Ανοικτό Πανεπιστήμιο Κύπρου

Σχολή Faculty of Pure and Applied Sciences

Μεταπτυχιακό Πρόγραμμα Σπουδών

Sustainable Energy Systems

Μεταπτυχιακή Διατριβή

Energy Upgrade of School Buildings

Thomas Paraskevas – Id 11502620

Επιβλέπων Καθηγητής
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Η παρούσα μεταπτυχιακή διατριβή υποβλήθηκε προς μερική εκπλήρωση των απαιτήσεων για απόκτηση μεταπτυχιακού τίτλου σπουδών
Στο Sustainable Energy Systems
από τη Σχολή Faculty of Pure and Applied Sciences
του Ανοικτού Πανεπιστημίου Κύπρου.

Δεκέμβριος 2018

Περίληψη

Το φαινόμενο του θερμοκηπίου συνέβαλε σημαντικά στη διαμόρφωση της νομοθεσίας της Ευρωπαϊκής Ένωσης σχετικά με τα συστήματα ενεργειακών τεχνολογιών και στη χρήση αποδοτικότερων και "πιο πράσινων" συστημάτων στον τομέα των κτιρίων. Η ευρωπαϊκή οδηγία 2009/28 / ΕΚ προωθεί τη χρήση ανανεώσιμων πηγών ενέργειας σε όλους τους τομείς, όπως οικιστικά και δημόσια κτίρια, αλλά και σε κτίρια γραφείων και βιομηχανικών κτιρίων. Για την επίτευξη του στόχου που τέθηκε, εκδόθηκε μια άλλη ευρωπαϊκή οδηγία. Σύμφωνα με την Ευρωπαϊκή Οδηγία 2010/31 / ΕΕ έχει θεσπιστεί γενικός οδηγός για την αξιολόγηση και τον υπολογισμό της κατάστασης ενεργειακής απόδοσης κάθε κτηρίου. Έτσι, όλα τα υπάρχοντα και τα μελλοντικά κτίρια πρέπει να υποβάλλονται σε ενεργειακό έλεγχο για τον προσδιορισμό της υφιστάμενης κατάστασης ενεργειακής απόδοσης ή της μελλοντικής κατάστασης ενεργειακής απόδοσης του κτιρίου που βρίσκεται στη διαδικασία σχεδιασμού. Η αξιολόγηση της κατάστασης της ενεργειακής απόδοσης κάθε κτηρίου αποτελεί προτεραιότητα, καθώς πρόκειται για ένα κτίριο που χρησιμοποιείται από πολλούς και πρέπει να καθοριστεί ένα ελάχιστο καθεστώς ενεργειακής απόδοσης. Έτσι, το αντικείμενο του παρόντος εγγράφου είναι να αξιολογήσει την κατάσταση ενεργειακής απόδοσης ενός υπάρχοντος δημόσιου κτιρίου, σύμφωνα με τα πρότυπα που ορίζουν οι ευρωπαϊκές οδηγίες, να υποβάλει προτάσεις για τη βελτίωση της αποδοτικότητας των συστημάτων του κτιρίου και να παρέχει μια κατά προσέγγιση εκτίμηση της εξοικονόμησης ενέργειας με χρήση της εφαρμογής Edge.

Abstract

The greenhouse effect has been a major contributor to the formation of the European Union legislation concerning Energy technology systems and the use of more efficient and “greener” systems in the buildings sector. The European Directive 2009/28/EC is promoting the use of renewable energy in every sector, such as residential and public buildings, but also in office and industrial buildings. To achieve the goal set, another European Directive was issued. According to the European Directive of 2010/31/EU there has been an establishment of a general guide concerning the evaluation and calculation of each building’s energy efficiency status. Thus all existing and future buildings must be subjected to an energy audit to determine the existing energy efficiency status or the future energy efficiency status of the building that is in the design process. The evaluation of each public building’s energy efficiency status is a priority, as it is a building that is used by many people and a minimum energy efficiency status must be established. Thus the subject of this paper is to evaluate the energy efficiency status of an existing public building, according to the standards set by the European Directives , make proposals to improve the efficiency of the building’s systems and provide an approximate estimation of the energy savings with the use of the Edge application.

Ευχαριστίες

Ευχαριστώ τους καθηγητές μου, και ειδικά την κ. Εφροσύνη Γιαμά για την υπομονή της και την βοήθεια που μου πρόσφερε για την συγγραφή της διπλωματικής μου εργασίας. Επιπλέον ευχαριστώ την οικογενειά μου για την συνεχή υποστήριξη και κατανόηση σε όλη τη διάρκεια του Μεταπτυχιακού Προγράμματος.

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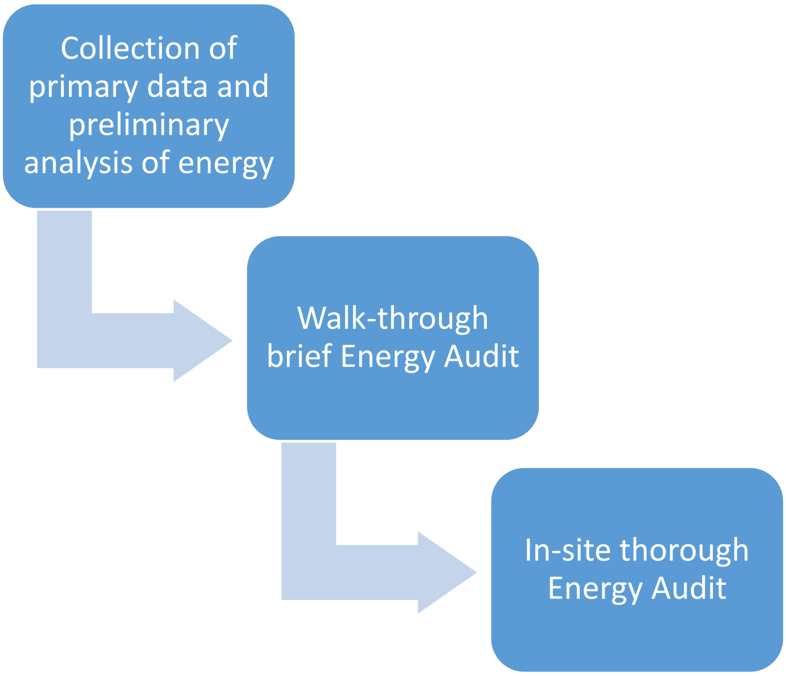
Introduction

