OPEN UNIVERSITY OF CYPRUS

Faculty of Pure and Applied Sciences

MSc Sustainable Energy Systems

Master Thesis

Energy Assessment of Thermal Indoor Conditions in Office Buildings

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Supervising Professor

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Summary

Throughout the years, society has become a highly enegy consuming one, that keeps on exceeding its basic needs. Moreover, urbanization has led to a construction frenzyness, both in the residential and the tertiary sector, in order to serve the centralization of population in the urban centres. The energy consumption of buildings results to a significant increase in CO_2 emissions that in turn, feeds the global warming and the climate change. Additionally, old and poorly designed buildings, whose interior is succeptible to the "penetration" of the ambient conditions (occasionally severe) and outdoor disturbances, are affected in terms of the indoor climate. Thus, the deterioration of the thermal comfort of its occupants, either in residencies or in workplaces is unavoidable. Given the fact that the building sector is responsible for the 40% of the final energy consumption in the European Union, a legislative framework was enacted and introduced to its Member States, for implementation. Each country is flexible to adopt the EU Directives to their national characteristics, as long as their individual measures meet the targets and timeframes originally set. In Greece, where the building sector consumes the 37% of the total final energy, the Regulation of Building's Energy Efficiency (KENAK) describes among others the methodology for the energy classification of the buildings through energy audits, and the proper techniques for the reduction of energy consumption and the overall upgrade of the existing constructions. This Thesis presents the energy audit that was conducted in an office building that belongs to the public sector. It uses a methodical process of gathering records, making calculations and measurements so as to calculate the annual primary energy consumption for 2016. Based on the buildings' consumptions and requirements, a number of measures (including technical analysis and financial calculation) in order to achieve energy savings, are proposed. Finally, the results of a questionnaire that was shared and filled by the buildings' occupants and reflects their point of view regarding thermal comfort, was evaluated and followed by the proposal of corresponding measures towards its improvement. <u>For the Energy Audit, NO computer software was available for use, therefore the extensiveness of the inspection and its findings, is limited.</u>

Contents

CHAPTER 1: INTRODUCTION

The increasing energy demand in Europe in the last decades, have caused significant problems in the balance of the environment. The scientific evidence on climate change, the high energy prices, the rising dependence on imported energy and its potential geopolitical implications of this dependence, led the European Union to adopt drastic measures. More specifically, until 2020 each EU country must achieve 20% saving in energy consumption, also produce 20% of its consumed energy from renewable energy sources and achieve 20% reduction in the gas emissions to the atmosphere. These goals may seem achievable, nevertheless they are particularly high and difficult if not properly measures aren't taken. The energy saving and the use of renewable energy sources (RES) can lead to a viable solution to the environmental problems with multiple benefits in social, economic and environmental level. The 20% reduction of energy consumption by 2020, equals to 390 MTIP (Million Tons of Oil Equivalent) and will result in large energy and environmental benefits. The policy of the European Union is to provide for its residents more energy efficient products, the construction of buildings with low energy consumption and the installation of the most energy efficient systems. For this reason, the European Commission has carried a series of measures, which are:

I) *Measures for the Energy Performance in the Building Sector*

The tertiary sector is responsible for 40% of the total energy consumption and 40% of CO_2 emissions. For that reason, the appropriate Directives were established and they include measures for the energy performance of buildings. The Directive 2002/91/EC is the current legislation. In 2010, it was revised because of some ambiguities that needed to be cleared and some operational problems that needed to be solved.

II) *Measures for the Energy Performance of Products*

The ecological design of products and electrical appliances is vital for reducing the energy consumption. For this reason, the Directive 92/75/EEC was established and it includes the appropriate instructions and measures related to these products.

III) *Cogeneration*

Cogeneration of Heat and Power (CHP) is a fairly efficient measure to achieve the predefined goals. That is why the EU adopted the Directive 2004/8/EC.

IV) *Financing*

To achieve the mentioned objectives, large funds are required since the technologies that will be used demand a quite large initial cost. The European Reconstruction and Development Bank, the European Investment Bank and other EU bodies, will support financially the Directive's implementation on energy performance in building sector.

1.1 The Building Sector in Europe

The Building Sector in European Union countries accounts for the 1/3 of carbon dioxide (CO_2) emissions and for about 40% of the total energy consumption. This fact proves both the importance of the building sector in the overall energy balance and the huge potential of their energy consumption reduce and the improvement of their energy performance. The inadequate protection of existing buildings from the outside environment, the unconventional design of new buildings as the consequence of an environmental "arrogant" perception of architecture that ignores the local climatic conditions, and the absolute lack of modern legislation on the energy and environmental protection of buildings have caused:

- The expansion of the energy balance of the countries.
- The economic and social pressing of the low-income citizen groups.
- The rise of the energy "poverty" of countries.
- The cancellation of the international commitments of the countries to the protection of environment, such as the Kyoto Agreement and the Directive 2002/91/EK of the European Parliament and the EU Council on the Energy Performance of Buildings.

The increasing of thermal degradation in large urban centers, the dramatic increase in ambient temperature, as a consequence of local and global climate changes, the insistence on the use of empirical and outdated urban planning techniques (especially concerning urban space and buildings), and the deforestation of the urban and the suburban green, cause discomfort conditions in the urban fabric, maximize the need for use of energy intensive mechanical means for the ensurance of thermal comfort, and create a significant problem in survivability to an important part of the population that is unable to respond financially to this new reality. The energy and environmental technology for the built environment has taken serious steps towards improvement worldwide. The energy consumption of buildings now tends to zero and major countries such as the United Kingdom and France have already devised and have implemented plans in order to achieve positive energy balances for the building sector from the middle of the next decade, by applying new ideas and design concepts At legislative level, the European Directive on buildings 2002/91/EC (EPBD, 2003) for the Energy Performance of Buildings, has set the foundations and the prospects for the construction sector. In most European countries, a cosmogony of changes is observed for the benefit of both citizens and the market itself. It is obvious that both the state and the market key players can no longer turn their back to the new reality.

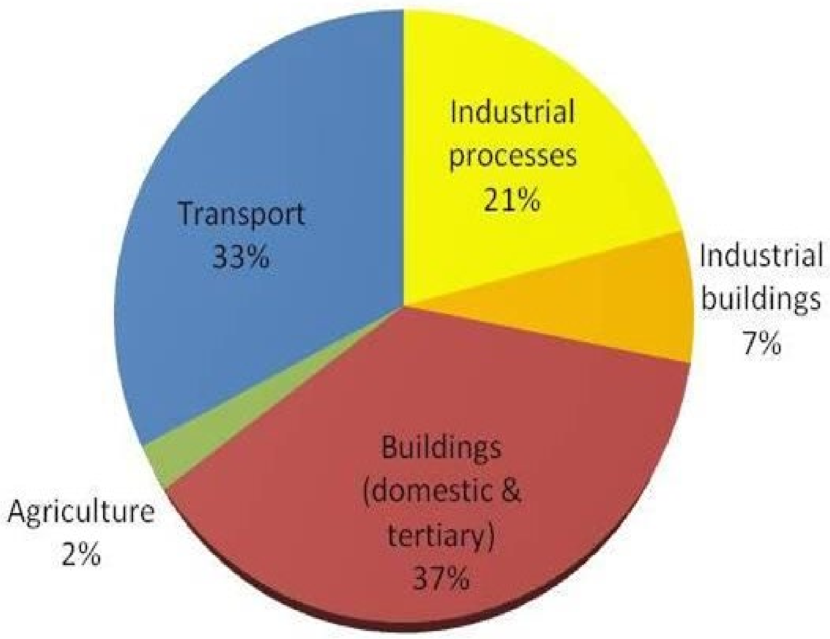

Figure 1: Energy Consumption per Sector in the European Union (Source: www.glassforeurope.com)

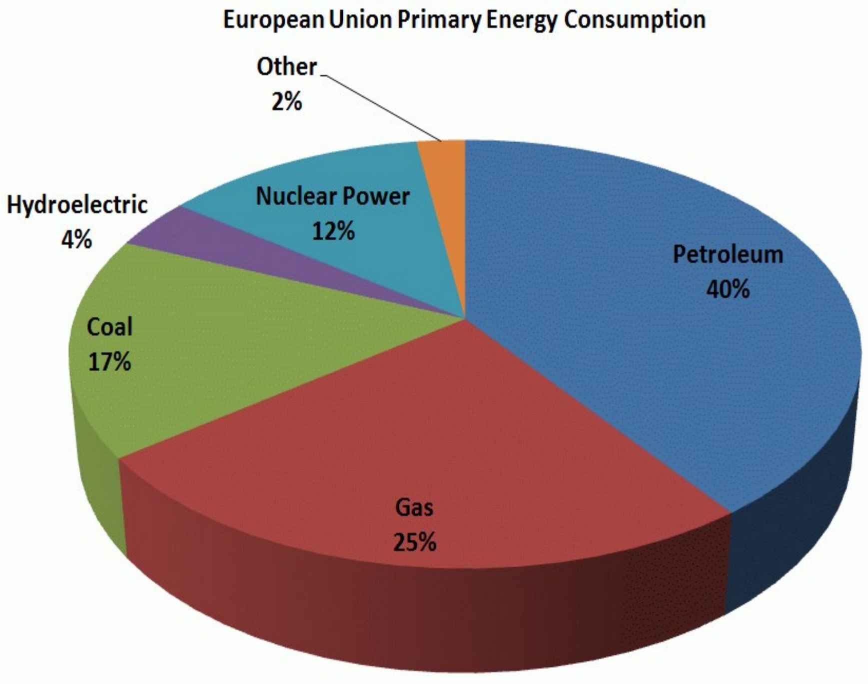

Figure 2: Greenhouse Gases of the Building Sector in the European Union (Source: kr.nlh1.com).

One of the most serious problems that the global community is facing in recent years, is global warming. This is due to the ozone hole which in turn is caused by the reckless emission of pollutants. The pollutants are produced by the combustion of fossil fuels (oil, coal, etc.), that emit large amounts of CO_2. The emission of carbon dioxide comes primarily from the production of electric power. As clearly shown in **Figure 1**, the domestic sector is responsible for about 13% of the total CO_2 emissions from human factors. This field has much room for improvement regarding to energy savings, as with the appropriate measures taken, the total energy savings in 2020 will reach 11%. Thus, for achieving the main objective of reducing the greenhouse gas emissions, and increasing the electrical output production to 20%, the upgrading of the tertiary sector is a necessary and a very substantial issue. Also the activities related to the building sector, form an important part of EU economy, about 9% of EU GDP and 7-8% of EU employment respectively. Thus, besides environmental benefits, the energy upgrading of buildings will bring additional new jobs and significant social and financial benefits. For those reasons, the EU adopted guidelines for energy saving in the building sector, so as to give the main impetus to the Member States. Finally, an important innovation of EU for reducing emissions, is the ETS (Directive 2003/87/EC).

The countries that participate, may buy or sell emission units their allocated within the limits of total EU emissions. The system the first of its kind, allows countries to reduce greenhouse gas emissions with a cost effective manner. The system applies to all EU Member States as well as to Norway, Iceland and Liechtenstein. Given that today it covers 10,500 energy and industrial plants that account for the 40% of the total greenhouse gas emissions in the EU, the potential for an effective action is enormous. EU has extended the scheme so as to include more greenhouse gases like nitrous oxide (fertilizer production) and perfluorocarbons (aluminum production) as well as all major industrial emitters such as power stations. Although the system itself is limited to specific sectors only, the EU policy also covers other important areas of greenhouse gas production such as agriculture, waste, construction, and transport. Each country participating in the system sets a national target, while taking its share of responsibility.

1.2 The European Union Legislation

I) *Directive 2002/91/EC (16 December 2002)*
This Directive applies to the energy performance of the building sector. It constitutes the legal instrument of the European Community which aims at the rational use of energy in the building sector. Its legal provisions cover the energy needs for heating, hot water production, cooling, ventilation and lighting for both new and existing buildings. The Directive combines different elements of regulatory and informative nature. It is important to mention that the EPBD does not fix the levels and the legislation for each member; instead, the members must establish the corresponding mechanisms and requirements by taking into account the local climatic, economic and social conditions. The good news is that EPBD has been incorporated into the political agenda and the urban planning laws of most EU Member States. Positive also, is the response from the European Community citizens. The main points of the EPBD are:

- A common methodology for the calculation of the energy performance of a building.
- The establishment of minimum limits on the energy performance of buildings that undergo a major renovation (over 25% of their initial value or over 25% of their total occupied area).
- The adoption of regulations regarding the energy performance certificates, for new and existing buildings, as well as the publishing of these certificates for public building cases. These certificates should not have been issued earlier than five years.
- The regular inspections of boilers and air handling units in both new and existing buildings, and the assessment of the building heating facilities whose system is older than 15 years.

The scope of the Energy Performance of Buildings Directive focuses on the residential and the tertiary sector (offices, public buildings etc.). It doesn't include buildings with historical significance, structures with size smaller than 50 m^2, also buildings that are not permanent residences and have low energy consumption, and worksites. The energy performance certificates must be available when the buildings are constructed, sold or rented. The directive also states that the building users should be able to be able to manage and regulate the energy consumption for heating and hot water consumption, to the extent that it is economically profitable.

II) *Directive 2010/31/EU (Energy Audit of Buildings)*
This Directive is a revision of the previous one and came to fill gaps and clarify certain concepts. The objections occurred against the previous Directive, include:

- The abolition of the 1000 m^2 limitation. According to the last Directive, buildings that needed to be refurbished were only those whose surface was larger than 1000 m^2. Given the fact that the majority of buildings are smaller than 1000 $m^2$and they are mostly responsible for energy consumption, that limitation should be modified.
- Member States must set a minimum limit to technical facilities like boilers and air handling units.
- The new Directive also refers to products and appliances about to be promoted to the market. A list of specifications for energy efficiency of appliances, has been added.

The EU Member States (MS) must adopt a methodology for calculating the energy performance of buildings at national or local level, which considers the following:

- The thermal characteristics of the building (insulation, heat capacity, etc.).
- The insulation of the heating system and the hot water system.
- The air conditioning installations.
- The lighting installations.
- The internal climate conditions.
- The production of electricity from CHP.
- The positive effect of the building exposure in suitable orientation conditions for the maximum sunshine effects.

Member States should set the minimum energy requirements that a building should display, as well as the methodology which will define the economically optimum solution for the implementation of the Directive. They also have the right to alter those limits depending on the operation of building (offices, factories, hospitals) and whether the building is new or existing. The installation of smart metering devices in new and existing buildings is recommended. As of 31/12/2020, all new buildings must be nearly zero energy consumption ones and from 31/12/2018, all buildings owned or occupied by public sector must also be of almost zero energy consumption. Member States should implement national plans, aimed to:

- The implementation and the precise definition of the term "Zero Energy Building".
- The creation of interim targets to improve the energy performance of new buildings.
- Providing information on energy policy and on economic measures to be taken.

Member States should establish a list with the existing organizations that promote the improvement of energy performance of buildings. This list must be renewed every three years. If the building is bigger than 500 m^2 and its used by the public sector, or its frequently visited by the public (e.g. a theatre), the certificate must be clearly visible.

III) *Directive 2006/32/EC (Energy Performance for End Use - Energy Services)*
This Directive replaced its predecessor (Directive 93/76/EEC). Its basic points:

- It sets indicative measures, incentives, as well as the financial and legal frameworks so as to remove the barriers from the energy market and the imperfections that may prevent the effective use of energy.
- It creates the conditions for the development and promotion of an energy market, oriented towards the use of certified energy services, so that more energy saving programs can be implemented, to contribute to the improvement of energy efficiency.

Under this Directive, Member States must adopt and achieve a 9% reduction in power consumption, meeting this way the targets of their National Plans on energy performance (ΝΕΕΑΠ). They are also responsible for the creation of independent public bodies, which will be monitoring the progress of the implementation of the National Plan targets. The public sector also needs to take measures so as to obtain appliances and vehicles which consume low amounts of energy, and to secure the establishment of financial support instruments. Another important point, are the bills that the citizens of each Member State are paying. The charge for the energy market should count only on the energy consumption itself. The energy meters that indicate the amount of energy consumed by each user, should be installed individually.

IV) *Directive 2004/8/EC (Promotion of Cogeneration in the Internal Energy Market)*
The Directive's aim is to create a framework to promote the actions for the use of cogeneration. CHP plants can achieve energy efficiencies up to 90%. Its divided into:

- Short Term
The existing CHP facilities must be stabilized and creation of new ones be promoted.
- Long Term
The Directive must provide the appropriate framework for high efficiency CHPs in order to significantly reduce the greenhouse gas emissions.

Member States must check every four years the performance of the CHP plants. They should also encourage the creation of new CHP units and to take measures so as to eliminate the financial weaknesses that slow down the promotion of CHP technology.

V) *Directive 2010/30/EU (Directive on the Energy Labeling)*
This directive refers to the products that have a direct or indirect effect to energy consumption. It abrogates the Directive 92/75/EEC. Implementation from 20/07/2011 The suppliers of those products have to put them labels that shall give a brief description of the product, and will indicate the energy consumption of the product, the results of scientific measurements and the test calculations during its design, and shall provide the relevant references that allow the presentation of other products. Finally, they must present the energy classification of the product, on an A to G scale, with G being the less efficient. The most energy efficient symbol is A +++.
VI) *Directive 2009/125/EC (Directive on Ecodesign Requirements for Products)*
The chances of a product to be labeled as environmentally friendly depend on every phase of the design of (raw material extraction, manufacturing, distribution and transportation, installation and maintenance, usage, recycling). That is why the EU requires all market products to have the CE mark (Conformite Europeene in French). If a product does not meet the criteria that have been set by each Member State, it shall be banned from entering the market.

VII) *Decision 2006/1005/EC (US - EU Agreement for Office Equipment Tag Additions)*
This Directive applies to office equipment. The EU together with the US, signed an agreement about the Energy Star label. According to this agreement, office equipment such as computers, printers, fax, and multifunctional appliances, must be tagged with the Energy Star label, which indicates their low energy consumption.

