 to 110 days in the mainly rural areas. Snow is usual enough between early December and early March in cities like Milan, Bologna and Turin, but sometimes it appears in late November or late March and even April.

Summer temperatures are usually contiguous south to north and the coldest month is January [58].

5.3.2 Building typology of Italian buildings

The distribution of final energy consumption in the residential sector in Italy shows that heating is responsible about 70% due mainly to the characteristics of Italian households, but cooling demand is constantly increasing. In Italy, the new buildings represent less than 2% of the national total building stock and a percentage of 20% of the buildings were built before 1919. Today, more than 30% of the buildings are at least 50 years old and a percentage of 64% is made up of houses built before the Law 373/1976, the first Italian law to control heating energy consumption in buildings. It is easy to understand that the energy quality of the national building stock is far from the requirements introduced by national and European regulations, however for this reason, the improvement can be relevant [59].

5.3.3 Smart meters in Italy

According to Livio Gallo, who is director of Enel's Infrastructure and Networks Division, Italy has been one of Europe's forerunners in implementing smart metering systems to help households keep track of their electricity consumption.

In 2001, Enel began an investment program of 2.000.000.000 € that attempted to substitute conventional electromechanical meters with recent contemporary electronic devices over five years. These new meters, managed by the Enel Automated Meter Management (AMM) Solution for its 32.000.000 Italian customers, can be remotely and locally controlled. The project was integrated in 2006.

The dominant guides towards the entire application of the Enel Automatic Meter Management Solution are to empower consumers, who are now able to control their energy consumption, to increase energy efficiency by cutting their emissions, and to help network operators decrease operational costs thanks to the meter's remote management system.

As recommended by the Third Energy Package, smart meters can assist on increasing energy efficiency. Enel evaluates a 5% reduction in peak consumption as a result of increased customer knowledge, energy price signals that they will be able to receive and reduce energy losses.

The next step is to farther decrease global warming effects by optimizing the implementation of distributed renewable sources within the power grid. This is planned to be managed through the use of aggregators, which will assist on matching the power provided by diverse distributed renewable sources and the demand by the consumers equipped with smart meters. In Spain the installation of 13 million smart meters based on the technology of Enel Automatic Meter Management system has already started.

Enel's smart meter permits power billing accordingly to different tariff profiles on a multi-hour, daily, weekly and seasonal basis. Furthermore, it procures data on the total energy consumption during the present and the latter billing period (two months for households, one month for small businesses/free market).

Above all, the meter illustrates on its display screen the energy consumption data referred to each active tariff rate for the present and the latter billing period.

In 2008, smart meters collected 50.000.000 load curves (one specimen every 15 minutes). The compilation of load curves allows us to combine the energy consumption data related to each active tariff rate to a determinate week, a determinate day and a determinate temporal section of the day.

Enel customers can be currently informed for their energy consumption, rates, and contract on the meter display screen.

Enel smart meters can also provide access to detailed usage data (such as consumption graphs) via an in-home display connected to the meter, as soon as it is approved by the Italian Energy Authority (AEEG).

Moreover, observing the importation of smart meters, the average number of minutes of service interruption per customer per year fell from 128 minutes to 49 minutes, and the related costs for DSOs reduced remarkably from 80 €/customer to current 49 €/customer per year [60].

5.3.4 Conclusions from the application in Italy

32 million Italian consumers lived the experience of using smart meters in order to manage their energy consumption and increase energy efficiency, while achieving cutting emissions and helping network operators reduce operational costs. 50 million load curves were studied to end up in a 5% reduction of the energy consumption. The fact that Spain has proceeded to apply the same effort, declares that the venture had positive multifaceted results concerning both the reduction and the users’ acceptance. The whole project was undertaken by Enel (PPC of Italy) and the next step is the introduction of distributed renewable energy sources to the power grid. Thus, it is noted that after a continuation of this project is planned, the whole venture is at least promising.

6 The situation in Greece

In 2005 the European residential sector accounted for 26,6% of the final energy consumption, whilst the per capita household energy consumption increased during the period 1990–2005 in the majority of the Member States (EU-27) by 11,6%, whilst only five Member States managed to decrease their per capita energy consumption. This situation in accordance with the fact that final energy consumption increases, while total primary energy production decreases as shown in figure 10, indicates how significant are the energy saving measures to be implemented in the residential buildings. More importantly, space heating is the largest component of energy use in virtually all Member States, accounting for 67% at the level of the EU-15, followed by water heating and appliances/lighting [48].

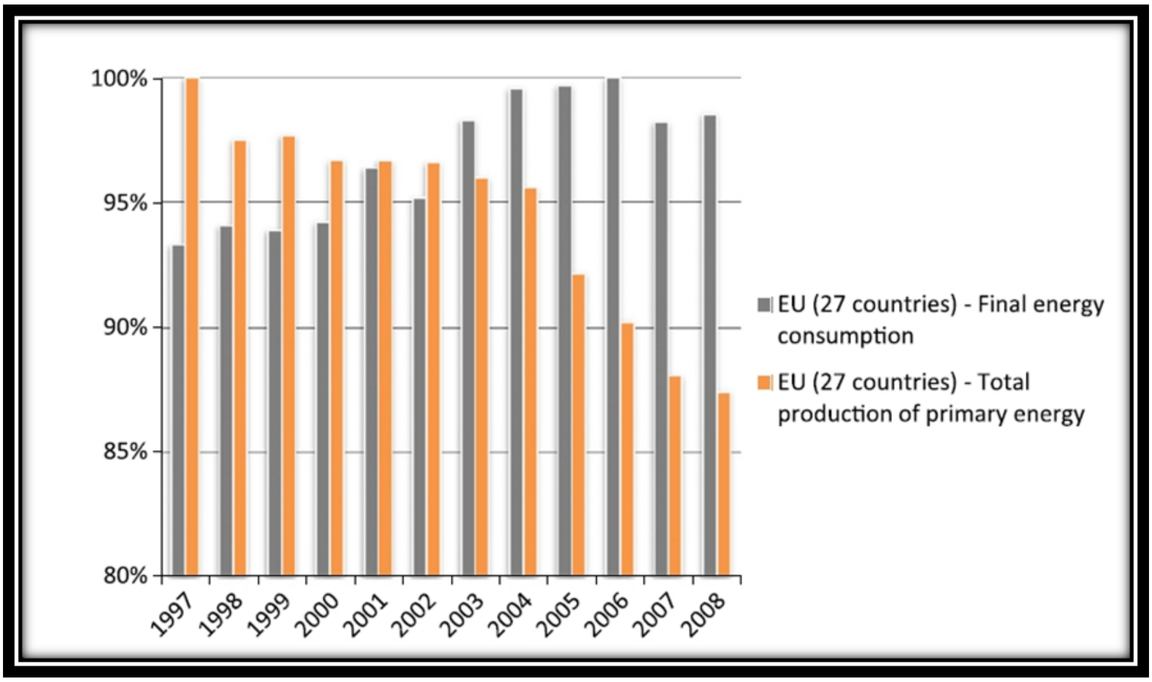


Figure 12: Total production of primary energy and final energy consumption in EU-27 since 1997 [48]

In this chapter, based on the experience we have got from the three countries we studied, we will examine the results of the application of smart meters in a large scale in Greece.

6.1 Climatic characteristics of Greece

Greece is situated at the southeastern part of Europe, and borders the East Mediterranean Sea, the Ionian Sea and the Aegean Sea.

The climate in Greece can be characterized as a typical Mediterranean climate with relatively dry and warm summers, rainy and mild winters and, broadly, extended sunshine for most of the year. A great diversity of climate types is encountered in many regions of Greece because of the Mediterranean climate frame. The reason is the way the topography (grand mountains along the country and other mountainous bodies) influence on the air mass that is coming from the moisture sources of the central Mediterranean Sea.

Hence, the weather varies from the wet climate of Western and Northern Greece to the dry climate of Athens and Eastern Greece.

In Greece, using climatological terms, the year is divided into two main seasons: the dry and warm season that lasts from April to September and the rainy and cold period that lasts from October to March.

During the second period the coldest months are January and February, with, a mean temperature minimum between 5 and 10 degrees of Celsius near the coasts and 0 and 5 degrees of Celsius over the mainland, with lower values in the northern part of the country.

The weather is mainly stable during the dry and warm periods, the sun is bright, the sky is clear and rainfall is rare.

Rainy days in a row are not frequent in Greece and the sky is mainly clear (without clouds) even in winter, something that does not happen in other regions of the world. The winter is milder in the Ionian and Aegean Islands compared to the Eastern and Northern mainland of Greece.

The hottest period occurs during the end of July and the beginning of August, when the mean maximum temperature ranges between 29 and 35 degrees of Celsius. Fortunately, during this period, there are fresh sea breezes in the coastal areas of the country and north winds blowing mainly in the Aegean [61].

6.2 Characteristics of the Greek building stock

According to the most recent census of the Greek building stock throughout the territory and the processing of relevant data collected by the Hellenic Statistical Authority (EL. STAT.), it is shown that the total number of dwellings (residential buildings) is amounted to be 5.627.549, of which 4.381.317 are registered as normal, and buildings are amounted to be 3.990.970.

At this point it is deemed necessary to clarify some terms that will be used in later chapters [62].

- *<u>Building</u>:* Each permanent and independent structure, which has walls and roof and consists of one or more rooms or other areas and has an area of over 4 m^2. As a rule, buildings have four walls. But a building is also a construction that might be open on one or both sides in order to be sufficient to use (e.g. workshop). Each building is defined by a code that depends on the code of the property in case of land or else the address.

- *Dwelling:* is generally an area of construction which is separate and independent, built or converted for housing needs or used for housing at the time of the census, even if it is not intended for this purpose. We do not consider it residential areas for habitation, but used at the time of the census entirely for purposes other than residential. Therefore a dwelling can be: a) A populated or empty house, apartment, room or series of rooms, b) A warehouse, mill, cave or any other covered area, used for habitation at the time of the census. A key element of the house is that it is "separate and independent". The area is considered 'separate' if it is enclosed by walls, fences etc., and is covered by a roof, so that the person or group of people can be isolated from other people, to sleep or to prepare and take meals or to protect against the risks of climatic conditions of the environment. The area is considered independent when it has direct access from the street by a common staircase, passage from the arcade, and when the residents can enter and leave the site without going through the space of another household. The dwellings are divided into normal, abnormal and collective.

- *Normal dwelling:* is a permanent and independent structure, which consists of at least one regular room and is used for housing the household.

- *Abnormal dwelling:* the dwelling that is used for housing purposes only during the time of the census.
- *Collective dwelling*: include various categories of accommodation, such as hotels, residential partnerships and collective shelters.

In this thesis, normal dwellings are the object of study, and hereinafter on the terms residence, house, dwelling etc. are referred to them.
The Regulation of Rational Use and Conservation of Energy separates Greece into four climatic zones (A, B, C, and D). The relative position of buildings largely determines their energy needs. As outlined in the table below, most of its buildings are in B climate zone followed hierarchically by C, A and D zone. The largest concentration of dwellings appears in the B zone and C, A and D follow hierarchically.

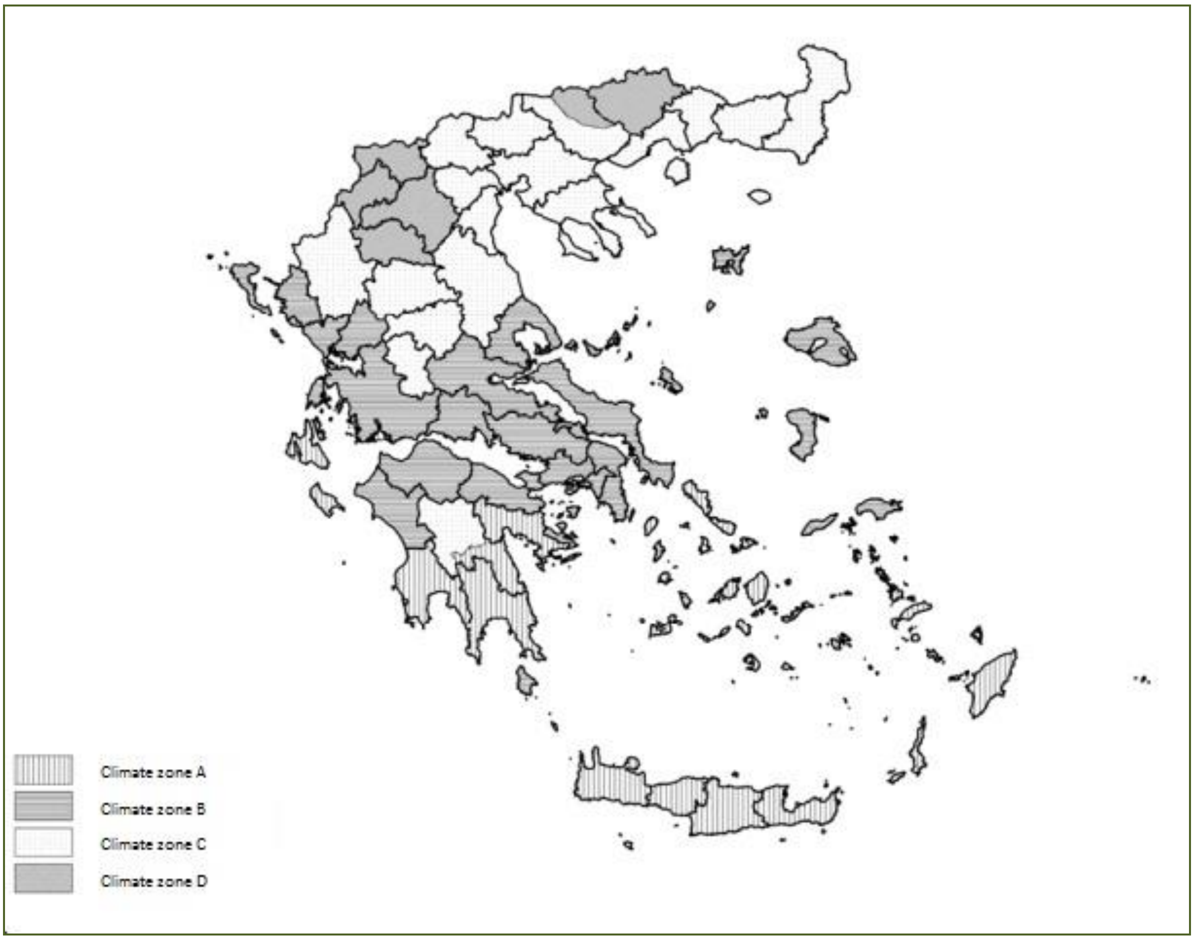


Figure 13: Depiction of climate zones in Greek territory [63]

Table 1: : Buildings, Dwellings and Normal Dwellings per climate zone, Source: Processed data [47]

Climate zone	Buildings	%	Dwellings	%	Normal Dwellings	%
A	797.548	19,98	857.225	15,23	717.942	16,39
B	1.865.311	46,74	3.072.198	54,59	2.400.712	54,79
C	1.185.618	29,71	1.551.344	27,57	1.148.896	26,22
D	142.493	3,57	146.782	2,61	113.767	2,60
Sum	***3.990.970***	***100***	***5.627.549***	***100***	***4.381.317***	***100***

The year of construction of buildings determines the existence of insulation, hence the level of energy consumption. The corresponding data show that in theory, and where studies of buildings had been applied in practice, only 30% of the buildings consist of insulation. In particular, only those of the construction period 1981-1985 which represent 10,13% and those made from 1986 until today (18,31%), as well as under construction (1,44%) buildings include insulation.