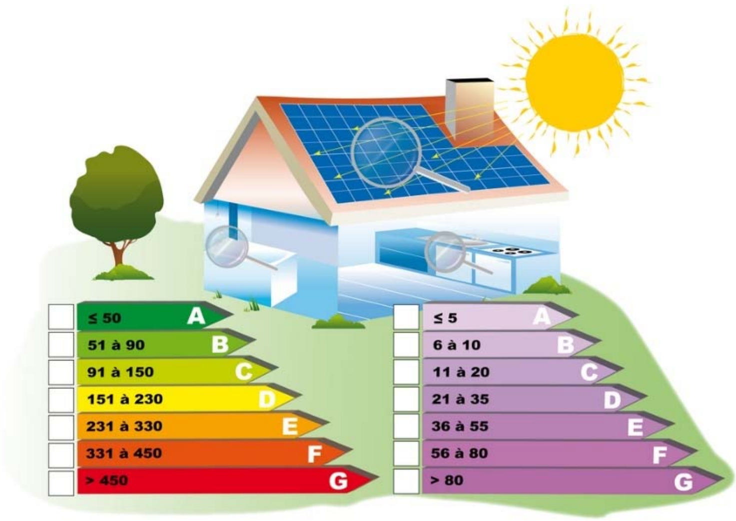
As the technology evolves and the energy needs of each individual become more and more complicated, the consumption numbers have followed an inclined path. The high dependency on fossil fuels for the production of energy is the major problem that in combination with the ever evolving energy needs is the drive force behind the ecological problem of the greenhouse effect. The uncontrolled and CO_2 emissions are responsible for the rise of the planet temperature and the climate change. As a result the European Union has issued multiple directives in order to reduce the energy consumption of its member states and to achieve the energy consumption goals that these directives have set. Part of the solution to the problem is the reduction in the energy consumption of the building sector, through the increase of efficiency of the existing and future buildings. Thus through the European Directive of 2010/31/EU and 2016/1318/EU the guidelines for the establishment of the energy audits of buildings have been placed. Energy Audit of a building, is a procedure which evaluates the energy efficiency status of the building after a careful survey of the building envelop, to determine the energy loss through the walls, windows, floors and ceilings, and the other vital parts of the building. The energy audit estimates the overall efficiency of the building by assessing the efficiencies of the systems of the building. The heating and cooling systems are assessed, to determine how much energy is consumed in order to achieve the desired temperature to the building. Along with the heating and cooling systems of the building, the lighting efficiency and the indoor air quality are assessed. After the energy audit of a building, the energy category of the building is decided and proposals to improve the energy efficiency are made. Such proposals could be the upgrade of the old low efficiency boiler with a newer and more efficient, or the total change of the heating system with another more efficient and a fuel, that is less environmental threatening, as the source of power. The above focus mainly in the old existing buildings and their efficiency improvement, but according to the new European Union legislation, energy audits take place also in the design phase of new buildings to assure that they will achieve at least the minimum efficiency goals of new buildings that have been set. This will help the future buildings be more efficient and energy saving, and as the technology evolves to achieve the ultimate goal of the Zero Energy Building. Finally Greece , having being committed from the early 1990's to this goal, promoted energy efficient and environmental friendly technologies , along with measures to organize and administrate the existing and future building stock , through the participation in declarations and EU programs according to (Centre For Renewable Energy Sources). The results of the above agreements and programs is going to prove significant energy saving and beneficial , not only to Greece as a whole but also its citizens.

The stages of an Energy Audit

The main theme of this paper will be a preliminary energy audit - assessment of a public elementary school in the city of Trikala in Greece and then some actions will be proposed in order to achieve an energy upgrade of the building. Depending on the level of detail on the collected information, energy audits can be distinguished into two types, the walkthrough and the more detailed – diagnostic energy audits. According to the (Centre For Renewable Energy Sources) energy audit guide, the first step in the energy audit process is the scheduling of an energy audit and more importantly the collection of primary data and a form of preliminary analysis of energy. At this step, the energy auditor must come in contact with the building manager who authorized the energy audit. The building manager will provide the necessary initial data and information about the building. These data will be acquired through the completion of a questionnaire. The questionnaire is specifically structured in order to provide the energy auditor with an overview of the past and present energy profile of the building in audit, along with the uses of each space in the building and its construction information. The energy auditor must be provided also with energy consumption data in the form of fuel bills/invoices technical drawings of the building and recorded measurements, if they exist. The next phase in an official energy audit according to (Centre For Renewable Energy Sources) is the walk-through brief Energy audit. At this phase the auditor performs a quick inspection of the building shell and the electromechanical systems of the building. In addition some measurements are conducted in order to supplement the findings of the inspection. Having categorized the findings above , an assessment of the current efficiency of the building follows and a decision is made concerning the energy savings potential of the building. As a result energy saving measures can be roughly proposed in certain areas and a categorization of them, as high, medium, low, according to the impact they will have to the building. Having succeded in the above , it is time for the 3rd and final stage of the energy audit. At this stage the energy auditor will visit the building again in order to make an in-site thorough inspection. This inspection will involve the full examination of the installed energy systems of the building along with in-site measurements. Such measurements are the indoor air quality , and the working condition of the HVAC systems, the efficiency of the lighting systems of the building and the thermal and visual comfort of the building during peak operation hours. The above data and measurements will help the energy auditor to decide the energy rating of the building along with feasible measures , that are accompanied by a sound techno-economical evaluation, that will help the building be more efficient and upgrade its current energy rating.