VIII) *Directive 2000/55/EC (Energy Efficiency Requirements for Fluorescent Lamps)*
This Directive applies to the installation of artificial lighting in a building. In particular, through the SAVE program, the European Commission encourages the use of ballast at luminaires with a view to a greater efficiency and therefore the lower CO_2 emissions. All fluorescent lamps contain ballasts which must carry the CE tag.

1.3 Zero Energy Buildings and Smart Grids

Generally, Zero Energy Buildings (ZEBs) are buildings that work in synergy with the grid, avoiding putting additional stress on the power infrastructure (Li et al., 2013). Achieving a ZEB includes apart from minimizing the required energy through efficient measures and covering the minimized energy needs by adopting renewable sources, a series of optimised and well balanced operations between consumption and production were coupled with successful grid integration (Carlisle et al., 2009). The Information and Computer enabled Technologies (ICT) and smart grids implementation are the keys to achieve the aforementioned zero energy goals (Privat, 2013). ICT for energy management in buildings has evolved considerably the last decades leading to a better understanding and the deep penetration of the term “smart buildings” (Nikolaou et al., 2012).

Advances in the design, operation, control, and optimization of energy-influencing building elements (e.g. HVAC, solar, fuel cells, CHP, shading, natural ventilation, etc.), unleashed the large potential for the realization of significant energy savings and efficiencies in the operation of both new and existing dwellings worldwide (Kolokotsa, 2015). Smart buildings ready to be interconnected with smart grids should comply with the following requirements:

- Incorporation of smart metering.
- Demand response capabilities.

- Distributed architecture.
- Interoperability.

Smart Grids can be considered very promising for the energy and for the building environment industry due to the fact that they create a physical proximity between consumers and micro energy sources that help increase consumer awareness towards a more rational use of energy (Kolokotsa, 2015). Moreover, smart grids can offer new opportunities for the reduction of gas emissions by creating technical conditions that increase the connection of devices and renewable energy resources at the low voltage level. In addition, smart grids in the building sector offer a great opportunity for improving the power quality and reliability of energy sources due to the fact that it offers the decentralization of supply, better supply and demand matching, reduction of any transmission losses and minimization of downtimes. Thus, energy investments can be shifted from the expansion of transmission and large scale generation systems to the energy efficiency in the building sector, i.e., improving building fabric, increasing green infrastructure in the community, and improving indoor and outdoor environment interaction by landscape solutions (Kolokotsa, 2015).

1.4 The European Built Heritage and Energy Efficiency

Historic centres shape European cities; they are part of a city's culture. The buildings they comprise have specific values arising from their form and construction, which relate to the material evidence of the past. Historic buildings represent a significant part of the European building stock and have an important role to play in improving energy efficiency in cities. These buildings are protected by law: a few of them are monuments and many others constitute the fabric of the European compact city which holds a special quality for citizens. They differ from modern structures both in architecture and in construction, which increases the difficulties in assessing and improving their energy efficiency. In many cases, historic buildings do not respond well to modern needs. As a result, they can be less desirable and may remain empty and ultimately decay, detracting from the city image but also damaging our cultural inheritance. In general, the best conservation strategy will be to ensure their continued use. Meanwhile, although special attention is always devoted to historic landmarks, a major retrofit challenge is how to successfully retain those historic buildings which do not have extraordinary architectural or artistic value, while bringing them up to satisfactory comfort levels and energy standards. The different hygrothermal characteristics of historic and traditional buildings (how they react to humidity and temperature) require careful consideration of the applicability of codes and standards developed for modern construction technologies. Normally, facades are fully retained and only minimal alterations can be made to their internal form and structure. The internal installation of double-glazed windows, floor, ceiling and wall insulation is sometimes permitted. Other options include improving the efficiency of building services such as heating and lighting and engaging users in energy or water-saving campaigns. The use of renewable energy in certain cases may also be allowed. Interventions should preferably be reversible. Possible retrofit measures for historic buildings need to suit the specific building while respecting its individual qualities and the needs of the users. The best way to keep historic and traditional buildings alive is to ensure their continuous and proper use. This means adapting them to current needs. Until recently, heritage was exempt from the energy discussion, because improving the energy efficiency of historic buildings usually meant alterations, which impact upon their integrity and historical value. The general exemption of historic buildings from energy regulations is increasingly questioned, including by conservation interests. Historic and traditional buildings have different thermal behaviour characteristics when compared to modern construction, which puts in doubt how realistic it is to talk about standards and certificates, as it is evident that there are no simple, "one-size-fits-all" solutions. Any change must be undertaken with great sensitivity to the preservation of the unique qualities of the individual building or complex whose importance is derived, and with thorough understanding of the building physics implications. A number of EU initiatives can potentially support European cities in preserving and upgrading their built heritage, and recognise the key role of historic city centres in sustainable urban development (Lewis et al., 2013).

1.5 The Building Sector in Greece

In Greece, up to 30% additional energy is required to satisfy the thermal comfort and air quality conditions in buildings, the majority of them, are facing problems of adequate insulation, especially those built before 1980. Among the most intensive buildings in the EU, those in the Greek territory absorb the 1/3 of the consumed energy and have heat losses through windows and doors, therefore they wasting precious energy and money while emitting unnecessary quantities of hazardous pollutants responsible for the "Greenhouse Effect". The building sector accounts for the 45% of the country's CO_2 and the consumption of the 35% of the total energy. Indeed, there was a 25% increase of the necessarry energy for heating, cooling, and energizing of our buildings during the last five years. Noteworthy is the fact that Greece along with Spain, recorded the biggest increase in consumption of energy for heating among Member States, while countries of the northern hemisphere that suffer from harsh winters like Sweden and Belgium, managed to reduce their energy consumption by 5%. Greece has a temperate climate with much less heat demands because of the mild winter, therefore the demands for residential heating count approximately for the 70% of the total energy consumption. The energy consumption for household appliances, lighting and air conditioning amounts to 18% of the total energy balance. Housings with a central heating system where oil exclusively used, equal to 35.5% of the total. The remaining 64% are self heated homes that use oil, natural gas, electricity and firewood. Unlike the total of the EU, energy consumption in Greece shows an increasing trend with an average annual growth rate of 7%. If the building regulations of Denmark (which is much stricter) were implemented in Greece, the new buildings would consume only half of their energy needs for heating. Actually the Directive 2002/91/EC (EPBD) for the energy efficiency of buildings, pursues that cause. As a consequence, a Greek house consumes 70-80% more energy for heating, compared to a respective house in Denmark, due to inadequate insulation measures and the use of inefficient heating systems. According to official data from the Greek Ministry of Development, the residential buildings represent the 76% of the total. From those, the 70% were not insulated by 2001 and only the 29% were built after 1981. The potential savings are huge, if we take into account the 2001 official data for the total of buildings, showing that:

- 2.1% are double glazed.
- 30.4% have insulated roof.
- 12.7% have insulated flats.
- 1.5% have floor insulation.
- 4.2% have insulated pipes in the heating system.
- 20% have insulated exterior walls (since 29% were builted after 1981, when the thermal insulation regulation came into effect).

Indicatively, the average annual final energy consumption in houses runs between 60 kWh/m^2/year and 200 kWh/m^2/year and in the tertiary sector buildings between 200 kWh/m^2/year (office buildings) and 450/m^2/year (hospitals). Despite the rise in total energy consumption per resident in Greece from 25.47 kWh/capita in 1990 to 29.89 kWh/capita in 2002, we are still way below than the EU27 average, which is 42.8 kWh/capita. On the other hand, the fact that the CO_2/capita emissions have been increased by 6.998 kg/inhabitant in 1990 at 8.559 kg/capita in 2002 while the average emissions were 8.566 kg/inhabitant in 1990 and dropped to 8.233 kg/inhabitant in 2002 in the EU-27, is alarming. Greece holds the second place to CO_2 emissions in the residential building sector for the 1990-2002 period, a 82% rise. The rise of energy requirements in the last ten years in the Greek buildings (domestic/industrial) is attributed to the growth of the number of new buildings and the creation of a more comfortable interior living environment to satisfy the (continuously) rising living standards. Household buildings account for 23.6% of the total energy consumption and they consume 32.7% of the total electricity production, and 21.5% of the total thermal energy. The total energy consumption for residential buildings is 73.6% of the total consumption of buildings (the rest 26.4% is consumed by the tertiary sector).

From the extensive analysis above, it is clear that the need for energy savings in the building sector, grows throughout the years. The size of the economic and environmental gains, as a result of proper planning and the increase in energy performance of buildings, can amount up to 30% in consumption.

1.6 Legislation in Greece

Greece as a member of EU, participates in the upgrade of the building sector to reduce energy consumption. The European Commission made clear that the Member States will establish their own guidelines, taking into account the local climatic, economic and social conditions. To this direction, KENAK (Energy Performance of Buildings) was created. The first attempt of the country to save energy in buildings came in 1979 with the Thermal Insulation of Buildings Regulation (ΚΘΚ).

I) *ΚΘΚ*

The Greek Thermal Insulation Building Regulation, was based mainly on the German DIN 4108. It contains many essential elements for the calculation of thermal needs. The calculation method that prevailed afterwords, is the one that refers to the two newer versions of the German DIN 4701, as they've been differentiated because of the effects of the energy crisis and the progress in automation. Generally, the calculation method of loads as included in the DIN 4701/1959, was maintained in the new edition of 1983. The primary objective of ΚΘΚ is to reduce the heat loss from the building shell so that the heating requirements will drop to their minimum. It doesn't refer to the existing buildings. The required calculations are based on the separation of the country into three climatic zones, the use of the materials thermal conductivity table, and the use of the U categories of frames table.

II) *KENAK*

The Regulation of the Energy Performance of Buildings (KENAK), approved by the Δ6/Β/οικ.5825/30-03-2010 Common Decision of the Ministers of Finance and Environment, and Energy and Climate Change (ΦΕΚ Β' 407) was created and contained all the necessary regulations for the full implementation of the Law N.3661/2008 (ΦΕΚ Α′ 89), as it was modified by the article 10 of the Law N. 3851/2010 (ΦΕΚ Α′ 85) on the energy performance of buildings. It is the first complete effort by the Greek State for setting all the parameters that affect the energy performance of a building. In particular, KENAK focuses on reducing the consumption of conventional energy for heating and cooling, lighting and hot water supply (HWS). It refers to techniques such as the shell energy planning, the efficient building materials used, the electromechanical installations, the renewable energy sources (RES) and the cogeneration of heat and power (CHP). So, with KENAK:

- A methodology for calculating the energy performance of buildings in order to assess their energy consumption for HVAC, lighting, and HWS, is defined.
- The minimum requirements for energy efficiency and the categories for the energy classification of buildings are set.
- The contents of the study for the energy efficiency of buildings are given.
- The format of the Building Energy Performance Certificate, as well as the data it will include, is analysed.
- The minimum standards for the architectural design of the buildings, the thermal characteristics of the structural elements of the building shell, and the specifications concerning the electromechanical installations of a building under design or a radically renovated one, are presented.
- The process of the energy audits of buildings, and the process of the inspection of boilers, heating systems and air conditioning, is determined.

The basic parameters of the calculation of energy efficiency of a building, are:

- The building's use, the desired indoor environment conditions (temperature, humidity, ventilation), the operational characteristics, and the number of users.
- The climatic data of the building's location (temperature range, relative and absolute humidity, wind speed and solar radiation).
- The geometrical characteristics of the structural elements of the building envelope (shape and form of the building, transparent and non transparent surfaces, awnings, etc.), in relation to the orientation and the characteristics of internal structural elements (f.e. partitions).
- The thermal characteristics of the structural elements of the building envelope (thermal transmittance, absorbance of solar radiation, reflectance, and emission of thermal radiation).
- The technical characteristics of the space heating system (type of system, distribution network, system performance, etc.).
- The technical characteristics of the HVAC installation (type of system, distribution network, system performance, etc.).
- The technical characteristics of the ventilation installation (type of system, distribution network, system performance, etc.).
- The technical characteristics of the HWS installation (type of system, distribution network, system performance, etc.).

- The technical characteristics of the lighting installation for buildings in the tertiary sector.
- The passive solar systems.

For each building study case, the positive effect of the following systems is considered:

- The energy produced with electricity/heat cogeneration technologies (CHP).
- The central heating and cooling systems on a building block, or area scale.
- The natural lighting.
- The active solar systems, and other production systems for heat, cooling, and power, using renewable energy.

1.7 Power Saving Programs

Through the implementation of various energy saving programs, both under the European label and by its own National Energy Efficiency Action Plan (NEEAP), nevertheless suited to its unique land settings and its citizens behavioural characteristics, Greece has the ambition to raise the interest and bring significant changes to the energy consumption patterns by upgrading the existing building stock, while providing in the same time, the framework for the construction of new and energy efficient buildings, in public and private sector. This is supported by making extensive promotion campaigns so as to raise awareness and stress the financial incentives, given to those who will invest in the power saving programs.

1.7.1 The European Program “Green Building”

The General Directorate for Energy and Transport has launched a series of actions under the "Intelligent Energy for Europe" program. One of these actions is the “Green Building Program”. Its implementation began in January 2005, focuses on private and public buildings of the tertiary sector. Instructions that determine the basic framework and the rules of the program on energy management, are given. These instructions are accompanied by technical manuals that help businesses to implement specific active measures such as the choice of energy efficient products and devices, the power management control and the dynamic participation of users. Furthermore, additional instructions with energy capture and management methods, and economic analysis are supplied. The Green Building Program is designed so as to be:
- Flexible and open, so that it can be applied to both existing and new buildings.

- Fairly accurate, so as to ensure that all members who implement energy operations and fulfill their commitments will achieve significant energy savings.
- Adaptable to a wide variety of national and local programs and energy carriers.
- Effective in spreading the energy efficiency of buildings and promoting its implementation.

Table 1 describes the energy management categories according to the cost and to the complexity of the application, as listed in the instructions of the program:

CATEGORY	INVESTMENT COST
I	It requires no initial costs or interruption of business. Usually it refers to “small fixing” measures such as turning off the air conditioning and lighting for spaces that aren't used, properly adjusting the air conditioning temperature settings, etc.
II	It relates to low cost investments with limited building operation interruptions (e.g. the installation of timers that can automatically terminate the operation of systems, the replacement of T8 fluorescent lamps with the energy saving T5 fluorescent lamps, etc.).
III	Its about investments of a relatively high cost, with long duration to the shutdown of the building operation (e.g. the addition of variable speed engine motors, the installation of proper power factor correction equipment, replacement of chillers etc.).

Table 1: Energy Management Categories.

1.7.2 The “Saving Energy at Home” Program

The Program aims at providing financial incentives for interventions in the residential building sector with a view to reducing energy needs. The types of housing supported are:

- Single-family houses.
- Apartment blocks, for the part of the block which relates to all the apartments.
- Individual apartments.

The types of apartments must meet the following criteria (Iatridis et.al. , 2015):

- Must be located in areas with a price band lower or equal to EUR 2100/m^2, as this has been designated until 31 December 2009.
- Must have a building permit.
- Must be included under the Energy Performance Certificate (EPC) class D or lower.
- Must not have been scheduled to be demolished.

The proposal (combination of interventions) for energy upgrade which is submitted with the application should cover the following requirement which is the minimum energy objective of the Program: It must upgrade by at least one energy class or, alternatively, provide an annual primary energy savings greater than 30% of the reference building consumption (kWh/m^2). To make sure that this requirement is met, the materials and systems to be used for the interventions must be energy certified. The building materials and electromechanical systems which are subject to a relevant requirement under applicable law, should bear the CE mark . The eligible categories of interventions for improving energy efficiency are:

- Replacing window frames/glass panes and installing shading systems.
- Upgrading the heating and domestic hot water system.
- Installing thermal insulation in the building envelope, including the roof and open parking space in place of the ground floor.

The income categories of beneficiaries are as follows:

- Category A1

Beneficiaries whose individual or family declared income does not exceed EUR 12,000 or EUR 20,000 respectively. The incentives offered include a loan of 30% with 100% interest subsidy and a grant of 70% of the final eligible budget, as decided after the second energy inspection.

- Category A2

Beneficiaries whose individual declared income is greater than EUR 12,000 and no more than EUR 40,000 or whose family income is greater than EUR 20,000 and no more than EUR 60,000. The incentives offered in this category include a loan of 65% with 100% interest subsidy and a grant of 35% of the final eligible budget.

- Category B

Beneficiaries whose individual declared income is greater than EUR 40,000 and no more than

EUR 60,000 or whose family income is greater than EUR 60,000 and no more than EUR 80,000. The incentives offered in this category include a loan of 85% with 100% interest subsidy and a grant of 15% of the final eligible budget, as established after the second energy inspection, as established after the second energy inspection (Iatridis et al., 2015).

By September 2014, approximately 70,000 applications to join the program had been submitted. Out of them, 48,000 have already joined, and more than 33,000 have completed the energy efficiency improvement interventions with a total eligible budget of EUR 325.5 million.

1.7.3 Energy Saving Interventions in Public Buildings

The measure concerns the implementation of energy interventions in public buildings to improve energy efficiency. Projects orientated to this target will be financed under the program "Standard demonstration projects on the use of Renewable Energy Sources (RES) and/or Energy Saving (ES) in public buildings" to reduce energy requirements for heating, cooling, lighting and domestic hot water. The program aims at achieving energy savings in the central and the general government, encouraging and increasing the use of RES through standard demonstration projects, reducing air pollution and reducing emissions of gases that cause climate change (Iatridis et al., 2015). The funded actions include:

- Applying heat insulation.
- Replacing window frames and glass panes.
- Passive solar systems.
- Natural lighting and ventilation systems, external shading systems for the openings.
- Mechanical cooling-ventilation systems.
- Extensive roof planting.
- Replacing burner systems/boilers with a RES, natural gas, LPG system.
- Replacing old air conditioning systems with new central high-efficiency ones.
- Interventions for a compensation system in the burner/boiler and insulation of pipes.
- Installation of measuring, data recording and monitoring systems for the energy installations in buildings. The application period was from 20/07/2010 to 15/04/2011.

1.8 The LEED Certification

LEED stands for Leadership in Energy and Environmental Design. Its a rating certification system for green buildings, developed by the USGBC (U.S. Green Building Council). It is a “voluntary, consensus-based and market-driven” system. There are currently more than 69,000 projects in more than 150 countries participating in LEED (U.S. Green Building Council, 2015). LEED consist of five rating systems currently, visible in **Figure 3**:

Figure 3: LEED Rating Systems (Source: U.S. Green Building Council, 2015).