Both buildings and normal dwellings are separated into two main categories depending on whether they are located in urban or rural areas. Formerly, El.Stat. used the category of "suburban" area, which is no longer applicable in the context of the harmonization with the practices of Eurostat. In Greece, the population of dwellings in urban areas is higher (65,24%) than in agriculture ones (34,76%).

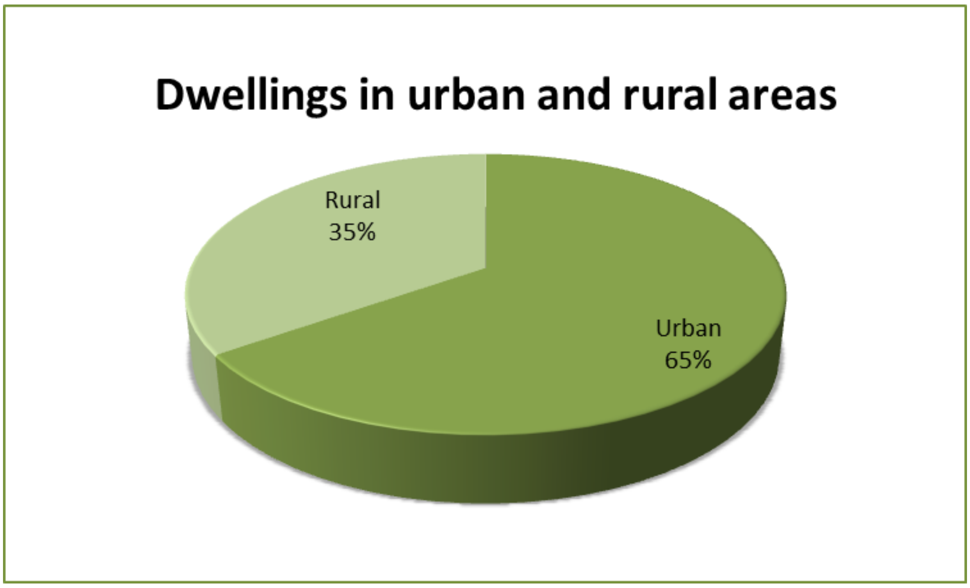


Diagram 1: Distribution of normal dwellings in urban and rural areas per climate zone [47]

The following table shows in detail the number of dwellings in urban and rural areas. In A and D climate zones, rural dwellings are more than urban dwellings, whereas in B and C urban dwellings are more than rural ones.

Table 2: Distribution of normal dwellings in urban and rural areas per climate zone, Source: [47]

Climate zone	Dwellings	Urban	%	Rural	%
A	717.942	310.026	43,18	407.916	56,82
B	2.400.712	1.821.279	75,86	579.433	24,14
C	1.148.896	681.863	59,35	467.033	40,65
D	113.767	45.173	39,71	68.594	60,29
Sum	*4.381.317*	*2.858.341*	*65,24*	*1.522.976*	*34,76*

The way of construction of buildings and particularly the existence of insulation in their envelope is directly related to the year of construction. The introduction of Regulation of Insulating Buildings in 1979 and its implementation by 1981 and on, in conjunction with the fact that before that the insulation was practically an unfamiliar concept to the Greek construction, allows us to classify the buildings respectively. The distinction is particularly important, as the regulation is the only legislative tool improving the energy performance of buildings in Greece.

In climate zone A, more dwellings were constructed in the period 1946-1980 and the periods that follow hierarchically are: before 1945, 1986 until today and 1981-1986. In climate zones B, C and D, more dwellings were constructed in period 1946-1980 and the periods that follow hierarchically are: 1986 until today, before 1945 and 1981-1985.

Table 3: Distribution of normal dwellings according to the age of construction, in urban and rural areas per climate zone, Source: [47]

Climate zone	**Buildings**	**Before 1945**	**%**	**Urban**	**Rural**	**1946-1980**	**%**	**Urban**	**Rural**
A	797.548	208.751	26,17	38.773	169.978	356.412	44,69	128.329	228.083
B	1.865.311	257.712	13,82	89.934	167.778	1.004.479	53,85	652.033	352.446
C	1.185.618	123.112	10,38	48.254	73.858	723.742	61,04	290.469	433.273
D	142.493	16.568	11,63	3.910	12.658	79.439	55,75	22.411	57.028
Sum	*3.990.970*	*606.143*	*15,19*	*180.871*	*424.272*	*2.164.072*	*54,22*	*1.093.242*	*1.070.830*

Climate zone	**Buildings**	**1981-1985**	**%**	**Urban**	**Rural**	**1986 till today**	**%**	**Urban**	**Rural**
A	797.548	66.952	8,39	26.597	40.355	147.496	18,49	56.893	90.613
B	1.865.311	210.789	11,30	136.466	74.323	348.440	18,68	230.444	117.996
C	1.185.618	113.531	9,58	55.146	58.385	204.889	17,28	109.879	95.010
D	142.493	13.031	9,15	3.643	9.388	29.877	20,97	8.225	21.652
Sum	*3.990.970*	*404.303*	*10,13*	*221.852*	*182.451*	*730.702*	*18,31*	*405.441*	*325.271*

6.3 Consumption in Greek buildings

For this thesis, the climate data that are used concern four Greek cities corresponding to the four different climatic zones of Greece, according to the Regulation of Rational Use and Conservation of Energy and the Regulation of the Energy Performance of Buildings (KENAK). These cities are Heraclion, (climate zone A), Athens (climate zone B), Thessaloniki (Climate zone C) and Kastoria (Climate zone D).

According to a study that was made by cooperation between Greek universities, the results of an assessment of the energy savings that can be achieved in detached houses and apartment buildings with intervention measures at their envelope, are shown below. These intervention measures concern different insulation thickness and double glazed frames. The following table refers to specific residential buildings for the four climate zones.

Table 4: Energy consumption of a detached house in reference condition and after interventions per climate zone, Source: [64]

Detached house								
Climate Zone	A	% (of reduction)	B	%	C	%	D	%
Energy consumption in reference condition (kWh/m^2)	148		217		302		338	
3cm insulation + frames	84	43,2	124	42,9	170	43,7	178	47,3
5cm insulation + frames	77	48,0	113	47,9	156	48,3	162	52,1
6cm insulation + frames	75	49,3	110	49,3	152	49,7	157	53,6
7cm insulation + frames	73	50,7	108	50,2	149	50,7	153	54,7
Cold roof	77	48,0	107	50,7	149	50,7	152	55

Table 5: Energy consumption of an apartment building in reference condition and after interventions per climate zone, Source: [64]

Apartment building								
Climate Zone	A	% (of reduction)	B	%	C	%	D	%
Energy consumption in reference condition (kWh/m^2)	96		146		213		250	
3cm insulation + frames	58	39,6	89	39,0	130	39	146	41,6
5cm insulation + frames	55	42,7	84	42,5	123	42,3	137	45,2
6cm insulation + frames	54	43,8	83	43,2	121	43,2	135	46
7cm insulation + frames	53	44,8	81	44,5	119	44,1	132	47,2
Roof	89	7,3	136	6,8	200	6,1	234	6,4
Frames	83	13,5	127	13,0	185	13,1	214	14,4

According to the figure 14, the energy consumption referring to the space heating and the domestic hot water constitutes almost 70% of the total energy consumption of a residential building in Greece. Hence, taking into account the following figure and the abovementioned study, the tables that contain the total current energy consumption of the buildings were completed and are presented below. In these tables, there is a combination among the climate zone, the age and the total current energy consumption of the buildings per square meter. The calculations go back to square meter for greater accuracy.

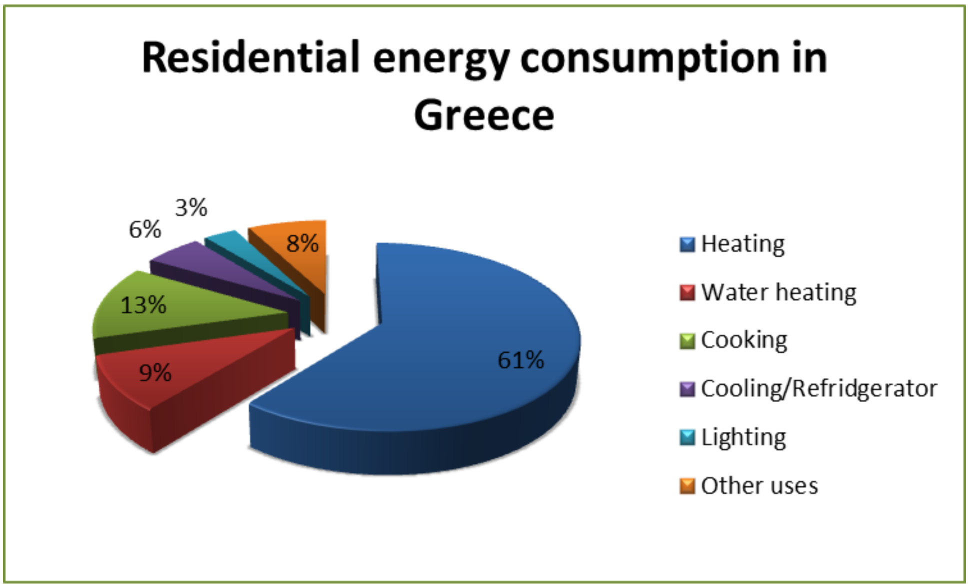


Figure 14: Energy consumption in Greek residential sector [65]

Table 6: Energy consumption per m^2 in the apartment building before any intervention per climate zone and age, Source: Proceeded data [64]

Apartment building						
Climate zone	**Age**	**Total current consumption per m^2 (kWh/m^2)**	**Age**	**Total current consumption per m^2 (kWh/m^2)**	**Age**	**Total current consumption per m^2 (kWh/m^2)**
A	1946-1980	198	1981-1985	176	1986 till today	172
B	1946-1980	246	1981-1985	236	1986 till today	236
C	1946-1980	274	1981-1985	322	1986 till today	322
D	1946-1980	318	1981-1985	316	1986 till today	316

Table 7: Energy consumption per m^2 in the detached house before any intervention per climate zone and age, Source: Proceeded data [64]

Detatched house						
Climate zone	**Age**	**Total current consumption per m^2 (kWh/m^2)**	**Age**	**Total current consumption per m^2 (kWh/m^2)**	**Age**	**Total current consumption per m^2 (kWh/m^2)**
A	1946-1980	210	1981-1985	228	1986 till today	218
B	1946-1980	320	1981-1985	310	1986 till today	280
C	1946-1980	452	1981-1985	342	1986 till today	322
D	1946-1980	516	1981-1985	386	1986 till today	376

The results of the interventions (insulation, frames) that were made theoretically in these buildings in order to reduce their current energy consumption are shown in tables 8 and 9.

Table 8: Energy consumption per m^2 in the apartment building after interventions per climate zone and age, Source: Proceeded data [64]

Apartment building						
Climate zone	**Age**	**Total consumption per m^2 (kWh/m^2) after interventions**	**Age**	**Total consumption per m^2 (kWh/m^2) after interventions**	**Age**	**Total consumption per m^2 (kWh/m^2) after interventions**
A	1946-1980	116	1981-1985	116	1986 till today	116
B	1946-1980	168	1981-1985	168	1986 till today	168
C	1946-1980	240	1981-1985	240	1986 till today	240
D	1946-1980	264	1981-1985	264	1986 till today	264

Table 9: Energy consumption per m^2 in the detached house after interventions per climate zone and age, Source: Proceeded data [64]

Detatched house						
Climate zone	**Age**	**Total consumption per m^2 (kWh/m^2) after interventions**	**Age**	**Total consumption per m^2 (kWh/m^2) after interventions**	**Age**	**Total consumption per m^2 (kWh/m^2) after interventions**
A	1946-1980	168	1981-1985	168	1986 till today	168
B	1946-1980	226	1981-1985	226	1986 till today	226
C	1946-1980	304	1981-1985	304	1986 till today	304
D	1946-1980	306	1981-1985	306	1986 till today	306

Energy savings resulting from the difference of total existing consumption of heating and cooling and the total consumption of heating and cooling after the implementation of the integrated interventions, mentioned before, on detached houses and apartment blocks are presented in the next tables.