Picture 1 Stages of Energy Audit



Picture 1 Building Energy Rating Index

According to the (EU Directive 2010/31/EU) , which was updated on (EU) 2016/1318, on the energy performance of buildings, all new buildings must be nearly zero energy buildings by 31 December of 2020, with an exception of the public buildings that must be near zero energy rating by 31 December 2018. This means that by 2018 all public buildings must have an energy rating of A+ with a prospect of reaching even higher in 2021.

Collection of data & analysis of energy

In this paper we will try to implement most of the necessary stages of an energy audit into a public building and then propose energy upgrade scenarios. The public building in question is an Elementary school in the city of Trikala , on which the acting administrator was kind enough to provide some fuel bills and invoices , in order to have a collection of data to perform an evaluation of the buildings energy state. In our case of study and due to the fact that this paper is not an official energy audit of the school, the detail of the collected data provided by the municipal services is not high enough to perform a detailed diagnostic energy audit. As a result the energy audit on this paper will not advance to the third and final stage of an energy audit , as it is described above. In addition the above, there are some measuring tools needed to achieve a higher level of detail in the audit, that we do not possess. Such measurement tools are tools that measure liquid and gas fuel flows , tools for electrical measurements such as voltage , current intensity and power, tools to measure the temperature , the pressure of fluids in tubes , emission measurement tools , relative humidity levels and luminance levels. Thus the level of detail of the energy audit performed in our case will be that of a walk-through energy audit , which will assess the site energy consumption and relevant costs on the basis of some energy bills-invoices that have been provided by the school administration and a short on-site autopsy. Based on the above some basic energy saving measures will be proposed , along with a projected cost. This chapter will involve the collection of data concerning the building , and a basic analysis of energy performance.

Building Identity

One of the first and most basic things in an energy audit is the establishment of the building's identity. The term of identity is a summary of all the basic information of the building , such as the history of the building and the location , the characteristics of that location, orientation, altitude, weather , open space or crowded building area. Important factors in the establishment of that identity is also the history of the building and the year of construction, as these information can reveal the design principals of the year of construction and provide insight over the materials used and their properties. The building administrator and manager will provide most of the above with the completion of the energy audit questionnaire. In our case the administrator of the public Elementary school is the one who filled the energy audit questionnaire and helped through the entire process and provided the required bills/invoices in order to have some clue about the school's energy consumption and time periods of the consumption.

Picture 3rd public Elementary school of Trikala (Google Maps, n.d.)

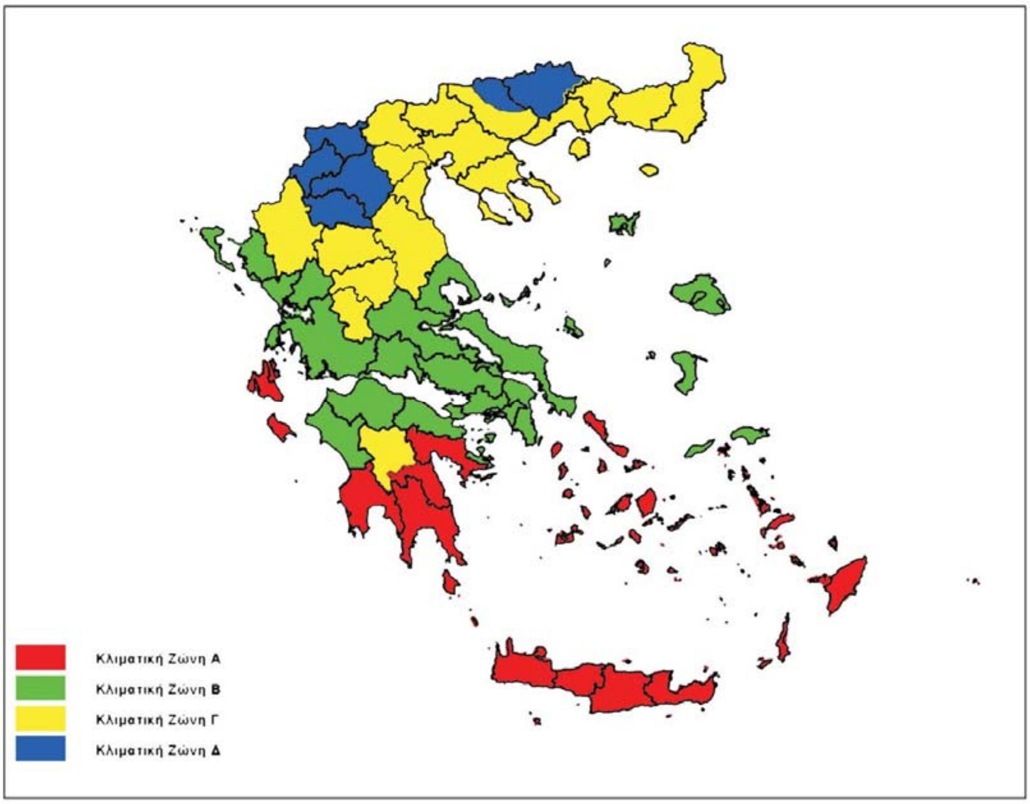
Picture 4rd public Elementary school of Trikala (Google Maps, n.d.)

Picture 43rd public Elementary school of Trikala (Google Maps, n.d.)

Climatic Zones of Greece

The Thermal Insulation Regulation effective in Greece since 1979, divides the country into four climatic zones, which are presented below. Buildings of the climatic zone A, which is characterized by a mild climate, have high cooling and low heating requirements. Buildings in zone B have equally balanced heating and cooling requirements, while buildings in zone C, which is one of the coldest zones, have high heating and low cooling requirements. The fourth zone is the zone D and is the locations that are in the most northern part of the country. Four characteristic locations, one for each zone are Chania for zone A, Athens for zone B, Thessaloniki for zone C, and Drama for zone D.