- LEED Building Design and Construction (BD+C) applies to newly produced or major renovation buildings including: New Construction, Core & Shell (CS), Schools, Retail, Hospitality, Data Centers, Warehouse & Distribution Centers and Healthcare.
- LEED Interior Design and Construction (ID+C) applies to projects managing interior developments including: Commercial Interiors, Retail and Hospitality.
- LEED Building Operations and Maintenance (O+M) applies to existing buildings within following sectors: Existing Buildings, Schools, Retail, Hospitality, Data Centers and Warehouse & Distribution Centers.
- LEED Neighborhood Development (ND) applies on new land development or redevelopment projects including residential usage, nonresidential usage or a mixture of both. This system can be applied at any point of the project development.
- LEED Homes (HOMES) applies to project types containing single-family, multifamily lowrise and multifamily midrise homes.

The LEED Green Building Rating System evaluates and give credits based on five key categories, as seen in **Figure 4**, with two additional categories, were additional credits can be awarded (Richards, 2012; Matisoff, et al., 2014). The distribution of points depends on the fulfillment of each requirement (US Green Building Council, 2009). The requirements are based on the possible environmental impact and human benefits, the definition of the impacts, the effects and outcome of the operation and of the maintenance of the building and also the design and construction (Torkaman et al., 2015).

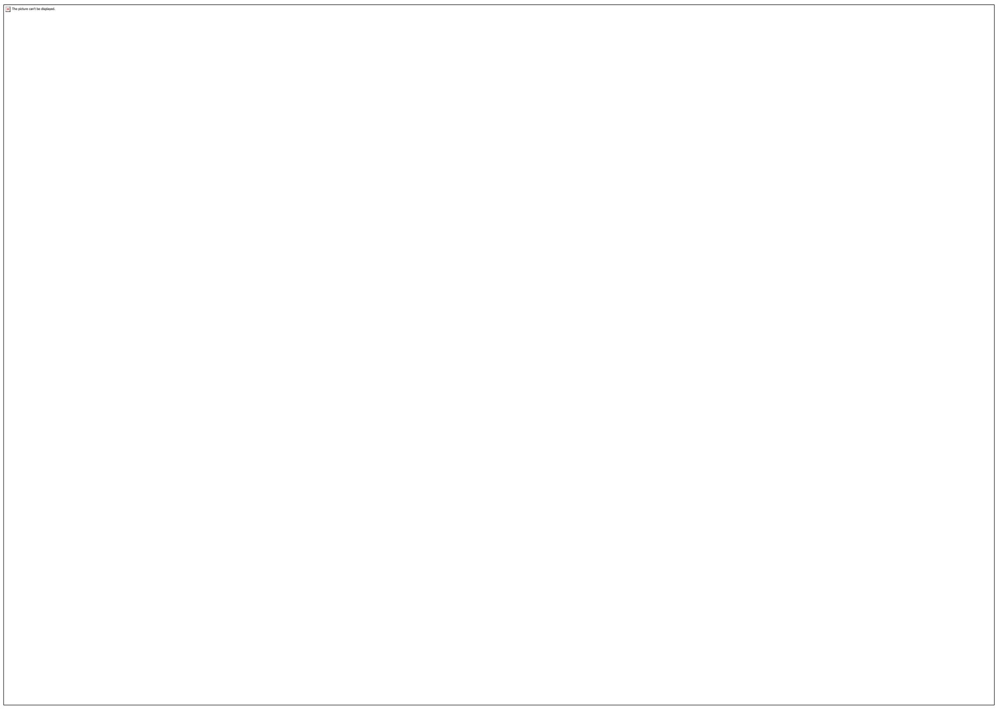

Figure 4: Credit Categories for LEED (Source: http://westerndisposalservices.com).

1.9 Obstacles in Implementing the Energy Saving Policy

Both in Greece and abroad, many factors which are hampering the investments that aim at the more efficient use of energy, have been identified. The identification of those barriers that slow down the rate of adopting energy efficient technologies and practices, can contribute to their full understanding and can trigger ways to overcome them by the policy makers, resulting to make the energy saving policy more attractive for the stakeholders. So, the main problems, arising from the efforts to implement power saving schemes are the following:

I) *The Availability of Funds for Energy Saving Investments*
A major obstacle to achieving any improvements in energy management is the scepticism towards the lack of investment capitals. However, even in cases where available funding is present, the long payback times of the own capitals or the repayment of borrowed funds for

energy saving projects, hold back the decisions for the respective investments.

II) *The Lack of Awareness of the Wider Benefits of an Improved Energy Management*

The lack of knowledge and awareness for both the economic benefits resulting from the energy management, and the contribution of energy management itself to the protection of the environment, hinders the progress in this direction. In many cases, the building sector emphasizes in reducing the construction cost and focusing in the aesthetic factor, against the energy efficiency.

III) *Incentives of Staff*

Often, managers avoid to take initiatives for projects that may entail some investment risk, meaning that the consequences of a possible failure appears to be more severe on a personal level, than the total benefits. The attitude and the interests of the maintenance and installation personnel can pose a weakness to any efforts in order to achieve an improved energy efficiency. Also, with regard to the public projects that are developed under the local government (municipalities, prefectures) jurisdiction, the elected officials tend to prefer to implement projects of a short term investment, that can be completed within their mandate incumbency and with immediate results for their voters.

IV) *The Lack of a Suitable Organizational Framework for the Implemention of an Integrated Energy Saving Program*

Up to date, it has not been possible to set an organizational framework; this could create the sufficient infrastructure for overcoming any accounting and bureaucratic problems of public administration that might appear. Apart from that, it will push in making decisions by adopting measures for implementing an integrated and feasible energy saving program. The lack of a sufficient organizational-management framework due to the inadequate use of EU resources, is visible. As a consequence, the country delays in integrating environmental friendly technologies (Egmond et al., 1993).

V) *The Tax Policy on Imported Energy*

Taxation in the price of the main imported fuel, oil that is, yields a significant income to the national economy while the promotion of the concept of saving energy with long-term economic benefits has been weakened.

VI) *The Low Priority given to Energy*

Administrations, generally take into account the relatively low price of energy and consider projects that lead to small cuts in expenditure, like those for the energy saving of low priority.

VII) *The Failure to Create an Energy Database*

The lack of data is one of the main problems, since the energy saving targets, which supposed to be based on reliable data, cannot estimated correctly. This situation happened because there is not an official body for gathering the incoming information, and because suspicion towards the authorities, is spread among consumers. Finally, the ignorance of consumers on energy consumption issues, is a major barrier to providing the required information.

VIII) *The Failure in Monitoring and Controling the Implementation of the Existing Laws*

The measures that have been adopted, faded away over time due to the lack of a suitable central control body, the prevailing attitude and the vagueness of regulations. Exception is the thermal regulation and the limits for the proper operation of boilers.

IX) *The Low Performance Grade of the Existing Energy System*

The country's total energy system (energy industry, industry, transportation, residential sector, commercial sector, agricultural sector) is heavily outdated.

X) *The Weakness in the* "Commercialization" *of RES*

A few financial incentives in order to promote and exploit the renewable energy sources were given recently. However, the high initial cost of installation as well as the operating expenses, continue to exist as major inhibitors. The implementation of an energy saving policy is caused also by administration issues, bureaucracy issues,   problems caused by shared and "confused" jurisdictions between different ministries.

CHAPTER 2. ENERGY EFFICIENCY

The term "Energy Efficiency" is mainly associated with the end-use efficiency. It's the relation between the amount of supplied energy and the level of the delivered "energy services", where the desired is an equal or even larger quantity of energy offered for end-use. Energy services include heating, cooling, lighting, driving motors (e.g. elevators), operating equipment and appliances.

2.1 The Need for Energy Efficiency

With the pertinent threat of climate change looming over humanity, the building sector needs to adapt in a different way; by minimizing the energy, carbon and environmental footprint. The change will have to be driven by curtailing waste and optimizing and conserving resources including energy. This can be achieved through emerging and transformative technologies. Substantial effort is needed to reduce the operating cost and the environmental impact of the buildings, while increasing their functionality, performance and appeal to the occupants. The main drivers for the implementation of Energy Efficiency (EE) in buildings can be financial, environmental and technological (IIEC, 2015).

I) *Financial Drivers*

EE in commercial and public buildings is becoming an attractive option with rising energy prices, and it also indirectly contributes to energy security and efforts against climate change. The financial savings achieved from EE are based on use of better technology which translates into reduction in energy used and maintenance costs relative to inefficient older technology.

II) *Environmental Drivers*

Energy consumption and emissions reduction in the building sector are vital to any long-term strategy to curb carbon intensity. With more than half the current global building stock expected to still be standing in 2050, and considering that buildings can last for over 100 years, actions cannot be limited to tighter controls on new constructions. There is a huge energy saving potential in commercial and public buildings and consequently GHG abatement potential.

III) *Technological Drivers*

With advanced EE technology, it is now possible to save large amount of energy compared to older inefficient technologies. With new designs and their commercialization, it becomes imperative that the building sector moves towards Energy Efficiency. EE lighting technology like Light Emitting Diodes (LED) lamps have 5 times higher service life at less than half the energy consumption compared to conventional lighting technologies like incandescent lamps. It has been proven that with commercially viable EE technologies, the energy consumption in both new and existing buildings can be cut by an estimated 30 to 80% with potential net profit during the buildings life span. From a lifecycle perspective, Energy Efficiency technologies are the clear winners, as they offer significant savings in terms of post installation energy and maintenance costs, even though typically they have higher upfront costs.

2.2 Energy Management

Energy Management is the systematic, organized and continuous activity which consists of a programmed set of administrative, technical and financial actions, aimed at the rational use of energy and the reduction of operational costs. The use of energy is an important part of the operating cost of a building and plays a key role in achieving the level of comfort of the occupants. Energy savings for buildings are ensured through the high efficiency of the installed energy and passive systems, as well as the implementation of an energy management system. The actions included in the context of energy management, aim at the more efficient use of energy (Egmond et al., 1993). Its implementation criteria are:

- The economic profitability and the profit growth of the building management's various players from the implementation of energy saving measures.
- The maintainance and improvement of buildings' safety, quality of life and service rendering.
- The maintainance or even the improvement of the environment quality.

- The control of the total operational energy costs, instead of the consumed fuel quantity.

In general, energy management can be implemented in the form of expertised interventions in a system or in the form of general interventions, common to all systems, through a comprehensive program which includes different measures and technologies. The energy savings, achieved by implementing an energy management system, are considered a profitable investment, since it is able to increase profits by reducing the operational costs. Energy savings also increase the ability to deal with external pressures (environmental terms), and make the society's attitude towards environment friendly applications, a welcoming one. However, investments in projects with short term depreciation of expenses are mostly preferred. The main objective of implementing an energy management plan is the reduce of the energy cost of the building to the minimum. Energy Management is an element of vital importance and a solid part of a company's integrated quality management system. The basic methods of a rational use of energy as dictated by its management systems are:

- The avoidance of unnecessary consumption (fuels, electricity).
- The reduction in energy demand per product unit (specific consumption).
- The improvement of the equipment performance.
- The waste recovery.
- The use of renewable energy sources.

Some of the key steps towards a more efficient use of energy are:

- The development of an energy policy and strategy.
- The conduction of energy auditing and inspection.
- The adoption of definitive criteria for energy investments.

- The integration of the energy efficiency in the planning and programming of the total procedures involved (in industry), buildings and electromechanical equipment.
- The integration of energy efficiency in the programmed maintenance procedures.
- The exploitation of the most appropriate technology.

2.3 Key Stages of Energy Management

The energy management procedure consists of four interdependent stages; the project organization, the energy audit, the technical and economical study of alternative solutions, and the implementation itself. Key tools in energy management are the energy inspection, the energy monitoring, the proper equipment maintenance, and the taking of measures for consumable energy savings. After the initial stage of determining the energy targets, it is necessary to carry out technical and economical feasibility studies during the implementation period, where the selection of new energy technologies will be explored (e.g. central automation control systems, cogeneration with natural gas, inovative technologies for the utilization of renewable energy potential, etc). Energy management also includes the controlling of the implementation of a program of rational operation and maintenance of building energy heating, air conditioning, lighting, appliances, hot water usage as well as finding ways to finance energy projects. During the implementation of a project, the monitoring of performance must be constant, even during the post construction period, in order to assess their usefulness over the building operation period. A critical parameter for the sustainability of the energy benefits of energy management is the updating and informing of building users and the raise of their awareness about the program objectives and their participation in it. This will be implemented through the training of the staff involved in the operation and the maintenance of the building and its facilities. According to recent legislation, it is mandatory to define an Energy Manager of the building. Among his duties, is the creation of a history archive of energy consumption and the continuous updating of it. It is also important to compile energy reports and submit them to the respective administrative body on a regular basis. Those reports will determine the appropriate energy consumption targets.

CHAPTER 3. ENERGY AUDIT

The critical issue for energy efficiency and energy management is to identify the services that are needed and make sure that these are being provided cost-effectively and for the least energy use. The energy audit facilitates those actions.

3.1 The Energy Audit as an Energy Management Procedure

An energy audit of a building is a feasibility study that assesses actual energy use in different operation areas of the building, and identifies the opportunities for energy conservation. The data generated by an energy audit helps the effective design of energy conservation measures for the building. It also provides the associated costs, and the benefits that have been achieved from the implemention of energy conservation measures (ECMs). **Table 2** presents the energy efficiency classes according to the Energy Performance Regulation of Building Sector:

CATEGORY	CATEGORY BOUNDARIES	CATEGORY BOUNDARIES*
A+	EP ≤ 0,33RR	T ≤ 0,33
A	0,33RR < EP ≤ 0,5RR	0,33 < T ≤ 0,50
B+	0,5RR < EP ≤ 0,75RR	0,50 < T ≤ 0,75
B	0,75RR < EP ≤1,0RR	0,75 < T ≤ 1,00
Γ	1,0RR < EP ≤ 1,41RR	1,00 < T ≤ 1,41
Δ	1,41RR < EP ≤ 1,82RR	1,41 < T ≤ 1,82
E	1,82RR < EP ≤ 2,27RR	1,82 < T ≤ 2,27
Z	2,27RR < EP ≤ 2,73RR	2,27 < T ≤ 2,73
H	2,73RR < EP	2,73 < T

Table 2: Categories and Category Boundaries of Energy Classification.

* T = Primary Energy of the Investigated Building/Primary Energy of the Reference Building

3.2 The Persons Involved in an Energy Audit

Many people are involved in the usage and saving of energy in a building, and a successful energy inspection program must ensure that all these people will assist and support it. Each individual has a clear role, however in some phases of the energy control procedure, their activities happen to coincide and even conflict. Depending on their status and the degree of involvement, the participants in the energy audit procedure, are divided into four categories:

I) *The Owners*

The owners choose the subject and start the procedure of the energy audit. They employ and pay for the staff and the engineers who will conduct the energy inspection. They also collect and classify any information about the functional costs of the building, the energy use and other necessary data for the energy audit. Also, they ensure the comfortable approach to the building by the engineers so that the latter can comfortably make the necessary inspections, and other possible adjustments and settings. Finally, whenever necessary they are prepared to facilitate the work of those who conduct the energy audit.

II) *The Energy Manager*

Essential prerequisite for the design, conduct and success of an energy audit in a building, is the presence of an expertise person, the energy manager, that is. He gets in cooperation with the official audit bodies and with specialized external technical consultants, he coordinates all the actions taken within the energy management plan, and he recommends to the owner of the building the proper applicable measures in order to ensure the rational use of energy on a permanent basis. The competencies that the energy manager must possess, are:

- Familiarity with the building and its energy systems.
- Ability to collect, analyze and evaluate data.
- Knowledge of energy-intensive equipment.
- Technical knowledge.
- Communication and collaboration skills with the administration hierarchy.

- Ability to select external partners.
- Complete understanding of the role of energy in the building.
- Ability to resolve problems or search for answers from different sources.

A qualified engineer is first of all capable of dealing with the complexity of an activity such as an energy audit, since he is knowledgeable of the production and consumption of energy, of the thermal and electrical building facilities, and the energy behavior that the shell of the building presents. The typical responsibilities of an energy manager are summarized in the following actions:

- Continuous data collection and monitoring of energy consumption in a building.
- Adoption of energy targets and calculation of energy vectors for each type of the examined building.
- Recording of the shell characteristics and error detection in shell operation and in the energy systems of a building that affect its energy behavior.
- Supervision of energy system maintenance programs.
- Encouragement and motivation to the building users so as to save energy.
- Identification, assessment and supervision of the implementation of energy saving measures in buildings.
- Preparation of reports to the administration and publication of its respective energy savings commitments.
- Communication with the people, under the responsibility for the operation of different building departments and the processing of the various services produced within them.

III) *The Operating Staff / Mechanical System Maintenance Companies*

Recruited by the owners to make the necessary measurements. They also undertake the maintenance of the equipment of the building. Finally, they perform various system performance checkings and they try to raise it as much as possible.

IV) *The Tenants and Users*

Users contribute to the implementation of the energy saving proposals. It's a very important category of people whose behavior significantly affects the rate of energy savings. Indicatively, they have to keep the doors closed, and set the thermostats at the right temperature. So, if final users respond precisely to the proposals received from the experts, they will surely achieve significant results in energy savings.