Table 10: Percentage savings of interventions in apartment buildings per climate zone and age

SAVINGS						
Apartment building						
Climate zone	**Age**	**%**	**Age**	**%**	**Age**	**%**
A	1946-1980	41	1981-1985	34	1986 till today	33
B	1946-1980	32	1981-1985	29	1986 till today	29
C	1946-1980	12	1981-1985	25	1986 till today	25
D	1946-1980	17	1981-1985	16	1986 till today	16

Table 11: Percentage savings of interventions in detached houses per climate zone and age

SAVINGS						
Detached house						
Climate zone	Age	%	Age	%	Age	%
A	1946-1980	20	1981-1985	26	1986 till today	23
B	1946-1980	29	1981-1985	27	1986 till today	19
C	1946-1980	33	1981-1985	11	1986 till today	6
D	1946-1980	41	1981-1985	21	1986 till today	19

6.4 Smart meter implementation

As it was discussed in the previous chapter, the best examples of smart meters applications all over Europe were those in Austria Ireland and Italy. Comparing the climatic characteristics of these countries to those of Greece, as well as the respective building typologies, most similarities were identified between Greece and Italy. Hence, the effectiveness of smart metering on the Italian building stock will also be adopted for Greece, in order to end up in numerical results. In Italy, the installation of smart meters by Enel ended up in 5% reduction of the energy consumption of buildings. In the table below, the results by this installation on insulated buildings in Greece are shown.

Table 12: Percentage savings of smart metering in apartment buildings per climate zone and age, Source: Proceeded data [64]

SAVINGS DUE TO THE SMART METERS APPLICATION						
Apartment building						
Climate zone	Age	%	Age	%	Age	%
A	1946-1980	46	1981-1985	39	1986 till today	38
B	1946-1980	37	1981-1985	34	1986 till today	34
C	1946-1980	17	1981-1985	30	1986 till today	30
D	1946-1980	22	1981-1985	21	1986 till today	21

Table 13: Percentage savings of smart metering in detached houses per climate zone and age Source: Proceeded data [64]

SAVINGS DUE TO THE SMART METERS APPLICATION						
Detached house						
Climate zone	Age	%	Age	%	Age	%
A	1946-1980	25	1981-1985	31	1986 till today	28
B	1946-1980	34	1981-1985	32	1986 till today	24
C	1946-1980	38	1981-1985	16	1986 till today	11
D	1946-1980	46	1981-1985	26	1986 till today	24

Analyzing the tables above, we can understand that the greater the surface of the building, the more savings are noticed. In addition, older houses, for example those built before 1980, when the Regulation of Insulating Buildings was not still introduced, exhibit a greater reduction of energy consumption. Moreover, buildings located in climate zones A and B; show greater savings than them ones in C and D, probably because air conditioning use is more widespread and necessary, due to climate conditions. Last but not least, the reduction in detached houses is less than in apartment buildings.

The following tables combine climate zone, age and surface for apartment buildings in three different conditions. These conditions refer to the existence of insulation or not, as well as the existence of smart meters in insulated buildings. These tables make it easier to watch the consumption changes. Many final prices are equal but the percentage of the reduction as shown in tables 10, 11, 12 and 13 is different.

Table 14: Total current energy consumption for apartment buildings per climate zone, age and different surface

Total current consumption					
m^2 Climate		**35**	**50**	**80**	**120**
A	1946-1980	6.930	9.900	15.840	23.760
	1981-1985	6.160	8.800	14.080	21.120
	1986 till today	6.020	8.600	13.760	20.640
B	1946-1980	8.610	12.300	19.680	29.520
	1981-1985	8.260	11.800	18.880	28.320
	1986 till today	8.260	11.800	18.880	28.320
C	1946-1980	9.590	13.700	21.920	32.880
	1981-1985	11.270	16.100	25.760	38.640
	1986 till today	11.270	16.100	25.760	38.640
D	1946-1980	11.130	15.900	25.440	38.160
	1981-1985	11.060	15.800	25.280	37.920
	1986 till today	11.060	15.800	25.280	37.920

Table 15: Total energy consumption for apartment buildings after interventions (insulation, frames) per climate zone, age and different surface

Total consumption after interventions					
m^2 Climate		35	50	80	120
A	1946-1980	4.060	5.800	9.280	13.920
	1981-1985	4.060	5.800	9.280	13.920
	1986 till today	4.060	5.800	9.280	13.920
B	1946-1980	5.880	8.400	13.440	20.160
	1981-1985	5.880	8.400	13.440	20.160
	1986 till today	5.880	8.400	13.440	20.160
C	1946-1980	8.400	12.000	19.200	28.800
	1981-1985	8.400	12.000	19.200	28.800
	1986 till today	8.400	12.000	19.200	28.800
D	1946-1980	9.240	13.200	21.120	31.680
	1981-1985	9.240	13.200	21.120	31.680
	1986 till today	9.240	13.200	21.120	31.680

Table 16: Total energy consumption for apartment buildings after interventions (insulation, frames) and smart metering installation per climate zone, age and different surface

Total consumption with smart meters implementation					
m^2 Climate		35	50	80	120
A	1946-1980	3.857	5.510	8.816	13.224
	1981-1985	3.857	5.510	8.816	13.224
	1986 till today	3.857	5.510	8.816	13.224
B	1946-1980	5.586	7.980	12.768	19.152
	1981-1985	5.586	7.980	12.768	19.152
	1986 till today	5.586	7.980	12.768	19.152
C	1946-1980	7.980	11.400	18.240	27.360
	1981-1985	7.980	11.400	18.240	27.360
	1986 till today	7.980	11.400	18.240	27.360
D	1946-1980	8.778	12.540	20.064	30.096
	1981-1985	8.778	12.540	20.064	30.096
	1986 till today	8.778	12.540	20.064	30.096

The same tables referred to the detached house are respectively presented below.

Table 17: Total current energy consumption for detached houses per climate zone, age and different surface

Total current consumption					
m^2 / Climate		35	50	80	120
A	1946-1980	7.350	10.500	16.800	25.200
	1981-1985	7.980	11.400	18.240	27.360
	1986 till today	7.630	10.900	17.440	26.160
B	1946-1980	11.200	16.000	25.600	38.400
	1981-1985	10.850	15.500	24.800	37.200
	1986 till today	9.800	14.000	22.400	33.600
C	1946-1980	15.820	22.600	36.160	54.240
	1981-1985	11.970	17.100	27.360	41.040
	1986 till today	11.270	16.100	25.760	38.640
D	1946-1980	18.060	25.800	41.280	61.920
	1981-1985	13.510	19.300	30.880	46.320
	1986 till today	13.160	18.800	30.080	45.120

Table 18: Total energy consumption for detached houses after interventions (insulation, frames) per climate zone, age and different surface

Total consumption after interventions					
m^2 / Climate		35	50	80	120
A	1946-1980	5.880	8.400	13.440	20.160
	1981-1985	5.880	8.400	13.440	20.160
	1986 till today	5.880	8.400	13.440	20.160
B	1946-1980	7.910	11.300	18.080	27.120
	1981-1985	7.910	11.300	18.080	27.120
	1986 till today	7.910	11.300	18.080	27.120
C	1946-1980	10.640	15.200	24.320	36.480
	1981-1985	10.640	15.200	24.320	36.480
	1986 till today	10.640	15.200	24.320	36.480
D	1946-1980	10.710	15.300	24.480	36.720
	1981-1985	10.710	15.300	24.480	36.720
	1986 till today	10.710	15.300	24.480	36.720

Table 19: Total energy consumption for detached houses after interventions (insulation, frames) and smart metering installation per climate zone, age and different surface

Total consumption with smart meters implementation					
m^2 / Climate		**35**	**50**	**80**	**120**
A	1946-1980	5.586	7.980	12.768	19.152
	1981-1985	5.586	7.980	12.768	19.152
	1986 till today	5.586	7.980	12.768	19.152
B	1946-1980	7.515	10.735	17.176	25.764
	1981-1985	7.515	10.735	17.176	25.764
	1986 till today	7.515	10.735	17.176	25.764
C	1946-1980	10.108	14.440	23.104	34.656
	1981-1985	10.108	14.440	23.104	34.656
	1986 till today	10.108	14.440	23.104	34.656
D	1946-1980	10.175	14.535	23.256	34.884
	1981-1985	10.175	14.535	23.256	34.884
	1986 till today	10.175	14.535	23.256	34.884

The average Greek residence has a heated surface of about 80 m^2. It is useful to see how the energy consumption varies between for example an insulated apartment building with installed smart meters in Athens (climate zone B) and an uninsulated one in Thessaloniki (climate zone C). The energy savings in the first case reaches approximately 34% whereas in the second case reaches 5%. This specific difference means that the house in Thessaloniki consumes about 8.000 kWh more than the one in Athens. An insulated building with smart meters in Heraklion (climate zone A) reduces the consumption by 38%; where as an insulated building with smart meters in Kastoria (climate zone D) reduces it by 21%. The difference here assigns to 10.245 kWh [66].

For an average Greek residence, the greater energy consumption is noticed in buildings of climate zone D, probably due to heavy winters. An average apartment building in Kastoria (climate zone D), built before 1980 consumes 25.440 kWhs. A sensitivity analysis based on the smart meters effectiveness before and after interventions is illustrated below, taking into account a reduction from 2% to 10% (pessimistic-optiistic scenario respectively). Pay attention to the fact that a building in any other climate zone of Greece will present greater savings than this one because of its location, as it is explained earlier (the building in Kastoria is the more pessimistic scenario according to the climate zone that plays a very important role).

Table 20: Sensitivity analysis in the building with the greater consumption

Savings in Apartment building in Kastoria							
Savings due to smart meter application	**Consumption (kWh)**	**2%**	**4%**	**5%**	**6%**	**8%**	**10%**
Before interventions	25.440	509	1.018	1.272	1.526	2.035	2.544
After interventions	20060	401	802	1003	1.204	1.605	2.006

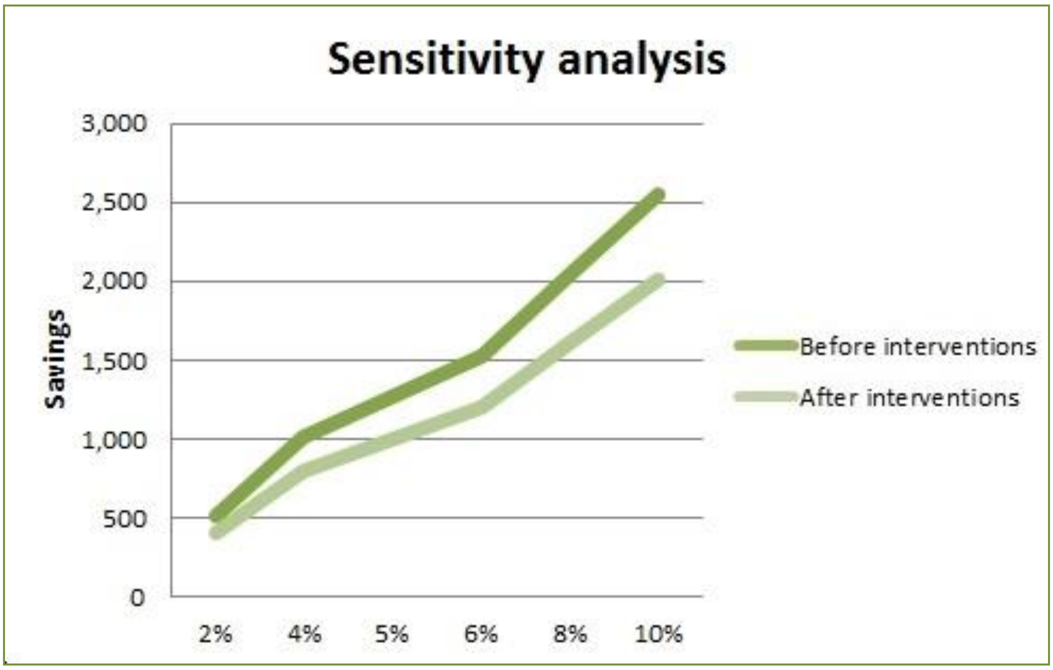


Diagram 2: Sensitivity analysis in the building with the greater consumption

7 Feasibility assessment of energy saving installing smart meters

It is widely accepted that the diffusion and the dissemination of technologies in general, and the principles and technologies of energy saving measures in particular, do not depend only on the technological advances and the economic conditions. The knowledge and support of the principles and the energy-saving technology by the general public in Greece is a particularly important condition for promoting policies to improve the building stock. Similarly, the lack of knowledge about the energy-saving technologies as well as the fear that usually accompanies the vertical contact with anything new, perhaps results in resistance to the adoption of common principles and energy-saving technologies, even if they show that they have strong backgrounds and offer solutions economically viable.

The information strategy of each project should aim at awakening the public about the energy saving measures, with actions that are closer to the experience and the imagination of consumers. The main issue in the dissemination of this strategy is the choice of appropriate instruments in order to become more widely accepted and achieve the targets that were set. To this end, everyone should be aware of the following key points. The incentives for the participation of the users and the profits from the participation, the results of the action in a level of improvement living conditions and reducing energy costs for the citizen and the results at the level of energy cost savings at national level.

This specific project will study the working out of the installation of 1.000.000 smart meters over the next five years by choosing a reasonable number of apartments which is 200.000 apartments per year. To be more specific, at the end of the application period, there will be 250.000 smart meters installed in every climate zone. From now on, the word user refers to the apartment that uses smart meters to control its energy consumption.

7.1 The total cost of smart meters

According to the literature (seen in previous chapters) and other studies we ended up in the following financial data for the purchase, installation and operation of smart meters in Europe. In Ireland, the purchase and the installation of smart meters cost 37-43€ once in a lifetime, plus 25-30€ operating cost every 10 years of operation. Ireland will have a net benefit from the implementation of smart meters in 10.000 apartments equal to 282.000.000€ for the next 15-20 years not only based on reductions on the accounts of customers, but also on the energy efficiency achieved and the environmental benefits. Numerically, this means that the annual net benefit of each apartment is 1.410 – 1.880€ (*attention: this amount is not only referred to the bill*) [39, 54].

In Italy, ENEL (PPC of Italy) replaced the old traditional meters with smart ones in 32.000 users, an action that cost 2.000.000.000€ [60].

Finally, the installation of smart meters in Germany, costs 88,5€ once in a lifetime. In the next table, the average installation cost of smart meters in each country is presented [67].

Table 21: Cost of smart meter application in different countries

Smart meters	
Country	**Cost (€)**
Ireland	**68**
Italy	**63**
Germany	**89**

According to this table, a pessimistic and an optimistic scenario (German and Italian cost respectively), as far as the cost is concerned, will be computed for Greece. The spreading rate of users will be 200.000 per year for five years. Hence, the total cost is shown below.