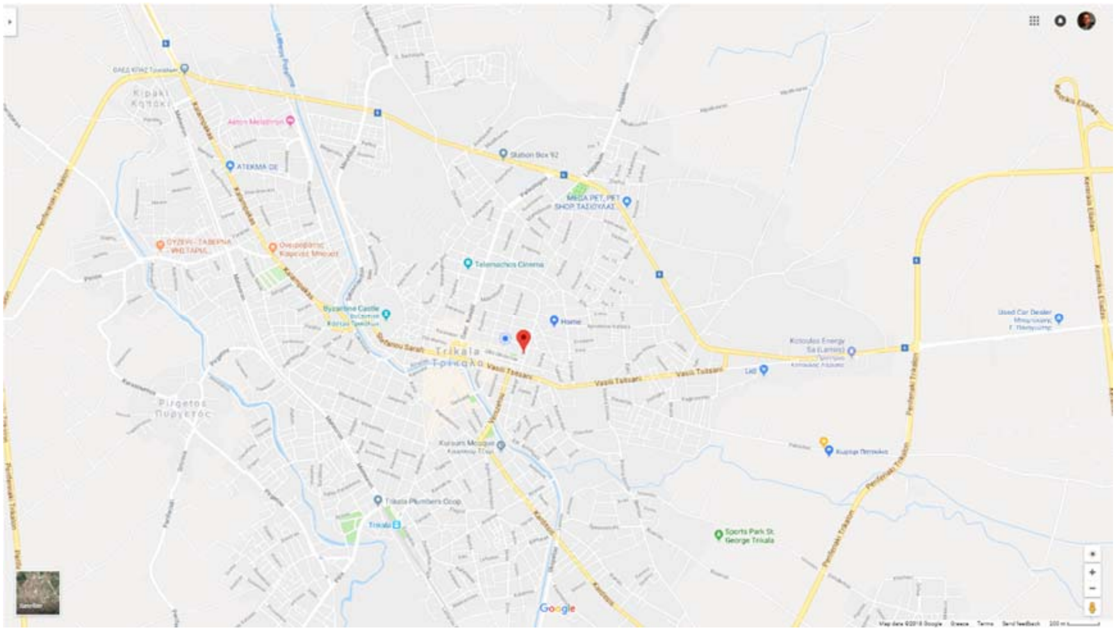
Despite that climate is a crucial factor in the thermal behavior of buildings, no specific distinction is made in the design or construction of school buildings depending on their climatic zone or location.



Picture Climatic Zones of Greece (Technical Chamber of Greece, 2017)

Region and orientation

The region and orientation of the building is an important factor in every energy audit, as the climate is differs from region to region and from altitude to altitude. For example , in higher altitudes that the climate is more harsh and the temperatures in winter are far lower in comparison to the low altitude plains , the achievement of a high energy rating building is a more complex and difficult task. The orientation of a building is also important , as it can show the direction the building faces and openings , and as a result the exposure of the openings in sunlight and northern or southern winds. The building that we will perform the energy upgrade is an Elementary school in the city of Trikala. Trikala is one of the regional units of Greece, forming the northwestern part of the region of Thessaly. Its capital is the town of Trikala. The regional unit includes the town of Kalampaka and the Meteora monastery complex. The southeastern part belongs to the Thessalian Plain. The forested Pindus mountain range dominates the western part. The northern part of Trikala is also mountainous and made up of forests and barren lands, the ranges here are Chasia and Antichasia. Its major river is the Pineios, flowing to the south and east. The city of Trikala is located in the central region of Greece in the plains of Thessaly. The region of Trikala is a region with a total area of 3383,48 km^2 and a population of 131,085 according to the census of 2011 (Greek Statistical Department) , leading to a density of 39 people / km^2. It is a small city with a size of 81,365 people and the city is spread to a space of 608,5 km^2 , with a population density of 130 people/ km^2. The size of the city space is large and along with the small numbers of the population has lead to the city’s development in horizontal space rather than height. Most of the buildings in the city have no more than 3 floors with the exception of the center that in a small area are 5 and 6 floor buildings. The altitude of the region is 107 meters above the surface of the sea according to google maps data that are considered accurate. The region of Trikala is in the climatic zone C according to the climate zones of Greece. The climate in Trikala is warm and temperate. The winter is more harsh that other locations in the zones A and B and there is much more rainfall than in summer. The average annual temperature is 16.0 °C and the rainfall averages 700 mm. The entrance of the building is on the east side and is at 85° degrees from the North axle. The building is located in its own building complex in the center of Trikala, beside the old and new Courthouse buildings. The school complex houses 2 Public Elementary Schools. The two Elementary Schools are the 3rd Elementary School of Trikala, the one which we will investigate, and the 32nd Elementary School of Trikala. The Schoold complex is surrounded by 3 streets, Georgioy Olympioy on the North, Averof on the East side and 28th Octomber on the South side. On the West side the building the Schoold yard is separated from the Courthouses by a paved pedestrian street and a small square. The longitude and latitude of the building according to google maps, is 39°33'21.0"N and 21°46'22.2"E.