3.3 The Energy Audit Procedure

The energy audit is conducted by registered energy inspectors, according to the Π.Δ 100/2010 titled "Energy Inspectors of Buildings, Boilers and Heating and Air Conditioning Installations" (ΦΕΚ 177/A/6.10.2010). The issuance of an energy performance certificate for each building is mandatory from 9 January 2011 and for any sale or lease of a building as a whole or of a part of it. According to the Building Energy Efficiency Regulation (KENAK), periodic energy inspections of boiler installations are established. The same applies for the heating and air conditioning installations (the initial inspection must have taken place within 4 years, i.e until 9 of July 2014). In particular, under Π.Δ 100/2010, the creation of an official body of energy inspectors that carry out energy audits is established, while with the 72/2010 Presidential Decree titled "Establishment, Administrative Organizational Structure and Staffing of the Special Service of Energy Inspectors" (Gov. Gazette 132/A/2010), a procedure for the control and sanctions has been developed. The computational method used to carry out the energy audit is the so called "semi-steady state of monthly step" as described in the European Standard ΕΛΟΤ EN ISO 13790 for the calculation of energy efficiency and the energy classification of buildings. This is the method proposed by KENAK. To carry out the energy audit and the energy classification of the building, the following steps have to be taken:

- Determination of thermal zones.
- Calculation of general building data (use, climatic data, geometric data). The data are inputted to the TEE-KENAK software.
- Calculation of general elements for each thermal zone and the parameters of their surfaces (opaque surfaces, transparent surfaces, surfaces in contact with the ground).
- Calculation of system components (cooling, heating, lighting) for each thermal zone
- Calculation of data for the surfaces of the non-heated areas.
- Entry of data in the TEE-KENAK software.
- Energy classification of the building under inspection.
- Making of building energy-upgrading scenarios.

The energy audit and the issue of energy efficiency certificates of buildings, provide the real estate market, the potential investor or the leaseholder with a precious tool, because it will serve as a true and solid element of the added value of the property.

Figure 5 summarizes the sequence of steps involved in the audit methodology:

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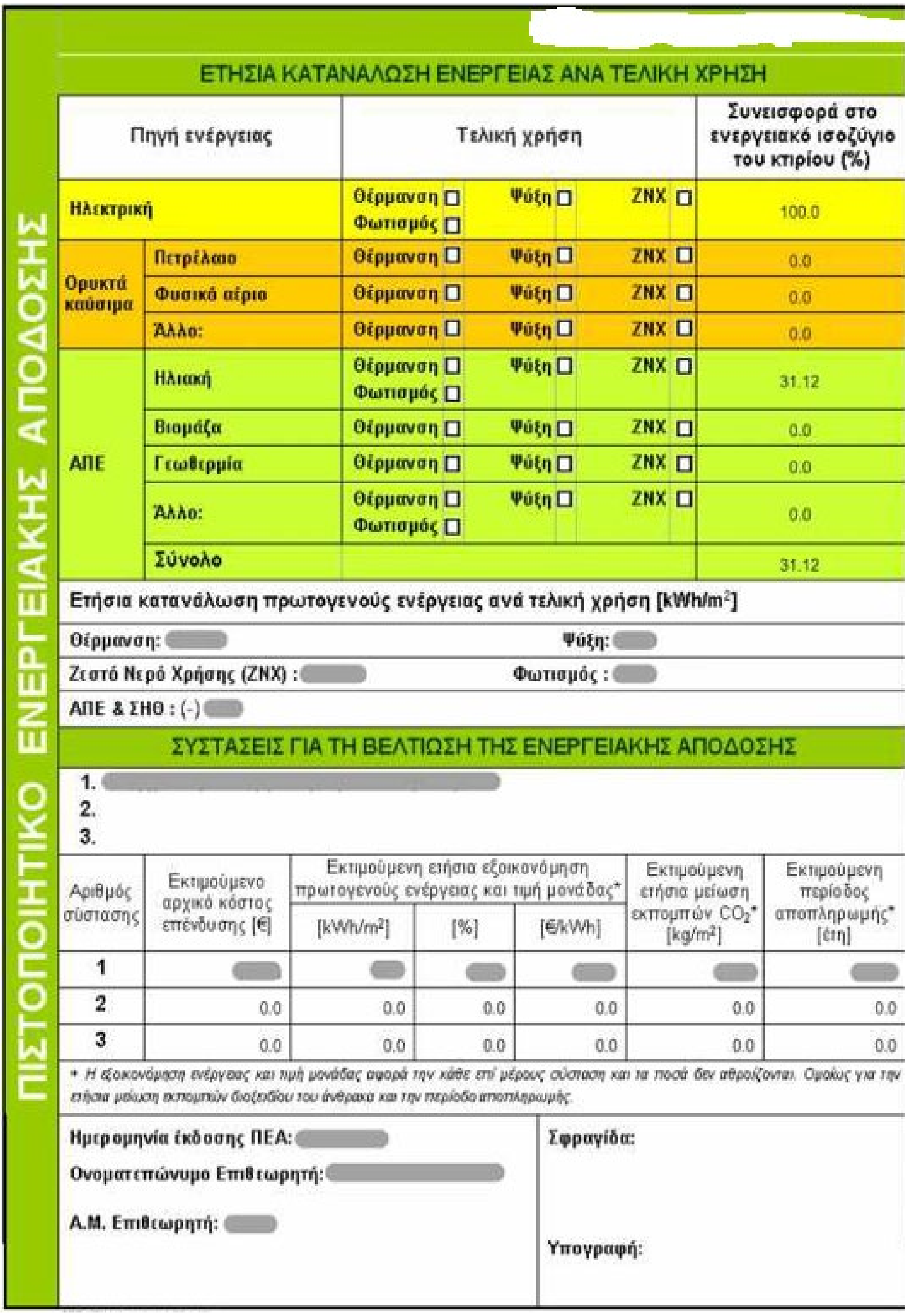
Figure 5: Audit Process Flow Chart (Source: www.energy.gov.za).

A sample of an Energy Performance Certificate is illustrated in **Figures 6** and **7**:

Figure 6: Energy Performance Certificate (Source: kenak.gr).



ΠΙΣΤΟΠΟΙΗΤΙΚΟ ΕΝΕΡΓΕΙΑΚΗΣ ΑΠΟΔΟΣΗΣ

ΕΤΗΣΙΑ ΚΑΤΑΝΑΛΩΣΗ ΕΝΕΡΓΕΙΑΣ ΑΝΑ ΤΕΛΙΚΗ ΧΡΗΣΗ

Πηγή ενέργειας		Τελική χρήση	Συνεισφορά στο ενεργειακό ισοζύγιο του κτιρίου (%)
Ηλεκτρική		Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐ Φωτισμός ☐	100.0
Ορυκτά καύσιμα	Πετρέλαιο	Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐	0.0
	Φυσικό αέριο	Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐	0.0
	Άλλο:	Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐	0.0
ΑΠΕ	Ηλιακή	Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐ Φωτισμός ☐	31.12
	Βιομάζα	Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐	0.0
	Γεωθερμία	Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐	0.0
	Άλλο:	Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐ Φωτισμός ☐	0.0
	Σύνολο		31.12

Ετήσια κατανάλωση πρωτογενούς ενέργειας ανά τελική χρήση [kWh/m^2]

Θέρμανση: Ψύξη:

Ζεστό Νερό Χρήσης (ΖΝΧ) : Φωτισμός :

ΑΠΕ & ΣΗΘ : (-)

ΣΥΣΤΑΣΕΙΣ ΓΙΑ ΤΗ ΒΕΛΤΙΩΣΗ ΤΗΣ ΕΝΕΡΓΕΙΑΚΗΣ ΑΠΟΔΟΣΗΣ

1.
2.
3.

Αριθμός σύστασης	Εκτιμούμενο αρχικό κόστος επένδυσης [€]	Εκτιμούμενη ετήσια εξοικονόμηση πρωτογενούς ενέργειας και τιμή μονάδας*			Εκτιμούμενη ετήσια μείωση εκπομπών CO_2* [kg/m^2]	Εκτιμούμενη περίοδος αποπληρωμής* [έτη]
		[kWh/m^2]	[%]	[€/kWh]		
1						
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0

* Η εξοικονόμηση ενέργειας και τιμή μονάδας αφορά την κάθε επί μέρους σύσταση και τα ποσά δεν αθροίζονται. Ομοίως για την ετήσια μείωση εκπομπών διοξειδίου του άνθρακα και την περίοδο αποπληρωμής.

Ημερομηνία έκδοσης ΠΕΑ:

Ονοματεπώνυμο Επιθεωρητή:

Α.Μ. Επιθεωρητή:

Σφραγίδα:

Υπογραφή:

Figure 7: Energy Performance Certificate (Source: kenak.gr).

3.4 Types of an Energy Audit

In general, there are three major types of an energy audit in buildings. They are classified according to their thoroughness, a factor which in turn is related to the data sources available, the instruments (e.g. computer software) that will be used, the time period consumed, the level of importance of the certification that will be issued, and the fees of the energy inspector. Summarizing, the degree of sophistication of the energy management program defines the complexity and the choice of each energy audit model.

3.4.1 Walk Through Energy Audit

A walk-through energy audit process could be relatively straightforward, if the blueprints and other preliminary information available describe the building and its operation accurately. The process could begin with a walk around the building to study the building envelope. Building features such as building wall color, external sun-shading devices, window screens and tint are noted. The survey inside the building would include confirmation that the air conditioning system is as indicated in the plans, and any additions or alterations are noted. The type and condition of the windows, effectiveness of window seals, typical lighting and power requirements, office equipment, pumping and water heating requirements, occupancy and space usage’s are noted. System and plant data can be obtained by a visit to the mechanical and plant rooms. Nameplate data can be compared against those in the building's documents, and spot readings of the current indicating panels for pumps and chillers recorded for estimating the load on the system. After evaluating the results of walk-through energy audit, a more detailed energy audit can be considered if necessary (IIEC, 2015).

3.4.2 Investment Grade Audit

Investment Grade Audit (IGA) relies on complete engineering studies in order to detail the technical and economic issues necessary to justify the investment related to the future transformations. In some cases, detailed hour-by-hour computer simulation modeling will be required. This audit includes weighing financial risk into the economic calculations. It often include computer simulation and enhanced financial analysis tools such as life cycle costing. This type of audit is utilized to obtain funding for the projects identified. In companies and other corporate settings, upgrades to a facility’s energy infrastructure must compete for capital funding with non-energy-related investments. Both energy and non-energy investments are commonly rated on a standard set of financial criteria that generally stress the expected return on investment (ROI) and often the life cycle costs. The projected operating savings from the implementation of energy projects must be developed in such way that they provide a high level of confidence. IGA comes in play when EE improvements are taken up through Energy Savings Performance Contracts (ESPC) and the improvements are carried out by a professional outfit like an Energy Service Company (ESCO) where the client expect guaranteed savings (IIEC, 2015).

3.4.3 Detailed Energy Audit

The basic difference between the detailed and the concise energy audit is that in the detailed audit, the procedure takes a longer time and the use of the appropriate metering gear is needed. This activity is part of the energy audit procedures and one of its main purposes is to certify the obtained results from the walk-through energy audit of the building and to fill any missing energy data. Checking and recording is done through the surveillance of the shell and the electromechanical installations of the building, as well as through instant or continuous measurements of specific energy consumption parameters. The conclusions from energy auditing and recording contribute notably to the final presentation of the building's energy balances and to the proper study and evaluation of the proposals for implementing energy-saving measures. The energy auditing program should include:

- Presentation of the results of the brief energy audit with a view to informing the management body of the investigated building, identifying the "data lacking" points, and discussing and clarifying the way and the scope of filling in missing information.
- Presentation of the energy support metering equipment for each energy subsystem of the building (shell, heating, air conditioning, lighting, and electric drive). Such equipment should include a thermometer, a humidity meter, a flowmeter, a pressure gauge, an anemometer, a power analyzer, an exhaust gas analyzer, and if possible, a thermographic camera and solar radiation meters (**Figure 8**).

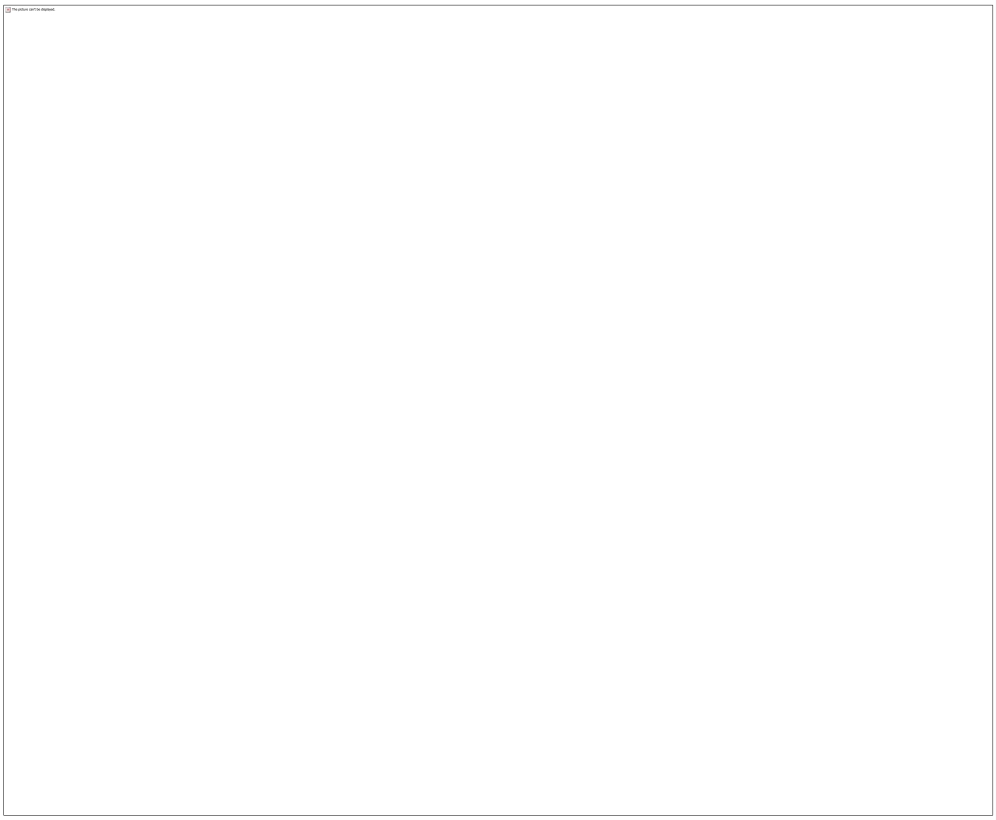


Figure 8 : Temporary Monitoring Instruments (Source: www.iiec.org).

The spots and systems where the detailed energy control applies, are:

I) *The Building Shell*

- The shape and orientation of the building (e.g. land plot, photos of the building, sketches).
- The characteristics of neighboring buildings (e.g. number of buildings, arrangement of roads, building contact with neighboring buildings, physical obstacles to natural ventilation and lighting, natural environment).
- The characteristics of the structural elements, the ceilings, the floors, the exterior walls, the openings (type, surface, layering of building materials, thermal coefficient, quality, condition, use of openings, quality and use of shading devices).
- The features of any integrated bioclimatic architecture elements as well as sun protection arrangements.

II) *The Heating, Ventilation, and Air Conditioning (HVAC) Installations*

- The existence of centralized energy-saving equipment (e.g refrigeration chillers, etc).
- The number of units, power, fuel, distribution system and use of the existing systems for the

coverage of space heating/cooling needs (boilers - burners, coolers – heat pumps, local heating - cooling - ventilation units).

- The elements of central boiler-burner systems (type, year of installation, rated unit power, fuel supply, thermostat settings, water temperatures, operating status, combustion parameter measurements, maintenance status, quality and current condition of boiler surfaces and insulation, status and color of the burning flame).
- The elements of central chiller-heat pump systems (type, year of installation, unit rated power, coefficient of performance, mode of A/C, quality and condition of the system complex, flow rate and working medium average temperatures, operating and maintenance status).
- The quality, condition and heat insulation of distribution system (radiators, fan coils, water pipe networks, fuel and air ducts, central air conditioning units, diaphragms, valves, pumps).
- The use of automation controls (e.g. timers, thermostats, full outdoor temperature compensators, central energy management systems etc).
- The elements of local autonomous heating units, air-conditioning and ventilation units (type, fuel, unit capacity, operating status and control).

III) *The Hot Water Installation*

- The number of units, total power, total water capacity, network water temperatures including storage and end use (central heaters - boiler circuit with thermal switching, electric water heaters, hot water heaters, gas heaters).
- The uses and mode of operation of systems.
- The quality, condition and thermal insulation of storage units and distribution systems (heaters, circulators, piping and valves).

IV) *The Lighting Installation*

- The type and surface of the illuminated space.
- The elements of any installed bulbs per room (type, number, wattage).
- The cover elements of installed luminaires per room (opaline, prismatic, reflectors) .
- The characteristics of the control system (switches, timers, light sensors).
- The quality and state of installation.

V) *The Service Equipment and Household Appliances*

- The type, number, and total installed power.
- The operating hours.
- The maintenance.

The support for a detailed energy audit usually requires the recording of some critical parameters over time and for long periods, so that it is possible to distinguish the periodicity and the effect of specific factors for the operating duration. Keeping a long-term record, both for energy subsystems separately and for the centralized building system itself, although it is generally recommended, it is not always advisable (as it requires the use of expensive equipment) unless the importance and neccessity of the needed energy targets, forces it. All the measurements related to the quality of thermal and visual comfort in the building's premises (temperature, relative humidity, air speed, brightness) as well as the electrical measurements to determine the daily power demand profile, and the composite measurements for the operation of the air conditioning system (cooling/heating/ventilation), are part of the detailed energy audit context. The number, duration and accuracy of those measurements, closely depend on the breadth and depth of the detailed energy audit actions. The outcomed results from the above actions should be analyzed through the elaboration of the measurements and calculations based on the on-site inspection data and in theoretical estimates, so that:

- The uses of the remaining energy for the final statement of the annual energy consumption per use, to be quantified.
- The causes that create the current image of the building's energy behavior and the potential for energy savings in each examined system, to be identified.
- The energy losses from the building uses in order to express the final energy balances per system through the Sankey energy flow diagrams, to be calculated.

The detailed energy audit ends with the creation of a report that contains the results of all recordings and measurements and that concludes with a series of proposals for improving the energy efficiency of the investigated building. Those proposals are related to household, low cost, and reconstruction activities. The latter two, depend on their viability based on the economic appraisal criteria for investment projects.