Table 22: Optimistic and pessimistic scenario for smart meter implementation cost in Greece

Smart Meters cost (€)		
Greece	**Optimistic scenario**	**Pessimistic scenario**
1st year	**12.600.000**	**17.700.000**
2nd year	**12.600.000**	**17.700.000**
3rd year	**12.600.000**	**17.700.000**
4th year	**12.600.000**	**17.700.000**
5th year	**12.600.000**	**17.700.000**
Total	***63.000.000***	***88.500.000***

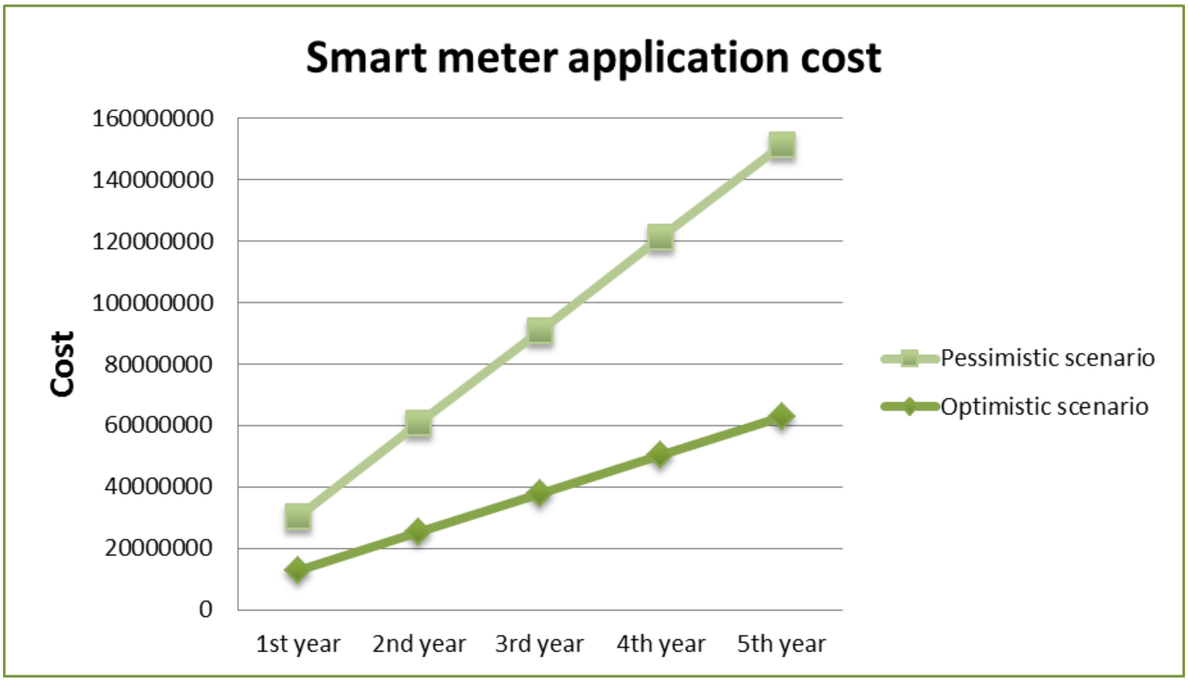


Diagram 3: Smart meter application cost in Greece, Optimistic-Pessimistic scenario

According to the table and the diagram presented above, the total cost of the implementation of 1.000.000 smart meters in the next 5 years, in the optimistic scenario is 63.000.000€ and in the pessimistic scenario is 88.500.000€.

7.2 Savings by applying smart metering

The whole venture aimed to calculate the energy savings that will be achieved by the replacement of traditional-conventional meters by the recent smart meters. The use of smart meters gives the consumer the advantage of monitoring their own energy consumption, leading to the adoption of a preferable profile. Each profile can have differentiated targets in order to satisfy the consumers’ preferences. These targets can be a computable decrease in the bill by an economic point of view that it is the main incentive for the majority of the population or the reduction of the consumption and the greenhouse gas emissions for those who are more sensitive to environmental issues. This can be easily succeeded by shifting the demand by the peak to off-peak hours or by consuming during the periods of lower energy cost (€/kWh) in the case of dynamic pricing. As a result, the Demand-Response mechanism is activated and the goals are easily managed.

As it is mentioned in earlier paragraphs, 250.000 smart meters will be installed in each one of the four climate zones of Greece. In order to calculate the savings, we took into account that the surface of every building is $80m^2$ and the consumption per m^2 (kWh/m^2) results from the use of the average function for the consumption according to the age of the buildings in each climate zone.

The following tables and diagrams present the difference in consumption before and after the smart meter installation, in apartment buildings and detached houses respectively.

For apartment buildings:

Table 23: Savings of smart meter application in apartment buildings, per climate zone

Apartment buildings		
Climate zone	**Annual current consumption (kWh)**	**Annual consumption with SM application (kWh)**
A	**3.640.000.000**	**2.204.000.000**
B	**4.786.666.667**	**3.192.000.000**
C	**6.120.000.000**	**4.560.000.000**
D	**6.333.333.333**	**5.016.000.000**
Sum	**20.880.000.000**	**14.972.000.000**
Savings	***5.908.000.000***	

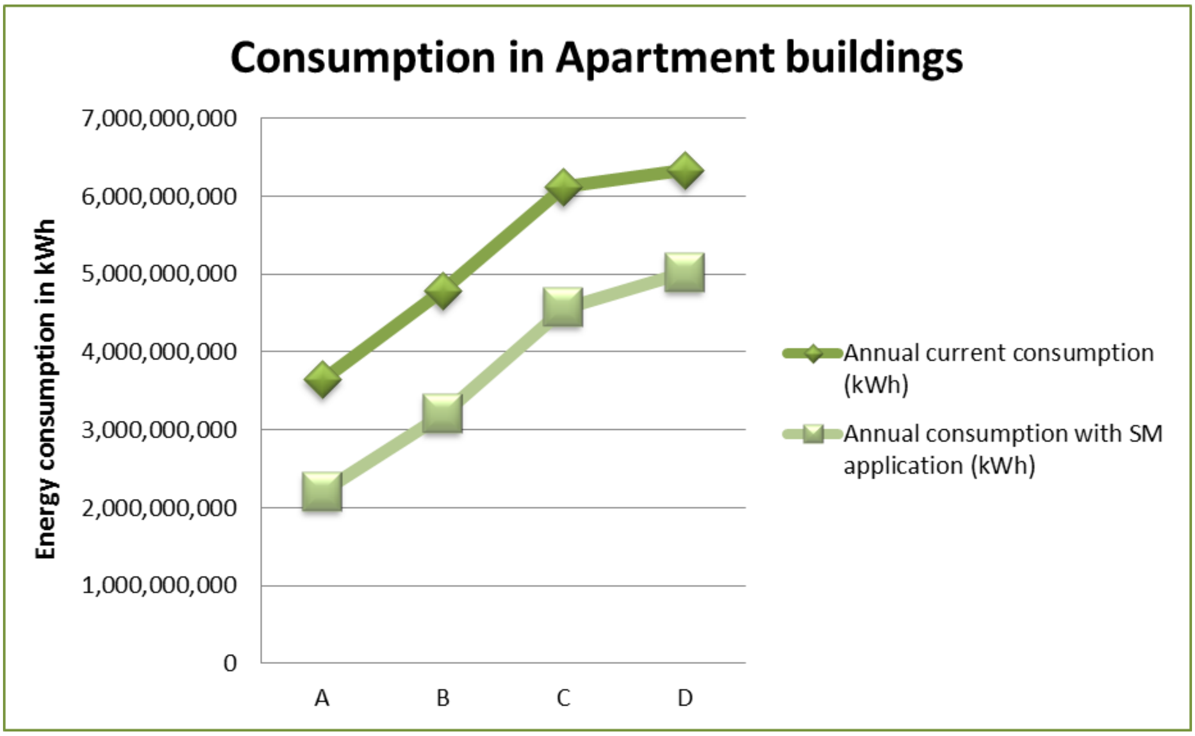


Diagram 4: Savings of smart meter application in apartment buildings, per climate zone

In apartment buildings, the total savings that are noticed by the smart meter implementation are equal to 5.908 million kWh per year, for 1.000.000 users (28,2% reduction).

For detached houses:

Table 24: Savings of smart meter application in detached houses, per climate zone

Detached houses		
Climate zone	**Annual current consumption (kWh)**	**Annual consumption with SM application (kWh)**
A	**4.373.333.333**	**3.192.000.000**
B	**6.066.666.667**	**6.441.000.000**
C	**7.440.000.000**	**5.776.000.000**
D	**8.520.000.000**	**5.814.000.000**
Sum	**26.400.000.000**	**21.223.000.000**
Savings (kWh)	***5.177.000.000***	

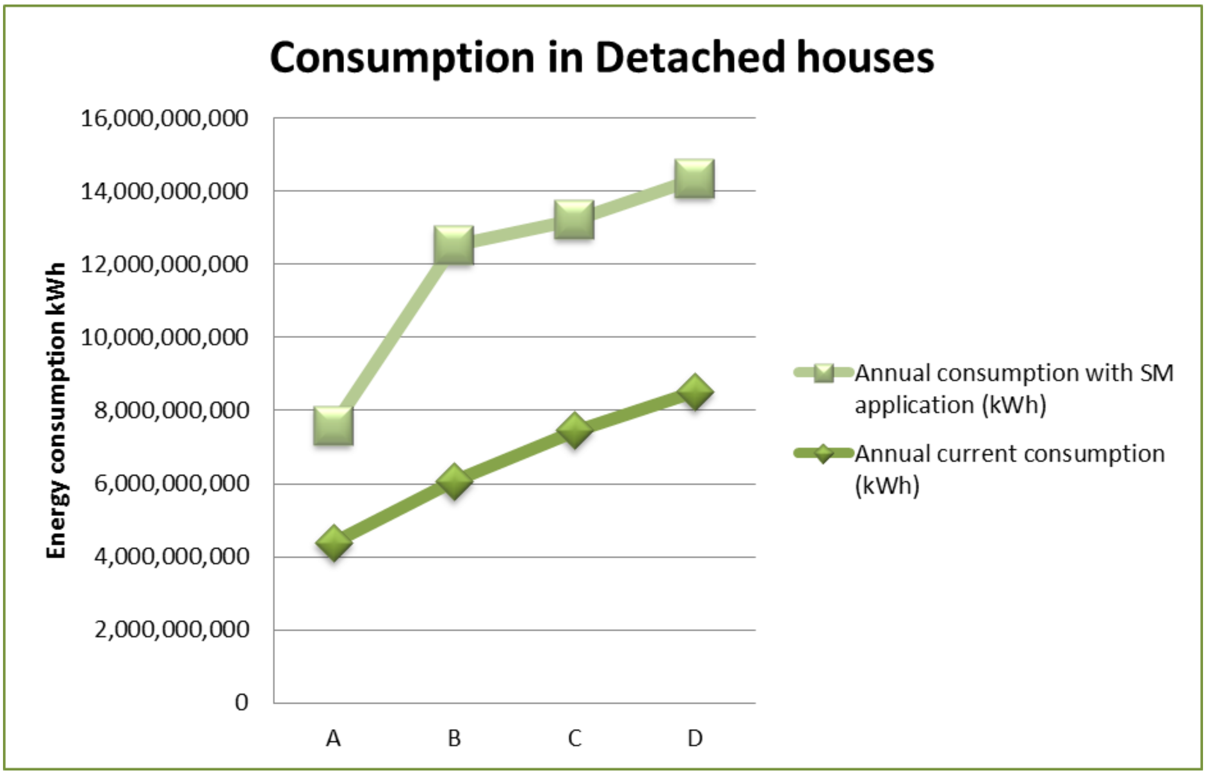


Diagram 5: Savings of smart meter application in detached houses, per climate zone

In detached houses, the total savings that are noticed by the smart meter implementation are equal to 5.177 million kWh per year, for 1.000.000 users (19,6% reduction).

7.3 Financial approach

In order to calculate the total cost of the venture, a cost estimation of the pre- smart meter application stage is required. This stage contains the insulating measures that applied for the energy upgrading of the buildings. The matching of the components needed with the components existing in the market is some-times very difficult because there is a great variety according to the quality and the cost. Even if the market prices are found though, other parameters like the profit margin of the retailer as well as the transportation and installation costs are difficult to be determined. For the above mentioned reasons, the system cost was estimated, based on prices of similar components and cost analyses of previous studies on energy upgrading buildings [64]. The estimation used for the calculation of the initial cost of these systems is presented in table 25.

Table 25: Estimation for pre- smart meter application cost, Source: [64]

Intervantions before SM application	Cost (€/m^2)		
Integrated system of external insulation	41,4		
Insulating series in sliding doors	100		
Sum	141,4	*Sum for users as a whole (€)*	11.312.000.000
Other interventions per building	4.270	*Sum for users as a whole (€)*	4.270.000.000
		Total (€)	15.582.000.000

The total cost the interventions incurred before smart meter installation is estimated to be 15.582 million € per year, for 1.000.000 users. "Other interventions" refer to sealing openings, boiler replacement with a more efficient one for oil or gas, installation of sensors to control the operating temperature of the heating system, thermostat installation etc.

Moreover, in order for the feasibility analysis to be conducted, there were also some other parameters needed to be determined:

- The heating oil price in Greece was considered at 1,03 €/lt as the mean annual oil price for 2014 [68].

- The annual increase in the price of oil was set at 3%, based on the projections of IEA for the conventional fuel prices for the next years [69].

- The natural gas price in Greece was considered at 0.08 €/lt as the mean annual natural gas price for the residential sector for 2014 [70].

- The annual increase in the price of natural gas was set at 10%, based on the projections of the Oxford Institute for energy studies [71].

- The discount rate used in the analysis was 8%, similarly to the discount rate used by Faruqui *et al.* (2010) [72] at their study.

- According to literature, the whole venture is paid once in a lifetime. For convenience, we study the economic performance of the project at a depth of 20 years, as the majority of projects is calculated.