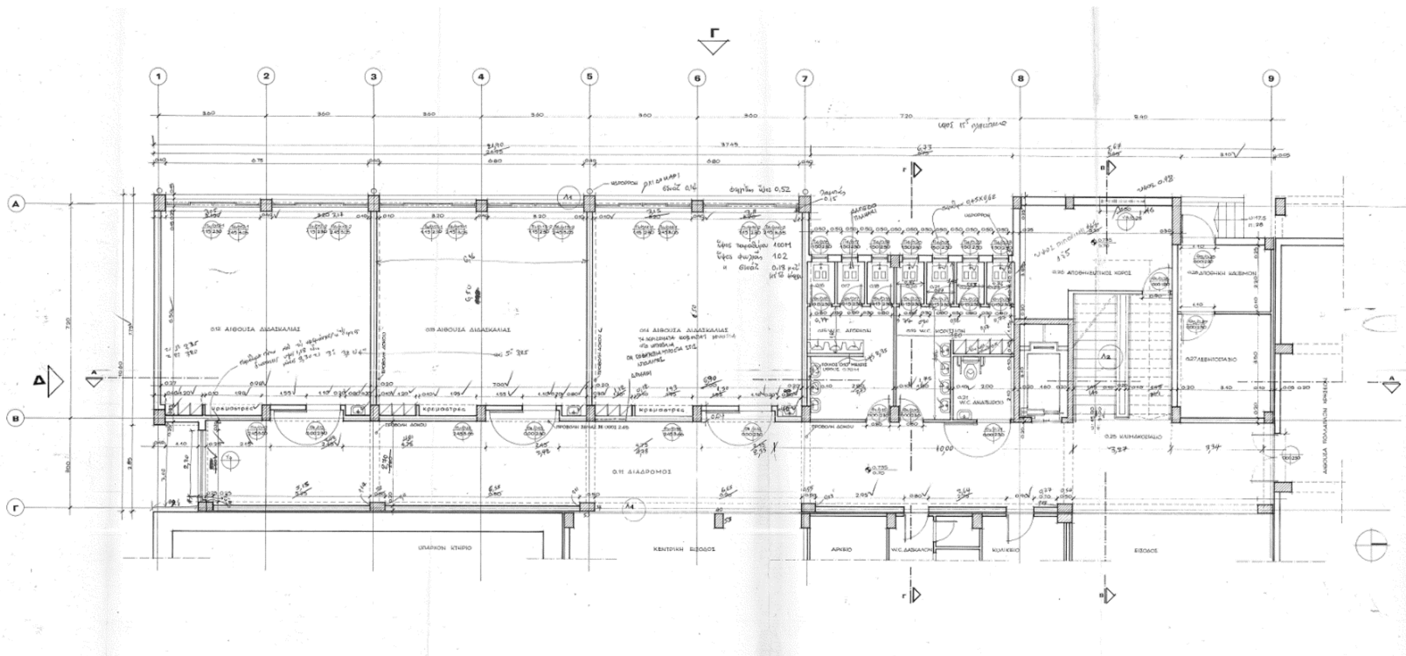
Picture 3 Map of the city of Trikala (Google Maps, n.d.)

Picture 4 Location and Orientation of the School (Google Maps, n.d.)

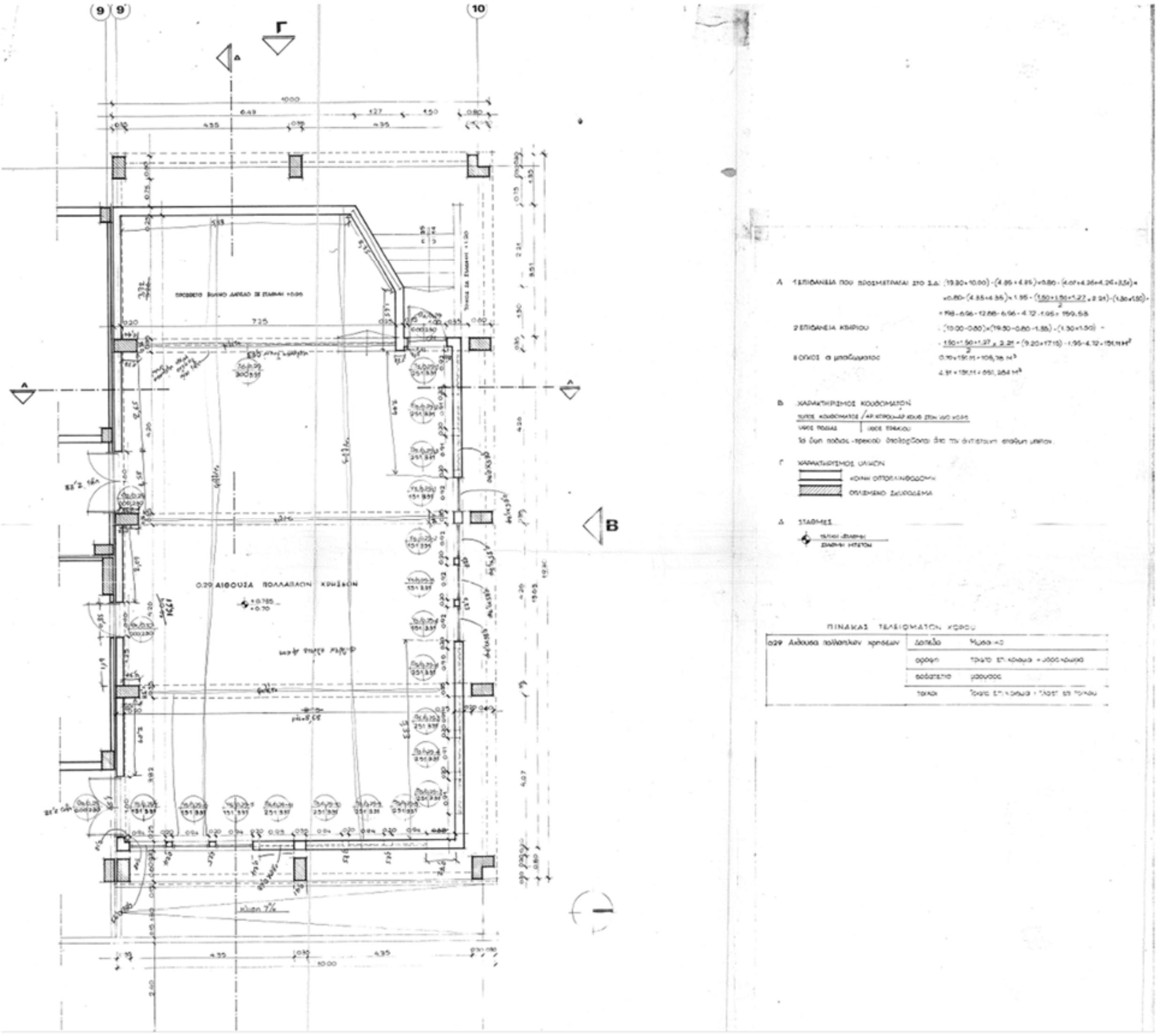
Building characteristics

Each building has its own special shape and plans , and other traits that make the building unique. Such traits can be the position of openings and the direction they face, along with the area of the openings in each direction. Also one building characteristic is the number of floors , the existence of a basement and the surrounding space and many more. Each specific trait of a building helps the energy auditor create a draft profile about the conditions that the building is exposed , such as if there is shading in the needed areas , where the shading comes from and if the building has free space surrounding it.