3.5 Funding an Energy Audit

The scope and level of detail of the energy audit can be a big driver in costs. Establishing criteria for cost-effectiveness prior to conducting the audit can help limit the scope to pursuing only viable projects (Baechler et al., 2011). Capital improvement and operation and maintenance budgets are key funding sources for energy audits. In some cases the cost of an energy audit can be seen as a temporary investment rather than a cost, due to the payback from implementing no-cost or low-cost energy savings measures recommended during the energy audit. For example, one may already have a capital improvement plan to replace an aging, inefficient chiller or to complete a major overhaul of his building's lighting system; an energy audit could direct the capital investment in the most cost-effective way and ensure that energy savings are maximized (Baechler et al., 2011). Other potential funding sources:

- ESCOs will finance and manage the energy efficiency improvement projects and share the energy savings. This is worth pursuing in cases where significant installations are considered.
- Utilities may offer incentives or partial funding for energy audits. Some utilities may even provide consultation during energy audits. Funds may also be available for the installation of financially-viable energy efficiency measures.

Some non-profit organizations or product vendors may offer no-cost or low-cost audits. But, audits conducted by inexperienced staff, or vendor-sponsored audits geared toward a specific technology or product, may highlight simple individual energy efficiency recommendations but overlook other significant opportunities (Baechler et al., 2011). Recommendations by unqualified auditors, could result in no energy savings (or worse, increased energy usage or damage to the owner's equipment). Cost is an important factor in selecting an energy auditor, but to ensure a quality audit, cost should not be the driving factor. Auditor experience, certifications and successful past project examples are other key considerations when choosing an energy auditor.

CHAPTER 4. THERMAL COMFORT

Thermal Comfort is defined as the condition of mind which expresses satisfaction with the thermal environment. The thermal indoor environment is a composition of many and diverse aspects. Hence, the perspective on thermal comfort may change its evaluation by occupants (Corgnati et al. 2011). In the building sector, the thermal environment consists of the building environment (e.g. building skin, systems) and the subjective (the human body).

4.1 Thermal Comfort in the Workplace/Office Buildings

The indoor environment and microclimate of a building is one of the most important factors that will come to define the success of the building being used for its designed purpose. A modern multi-story office building is of no use for its intents and purposes if it cannot sustain a relative degree of comfort for its human occupants (Cubick, 2016). Humans, by nature, are incredibly sensitive to their environment and because of this, the indoor climate of a building is a directly determining factor of workplace productivity and health. However, achieving a level of thermal comfort that functions as a sustainable means of keeping human occupants satisfied with their environment and able to work and function optimally is highly complex. People adapt their behaviour to cope with their thermal environment, for example adding or removing clothing, unconscious changes in posture, choice of heating, moving to or away from cooling/heat sources, etc. The problems arise when this choice (to remove a jacket, or move away from heat source) is removed, and people are no longer able to adapt. In some instances the environment within which people work is a product of the processes of the job they are doing, so they are unable to adapt to their environment. Proper management of thermal comfort leads to the improvement in productivity as well as in health and safety conditions. People working in uncomfortably hot and cold environments are more likely to behave unsafely because their ability to make decisions and/or perform manual tasks deteriorates. For instance, employees might not wear personal protective equipment properly in hot environments increasing the risks.

Moreover, an employee’s ability to concentrate on a given task may start to drop off, which increases the risk of errors occurring. Regarding to the instabilities occure by the lack of thermal comfort in workplaces, the employers or supervisors should be aware of these risks and make sure the underlying reasons for these unsafe behaviours are understood and actively discouraged and/or prevented.

4.2 Factors that Affect Thermal Comfort in Buildings

Six major factors have been identified to define the concept of thermal comfort. Of these six, four constitute environmental factors while two are personal. Two personal factors are beyond the control of designers while the four environmental factors could definitely be considered during the preliminary design phases. The four environmental factors affecting thermal comfort are:

I) *Air Temperature*
It's the air contact temperature measured by the dry bulb temperature (DBT). The problem that appears when studying the air temperature as a thermal comfort parameter, is that there is not an ideal temperature value to be selected, but a range of values which are affected by various reasons. The reasons that shape the internal air temperature, are:

- The external environment.
- The orientation of the building.
- The construction materials and the thermal insulation materials.
- The type of the building's ventilation system (natural or mechanical).
- The type of mechanical ventilation, in terms of design, construction, operation, maintenance.
- The type of a natural ventilation, in terms of design.
- The number and type of any electric appliances that act as heat sources (e.g. PC screens).
- The way that the building occupants handle and operate the HVAC systems.
- The type of heating and cooling system, in terms of design, construction, operation, maintenance.

II) *Air Velocity*
This describes the speed of air moving across the employee and may help cool them if the air

is cooler than the environment. Air velocity is an important factor in thermal comfort because:

- Still or stagnant air in indoor environments that are artificially heated may cause people to feel stuffy. It may also lead to a build-up in odour.
- Moving air in warm or humid conditions can increase heat loss through convection without any change in air temperature.
- Physical activity also increases air movement, so air velocity may be corrected to account for a person's level of physical activity.
- Small air movements in cool or cold environments may be perceived as a draught as people are particularly sensitive to these movements.

III) *Radiant Temperature*

Radiant heat is heat that is transmitted from a hotter body to a cooler body with no effect on the intervening space. An example of radiant heat transfer is the sun radiation. The radiant temperature is the temperature at which a black sphere would emit as much radiant heat as it received from its surroundings. In an occupied space, the floor, walls and ceiling may be at a temp that is very close to the air temperature. For internal spaces, where the temp of the walls, floor and ceiling are almost the same as the air temperature, the radiant temp will be constant in all directions and virtually the same as the air temperature. When a person is sitting close to a large window on a cold, cloudy, winter day, the average radiant temp may be significantly lower than the air temperature. Similarly, in spaces with radiant floors or other forms of radiant heating, the average radiant temp will be above the air temperature during the heating season.

IV) *Relative Humidity*

It's the ratio between the current amount of water vapour in the air and the maximum amount of water vapour that the air can hold at that air temperature, expressed as a percentage. Relative Humidity (RH) is an important variable for Thermal Comfort and the well-being of humans. If the air is too dry, respiratory problems coupled with skin and eye irritation can occur. Very high levels of RH can lead to respiratory ailments, thermal discomfort and condensation problems (HEVAC, 2016).

Holness considered the interaction between human comfort and indoor air quality (IAQ), in particular the influence of ventilation rate, air circulation and control of humidity. Toftum and Fanger in 1999 proposed a model to evaluate the impact of high relative humidity levels on human comfort. Humidity has a direct impact upon the structure and fabric of buildings (mould growth, fabrics and furniture) and the control of RH in buildings is essential for occupant wellbeing (HEVAC, 2016). Buildings rely on a properly designed ventilation system to provide an adequate supply of cleaner air from outdoors or filtered, recirculated air. Rooms are often designed with specific conditions in mind including temperature, relative humidity, brightness, noise, and air flow. Careful engineering and implementation of building automation and control is the only way to ensure energy efficiency and building operation conditions are met during occupancy, at the lowest possible costs with the least possible impact on the environment.

The two personal factors influencing thermal comfort, which the designer cannot influence, are the metabolic heat (the heat humans produce through physical activity; usually, a person which stays is feeling cooler than other who is moving) and clothing (clothes insulate a person from exchanging heat with the surrounding air and surfaces). There are also additional contributing factors that could be considered, like the lighting and sound factors:

- Audio / Sound Factors

The sound of the environment that a person is in, greatly affects its comfort in the building. Sound is a form of energy that is transmitted in pressure waves and changes depending on the pressure of the air in the room. It has two different sources and types where it can originate from; they are air-borne and impact/structure-borne sound. Air-borne sound travels through the air before reaching a partition. Main sources of air-borne noise are; voices, radios and musical instruments. Impact sound is vibrations that are generated on the partition and a continuous vibration can be classed as a series of impact noises in succession. The main sources of impact noise are; footsteps, slamming door and vibrating machinery. Both types of sound have different ways of preventing, so different installations must be put in to insulate from the type of sound. Air-borne sound can be prevented by mass of partitions, e.g. thick walls as lightweight particles give very little resistance unless they are in layers. The main ways that impact sounds are prevented is by using vibration pads and soft covering on floors and walls. Sound reverberates, so if a sound suddenly stops the sound will not stop instantly. The time taken for the reverberation of a sound decays at different rates depending on the area of the exposed surfaces, sound absorption values of the materials used in the building, the distance between the surfaces and the sound and the frequency of the sound.

- Visual / Lighting Factors

Another factor that affects human comfort is light intensity. If the light levels are too low or too high then it will not be as suitable. Light travels in rays and bounces off objects and into the eye. The rays cannot bend so they must go in straight lines, but light can be refracted through certain materials which can bend the beam slightly. The light needs to be the right intensity so that the eyes don't have to strain too much if it is too dark or if the light is too bright it may blind. Light can be controlled by letting certain amounts of natural light through windows and also by the brightness of the artificial light from the light bulbs. Natural light can be controlled by using darkened windows and the artificial light can be controlled by having dimmers on the lights to change the intensity as the intensity of natural light changes. Glare can affect the human comfort, glare is a light intensity that is too high reflecting off a surface and reflecting into the eyes making it difficult to see detail or may cause visual discomfort.

4.3 Legislation for Thermal Comfort in the Building Sector

Thermal comfort in buildings is described and set into regulations by design standards such as the ASHRAE Standard 55, the Thermal Environmental Conditions for Human Occupancy, and the International Organization for Standardization (ISO) Standard 7730. Building codes and other regulations incorporate these standards, and they are used by manufacturers to develop heating, ventilation, and air conditioning (HVAC) equipment and for designing environmental control systems for buildings (Levin, 1995). ISO 7730:2005 presents methods for predicting the general thermal sensation and degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments. It enables the analytical determination and interpretation of thermal comfort using the calculation of PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) and local thermal comfort, giving the environmental conditions considered acceptable for general thermal comfort as well as those representing local discomfort (Crahmaliuc, 2016). This standard was reviewed and confirmed in 2015. The Greek Technical Chamber (TEE), in the field of its scientific activities and during the years 1985-1986, prepared and published ten volumes of technical instructions, the first of their kind, that were ratified for compulsory application by the Ministerial Decision of ΠΕΧΩΔΕ (Stamatellos, 2008). They are available for reading only, in the Office for Standardization and in the regional libraries of the TEE, while they are available for purchase at the TEE offices. Especially, the 2425/86 technical instruction, sets as recommended design conditions for the airconditioned premises, the following values presented in **Table 3**. Those conditions are divided into two categories and they are defined by the current time period, the heating or cooling season that is. The purpose of this technical instruction is to determine the internal design conditions on the basis of which the heating and cooling loads of buildings are calculated, so as conditions of wellness are to be achieved.

Recommended Design Conditions for Air Conditioned Space Winter Period (TOTEE 2425/86)		
Space Category	**Temperature**	**Humidity**
Residencies	22	30-50
Office Buildings	21-23	30-35
Libraries - Museums	20-22	40-50
Hospitals	24	30
Restaurants and Entertainment Centers	21-23	30-40
Recommended Design Conditions for Air Conditioned Space Summer Period (TOTEE 2425/86)		
Space Category	**Temperature**	**Humidity**
Residencies	25-26	40-50
Office Buildings	25-26	40-50
Libraries - Museums	22	40-55
Restaurants and Entertainment Centers	23-26	50-60
Educational Buildings	26	45-50
Hospitals – Waiting Rooms	24	45-50
Hospitals – Surgical Rooms	20-24	50-60
Hospitals - Sanitariums	24	50-60

Table 3: Recommended Design Conditions for Air Conditioned Spaces (Source: TOTEE 2425/86).

In the 2423/86 technical instruction, the proper values for space ventilation and noise levels, regarding the thermal comfort, are recommended. They are presented in **Table 4**:

Indicative Air Velocity Values for Closed Spaces* (TOTEE 2423/86)		
Air Velocity (m/s)	**Effect**	**Recommended Use**
0 – 0.08	Complaints about Lack of Air Movement	
.0,125	Ideal Situation	
0.125 – 0.25	Very Satisfactory Situation (0.25 Approaches the Max Value)	
.0.325	Not Satisfactory for Office Spaces	
.0.375	Max Allowed Value for Moving Persons	Commercial Shops
0.375 – 1.5		Industrial Applications Only

* Occupational Zones of each Space (from floor level to 2m height).

Table 4: Indicative Air Velocity Values for Closed Spaces (Source: TOTEE 2423/86).

4.4 Measuring Thermal Comfort

A simple way of estimating the level of thermal comfort in a workplace is to ask the employees or their safety representatives (such as unions or employee associations) if they are satisfied with the thermal environment. Thermal comfort checklists and questionaires should be prepared in such a way that they help the energy auditor to identify whether there may be a risk of thermal discomfort to the employees. It should be noted that this is a basic checklist and does not replace a suitable and sufficient risk assessment, taking account of thermal comfort. It's generally accepted that thermal comfort is the measure of a relationship between surveyed satisfaction vs. dissatisfaction with individuals' environment e.g. an 80% overall satisfaction with the thermal environment would be a positive indicator of satisfactory thermal conditions being maintained in the building (Cubick, 2016). Due to individual differences, it is impossible to specify a thermal environment that could satisfy everybody. There will always be a share of dissatisfied occupants but its possible to specify environments that are likely to be acceptable for a certain percentage of the occupants. If they have some kind of personal control (change of clothing, setting of room temperature in a single office, increase of air velocity, change of activity level and posture), the overall satisfaction with the environment will increase significantly and every occupant may be satisfied (Kalz et al., 2014).

Due to local or national priorities, technical developments and climatic regions, a higher thermal quality (less dissatisfied occupants) or a lower one (more dissatisfied occupants) may be sufficient in some cases. For most parameters describing the thermal environment, relationships between the parameter itself and a predicted percentage of people rating the indoor condition as (un)acceptable are established (Kalz et al., 2014). People may be dissatisfied due to general thermal comfort and/or local thermal comfort parameters. However, there is no method for combining these percentages of dissatisfied persons to give a good prediction of the total number of occupants deeming the thermal environment unacceptable.

4.5 Control of Thermal Comfort in an Office Environment

The aim is to keep the indoor conditions at a comfortable level as much as possible with a minimum dissatisfaction, while keeping the costs and energy consumption at a reasonable level (Gungor, 2015). Some important aspects to consider for controlling and improving the thermal comfort in an office space, are:

- Selected Retrofits for the Building Envelope

When an element of the building envelope is not insulated or poorly insulated, it may be cost effective to add insulation in order to reduce transmission losses. To improve the air tightness of the building envelope several methods and techniques are available, including "caulking" (materials such as urethane, latex, polyvinyl, etc. can be applied to seal various leaks, such as those around the window and door frames, and any wall penetrations, such as holes for water pipes), weather stripping (by applying foam rubber with adhesive backing, windows and doors can be air sealed), and air retarders (they consist of one or more air-impermeable components that can be applied around the building exterior shell to form a continuous wrap around the building walls).

- Placement of Inlets and Outlet Point

The general idea is that hot air rises while cold air settles down displacing the hot air that originally sat there. However, the placement of the inlets and outlet ducts could prove quite consequential. Placing an outlet duct in the opposite direction can significantly increase the space turbulence (or internal air velocity). Finding an optimal location for inlet and outlet could significantly reduce the energy costs necessary to remove/drive the hot and stale air.

- Exposure and Orientation of Windows

Most workspace walls can be considered to be well-insulated and at a constant temperature. However, depending on the orientation of the windows (towards North or South) it could be an important aspect to consider not only the amount of sunlight but also heat addition from it. Office spaces with windows facing south are much more heated by sunlight compared to those with windows facing north. Construction of window structures and their placement depth can also slightly modify the exposure to sunlight due to the shadow of the structure.

- Insulation of the Walls and Roof

The internal and external walls can be differentiated based on their insulation types. The internal walls can be thinner facilitating for heat transfer across rooms (or constant heat flux or zero temperature gradient). The external walls can be considered to be of constant temperature or also allow slight heat transfer. In addition, depending on the placement of the office in the building, either the roof can be considered to be constant temperature or could again be assumed to facilitate heat transfer.

- Presence of Electrical Appliances

The heat transfer from the electrical appliances can be modeled as a natural convective process. For the steady-state, they can be considered as a constant temperature source. In addition, several other aspects like effects of a courtyard, external shading due to trees, a fountain in courtyard etc. can always be added and can also affect the overall thermal comfort.

Besides interventions that demand a cost analysis, there is a variety of initiatives that the administration of a workplace and even the employees themselves can take in order to adjust their attitude towards an improved thermal comfort feeling. Administrative controls are generally of a short-term, temporary nature. Although some can be of a permanent nature, for example emergency procedures and the provision of appropriate welfare facilities, such as competent first aiders with additional knowledge in the management and recognition of heat-related illnesses and injuries as well as ensuring the availability of appropriate first-aid equipment. Administrative controls include planning and rescheduling work times and practices and rest schedules, e.g. scheduling “hot” work for cooler times of the day or allowing employees to have flexible hours to avoid the worst effects of working in high temperatures. The occupants, given the dress code flexibility of their workplace, should adapt their clothing where possible. They should also be able (after a relevant training) to use and adjust the HVAC equipment (e.g. thermostats) without exceeding the prespecified acceptable limits.

CHAPTER 5. CASE STUDY

The building under investigation is the Transport and Communications Directorate of the Evrytania Prefecture. It is located in the city of Karpenhsi, and it is actually an office building complex as it consists of four (4) buildings: Building 1 is the Vehicle Technical Control Center (KTEO), it occupies three employees and it serves as a garage. Its a non heated space. Building 2 is the Technical Department Office and the Vehicle Licensing Department (there are also restrooms), it is staffed by two employees, building 3 houses the Driving Licensing Exams Room (used on a weekly basis), and in building 4 is the Direction and Secretariat Office (it includes restrooms) that occupies 3 persons. Finally, there is an independent basement which storages the central heating boiler, the network servers and the scrap material (e.g. expired documents). The energy audit will cover all areas but will mainly focus on the office buildings 2 and 4, where the human presence is daily, and the thermal comfort needs are higher.

5.1 Building Identity

Date of Construction: 1984

Location: 3rd km of Karpenhsi – Lamia National Road (E952)

Coordinates: Longitute 38.907501, Latitude 21.817124

Altitude: 1001m

Orientation: SW

Ownership of the Building: Prefecture of Evrytania.

Use: Offices

Area: 750 m^2

Position: Ground Floor.

Number of Users: 8 Employees and 40 Citizens (daily average).

Adjacency according to the General Construction Regulation: No Adjacent Buildings.

Special Features: Buildings 2 and 3 are interconnected through a common corridor.