7.4 Results of the feasibility analysis

In order to assess the economic feasibility of the insulating interventions and smart meters application, three evaluation tools are used, namely the simple payback period (PP), the Net Present Value (NPV) and the Internal Rate of Return (IRR). The three indexes find application in capital budgeting and are widely used by many companies around the world as decision making criteria.

In general, the simple payback period refers to the period of time required to amortize the initial investment, through the internal cash flow generation of the project. More specifically, in our case, the simple payback period calculates the time needed in order for the savings incurred by smart meters system to “repay” the initial investment cost of the system. The main advantage of this tool is the fact that it is easy to calculate and easy to understand for most people, regardless of their education and academic background. However, simple payback period does not take into account the time value of money which constitutes a main drawback. The Payback Period is calculated using the LOOKUP financial function in excel software, as well as the cumulative cash flows.

On the contrary, the time value of money is taken into account by the second evaluation tool, the Net Present Value (NPV). All the projected cash flows (in our case the projected savings achieved by the smart meters system) are discounted back to the present by the discount rate and are summed up in order to find the present value of the investment. In order for the smart meter system to be economical feasible, this value shall exceed the initial investment cost. Any project with a positive NPV is acceptable and for ranking of alternatives, the higher NPV, the better the alternative. If NPV is zero, there is no difference between putting the money in the bank and investing the money in the specific project. In case NPV is negative, the project is not accepted because there will be loss of money investing on the venture. NPV is more difficult to calculate and to use than the simple payback period, since it is difficult to determine the correct discount rate. In addition, knowledge of the basic financial concepts is required, in order for one to understand its meaning and correctly use it as a decision making criterion. The Net Present Value is calculated using the NPV financial function in excel software, as well as the suitable discount rate and the cash flows.

Internal Rate of Return is another Discounted Cash Flow measure. The internal rate of return (IRR) is based on discounted cash flows. Unlike the NPV rule, however, it takes into account the project's scale. It is the discounted cash flow analog to the accounting rates of return. Again, in general terms, the IRR is that discount rate that makes the NPV of a project equal to zero. One advantage of the IRR is that it can be used even in cases where the discount rate is unknown. While this is true for the calculation of the IRR, it is not true when the decision maker has to use the IRR to decide whether to undertake a project. At that stage in the process, the IRR has to be compared to the discount rate. If the IRR is greater than the discount rate, the project is a good one; alternatively, the project should be rejected. The Internal Rate of Return is calculated using the IRR financial function in excel software, as well as a hypothetical but rational discount rate and the cash flows.

Use of NPV and IRR for project evaluation can lead to contradictory results in some cases. The difference can arise due to a number of reasons:

- preference for higher return in IRR,
- the assumption of reinvestment at the IRR in any IRR computation and
- differences in the timing of cash flow.

If IRR and NPV provide contradictory results, normally it is preferred to follow NPV as the basis for selection [73, 74].

It should be noted at this point that in all evaluation scenarios, for convenience in calculations, the whole number of smart meters are assumed to be installed at the beginning of the venture, in year 0. For this reason, as initial investment cost it is considered the summation of the insulating interventions' cost plus the smart meter project cost. Another assumption refers to the total cost of smart meters as far as the optimistic and pessimistic scenarios are concerned (unit 7.1). The average of these two scenarios is taken into account because the difference related to the total initial cost is negligible.

The results derived from the feasibility analysis are presented below for the different evaluation scenarios.

Evaluation scenario 1

The first evaluation scenario examines PP, NPV and IRR taking into account the savings that occur in buildings that use oil to cover their energy needs. This means that the economic benefit that arises by reducing the consumption using smart meters is converted into money, with particular reference to the oil price. More specifically, (Savings in €) = (Cash flows) = (Savings in kWh) x (€/kWh of oil). The initial cost is put at year 0 as a negative (red) number because it is an expense. In the tables below, the calculation of the abovementioned measures is presented analytically. There is a different table, for each kind of buildings, apartment building and detached house.

For Apartment buildings:

Table 26: PP, NPV, IRR of the project with respect to oil price-Apartment building- Scenario 1

Apartment building		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	**15.657,8**	**15.657,8**
1	**6.085,2**	**9.572,5**
2	**6.085,2**	**3.487,3**
3	**6.085,2**	**2.598**
4	**6.085,2**	**8.683,2**
5	**6.085,2**	**14.768,5**
6	**6.085,2**	**20.853,7**
7	**6.085,2**	**26.938,9**
8	**6.085,2**	**33.024,2**
9	**6.085,2**	**39.109,4**
10	**6.085,2**	**45.194,7**
11	**6.085,2**	**51.279,9**
12	**6.085,2**	**57.365,1**
13	**6.085,2**	**63.450,4**
14	**6.085,2**	**69.535,6**
15	**6.085,2**	**75.620,9**
16	**6.085,2**	**81.706,1**
17	**6.085,2**	**87.791,3**
18	**6.085,2**	**93.876,6**
19	**6.085,2**	**99.961,8**
20	**6.085,2**	**106.047,1**

Discount rate	**8%**

Payback Period	**2.6**
NPV	**44.088**
IRR	**39%**

According to the calculations of Table 26, Payback period is equal to 2,6 years, NPV is positive and equals to 44.088 million €, while IRR is estimated to be 39%. This means that the specific investment is profitable for the buildings that use oil to cover their energy needs. The gain of this project is 44.088 million €, so it is preferable to put the money on the investment rather than in the bank. According to IRR, only if the discount rate overcomes the 39%, there will be a loss of money investing on the project.

For Detached houses:

Table 27: PP, NPV, IRR of the project with respect to oil price-Detached house- Scenario 1

Detached house		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	15.657,8	15.657,8
1	5.332,3	10.325,4
2	5.332,3	4.993,1
3	5.332,3	339,2
4	5.332,3	5.671,5
5	5.332,3	11.003,8
6	5.332,3	16.336,1
7	5.332,3	21.668,4
8	5.332,3	27.000,7
9	5.332,3	32.333
10	5.332,3	37.665,4
11	5.332,3	42.997,7
12	5.332,3	48.330
13	5.332,3	53.662,3
14	5.332,3	58.994,6
15	5.332,3	64.326,9
16	5.332,3	69.659,2
17	5.332,3	74.991,5
18	5.332,3	80.323,8
19	5.332,3	85.656,1
20	5.332,3	90.988,5

Discount rate	8%

Payback Period	2,9
NPV	36.695,7
IRR	33,96%

According to the calculations of Table 27, Payback period is equal to 2,9 years, NPV is positive and equals to 36.695,5 million €, while IRR is estimated to be 33,96%. This means that the specific investment is profitable for the buildings that use oil to cover their energy needs. The gain of this project is 36.695,5million €, so it is preferable to put the money on the investment rather than in the bank. According to IRR, only if the discount rate overcomes the 33,96%, there will be a loss of money investing on the project.

Evaluation scenario 2

In the second evaluation scenario PP, NPV and IRR are calculated taking into account the savings that occur in buildings that use oil to cover their energy needs. The difference of this scenario in relation with the previous one lies in the fact that here an annual increase rate of 3% of oil price is taken into consideration according to the projections of IEA. The following tables refer to apartment building and detached house, respectively.

For Apartment buildings:

Table 28: PP, NPV, IRR of the project with respect to a 3% annual increase of oil price- Apartment building- Scenario 2

Apartment building		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	**15.657,8**	**15.657,8**
1	**6.085,2**	**9.572,5**
2	**6.267,8**	**3.304,7**
3	**6.450,4**	**3.145,6**
4	**6.632,9**	**9.778,6**
5	**6.815,5**	**16.594**
6	**6.998**	**23.592**
7	**7.180,6**	**30.772,6**
8	**7.363,1**	**38.135,8**
9	**7.545,7**	**45.681,5**
10	**7.728,3**	**53.409,7**
11	**7.910,8**	**61.320,5**
12	**8.093,4**	**69.413,9**
13	**8.275,9**	**77.689,8**
14	**8.458,5**	**86.148,3**
15	**8.641**	**94.789,4**
16	**8.823,6**	**103.613**
17	**9.006,2**	**112.619,1**
18	**9.188,7**	**121.807,8**
19	**9.371,3**	**131.179,1**
20	**9.553,8**	**140.732,9**

Discount rate	**8%**
Payback Period	**2,5**
NPV	**56.700,9**
IRR	**42%**

According to the calculations of Table 28, Payback period is equal to 2,5 years, NPV is positive and equals to 56.700,9 million €, while IRR is estimated to be 42%. This means that the specific investment is profitable for the buildings that use oil to cover their energy needs. The gain of this project is 56.700,9 million €, so it is preferable to put the money on the investment rather than in the bank. According to IRR, only if the discount rate overcomes the 42%, there will be a loss of money investing on the project.

For Detached houses:

Table 29: PP, NPV, IRR of the project with respect to a 3% annual increase of oil price- Detached house- Scenario 2

Detached house		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	15.657,8	15.657,8
1	5.332,3	10.325,4
2	5.492,3	4.833,2
3	5.652,2	819,1
4	5.812,2	6.631,3
5	5.972,2	12.603,5
6	6.132,2	18.735,6
7	6.292,1	25.027,8
8	6.452,1	31.479,9
9	6.612,1	38.091,9
10	6.772	44.864
11	6.932	51.796
12	7.092	58.887,9
13	7.251,9	66.139,9
14	7.411,9	73.551,8
15	7.571,9	81.123,7
16	7.731,8	88.855,5
17	7.891,8	96.747,3
18	8.051,8	104.799,1
19	8.211,8	113.010,9
20	8.371,7	121.382,6

Discount rate	8%

Payback Period	2,9
NPV	24.278
IRR	36,73%

According to the calculations of Table 29, Payback period is equal to 2,9 years, NPV is positive and equals to 47.747,9 million €, while IRR is estimated to be 37%. This means that the specific investment is profitable for the buildings that use oil to cover their energy needs. The gain of this project is 47.747,9 million €, so it is preferable to put the money on the investment rather than in the bank. According to IRR, only if the discount rate overcomes the 37%, there will be a loss of money investing on the project.

Evaluation scenario 3

In the third evaluation scenario PP, NPV and IRR are calculated taking into account the savings that occur in buildings that use oil to cover their energy needs. The difference of this scenario in relation with the previous one lies in the fact that here an annual decrease rate of 5% of oil price is taken into consideration. That is because it would be useful to see what happens in a relevant case, when the price of oil descends. The following tables refer to apartment building and detached house, respectively.

For Apartment buildings:

Table 30: PP, NPV, IRR of the project with respect to a 5% annual decrease of oil price- Apartment building- Scenario 3

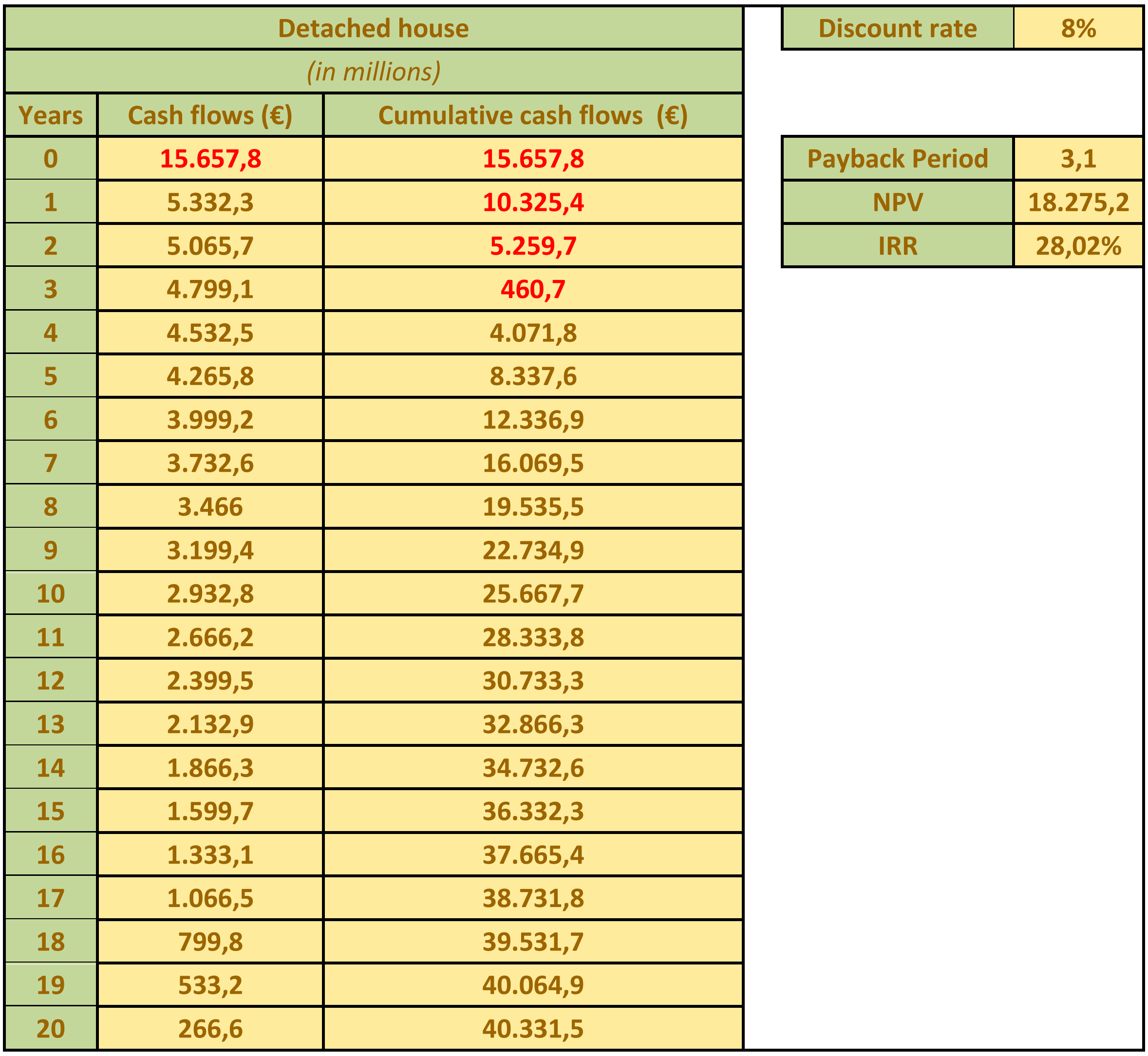
Apartment building		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	**15.657,8**	**15.657,8**
1	**6.085,2**	**9.572,5**
2	**5.781**	**3.791,5**
3	**5.476,7**	**1.685,2**
4	**5.172,5**	**6.857,6**
5	**4.868,2**	**11.725,8**
6	**4.563,9**	**16.289,8**
7	**4.259,7**	**20.549,4**
8	**3.955,4**	**24.504,8**
9	**3.651,1**	**28.156**
10	**3.346,9**	**31.502,9**
11	**3.042,6**	**34.545,5**
12	**2.738,4**	**37.283,8**
13	**2.434,1**	**39.717,9**
14	**2.129,8**	**41.847,8**
15	**1.825,6**	**43.673,3**
16	**1.521,3**	**45.194,7**
17	**1.217**	**46.411,7**
18	**912,8**	**47.324,5**
19	**608,5**	**47.933**
20	**304,3**	**48.237,3**

Discount rate	**8%**
Payback Period	**2,7**
NPV	**23.066,6**
IRR	**33%**

According to the calculations of Table 30, Payback period is equal to 2,7 years, NPV is positive and equals to 23.066,6 million €, while IRR is estimated to be 33%. This means that the specific investment is profitable for the buildings that use oil to cover their energy needs. The gain of this project is 23.066,6 million €, so it is preferable to put the money on the investment rather than in the bank. According to IRR, only if the discount rate overcomes the 33%, there will be a loss of money investing on the project.