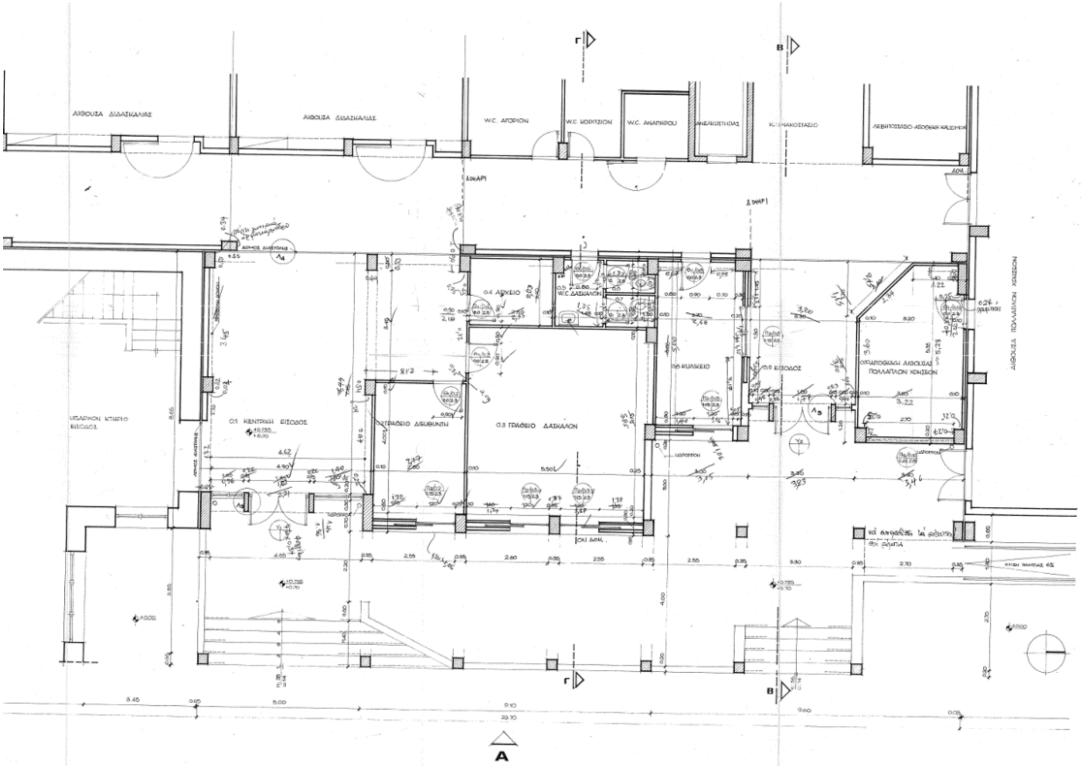
In our case the building is a public Elementary school located in the center of the city of Trikala. The building has been constructed in 1989, thus making it almost 30 years old, and has been in the ownership of the state from the start. The area of the location of the building is a high populated area with 5 storey buildings on the East and North sides of the School complex on Averof and Georg. Olympioy Streets, while on the West and South sides the building complex is surrounded by open spaces and squares. As a result the surrounding area Southwest of the building is free of obstacles leaving the wind masses to move freely around the building, while the Northeastern side has high buildings. While there are high buildings on the North and East side of the Complex, the distance of is of the high buildings (20.90meters on the Averof Str. and 41.70 meters on the Georg. Olympioy Str.) in the vicinity ensures that the building is not shaded by surrounding structures. The yard of the school is planted with deciduous trees on the southern side of the building that provide shading in the first floor of the building during the hot summer or spring days. The east side of the building is completely free of plants and is paved, as that side is the main entrance of the building and a place of gathering during morning and intermission. The building shape is almost rectangular as it was designed as an addition to the existing old building of 32nd Elementary School and is composed of two floors. The ground floor is elevated in a height of 0.70 meters from the ground , with each floor height being 4.30 meters. The building has no basement and as a result the elevation of 0.70 meters of the ground floor is filled with rubble. As the building has been designed as a school from the start, the building has window and door openings in all four directions. The total area of the building is 1455.83 m^2, with the area of the ground floor being 705.345 m^2 and the area of the first floor being 750.485 m^2. The total volume of the building is calculated at 6537.29 m^3 , with the volume of the ground and first floor being 3040.03 m^3 and 3497.26 m^3 accordingly. According to the plans that the urban planning department has provided , the ground floor is consisted of 3 classrooms , a recreation area , the boiler room , the room of the professors, the floor toilets, a secretarial support room, the office of the administrator, the Canteen, the Central hallway and Entrance and 3 storage rooms. The second floor is consisted of 6 classrooms, toilets, storage rooms and the central hallways. To move between floors there is a staircase in the top right corner of the building , that have a large opening to provide the space with natural sunlight. The building being a single storey building has no elevator, thus no additional energy demands for the movement between floors. Finally the building has a terrace and not an inclined roof. Below will follow the plans of the two floors, in order to provide an overall image of the faces of the building and the openings area percentage over each face.