Buildings 2 and 3 have their west wall as party wall with Building 1 east wall.

5.2 Climatic Conditions of the Surrounding Area

MONTH	AVERAGE DAILY TEMPERATURE (C°)
JANUARY	3.8
FEBRUARY	3.1
MARCH	5.4
APRIL	10.6
MAY	14.7
JUNE	18.9
JULY	21.6
AUGUST	20.9
SEPTEMBER	17.6
OCTOBER	12.4
NOVEMBER	6.8
DECEMBER	4.8

Table 5: Average Daily Temperature per Month (Source: T.O.T.E.E 20701-3/2010).

MONTH	AVERAGE RELATIVE HUMIDITY (%)
JANUARY	68
FEBRUARY	70.5
MARCH	73.9
APRIL	60.6
MAY	61.8
JUNE	55.6
JULY	52.2
AUGUST	53.8
SEPTEMBER	59.1
OCTOBER	66.2
NOVEMBER	73.8

DECEMBER	73.5

Table 6: Average Relative Humidity per Month (Source: T.O.T.E.E 20701-3/2010).

MONTH	**AVERAGE WIND SPEED (m/s)**
JANUARY	4.5
FEBRUARY	4.6
MARCH	4.9
APRIL	4.3
MAY	3.8
JUNE	6.2
JULY	4.0
AUGUST	4.4
SEPTEMBER	3.4
OCTOBER	3.7
NOVEMBER	3.8
DECEMBER	4.0

Table 7: Average Wind Speed per Month (Source: T.O.T.E.E 20701-3/2010).

The investigated building is situated in an area where low temperatures prevail for more than half of a year, as seen in **Table 5**. The high altitude and the natural surroundings bring high rates of relative humidity as well (**Table 6**). Finally, the absence of adjacent structures leaves the building at an open area which is exposed to wind conditions, whose average speed can be seen in **Table 7**.

5.3 Photographic Collection of the Investigated Building

Figure 9: General View of the Investigated Building.

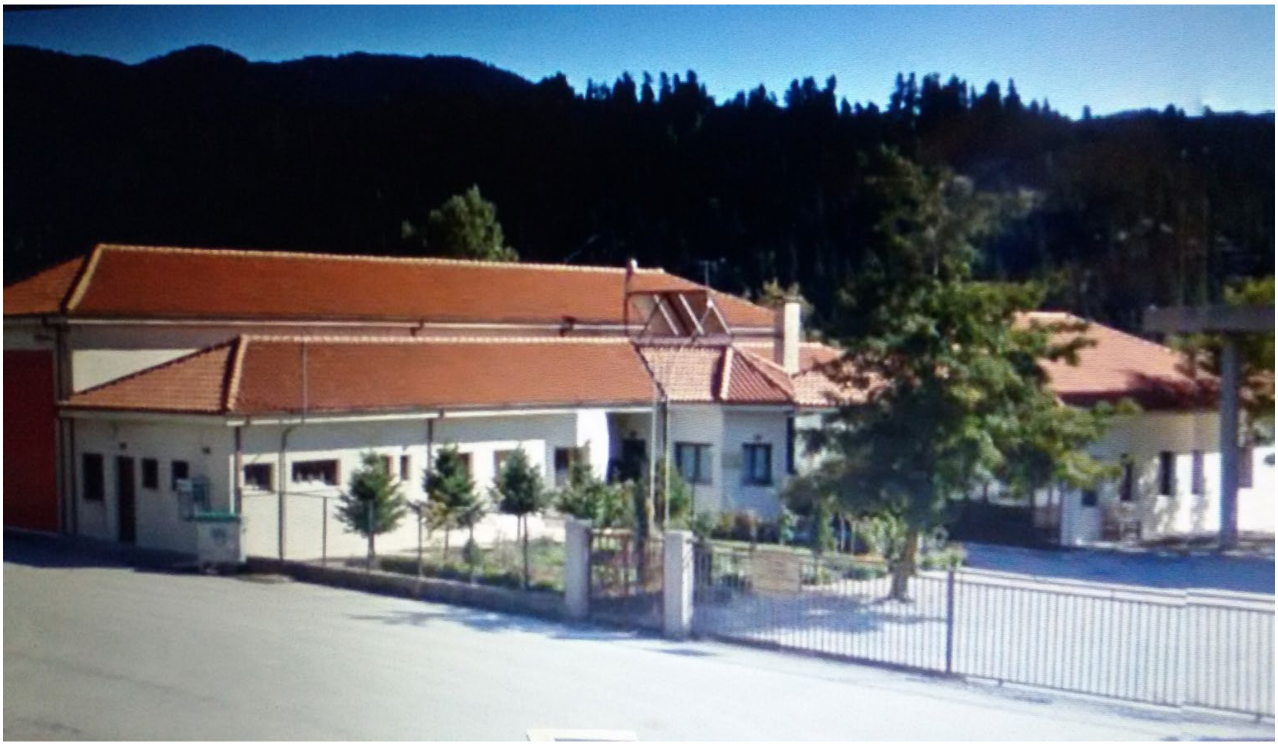


Figure 10: General View of the Investigated Building (Different Angle).

Figure 11: Buildings 1, 2, and 4.

Figure 12: Buildings 2, 3 and 4.

5.4 Layouts of the Investigated Building

Figure 13: Topographic Plot.

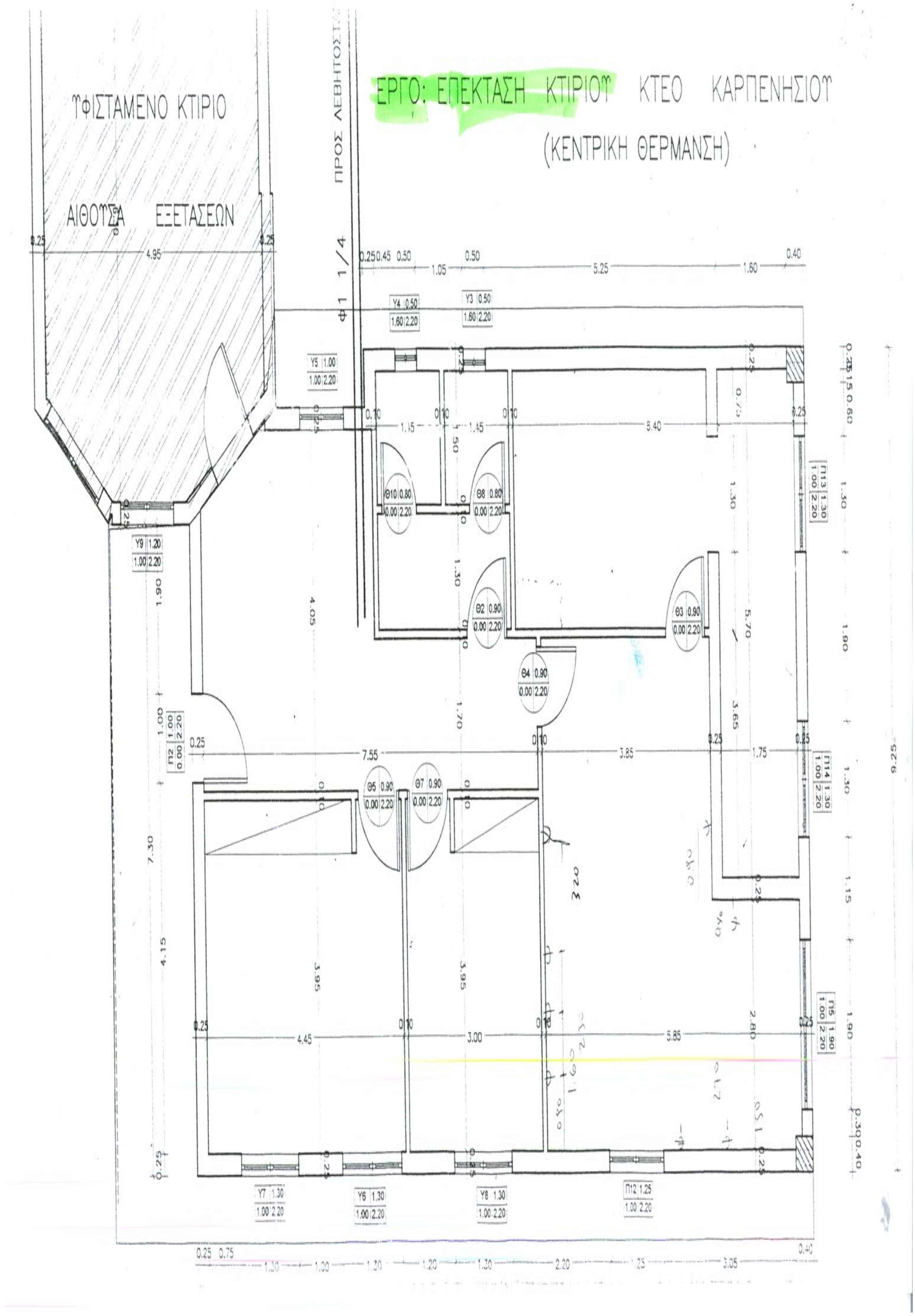


Figure 14: Building Schematics.

5.5 General Characteristics of the Building Envelope

Building 1 Surface Area: 54m^2

Building 1 Shell - Walls	
No.	**Wall Area (m^2)**
1 (facade) (reference wall)	4.5m x 5.5m = 24.75m^2
2 (90° east)	12m x 5.5m = 66m^2
3 (180°)	4.5m x 5.5m = 24.75m^2
4 (270°)	12m x 5.5m = 66m^2

Building 1 Shell - Roof	
No.	**Roof Area (m^2)**
1	4.5m x 12m = 54m^2

Building 1 Shell - Floor	
No.	**Floor Area (m^2)**
1	4.5m x 12m = 54m^2

Building 1 Shell - Openings	
No.	**Opening Area (m^2)**
1 (facade door) (garage door roll)	3m x 4m = 12m^2
2 (back room door) (sheet metal with glass)	0.8m x 2m = 1.6m^2

Tile Roof Area (45°): E = 54m^2/cos45° **=** 38.18m^2

Windows:

5 Windows 1m (W) x 0.8m (H) = $0.8m^2$ x 5 = $3m^2$

Special Features: The windows are only glass panels that serve as natural lighting openings.

Building 2 Surface Area: $30m^2$

Building 2 Shell - Walls	
No.	**Wall Area (m^2)**
1 (facade) (reference wall)	5m x 3m = $15m^2$
2 (90° east)	6m x 3m = $18m^2$
3 (180°)	5m x 3m = $15m^2$
4 (270°)	6m x 3m = $18m^2$

Building 2 Shell - Roof	
No.	**Roof Area (m^2)**
1	5m x 6m = $30m^2$

Building 2 Shell - Floor	
No.	**Floor Area (m^2)**
1	5m x 6m = $30m^2$

Building 2 Shell - Openings	
No.	**Opening Area (m^2)**
1 (facade door) (wooden frame)	0.8m x 2m = $1.6m^2$

2 (back room door) (wooden frame)	0.8m x 2m = 1.6m^2

Tile Roof Area (45°): E = 30m^2/cos45° **=** 21.21m^2

Windows:

4 Windows 0.5m (W) x 0.5m (H) = 0.25m^2 x 4 = 1m^2

1 Window 0.8m (W) x 0.5m (H) = 0.4m^2

1 Window 1m (W) x 0.5m (H) = 0.5m^2

4 Windows 1.5m (W) x 1.5m (H) = 2.25m^2 x 4 = 9m^2

Building 3 Surface Area: 24m^2

Building 3 Shell - Walls	
No.	**Wall Area (m^2)**
1 (facade) (reference wall)	6m x 3m = 18m^2
2 (90° east)	4m x 3m = 12m^2
3 (180°)	6m x 3m = 18m^2
4 (270°)	4m x 3m = 12m^2

Building 3 Shell - Roof	
No.	**Roof Area (m^2)**
1	6m x 4m = 24m^2

Building 3 Shell - Floor	
No.	**Floor Area (m^2)**
1	6m x 4m = 24m^2

Building 3 Shell - Openings	
No.	**Opening Area (m^2)**
1 (front door) (wooden frame)	0.8m x 2m = 1.6m^2

Tile Roof Area (45°): E = 24m^2/cos45° **=** 16.97m^2

Windows:

3 Windows 1.5m (W) x 1.5m (H) = 2.25m^2 x 3 = 6.75m^2

Building 4 Surface Area: 30m^2

Building 4 Shell - Walls	
No.	**Wall Area (m^2)**
1 (facade) (reference wall)	6m x 3m = 18m^2
2 (90° east)	5m x 3m = 15m^2
3 (180°)	6m x 3m = 18m^2
4 (270°)	5m x 3m = 15m^2

Building 4 Shell - Roof	
No.	**Roof Area (m^2)**
1	6m x 5m = 30m^2

Building 4 Shell - Floor	
No.	**Floor Area (m^2)**
1	6m x 5m = $30m^2$

Building 4 Shell - Openings	
No.	**Opening Area (m^2)**
1 (front door) (sheet metal with glass)	0.8m x 1.8m = $1.44m^2$

Tile Roof Area (45°): E = $30m^2$/cos45° **=** $21.21m^2$

Windows:

10 Windows 0.5m (W) x 1m (H) = 0.5m2 x 10 = $5m^2$

Special Features:
The Facade and its opposite side are covered by glass panels of different sizes, with metal frames.

5.6 Installations for Heating

Heating Type: Central Heating
Fuel Used: Petrol
Boiler Used for the whole Building: 110 kW
Hot Water Usage Daily Load: 0 lt/day

5.7 Lighting Systems

14 Incandescent Lamps (125W, 60W)
80 Fluorescent Lamps (36W)

5.8 Air Conditioning Installations

Two (2) A/C same type split units in the Inspected Building (rooms 2 and 4), 12,000 Btu each.

5.9 Natural Ventilation

Free flow of air through open windows.

5.10 Mechanical Ventilation

No Mechanical Ventilation Support.

5.11 Shading and Sun Protection

Natural Shading by surrounding trees.

No Awnings.

5.12 Consumptions and Costs of Energy

5.12.1 Electricity Consumption and Cost for Heating

Annual Energy Consumption of 2016:

YEAR	ELECTRICITY (kWh) (normal invoice)	DIESEL (lit)
2016	**32080**	**6600**

Annual Energy Cost of 2016 (€/Year) (State Taxes and Fixed Energy Costs Included):

YEAR	ELECTRICITY (€)	DIESEL (€)	TOTAL (€)

2016	**8990**	**6890**	**15880**

Average Supplied Diesel Price October 2015 – April 2016: 0.95 €/lit
Average Supplied Diesel Price October 2016 – April 2017: 0.92 €/lit

The lower calorific capacity of fuels, mainly used in Greece is:
Diesel = 42.700 kJoule/kg = 10.200 kcal/kg = 12 kWh/kg = 10 kWh/lit

Power agreed with the provider (under contract with Δ.Ε.Η): 8 (kVA)

Has there been any increase in the installed capacity in recent years?
YES ( ) NO (**X**)

Monthly Energy Consumption of 2016:

MONTH	ELECTRICITY (kWh) (normal invoice)	Diesel (lit)
JANUARY	3680	1500
FEBRUARY	2800	1300
MARCH	2680	1000
APRIL	2200	700
MAY	2400	-
JUNE	2760	-
JULY	2520	-
AUGUST	2400	-
SEPTEMBER	2520	-
OCTOBER	2800	300
NOVEMBER	2520	700
DECEMBER	2800	1100

5.12.2 Consumptions and Costs of Energy for A/C (Cooling Purposes Only)

Operation Period:

May to October (5 months, 105 working days excluding the public days off)

Average Operation Hours of A/C:

4h per day, approximately

Daily A/C Consumption:

Cooling Capacity = 12,000 Btu = 3,517 W

EER = 2.64

The energy consumption of each unit is 3,517/2.64 = 1,332 W = 1.33 kW

Thus, totally: 2 Units x 4 h Daily Use x 1.33 kW Consumption per Unit = 10.64 kWh/day

Seasonal Cooling Load of A/C:

105 days x 10.64 kWh/day = **1,117 kWh**

Seasonal Energy Costs of A/C:

1,117 kWh x 0.0946 €/kWh = **105.68 €**

5.12.3 Consumptions and Costs of Energy for Hot Water

There is NO Hot Water Consumption in the Inspected Building

5.12.4 Consumptions and Costs of Energy for Lighting

Lighting Distribution and Partial Consumptions:

Building 1: 8 Incandescent Lamps 125W each

Building 2: 34 Fluorescent Lamps 36W each + 4 Incandescent Lamps 60W each

Building 3: 12 Fluorescent Lamps 36W each

Building 4: 34 Fluorescent Lamps 36W each + 2 Incandescent Lamps 60W each

Average Operation Hours of Lighting Systems:

7 h per day, approximately

Daily Energy Consumption per Building:

Building 1:

Daily Hours per Lamp: 7 hrs

Daily Energy Consumption: (8x7x125) = 7,000 Watt-hr (7 kWh)

Building 2:

Daily Hours per Lamp: 7 hrs

Daily Energy Consumption: (4x7x60) + (34x7x36) = 10,248 Watt-hr (10.248 kWh)

Building 3:

Daily Hours per Lamp: 7 hrs

Daily Energy Consumption: (12x7x36) = 3,024 Watt-hr (3.024 kWh)

Building 4:

Daily Hours per Lamp: 7 hrs

Daily Energy Consumption: (2x7x60) + (34x7x36) = 9,408 Watt-hr (9.408 kWh)

Total Daily Consumption for Lighting: 29,680 Watt-hr or 29.68 kWh

Annual (2016) Energy Consumption for Lighting: (260x29.68) = 7,717 kWh

(Working Days per Year: 5 Days per Week x 52 weeks = 260 Watt Days)

Annual (2016) Cost for Lighting: 7,717 kWh x 0.0946 €/kWh = **730 €**

5.12.5 Primary Energy Consumptions

Primary Energy for Electricity:

Conversion factor for electricity is 2.9. Therefore, 3,208 x 2.9 = **9,303 kwh**

Primary Energy for Heating:

Operation Period: October to May = 138 working days (excluding official days off), 8 hours.