For Detached houses:

Table 31: PP, NPV, IRR of the project with respect to a 5% annual decrease of oil price- Detached house- Scenario 3



Detached house		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	15.657,8	15.657,8
1	5.332,3	10.325,4
2	5.065,7	5.259,7
3	4.799,1	460,7
4	4.532,5	4.071,8
5	4.265,8	8.337,6
6	3.999,2	12.336,9
7	3.732,6	16.069,5
8	3.466	19.535,5
9	3.199,4	22.734,9
10	2.932,8	25.667,7
11	2.666,2	28.333,8
12	2.399,5	30.733,3
13	2.132,9	32.866,3
14	1.866,3	34.732,6
15	1.599,7	36.332,3
16	1.333,1	37.665,4
17	1.066,5	38.731,8
18	799,8	39.531,7
19	533,2	40.064,9
20	266,6	40.331,5

Discount rate	8%
Payback Period	3,1
NPV	18.275,2
IRR	28,02%

According to the calculations of Table 31, Payback period is equal to 3,1 years, NPV is positive and equals to 18.275,2 million €, while IRR is estimated to be 28%. This means that the specific investment is profitable for the buildings that use oil to cover their energy needs. The gain of this project is 18.275,2 million €, so it is preferable to put the money on the investment rather than in the bank. According to IRR, only if the discount rate overcomes the 28%, there will be a loss of money investing on the project.

Evaluation scenario 4

The forth evaluation scenario examines PP, NPV and IRR taking into account the savings that occur in buildings that use natural gas to cover their energy needs. This means that the economic benefit that arises by reducing the consumption using smart meters is converted into money, with particular reference to the natural gas price. There is a different table, for each kind of buildings, apartment building and detached house.

For Apartment buildings:

Table 32: PP, NPV, IRR of the project with respect to natural gas price-Apartment building-Scenario 4

Apartment building		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	**15.657,8**	**15.657,8**
1	**472,6**	**15.185,1**
2	**472,6**	**14.712,5**
3	**472,6**	**14.239,8**
4	**472,6**	**13.767,2**
5	**472,6**	**13.294,6**
6	**472,6**	**12.821,9**
7	**472,6**	**12.349,3**
8	**472,6**	**11.876,6**
9	**472,6**	**11.404**
10	**472,6**	**10.931,4**
11	**472,6**	**10.458,7**
12	**472,6**	**9.986,1**
13	**472,6**	**9.513,4**
14	**472,6**	**9.040,8**
15	**472,6**	**8.568,2**
16	**472,6**	**8.095,5**
17	**472,6**	**7.622,9**
18	**472,6**	**7.150,2**
19	**472,6**	**6.677,6**
20	**472,6**	**6.205**

Discount rate	**8%**
Payback Period	**33,1**
NPV	**11.017,3**
IRR	**-4,39%**

As it is obvious from Table 32, Payback period is equal to 33,1 years, NPV is negative and equals to -11.017,13 million €, while IRR is estimated to be -4,39%. This means that the specific investment is not profitable for the buildings that use natural gas to cover their energy needs. The loss of this project is 11.017,13 million €, so it is preferable to put the money in the bank rather than on the investment. This is because the price of natural gas is too low.

For Detached houses:

Table 33: PP, NPV, IRR of the project with respect to natural gas price-Detached house- Scenario 4

Detached house		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	**15,657,8**	**15.657,8**
1	**414,2**	**15.243,6**
2	**414,2**	**14.829,4**
3	**414,2**	**14.415,3**
4	**414,2**	**14.001,1**
5	**414,2**	**13.587**
6	**414,2**	**13.172,8**
7	**414,2**	**12.758,6**
8	**414,2**	**12.344,5**
9	**414,2**	**11.930,3**
10	**414,2**	**11.516,2**
11	**414,2**	**11.102**
12	**414,2**	**10.687,8**
13	**414,2**	**10.273,7**
14	**414,2**	**9.859,5**
15	**414,2**	**9.445,4**
16	**414,2**	**9.031,2**
17	**414,2**	**8.617**
18	**414,2**	**8.202,9**
19	**414,2**	**7.788,7**
20	**414,2**	**7.374,6**

Discount rate	8%
Payback Period	**37,8**
NPV	**11.591,5**
IRR	**-5,42%**

As Table 33 shows, Payback period is equal to 37,8 years, NPV is negative and equals to -11.591,5 million €, while IRR is estimated to be -5,42%. This means that the specific investment is not profitable for the buildings that use natural gas to cover their energy needs. The loss of this project is 11.591,5 million €, so it is preferable to put the money in the bank rather than on the investment. This is because the price of natural gas is too low.

Evaluation scenario 5

In the fifth evaluation scenario PP, NPV and IRR are calculated taking into account the savings that occur in buildings that use natural gas to cover their energy needs. The difference of this scenario in relation with the previous one lies in the fact that here an annual increase rate of 10% of natural gas price is taken into consideration according to the projections of the Oxford Institute for Energy Studies. The following tables refer to apartment building and detached house, respectively.

For Apartment buildings:

Table 34: PP, NPV, IRR of the project with respect to a 10% annual increase of natural gas price-Apartment building- Scenario 5

Apartment building		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	**15.657,8**	**15.657,8**
1	**472,6**	**15.185,1**
2	**519,9**	**14.665,2**
3	**567,2**	**14.098**
4	**614,4**	**13.483,6**
5	**661,7**	**12.821,9**
6	**709**	**12.113**
7	**756,2**	**11.356,7**
8	**803,5**	**10.553,2**
9	**850,8**	**9.702,5**
10	**898**	**8.804,5**
11	**945,3**	**7.859,2**
12	**992,5**	**6.866,6**
13	**1.039,8**	**5.826,8**
14	**1.087,1**	**4.739,8**
15	**1.134,3**	**3.605,4**
16	**1.181,6**	**2.423,8**
17	**1.228,9**	**1.195**
18	**1.276,1**	**81,2**
19	**1.323,4**	**1.404,6**
20	**1.370,7**	**2.775,2**

Discount rate	**8%**

Payback Period	**18**
NPV	**7.751,8**
IRR	**1%**

As it is indicated in Table 34, Payback period is equal to 18 years, NPV is negative and equals to -7.751,8 million €, while IRR is estimated to be 1%. This implies that only if the discount rate falls to 1%, the investment will be probably profitable. The loss of this project, in the current case, is 7.751,8 million €, so it is preferable to put the money in the bank rather than on the investment.

For Detached houses:

Table 35: PP, NPV, IRR of the project with respect to a 10% annual increase of natural gas price-Detached house- Scenario 5

Detached house		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	**15.657,8**	**15.657,8**
1	**414,2**	**15.243,6**
2	**455,6**	**14.788**
3	**497**	**14.291**
4	**538,4**	**13.752,6**
5	**579,8**	**13.172,8**
6	**621,2**	**12.551,6**
7	**662,7**	**11.888,9**
8	**704,1**	**11.184,8**
9	**745,5**	**10.439,3**
10	**786,9**	**9.652,4**
11	**828,3**	**8.824,1**
12	**869,7**	**7.954,4**
13	**911,2**	**7.043,2**
14	**952,6**	**6.090,7**
15	**994**	**5.096,7**
16	**1.035,4**	**4.061,3**
17	**1.076,8**	**2.984,5**
18	**1.118,2**	**1.866,2**
19	**1.159,6**	**706,6**
20	**1.201,1**	**494,5**

Discount rate	**8%**

Payback Period	**19,6**
NPV	**8.730**
IRR	**0,26%**

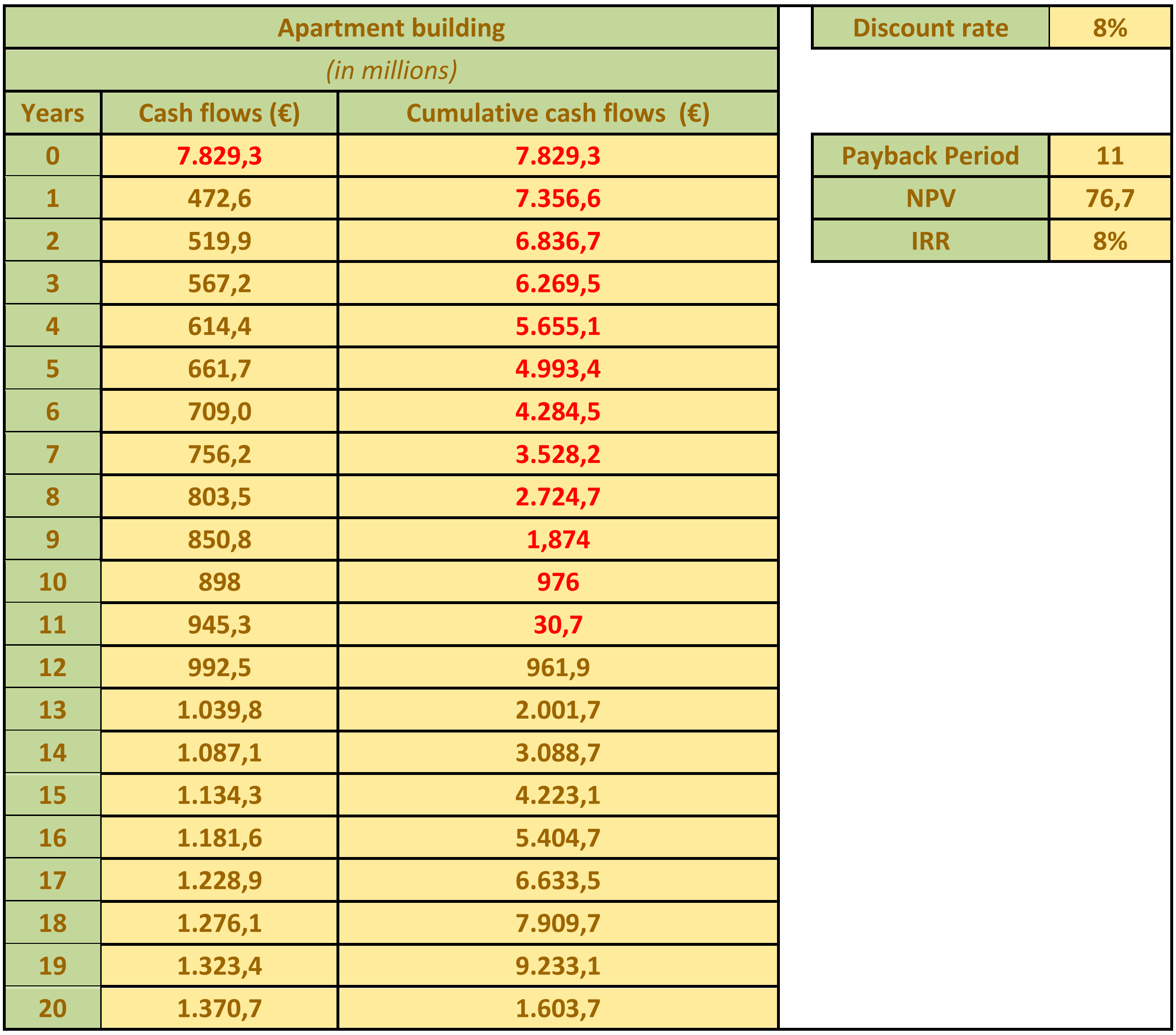
As it is indicated in Table 35, Payback period is equal to 19,6 years, NPV is negative and equals to -8.730 million €, while IRR is estimated to be 0,26%. This implies that only if the discount rate falls to 0,26%, the investment will be probably profitable. The loss of this project, in the current case, is 8.730 million €, so it is preferable to put the money in the bank rather than on the investment.

Evaluation scenario 6

This scenario is a continuation of the previous one. The difference of this scenario in relation with the previous one lies in the fact that except from the annual increase rate of 10% of natural gas price, we also add a reduction of the initial cost in half as a result of the implementation of the project on a large scale and the widespread availability and use of smart meters that will lead to lower costs. The following tables refer to apartment building and detached house, respectively.