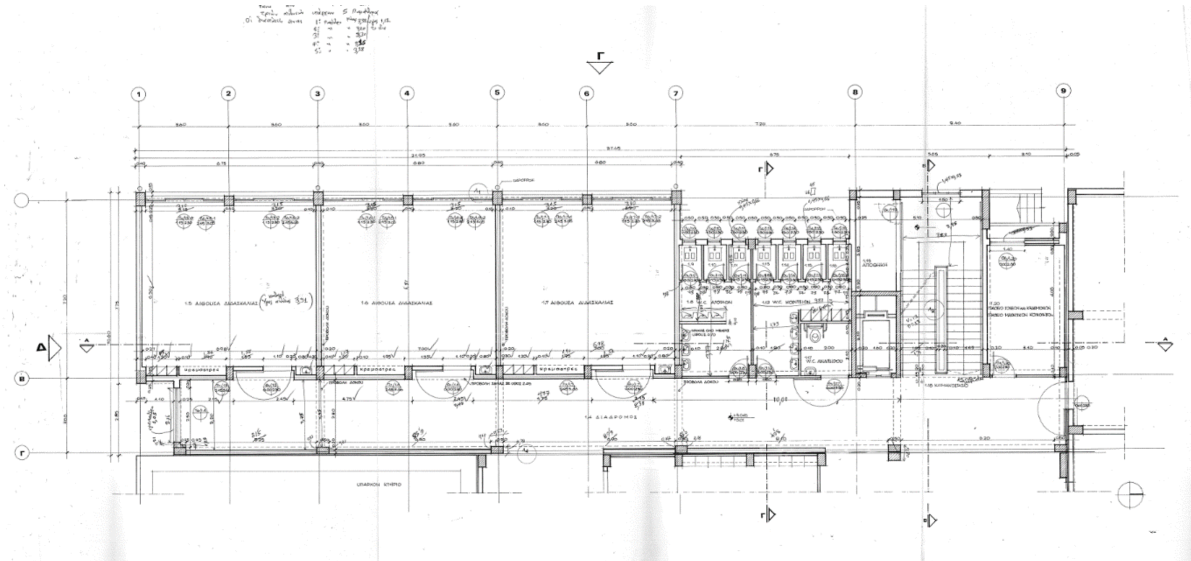
Picture 5 Ground Floor Plans (Urban Planning Department)



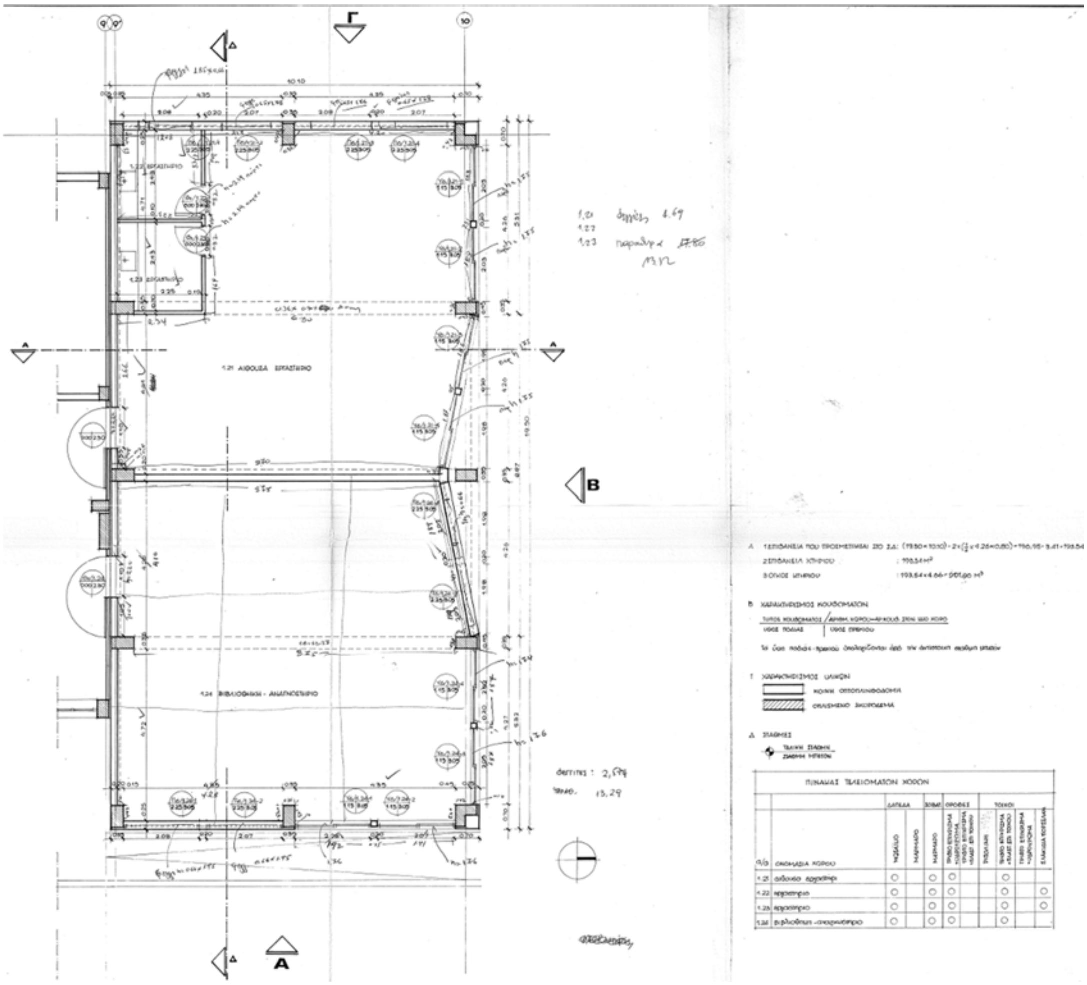
Picture 6 Ground Floor Plans (Urban Planning Department)