Total Litres Used: 6,600lt

Calorific Power of Oil: 11.9kW

Thus, 6,600lt x 11.9kW = 78,540kW

The boiler has efficiency rate 90-92% = 0.91

Therefore, 78,540kW x 0.91 = 71,471kW

Daily, 71,471kW/138days = 518kW/day => 518kW/8h = **64.7kWh**

Primary Energy for Cooling (A/C):

Building 2: Cooling Load = (1,117/2) kWh/30m^2 = 18.62kWh/m^2

Electric Energy Consumption = Cooling Load/EER = 18.62kWh/m^2/2.64 = 7.05 kWh/m^2

(Cooling) Primary Energy Consumption = 7.05 kWh/m^2 x 2.9 = 20.45 kWh/m^2

Building 4: Cooling Load = (1,117/2) kWh/24m^2 = 23.27kWh/m^2

Electric Energy Consumption = Cooling Load/EER = 23.27kWh/m^2/2.64 = 8.81 kWh/m^2

(Cooling) Primary Energy Consumption = 8.81 kWh/m^2 x 2.9 = 25.56 kWh/m^2

Total Primary Energy Consumption for Cooling = (20.45 + 25.56) kWh/m^2 = **46 kWh/m^2**

Primary Energy for Lighting:

7,717 kWh x 2.9 = **22,385 kWh**

5.13 Data Collection and Analysis

In order to evaluate the quality of the indoor environment, the following method of collecting and analyzing data was followed:

- Questionnaire survey: A questionnaire was distributed to the employees throughout the building with the purpose of collecting information related to the sense of quality of the internal environment and to the capabilities for microclimate control.

The first step in assessing the behavior of the building in relation to the current state of thermal comfort and indoor air quality is to capture the feeling of the habitat conditions of the occupants and their behavior towards the ventilation methods of the premises. In other words, the assessment of the indoor environment by the users of the building themselves, is investigated with the help of a properly formulated questionnaire, which was distributed to the occupants on all rooms of the building. During the distribution of the questionnaire, every necessary information and detailed instructions on how to complete it so as to minimize any possible misunderstandings that would lead to an incorrect completion, was given to all the participants. The collection of the questionnaires took place after one week from the day of its distribution. The questionnaire is divided into the Winter and the Summer Season categories, and in the first section, questions about air quality, lighting and noise assessment prevail. The second section deals with more specified questions about possible discomfort situations and the size of their effect. Its worth mentioning that each answering sheet of the eight people who work in this building, reflects their unique physical and emotional characteristics, their own sensitivity sensors and their adaptability. However, an average consensus towards their point of view about the thermal comfort in their workplace, was recorded. Indicatively, the 87.5% (7/8) stated their complaints about inadequate heating, while a 62.5% (5/8) pointed their dislike about the external noises (from the adjacent National Highway and from the KTEO Garage itself – the rest 38.5% that didn't concern about noises, were the mechanics of the garage, no surprise here!). In another field, a 75% (6/8) finds the ventilation not satisfactory in both season and that is explained by the fact that they cannot open the windows in winter and get cold while during summer, they close the windows for the Air Condition to become effective, leading to them being “trapped” in a “shielded” closed space. A sample of the Questionnaire is presented in **ANNEX A**.

CHAPTER 6. IMPROVEMENT MEASURES

This section describes the proposed interventions in order to achieve energy savings, and also to secure the overall satisfaction feeling of the building occupants, regarding the thermal comfort conditions. Those actions will result in the reduction of the building's energy consumption as well as in the building's operating costs.

6.1 Replacement of the Existing Lighting Equipment

The lighting sector is a major factor that influences the functionality, and consequently the productivity of a business. Especially in office buildings where the nature of work requires high levels of brightness and good quality of illumination, the lighting installation must be precisely designed and carefully placed. In office buildings, the lighting installation absorbs significant amounts of energy, making it one of the most energy demanding building consumptions. Therefore, depending on the installed lighting technology, there are large energy saving margins that can reach 80%. More specifically, the development of lighting technology has led to an increase in the bulb's brightness yeld (including the accompanying power supply equipment) of up to 90 lm/W, compared to 20 lm/W of a conventional incandescent lamp, with lower heat losses and extension of their the life span. In addition, the dimming feature is now optimized for all lighting technologies and can be automatically applied through an automatic luminance control system, reducing this way the power consumption by up to 60% (combined with room brightness because of natural lighting). Concerning the cost of lighting technologies and the application of lighting control and optimization techniques in a building, there are variations according to the technical characteristics and the ecological and economic benefits (savings) that they are expected to produce during their lifetime, nevertheless in recent years it has been stabilized. The major downside of LED lighting is the initial cost, which can be 5-10 times that of Fluorescent. But regarding tax incentives, rebates and long-term energy savings, LED's will depreciate faster.

6.1.1 Replacement of the Existing 60W Incandescent Light Bulbs

Each one of the existing six (6) 60W incandescent lamps has the following characteristics:
(Full Characteristics Table can be found in **ANNEX B.1**)

Model: Eurolamp A19 60W E27
Luminous Flux: 660 (lm)
Luminous Efficiency: 11 (lm/W)
Lifetime: 1.000 (h)
Unit Cost: 0.65 (€)
Daily Energy Consumption: (7 h x 60 W) = 420 Wh
Annual Energy Consumption: 420 Wh x 260 Watt Days = 109.2 kWh
Annual (2016) Cost: 109.2 kWh x 0.0946 €/kWh = 10.33 €

After market research, the selected lamp model to replace the existing 60W incandencent lamps is the "LED type lamp" Philips CorePro 8.5W. No replacement expenses, in terms of labour costs, are required. Its main characteristics (Full Characteristics Table can be found in **ANNEX B.2**) are :

Model: Philips CorePro D 8.5-60W A60 E27 827
Luminous Flux: 806 (lm)
Luminous Efficiency: 94.82 (lm/W)
Lifetime: 15,000 (h)
Unit Cost: 5,3 (€)
Daily Energy Consumption: (7h x 8.5 W) = 59.5 Wh
Annual Energy Consumption: 59.5 Wh x 260 Watt Days = 15.47 kWh
Annual (2016) Cost: 15.47 kWh x 0.0946 €/kWh = 1.46 €

It's clear that the annual energy savings are 93.73 kWh and the annual cost savings are 8.87 €
This translates into an annual 85.8% energy savings.

The depreciation for this investment will be:
Initial Cost for Purchase/Annual Cost Savings = (6 x 5.3)/8.87 = 3.6 years

6.1.2 Replacement of the Existing 250W Incandescent Light Bulbs

Each one of the existing eight (8) 125W incandescent lamps has the following characteristics: (Full Characteristics Table can be found in **ANNEX B.3**)

Model: Philips HPL-N 125W E27 SG 1CT/24
Luminous Flux: 6,200 (lm)
Luminous Efficiency: 49.6 (lm/W)
Lifetime: 16,000 (h)
Unit Cost: 7.91 (€)
Daily Energy Consumption: (7 h x 125 W) = 875 Wh = 0.875 kWh
Annual Energy Consumption: 0.875 kWh x 260 Watt Days = 227.5 kWh
Annual (2016) Cost: 227.5 kWh x 0.0946 €/kWh = 21.52 €

After market research, the selected lamp model to replace the existing 125W incandencent lamps is the "LED type" lamp OSRAM PARATHOM E27 20W. No replacement expenses, in terms of labour costs, are required. Its characteristics (Full Characteristics Table can be found in **ANNEX B.4**), are:

Luminous Flux: 2,452 (lm)
Luminous Efficiency: 122.6 (lm/W)
Lifetime: 15,000 (h)
Unit Cost: 13.35 (€)
Daily Energy Consumption: (7 h x 20 W) = 140 Wh
Annual Energy Consumption: 140 Wh x 260 Watt Days = 36.4 kWh
Annual (2016) Cost: 36.4 kWh x 0.0946 €/kWh = 3.44 €

It is clear that the annual energy savings are 191.1 kWh and the annual cost savings are 18,1 €

The depreciation for this investment will be:
Initial Cost for Purchase/Annual Cost Savings = (8 x 13.35)/18.1 = 5.9 years

6.1.3 Replacement of the Existing 36W Fluorescent Light Bulbs

Each one of the existing eighty (80) 36W fluorescent lamps has the following characteristics:

(Full Characteristics Table can be found in **ANNEX B.5**)

Model: Eurolamp T8 TRI-PHOSHOR 36W/865
Luminous Flux: 2,650 (lm)
Luminous Efficiency: 73.61 (lm/W)
Lifetime: 12,000 (h)
Unit Cost: 1.00 (€)
Daily Energy Consumption: (80x36) = 2,880 Wh = 2.88 kWh
Annual Energy Consumption: 2.88 kWh x 260 Watt Days = 748.8 kWh
Annual (2016) Cost: 455 kWh x 0.0946 €/kWh = 70.83 €

After market research, the selected lamp model to replace the existing 36W fluorescent lamps is the "LED fluorescent type lamp" V-TAC T8 18W 120 cm Nano. No replacement expenses, in terms of labour costs, are required, as both types use the same instant-start electronic ballast type. Its main characteristics (Full Characteristics Table can be found in **ANNEX B.6**), are:

Model: V-TAC VT-1285SMD
Luminous Flux: 2,300 (lm)
Luminous Efficiency: 127.77 (lm/W)
Lifetime: 20,000 (h)
Unit Cost: 7.50 (€)
Daily Energy Consumption: (80x18) = 1,440 Wh = 1.4 kWh
Annual Energy Consumption: 1.4 kWh x 260 Watt Days = 374.4 kWh
Annual (2016) Cost: 374.4 kWh x 0.0946 €/kWh = 35.42 €

It's clear that the annual energy savings are 374.4 kWh and the annual cost savings are 35.42€ This translates into an annual 50% energy savings.

The depreciation for this investment will be:
Initial Cost for Purchase/Annual Cost Savings = (80 x 7.50)/35.42 = 16.9 years

6.2 Add of Automation in Lighting Control

The simplest way to reduce the amount of energy consumed by lighting systems is to turn lights off whenever they are not required. Most people simply do not shut off lights when they leave rooms. One solution to this problem is occupancy sensors, which sense the presence of people in a space using infrared and/or ultrasonic motion sensors. These switches are appropriate in spaces where people pass in and out often, such as public offices, restrooms, storage areas, and conference rooms. These controls can also dim lights when there is plenty of daylight. Such systems can save 20-60% of lighting energy (M.R. Brambley et al., 2005). To respond appropriately as the distribution of sunlight in the room changes through the day, these systems require brightness sensors to be placed strategically in the room., Different sensors may actuate different lighting zones. Occupancy sensors and brightness sensors can be individual switches for individual lights or inputs to larger control systems. The most highly-optimized lighting control systems combine multiple sensors and a logic processor to control lights. These systems can often save 40% of overall lighting energy; sometimes even far more. In order to avoid continuous switching ON and OFF, a tolerance on the threshold values must be set. According to the TOTEEE. 20701-1 Instruction, the automation must control at least 60% of the installed lighting power of the building in order to be acceptable. For the investigated building and after market research, the wall mounted motion detector model "theLUXA S180" by THEBEN is selected. Its full characteristics Table can be found in **ANNEX Γ**. There gonna be 3 units placed to buildings 2, 3, and 4 respectively. The price for each unit is 24.90 € and the total cost will be 74.70 €. There are no installation costs.

Figure 15: Motion Detector for Lighting Control (Source: www.kafkas.gr)

6.3 Replacement of the Existing Air Conditioners

Rooms 2 and 4 are equipped with one (1) air condition unit each, that are used mostly during the summer period, for cooling purposes. Those units are considered conventional and old fashioned; they consume hugh amounts of energy and they have little contribution to the overall cooling needs (Full Characteristics Table can be found in **ANNEX Δ.1**). Therefore, their replacement with modern air condition units is highly recommended. After a market research, the model that prevailed in terms of efficiency and pricing is the "inverter A+++/A++" FINLUX FDCI-12QL46WF. It's main characteristics (Full Characteristics Table can be found in **ANNEX Δ.2**), are shown below:

Unit Cost: 419 (€)
Labour Costs for Removal and Installation = 60 (€)
Cooling Capacity = 12,000 Btu = 3,517 W
SEER = 8.53

Daily A/C Consumption (for the same operating period, as the existing units):
The energy consumption of each unit is 3,517/8.53 = 412.30 W = 0.41 kW
Thus, totally: 2 Units x 4 h Daily Use x 0.41 kW Consumption per Unit = 3.29 kWh/day

Seasonal Energy Consumption of A/C:
105 days x 3.29 kWh/day = **346.33 kWh**

Seasonal Energy Costs of A/C:
346.33 kWh x 0.0946 €/kWh = **32.76 €**

Compared to the existing A/C installation consumptions and costs, as presented in section **5.12.2** it's clear that the annual energy savings are 770.67 kWh and the annual cost savings are 72.92 €. This translates into an annual 31% energy savings.

The depreciation for this investment will be:
Initial Cost for Purchase/Annual Cost Savings = (2 x 479)/72.92 = 13.1 years

6.4 Replacement of the Existing Openings (Windows)

The openings are the most sensitive structural elements of the shell from an energy consumption point of view as the coefficient of their thermal conductivity is generally higher than the one of solid elements. In the case of old frames, there only two kinds of interventions that can be done, however leading to the significant improvement of the energy performance of the building.

- Their replacement with new, energy efficient ones. The use of twin windows is imperative while, depending on the climatic zone of the building, a frame material with good thermal properties (e.g. aluminum with thermal break, wooden frame), is selected.
- Installation of a second frame. If the constructional position of the opening allows it and if the owners agree, the placement of a second frame can contribute to the energy upgrading of the building.

The difference in thermal break systems is polyamide. Polyamide is a highly durable material, which has very low conductivity and high hardness, which contributes to the robustness and durability of the corresponding frames. Because it is a bad heat conductor, it interrupts the transmission of heat inside the frames. Consequently, thermal break systems are a good choice for energy saving in buildings. **Figures 16** and **17** visualize the difference of the two formats.

Figures 16 and 17: Aluminum Frames without and with Thermal Break (Source: www.profil.gr).

In the Case Study, the existing single glazing, non-soundprood windows and the old, of low quality, poorly maintained, wooden frames have a high coefficient of thermal conductivity and poor water tightness. The replacement of windows is also necessarry because the adjacency of the building to the National Road allows for high noise levels to enter the building and disrupt the occupants and disorganize their work and concentration. The replacement window will be a “double opening window with roller and reclination”. After market research the selected model is the “Prima 850 “ Series. It is especially designed to meet high requirements in terms of functionality and aesthetic result. It offers absolute water and air tightness, perfect fit, sturdiness and durability. It includes the Europa 990 system with aluminum foil, strap, and polyurethane. The glass is double crystal 4-10-5. Its full technical characteristics can be found in **ANNEX Z**. All the openings have perimeter mechanisms and Roto declination mechanism. The design of the replacement opening can be seen in **Figure 18**:

Figure 18: Double Opening Window Design (Source: www.etoimokoufoma.spatharakis.gr)

It is recommended that the openings with small dimensions to be neglected and to proceed with the replacement of the larger 1.5m x 1.5m ones. Building 1 cannot be approached in terms of thermal stability because of its function (the garage front door opens and stays open for many hours per day), while building 4 is covered by glass panels. For the rest buildings, the total surface of the openings is 15.75 m^2. Particularly:

BUILDING 2

4 Windows 1.5m (W) x 1.5m (H) = 2.25 m^2 x 4 = 9 m^2

BUILDING 3

3 Windows 1.5m (W) x 1.5m (H) = 2.25 m^2 x 3 = 6.75 m^2

The price offer for the replacement of the aforementioned openings, including labor costs and taxes, will be 570€ x 7 = 3990€.

6.5 Thermal Insulation of the Building Envelope

I) Walls

In order to reduce energy consumption and to achieve a pleasant climate of thermal comfort inside the building, the heat exchange between the indoor and outdoor environment must be minimized, without compromising the quality and comfort conditions. This is achieved by ensuring the thermal insulation of the structural elements of the building structure. In this way, both the heat losses to the external environment during the winter season, and the thermal overheating due to the influence of solar radiation during the summer, are reduced. As a rule, the external thermal insulation requires materials that are not affected by moisture and with the advantage of being able to limit the thermal bridges that are created primarily in the joints of the structural elements. Commonly used types of insulation in buildings include: Fibreglass (0,05W/mK), Polyurethane foam (0,024W/mK), Polystyrene foam (0,033W/mK), Cellulose insulation (0,04W/mK) and Rock wool (0,04W/mK). A vapour barrier is often used in conjunction with insulation because the thermal gradient produced by the insulation may result in condensation which may damage the insulation and/or cause mould growth.The installation of external thermal insulation is currently easy and secured, and its done by using special plugs and glues or by using metal guides. In the first case, the final surface is coated while in the second case, the final surface is usually formed by a panel, contributing at the same time to the radical renovation of its view. It is also possible to form a double-sided view with ready-made thermal insulating panels, a technique which is well-known abroad. Additionally, cold paint is a key factor in keeping thermal losses down. Cold materials in general, are special coatings that have the ability to reflect a higher percentage of solar radiation than the one of the colors commonly used.

For the case study building, the implementation of an integrated external insulation system to the wall masonry, at an almost twice its original thickness, is an option for investigation. The

material has high performance that allows it to maintain its characteristics unaltered over time and to carry out its insulating function even without a water vapor barrier. The system selected is the “3rd generation” DUROSOL eXternal. It presents higher thermal and mechanical properties than the conventional insulators that are used in external thermal insulation systems (e.g. EPS 60 or 80). Its thermal insulation coefficient is λ = 0,033W (mk), based on a German certificate (Full characteristics Table can be found in **ANNEX H.1**).
The Stages of the Installation of the selected thermal insulation system, are:

- Paste of the thermal insulation material on the outside of the walls with the bonding material.
- Installation of polyurethane foam at the points where external thermal insulation comes into contact with other building elements such as roof, windows, doors.
- Smoothing of the surface, so perfect flatness can be achieved.
- Installation of plugs for extra protection of the thermal facade from earthquakes and wind pressures.
- Mixing of the base coat with water and paste of the corners, the water coils and the expansion joint profiles wherever necessary. The entire surface of the thermal insulation material is then covered.
- Installation of the wire mesh.
- For perfect adhesion and for the color plaster that follow to be perfectly placed, a hand of primer (αστάρι) is placed.
- The color plaster is used for the final surface coating.