For Apartment buildings:

Table 36: PP, NPV, IRR of the project with respect to a 10% annual increase of natural gas price plus a reduction of initial investment in half-Apartment building- Scenario 6



Apartment building		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	7.829,3	7.829,3
1	472,6	7.356,6
2	519,9	6.836,7
3	567,2	6.269,5
4	614,4	5.655,1
5	661,7	4.993,4
6	709,0	4.284,5
7	756,2	3.528,2
8	803,5	2.724,7
9	850,8	1,874
10	898	976
11	945,3	30,7
12	992,5	961,9
13	1.039,8	2.001,7
14	1.087,1	3.088,7
15	1.134,3	4.223,1
16	1.181,6	5.404,7
17	1.228,9	6.633,5
18	1.276,1	7.909,7
19	1.323,4	9.233,1
20	1.370,7	1.603,7

Discount rate	8%

Payback Period	11
NPV	76,7
IRR	8%

According to the calculations of Table 36, Payback period is equal to 11 years, NPV is positive and equals to 76,7 million €, while IRR is estimated to be 8%. This means that the specific investment under specific circumstances is profitable. The gain of this project is 76,7 million €, so it is preferable to put the money on the investment rather than in the bank. According to IRR, only if the discount rate overcomes the 8%, there will be a loss of money investing on the project.

For Detached houses:

Table 37: PP, NPV, IRR of the project with respect to a 10% annual increase of natural gas price plus a reduction of initial investment in half-Detached house- Scenario 6

Detached house		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	**7.829,3**	**7.829,3**
1	**414,2**	**7.415,1**
2	**455,6**	**6.959,5**
3	**497,0**	**6.462,5**
4	**538,4**	**5.924,1**
5	**579,8**	**5.344,3**
6	**621,2**	**4.723,1**
7	**662,7**	**4.060,4**
8	**704,1**	**3.356,3**
9	**745,5**	**2.610,8**
10	**786,9**	**1.823,9**
11	**828,3**	**995,6**
12	**869,7**	**125,9**
13	**911,2**	**785,3**
14	**952,6**	**1.737,8**
15	**994,0**	**2.731,8**
16	**1.035,4**	**3.767,2**
17	**1.076,8**	**4.844**
18	**1.118,2**	**5.962,3**
19	**1.159,6**	**7.121,9**
20	**1.201,1**	**8.323**

Discount rate	**8%**
Payback Period	**12,1**
NPV	**901,5**
IRR	**6,68%**

As it is indicated in Table 37, Payback period is equal to 12,1 years, NPV is negative and equals to -901,5 million €, while IRR is estimated to be 6,68%. This implies that only if the discount rate falls to 6,68%, the investment will be probably profitable. The loss of this project, in the current case, is 901,5 million €, so it is preferable to put the money in the bank rather than on the investment.

Evaluation scenario 7

This scenario is a continuation of the previous one. The difference of this scenario in relation with the previous one lies in the fact that except from the annual increase rate of 10% of natural gas price, and the reduction of the initial cost in half, we also add an increase in savings by 30%, as a result of the evolution of technology and the practice and effective use of smart meters. The following tables refer to apartment building and detached house, respectively.

For Apartment buildings:

Table 38: PP, NPV, IRR of the project with respect to a 10% annual increase of natural gas price plus a reduction of initial investment in half and an increase of savings by 30%-Apartment building- Scenario 7

Apartment building		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	7.829,3	7.829,3
1	614,4	7.214,8
2	675,9	6.538,9
3	737,3	5.801,6
4	798,8	5.002,9
5	860,2	4.142,7
6	921,6	3.221
7	983,1	2.237,9
8	1.044,5	1.193,4
9	1.106	87,4
10	1.167,4	1.080
11	1.228,9	2.308,9
12	1.290,3	3.599,2
13	1.351,8	4.950,9
14	1.413,2	6.364,1
15	1.474,6	7.838,8
16	1.536,1	9.374,8
17	1.597,5	10.972,4
18	1.659	12.631,3
19	1.720,4	14.351,7
20	1.781,9	16.133,6

Discount rate	8%
Payback Period	9,1
NPV	2.448,4
IRR	11%

According to the calculations of Table 38, Payback period is equal to 9,1 years, NPV is positive and equals to 2.448,4 million €, while IRR is estimated to be 11%. This means that the specific investment under specific circumstances is profitable. The gain of this project is 2.448,4 million €, so it is preferable to put the money on the investment rather than in the bank. According to IRR, only if the discount rate overcomes the 11%, there will be a loss of money investing on the project.

For Detached houses:

Table 39: PP, NPV, IRR of the project with respect to a 10% annual increase of natural gas price plus a reduction of initial investment in half and an increase of savings by 30%-Detached house- Scenario 7

Detached house		
(in millions)		
Years	**Cash flows (€)**	**Cumulative cash flows (€)**
0	7.829,3	7.829,3
1	538,4	7.290,8
2	592,2	6.698,6
3	646,1	6.052,5
4	699,9	5.352,6
5	753,8	4.598,8
6	807,6	3.791,2
7	861,5	2.929,7
8	915,3	2.014,4
9	969,1	1.045,3
10	1.023	22,3
11	1.076,8	1.054,5
12	1.130,7	2.185,1
13	1.184,5	3.369,6
14	1.238,3	4.608
15	1.292,2	5.900,2
16	1,346	7.246,2
17	1.399,9	8.646
18	1.453,7	10.099,7
19	1.507,5	11.607,3
20	1.561,4	13.168,7

Discount rate	8%

Payback Period	10
NPV	1.176,8
IRR	9,6%

According to the calculations of Table 39, Payback period is equal to 10 years, NPV is positive and equals to 1.176,8 million €, while IRR is estimated to be 9,6%. This means that the specific investment under specific circumstances is profitable. The gain of this project is 10176,8 million €, so it is preferable to put the money on the investment rather than in the bank. According to IRR, only if the discount rate overcomes the 9,6%, there will be a loss of money investing on the project.

8 Parametric analysis

The feasibility analysis in the previous chapter revealed, that in some examined scenarios the installation of the interventions does not comprise an economically viable investment while in some others it does. The excessive initial cost of the specific system, in combination with the relative low natural gas price led to high payback periods and negative net present values. On the contrary, the situation is not the same considering the oil price. In this chapter, these parameters are examined, in order to find their influence on the results and the potential of the examined system to be economically viable.

8.1 Comparison between the different evaluation scenarios

In order to examine the economic viability of the project, 7 different evaluation scenarios were considered. The three of them study the influence of oil price on the results. The rest of them examine the effect of natural gas price. In the diagrams below, the comparison between the scenarios is obvious for both kinds of buildings.

Initially, the diagrams for apartment building are presented. A discussion will follow about the results.

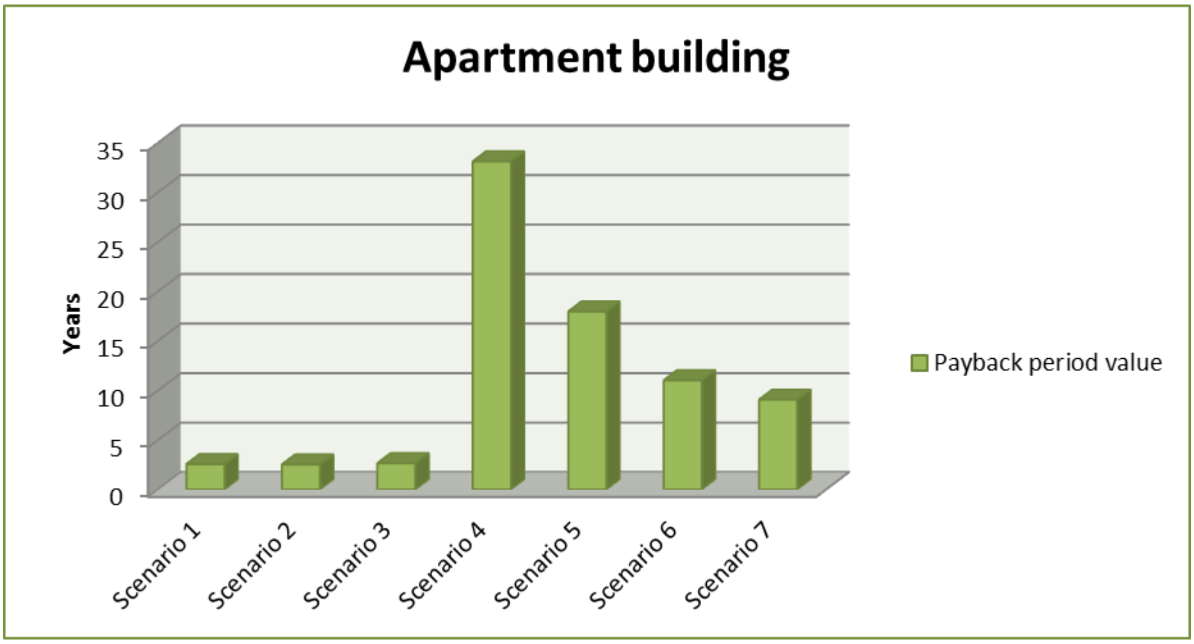


Diagram 6: Scenarios' comparison-Payback period- Apartment building

The project was studied at a depth of 20 years. For apartment buildings, taking into account the payback period measure, it is transparent that in six of the seven scenarios, the initial investment will be amortized in less than 20 years. The only case that the investment will be repaid over a longer period is the evaluation scenario 4, where the investment is compared with the current natural gas price. This is because, this price, today, is too low, so the project needs about 33 years to be amortized.

However, as it is mentioned in unit 7.4, the payback period measure does not take into account the time value of money. Hence, the NPV measure will lead to more reliable results. In the following diagram, the NPV comparison of the scenarios is illustrated.

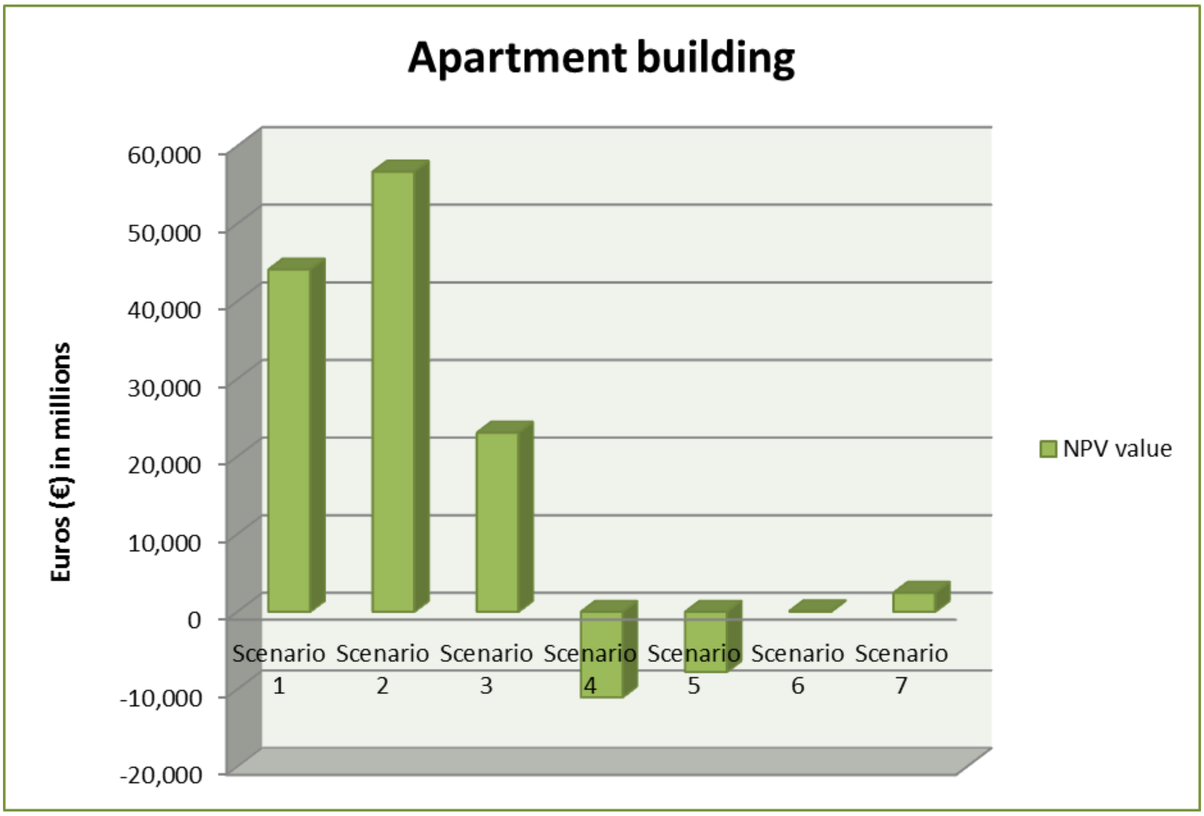


Diagram 7: Scenarios’ comparison-NPV- Apartment building

The *evaluation scenario 1* takes into consideration the net benefits of the investment according to the current oil price. It is obvious that the NPV is positive, so there are cash inflows after the implementation of the investment which means that every apartment that uses oil as fuel should invest on the project.

The *evaluation scenario 2* deals with a projected annual increase of 3% of oil price. As expected, with an annual increase of oil price, the savings of the project will be greater. Thus, the cash flows are positive again.

The aim of *evaluation scenario 3* was to examine the viability of the investment in a possible decrease of oil price. Hence, an annual decrease of 5% of oil price was considered, in order to pry the results. Although the scenario is unlikely to happen, the NPV is positive again. So, confidently, oil user will benefit from the investment.

The *evaluation scenario 4* takes into consideration the cash flows of the investment according to the current natural gas price. It is obvious that the NPV is negative, so there are cash outflows after the implementation of the investment which means that every apartment that uses natural gas as fuel should not invest on the project.

The *evaluation scenario 5* deals with a projected annual increase of 10% of natural gas price. The cash flows are negative again. Thus, the investment is not profitable either for an increase in price of natural gas.

The *evaluation scenario 6* is a continuation of the previous one. Here with a reduction of the initial cost in half, it is evident that the cash flows are positive. In this case, the investment is profitable for the natural gas users. Even if the NPV value is marginally greater than zero, related to the rest of gainful scenarios, it would be an advantage to think of the environmental benefits that, confidently, occur from the investment. However, numerical data do not exist since this represents an entirely different study.

Evaluation scenario 7 adds to the previous one an increase in savings by 30%. Here, it is evident that the NPV is positive, so there are cash inflows after the implementation of the investment which means that every apartment under these specific circumstances should invest on the project.

Additionally, the diagrams for detached houses are presented below and include many similarities.

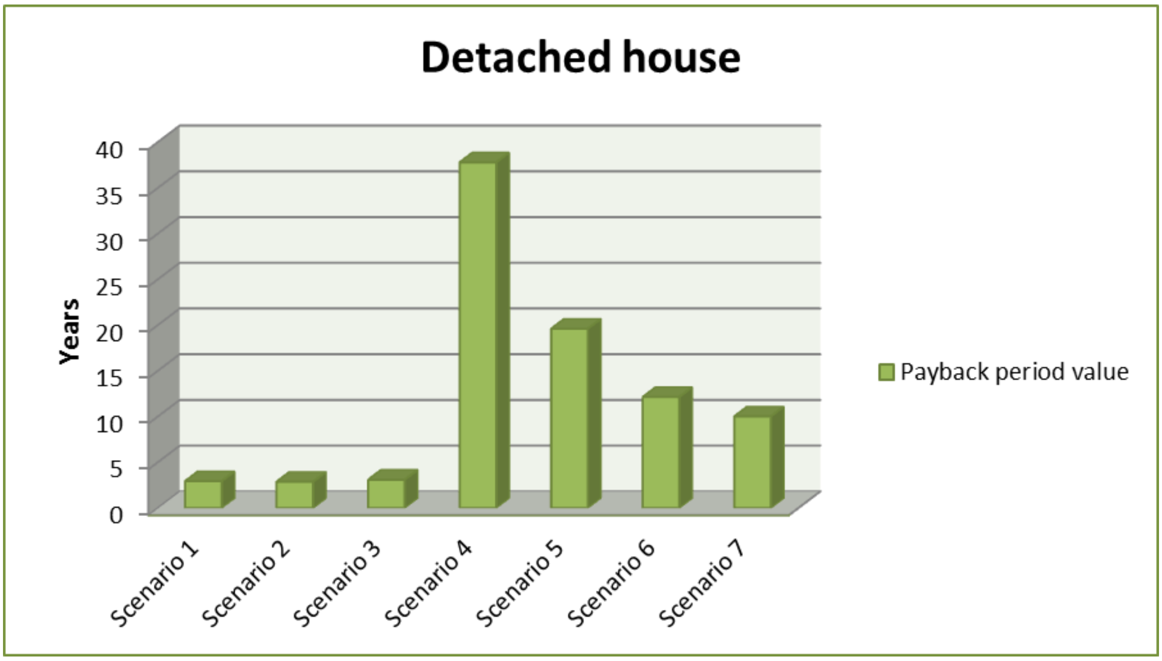


Diagram 8: Scenarios' comparison-Payback period- Detached house

For detached houses, taking into account the payback period measure, it is transparent that in six of the seven scenarios, the initial investment will be amortized in less than 20 years. However, evaluation scenario 5 is bounded within 20 years. The only case that the investment will be repaid over a longer period is the evaluation scenario 4 again, where the investment is compared with the current natural gas price. This is because, this price, today, is too low, so the project needs about 38 years to be amortized. As expected, a period greater than the one in apartment buildings.

Let's proceed with the NPV comparison.

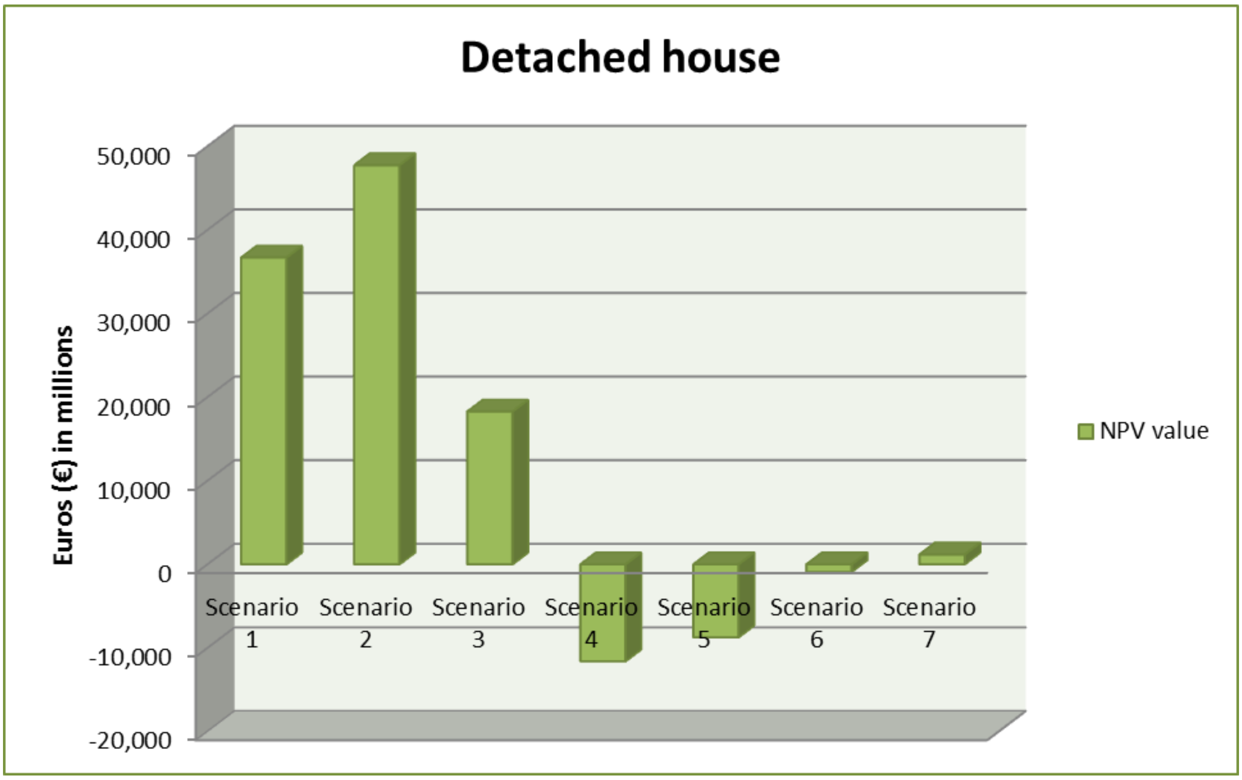


Diagram 9: Scenarios' comparison-NPV- Detached house

The only difference between the NPV and the scenarios of apartment buildings and detached houses is noticed in evaluation scenario 6. Here, even if the cost of the investment is decreased in half, the investment continues to be unprofitable for natural gas users of detached houses. Only a state subsidy or other financial incentives (tax reliefs, payment grants etc.) would make it gainful.

9 Conclusions

In a period in which issues like the climate change, the depletion of fossil fuels and the future of energy supply are high in the discussion agenda of all the developed countries in the world, the shift towards a more efficient management of energy appears to be a way to address these problems.

In the developed world, a large growth in energy consumption appears in the building sector. Buildings constitute one of the dominant energy consuming sectors as they account for about 40% -more than one third- of the total primary energy consumption. Consequently, there has to be a mean of monitoring and controlling the electricity consumption inside a household. This system has to be easily understood and handled by every consumer and the consumer should have the ability to intervene in real time in order to make changes at the time of the consumption. Smart meters are innovative systems, which with the help of modern information and communications systems; permit a rational control of energy consumption in a building, even in whole urban neighborhoods, in an easy way.

This dissertation deals with the effectiveness of smart metering on the energy performance of residential buildings. It examines the conditions under which it can be applied and the expected benefits, not bypassing eventual problems that may occur by using this technology. Finally, it investigates the circumstances that need to prevail so that it can be applied with success in the Greek building stock, contributing to the improvement of the overall energy efficiency.

Smart meters were chosen because they are a prerequisite for the realization of intelligent management. This is because the data that are elaborated in order to end up in optimal decisions are derived from the measurements of smart meters in real time and they are sent to administrators and users in digital form. Thus, all consumers have the ability to create their energy profiles and adjust their consumption to achieve their personal desires.

Various studies have been carried out so as to monitor the electricity consumption in the residential building stock. The legal framework has been updated in order to meet and cover the new needs and the design of the buildings is changed for the same purpose. Consequently, a number of relevant studies that have been carried out were presented and analyzed in order to get a general view of similar trials.

The buildings stock's features, then, were analyzed in order to ensure that the most suitable and efficient energy saving measures, with respect to the building's architectural, structural and operational characteristics were implemented. Aware that 71% of the Greek building stock was constructed years before the putting into effect of the first Thermal Insulation Regulation and given the fact that 83% of these buildings consist of residential buildings, indicates the large potential in energy conservation on the existing building stock.
In order to achieve this, a basic classification of Greek buildings had to be determined, taking into account their typology and their year of construction. The classification of the building stock, in seven classes, was based on the year of construction, the technical, historical, political and social proceedings.
Subsequently, integrated projects of smart metering installation and their results throughout Europe were examined (Ireland, Austria and Italy). The countries were not randomly selected. Each of them were of particular interest in issues of importing smart meters in everyday life, their rational use, the adoption of appropriate behavior by the users and finally their acceptance or not and their possible extension. These countries have made significant progress at the application of this project. In each understudy location, the climatic conditions were studied, as well as the building types in order to make the relevant comparisons with the Greek world. Comparing the climatic characteristics of these countries to those of Greece, as well as the respective building typologies, most similarities were identified between Greece and Italy. Hence, the effectiveness of smart metering on the Italian building stock was also adopted for Greece, in order to end up in numerical results. In Italy, the installation of smart meters by Enel concluded in 5% reduction of the energy consumption of buildings.

Afterwards, the characteristics of the Greek building stock were examined. A separation of the dwellings in urban and rural areas followed, as well as an assortment of them in the climate zones of Greece. Thereafter, buildings were put in three different classes according to their age of construction.

The next and the most important step was the estimation of the energy consumption in Greek residential buildings. First of all, the current energy consumption was assessed and calculated per m^2. In order for this assessment to be more reliable, dwellings were separated in two categories: apartment buildings and detached houses. The energy consumption of the buildings varies according to the age of construction and the climate zone.

The energy consumption referring to the space heating and the domestic hot water constitutes almost 70% of the total energy consumption of a residential building in Greece. According to a study that was made by cooperation between Greek universities, the results of an assessment of the energy savings that can be achieved in detached houses and apartment buildings with intervention measures at their envelope were also taken into consideration. These intervention measures concern different insulation thickness and double glazed windows for residential buildings in every city. Moreover, their cost was estimated to be 15.582 million € per year, for 1.000.000 users.

Analyzing the results of the interventions (insulation, frames) that were theoretically made in these buildings in order to reduce their current energy consumption, we can understand that the greater the surface of the building, the more savings are noticed. In the calculations where the buildings' surface took part, an assumption was made that every building has a surface of 80 m^2, as the average Greek residence. In addition, older houses, for example those built before 1980, when the Regulation of Insulating Buildings was not yet introduced, exhibit a greater reduction of energy consumption. Moreover, buildings located in climate zones A and B; show greater savings than those in C and D, probably because air conditioning use is more widespread and necessary, due to climate conditions. Last but not least, the reduction in detached houses is less than in apartment buildings.

A combination was made among climate zone, age and surface for apartment buildings and detached houses in three different conditions. These conditions refer to the existence of insulation or not, as well as the existence of smart meters in insulated buildings. So, we could easier watch the variation of the consumption.

Thereafter, 250.000 smart meters were installed, theoretically, in every climate zone and the total cost of them was also estimated to be 63.000.000€ in the optimistic scenario and 88.500.000€ in the pessimistic scenario. In order to calculate the savings, we took into account that the surface of every building is $80m^2$ and the consumption per m^2 (kWh/m^2) results from the use of the average function (in excel software) for the consumption according to the age of the buildings in each climate zone. These evaluations showed that in apartment buildings, the total savings that were noticed by the envelope interventions and the smart meter implementation were equal to 5.908 million kWh per year, for 1.000.000 users (28,2% reduction). In detached houses, the total savings that were noticed by the envelope interventions and the smart meter implementation were equal to 5.177 million kWh per year, for 1.000.000 users (19,6% reduction). Obviously, the savings are greater enough for apartment buildings.

7 different scenarios and 3 different financial functions (PP, NPV and IRR) were used in order to forecast the economic viability of the project at a depth of 20 years. According to the three first scenarios, the project is profitable for the oil users for both apartment buildings and detached houses, even if the oil price shows an annual increase or decrease. In the scenarios that natural gas price took part, the project was unprofitable, even if a projected annual increase of 10% of the price was taken into consideration, for both kinds of buildings. For the natural gas users, in the case of reducing the initial cost in half, the venture is gainful only for apartment buildings. The results are different if in the half initial cost, a 30% reduction of savings is added. Under these circumstances the project is economic viable for both buildings.

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Appendix

Table 40: Abbreviations

Abbreviations	
IEA	International Energy Association
EC	European Council
NZEB	Nearly Zero Energy Building
RES	Renewable Energy Sources
CRES	Center of Renewable Energy Sources
GHG	Greenhouse gas
EEA	European Environment Agency
EU	European Union
BAT	Best Available Technology
IT	Information Technology
CO_2	Carbon dioxide
AMI	Advanced Metering Infrastructure
CHP	Combines Heat and Power
BACS	Building Automotaion Control System
TBM	Technical Building Management
DR	Demand Response
SM	Smart Meter
DG	Distributed Generation
U.S.A.	United States of America
DOE	Department of Energy
DLC	Direct Load Control
EPBD	Energy Performance of Buildings Directive
BIM	Building Information Model
LC	Life Cycle
DM	Data Mining
IA	Intelligent Agent
OWL	Ontology Web Language
NIE	Nothern Ireland Energy
BCP	Behavior Change Program
TIR	Thermal Insulation Regulation
HVAC	Heating - Ventilating- Air Conditioning
El.Stat.	Hellenic Statistical Authority

EPIQR	**Energy Performance and Indoor Environmental Quality Retrofit**
GCR	**General Construction Regulation**
MF	**Multi-family**
OECD	**Organization for Economic Cooperation and Development**
ToU	**Time of Use**
HoH	**Head of Household**
CER	**Commission for Energy Regulation**
FB	**Feedback**
CPP	**Critical Peak Pricing**
RTP	**Real Time Pricing**
PTR	**Peak Time Rebates**
AMM	**Automated Meter Management**
DSO	**Distribution System Operator**