For the total structural elements surface to be insulated which is 367.5 m^2 ,the offer that came up after market research is 27.16 €/m^2 . The cost analysis for the materials and the labor costs can be found in **ANNEX H.2**. For the given price, the insulation for each building is as follows:

Building 1: 181.5 m^2 = 4,930 €

Building 2: 66 m^2 = 1,792 €

Building 3: 60 m^2 = 1,629 €

Building 4: 66 m^2 = 1,792 €

The total price for the thermal insulation of the building's structural elements will be 10,143€.

II) Roofs

Cool Roofs generally, are created by the application of a high reflection color or a reflective sheet and can reduce up to 30% the need for air-conditioning since they are designed to radiate more sunlight and absorb less heat than of a normal roof. This is due to the properties that specific materials have so as to reflect the solar radiation back into the atmosphere. As long as the roof surface remains cool due to the extremely low heat absorption (to such an extent that a cold roof may be 28-33 °C cooler than a conventional roof during very high temperatures), the indoor of the building is kept at a constantly cool temperature. A cold roof can benefit a building and its occupants:

- By reducing the energy bills because the need for air conditioning is also less.
- By improving the indoor comfort in areas that are not air-conditioned.
- By decreasing the roof temperature, which can extend the roof's life and any insulation in it.

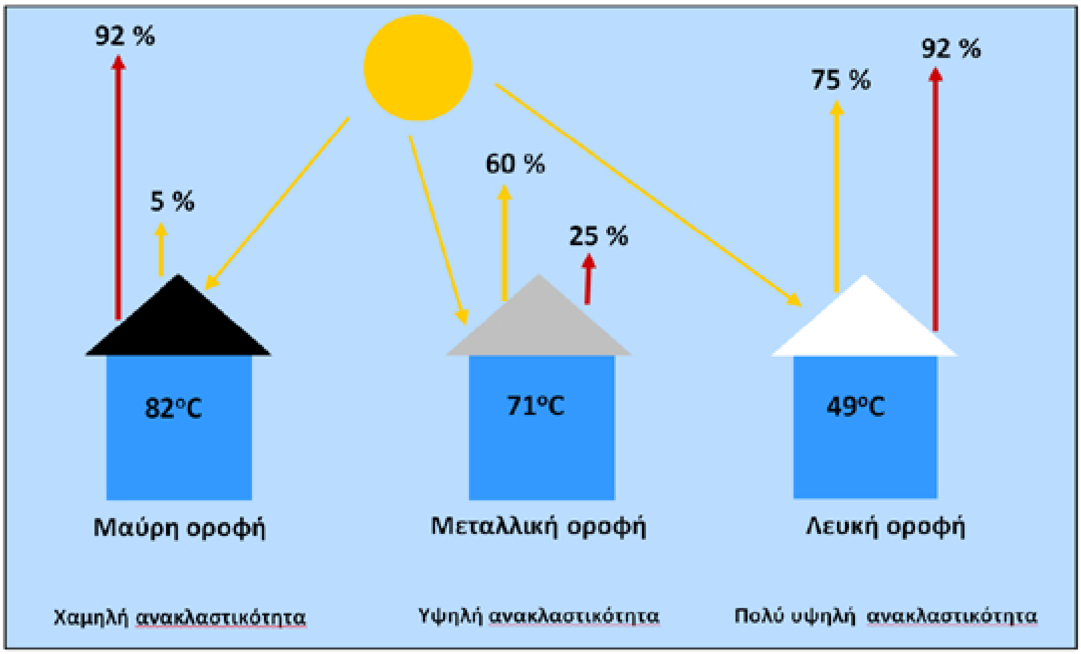


Figure 19: Roof Types and their absorption differences (Source: Physics Dept., ΕΚΠΑ).

The temperature of a dark-colored conventional roof reaches 66 °C on a hot summer day because it absorbs a significant proportion of the incident solar radiation. In contrast, the temperature of a white surface, which reflects the solar radiation and absorbs less heat, reaches 37 °C, remaining nearly 30 °C cooler than the conventional roof.

For the tile roofs of this case study building, the insulating system selected after market research is the “Iso Paint” that includes the insulating material “Isonit”. Its full characteristics Table can be found in **ANNEX H.3**. This insulation system is a very light insulating coating that is made with a special flexible thermoplastic polymer and special nanotechnology additives that give the coating excellent roof grip and high stability in solar radiation. Its elasticity due to its innovative construction can reach high rates (197%) and can cope well at extremely low and extremely high temperatures without any change over the years. The steps of the installation process are as follows:

- A special cleansing material is applied across the entire roof surface, which acts instantly, and then the roof is rinsed with an airless hot or cold water sprayer.
- The roof is sprayed with “a-clean” nano-cleaner and then the roof is washed with a special machine (robot).
- The base is sprayed (tegl primer).
- The main coating (isonite) is sprayed. The final layers are 2-3.
- The chimney (wherever present), as well as other openings such as roof windows and skylights are insulating sealed.

For the total structural elements surface to be insulated which is 367.5 m^2 ,the final offer that came up after market research is 12 €/m^2. For the given price, the insulation for each building is as follows:

Building 1: 38,18 m^2 = 458 €

Building 2: 21,21 m^2 = 255 €

Building 3: 16,97 m^2 = 204 €

Building 4: 21,21 m^2 = 255 €

The total price for the thermal insulation of the building's structural elements will be 1172 €.

The addition of thermal insulation is expected to drop down significantly the consumption of electricity and oil.

6.6 Installation of Mechanical Ventilation

Responding to the general feeling (62.5% totally – 100% from the people that work inside buildings 2 and 4) about low ventilation levels (at least 62.5% towards no air movement), as it was recorder in the questionnaire, and in order to ensure that the new air condition units will uniformly spread their filtered air throughout the closed spaces, the placement of mechanical ventilation is proposed. With a view to keep the relative costs low, the model selected is a "70W ceiling fan type" UCF651 by United. The height of the building (3m) allows for the safe operation of the fan, while its remote controlling ability guarantees for the comfortable use of it. Finally, there is a slot for screwing the lamp on, thus there is no need for repositioning. Each unit comes at the cost of 65€ each and the proposition encourages the purchase of 3 units, one for each office building, including the exam room. Total cost will be 195€ + 60€ for the installation costs, that sums up to 255€. A photo of the product is available in **Figure 20**:

Figure 20: Mechanical Ventilation (Source: www.united-electronics.gr)

6.7 Potential Measures

I) Placement of Shading Devices

Structures and/or Devices can reduce the summer heating load. Different types of shading devices are movable devices, internal blinds, external blinds, and overhangs. In our case, a simple installation of awnings can be used to reduce cooling loads by reducing solar radiation penetration, thus it is recommended. In such a senario, attention should be paid in having the air conditioning external unit covered, as long as possible, during daytime, from being exposed to the solar radiation, at any angle. This will increase the unit's performance. A replacement of the external unit might be necessary, if this condition isn't met.

II) Upgrade of the Central Heating System

The problems associated with central heating are the increased distribution losses due to inert pipelines, and the increased actual oil consumption for heating due to false system management by the building users. In order to limit the distribution losses, it is recommended to insulate the central column of pipelines, while for limiting the consumption of thermal energy beyond the needs of the building, it is proposed to place thermostatic valves in each one of the radiators. The insulation of the pipelines will be made with prefabricated material pieces, by foam plastic (elastomer), suitable for a temperature range from -75 °C to+105 °C. The insulating thickness for the 2 inch pipes is 13mm. The thermostatic valve is mounted on the heater switch and can be used to control the hot water supply by means of a remote sensor, isolating it when the temperature received by the sensor is equal to or higher than the desired temperature. This will give to the building the amount of heat that corresponds to its heating needs so that the room temperature is at the desired level, while energy expenditure in the central heating system is limited and the performance of all the radiators improves. The estimated energy savings appear due to the lower energy demand for heating, as a result of the lowest average indoor temperature that the building will have throughout the heating period, when it is estimated based on the desired indoor temperature of 20 °C. Adding thermal insulation is expected to reduce oil consumption as a consequence.

III) Management of the Surrounding Microclimate

As seen in the general view pictures, the surrounding area has some trees. The enforcement of the existing “green area” and its systematic care and further expansion, so as to create a suitable microclimate that will provide natural shading, natural wind and flood barrier and air filtration among others, is strongly recommended.

CHAPTER 7. CONCLUSIONS

Throughout the energy investigation of the case study building, it was found that there are many energy efficiency failures that originate in the age of the construction itself, at a time when the tendency for proper management of the energy consumption wasn't as “hot topic” as nowadays. That reflects the economic situation and the human attitude towards the environment, back in the 80's. However, the climate change and its consequences has turned the tide and currently, the need for taking drastic measures towards a more energy efficient building sector which is highly connected to a financially sustainable workplace in particular, and a developed country, overall. Developments in the production and management of energy are so rapid that in the near future, every business will be forced to retain permanent staff which will be responsible for energy management. The same goes for the public sector, where the energy inspections in terms of automated control systems, new materials and ways of insulating the building shell and equipment, developments in air conditioning, cooling systems and new maintenance technologies, should be frequent and spread in both the urban centres and the province (where the case study building location is). The particular building needs a series of energy management and thermal comfort improvement measures that rise the cost at a level where the eligibility for joining a funding program is imperative. The fact that the building is not a rented one but it belongs to the public administration may facilitate the relevant procedures. Besides the structure itself, we should concentrate on the human factor. If we can understand the variables of thermal comfort in our regional climatic contexts, and the mechanisms by which they operate in relation to human physiology, then we can design buildings that provide comfort in more rich and economical ways than a standard HVAC solution. design comfortable environments in a holistic manner.

ANNEX A

Questionnaire (Indicative)

The picture can't be displayed.

ANNEX B

LIGHTING CHARACTERISTICS

B.1 Existing 60W Incandencent Bulb Characteristics

Model: **A19 60W E27 CLEAR 12V**

Power supply (V) :12V

Power (W) :60W

Lamp Type :A60

Lamp Base Holder :E27

Lumen :660lm

Lifetime :1000h

Credentials : YES

Quantity (pcs) :1/10/100

Certifications : YES

Height :107mm

Diameter :60mm

Hertz :50-60Hz

Operation Temperature :-30/45

B.2 Replacement 8.5W LED Bulb Characteristics

B.3 Existing 125W Incandescent Bulb Characteristics

B.4 Replacement 20W LED Bulb Characteristics

B.5 Existing Fluorescent 36W Bulb Characteristics

Power supply (V) :220-240V

Power (W) :36W

Lamp Type :T8

Lamp Base Holder :G13

Kelvin :6500K

Lumen :2650lm

Lifetime :12000h

Credentials : YES

Quantity (pcs) :1/25

Certifications : YES

Diameter :26mm

Length :1200mm

Hertz :50-60Hz

Operation Temperature :-30/45

B.6 Replacement 18W LED Fluorescent Bulb Characteristics

Luminous flux	2300 lm
Wattage	18W
Voltage AC	220-240V
Beam angle	160°
Lifespan	20,000 hrs
Color Rendering Index	CRI - >80
Dimensions	Length 1200 mm Diameter 28 mm
Working conditions	Normal working conditions is -20° +45°
Certificates & standards	Energy efficiency class A++, Certification CE, EMC, ROHS
Body details	Material Nano Plastic, Body Colour White

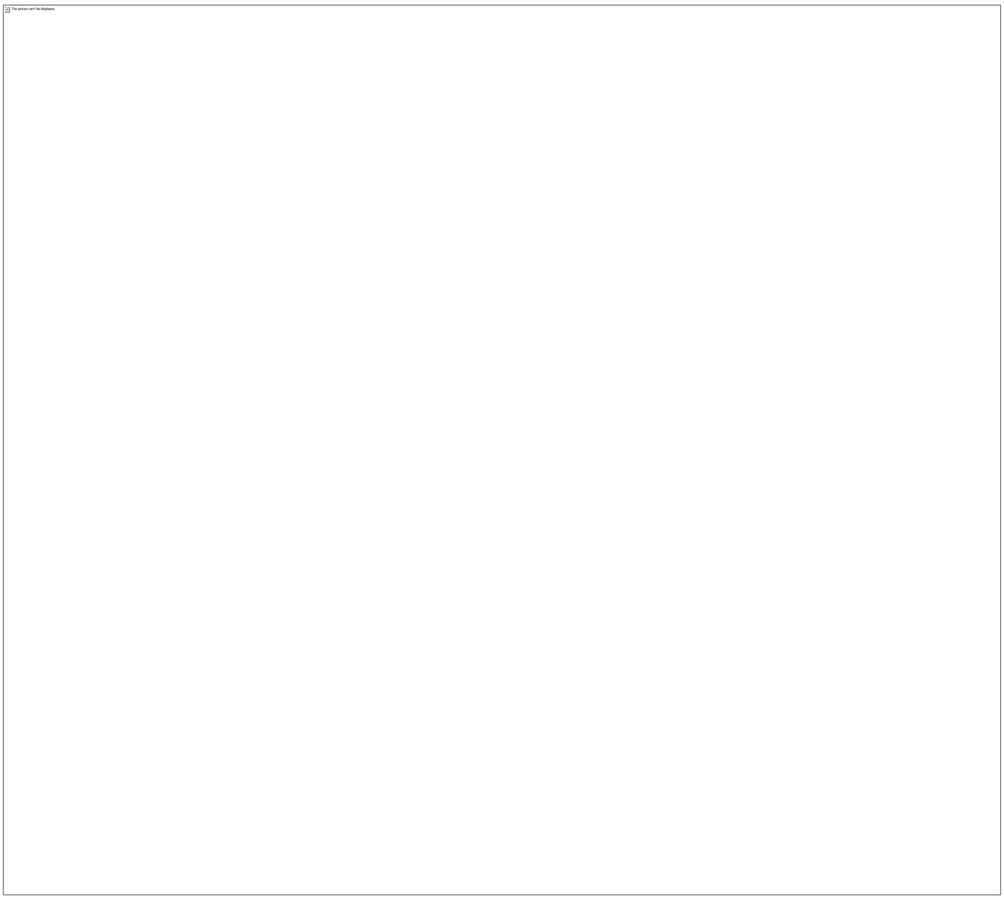
ANNEX Γ

Lighting Control Characteristics

ANNEX Δ

Air Condition Characteristics

Δ.1 Existing A/C Characteristics



Δ.2 Replacement A/C Characteristics

Cooling Power	12,000 Btu/h
Cooling Class	A+++
Heating Class	A++
SEER	8.53
SCOP	4.64
Operational Temperature Range for Cooling	-14 C / +47 C
Operational Temperature Range for Heating	-15 C / +28 C
Noise Level of Internal Unit (min/max)	29/41 dB
Noise Level of External Unit	52 dB
Refrigerant	R410A
Weight of Internal Unit	14 kg
Weight of Internal Unit	55 kg
Features	Inverter, Wi Fi, Dehumidification

ANNEX E

Indicative Electricity Bill

The picture can't be displayed.

ANNEX Z

New Openings Characteristics

The picture can't be displayed.

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ANNEX H

Thermal Insulation

H.1 Thermal Insulation Characteristics

Τεχνικά Χαρακτηριστικά:

-Ελάχιστη Πυκνότητα: 28 kg/m3

-Θερμική Αγωγιμότητα στους 10C: 0,033 W/(mk), 0,029 Kcal/mhC

-Θερμική Αντίσταση R για 10cm: 2,94m2K/W, 3,44m2hC/kcal

-Θλιπτική τάση σ10: 160

-Καμπτική Αντοχή Kpa: 365

-Αντοχή σε εφελκυσμό Kpa: 322

-Διατμητική Αντοχή (τ) Kpa: 170

-Συντελεστής Ελαστικότητας Kpa: 4500

-Συντελεστής Τριβής: 0,5-0,7

-Αντίσταση Υδροπερατότητας (μ): 40-100

-Αντίσταση Υδροαπορρόφηση Σε βύθιση (μέγιστο): έως 1,0

-Αντίδραση στη φωτιά: Αυτοσβενημενο

H.2 Thermal Insulation Cost Analysis

ΠΡΟΪΟΝ	ΔΙΑΣΤΑΣΕΙΣ	ΜΟΝΑΔΑ ΜΕΤΡΗΣΗΣ	ΤΙΜΗ	ΚΑΤΑΝΑΛΩΣΗ/Μ²	ΤΙΜΗ/Μ² ΕΦΑΡΜΟΓΗΣ
Θερμομονωτικό Υλικό 3ης γενιάς **Durosol eXternal**	1000X500X50	m²	5,75€	1m²/m²	5,75€
Ή Φθηνότερη εναλλακτική επιλογή **EPS 80**	1000X500X50	m²	2,89€	1m²/m²	2,89€
Υλικό Επικόλλησης **FGL-Thermo I**		m²	0,39€	4kg/m²	1.56€
Υαλόπλεγμα Ενίσχυσης **FGL-Mesh 5x5mm white 160gr/m²**	1x50m	m²	0,76€	1m²/m²	0,84€
Βύσματα Στερέωσης **FGL-Dowel**	90mm	Τεμάχια	0,12€	5τμχ/m²	0,60€
Βασικό Επίχρισμα **FGL-Thermo III**		kg	0,51€	4kg/m²	2,04€
Αστάρι Πρόσφυσης **Primer**		litres	3,10€	0,1litre/m²	0,310€
Τελικό Σιλικονούχο Επίχρισμα	κοκκομετρία 1-2,5mm	kg	1,7€	1,8-3,6kg/m²	3,06€*
Χρωμοσοβάς Leoplast					
ΚΟΣΤΟΣ ΕΡΓΑΣΙΑΣ (κατά προσέγγιση)					**13€/m²**
ΚΟΣΤΟΣ ΥΛΙΚΩΝ (με Durosol)					**14,16€/m²**
ΚΟΣΤΟΣ ΥΛΙΚΩΝ (με Eps 80)					**11,30€/m²**
ΣΥΝΟΛΙΚΟ ΚΟΣΤΟΣ					Με Durosol: **27,16€/m²**

H.3 Roof Thermal Insulation Characteristics

The picture can't be displayed.

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