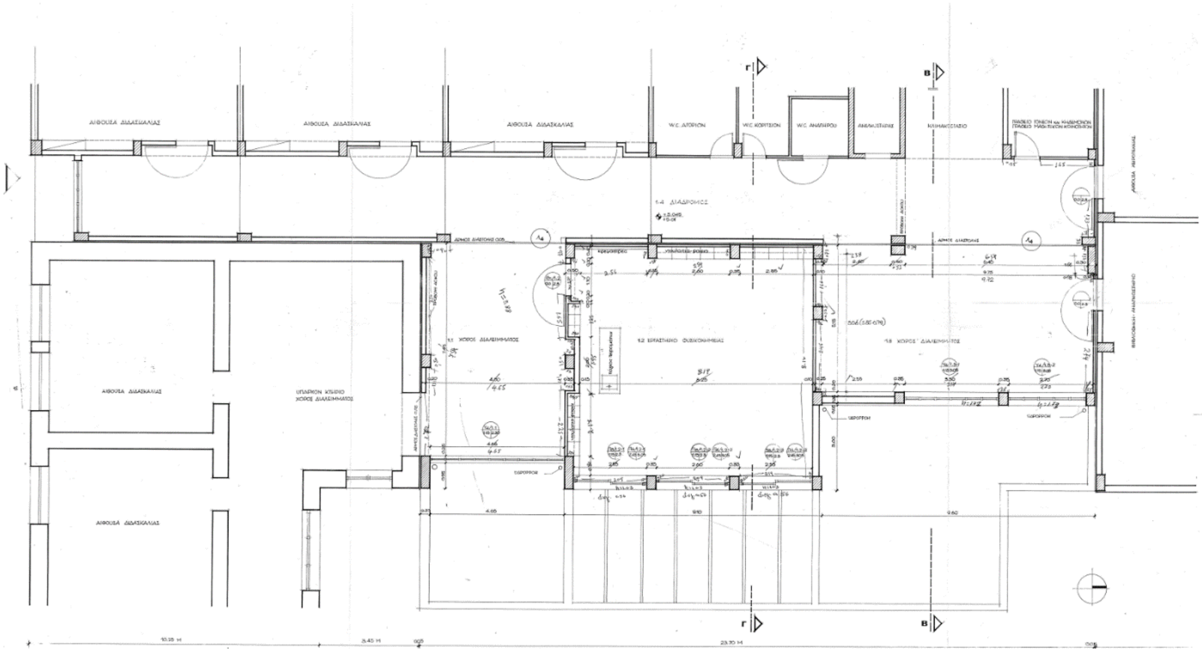
Picture 7 Ground Floor Plans (Urban Planning Department)



Picture 8 First Floor Plans (Urban Planning Department)



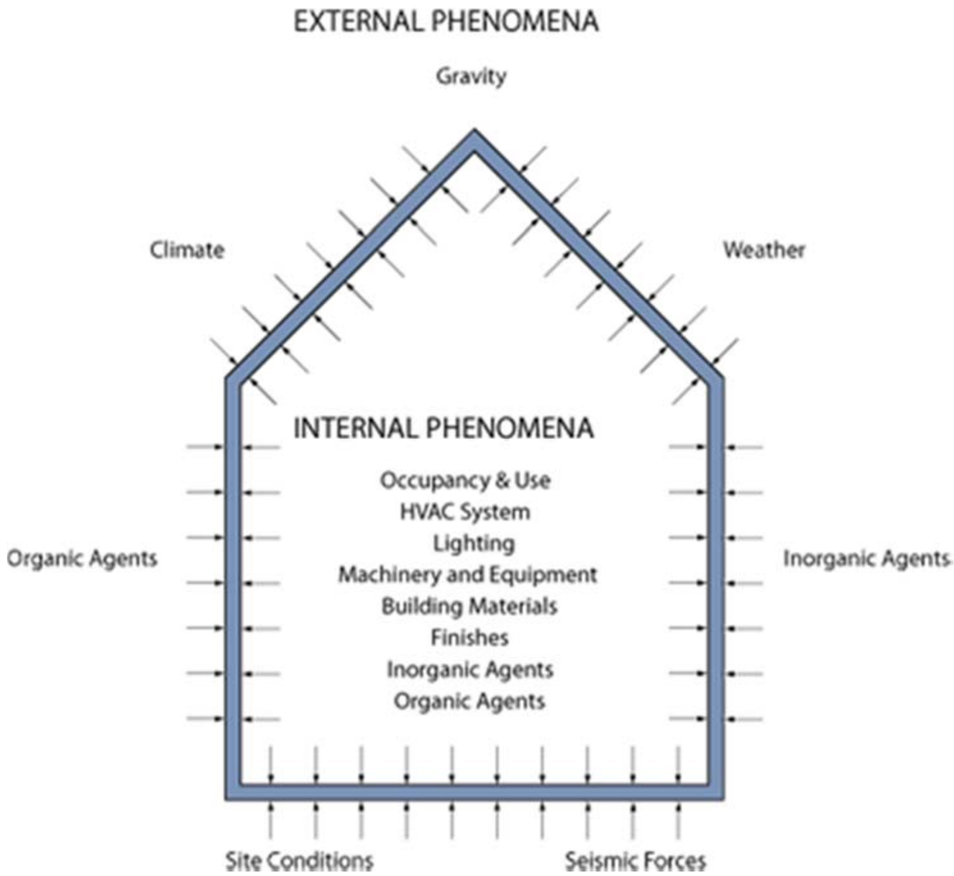
Picture 8 First Floor Plans (Urban Planning Department)



Picture 9 First Floor Plans (Urban Planning Department)

Building envelope

The building envelope is essentially the shell of the building, such as the external walls and windows , the roof, floors and doors, everything that separates and protects the inside of the building from the weather conditions. The importance of the envelope of the building is paramount if we want to achieve a highly energy efficient building. That is because the envelope is the barrier that provides protection to the inhabitants of the building from the cold temperatures during the winter and the high temperatures of the summer. Thus the importance of the proper insulation of the building envelope becomes clear. According to (Technical Chamber of Greece, 2017) with the thermal insulation of the structural elements of buildings we are trying to limit the heat exchange between the internal and external environment of a building to a minimum amount and at the same time achieve a user pleasant inner climate inside the building with the minimum possible energy consumption. In that way , during the winter (cold) season the thermal losses towards the external environment will be limited , and during the summer (hot) season the overheat of the building's interior because of direct sunlight will be limited.



Picture 11 Building Envelope - External Phenomena

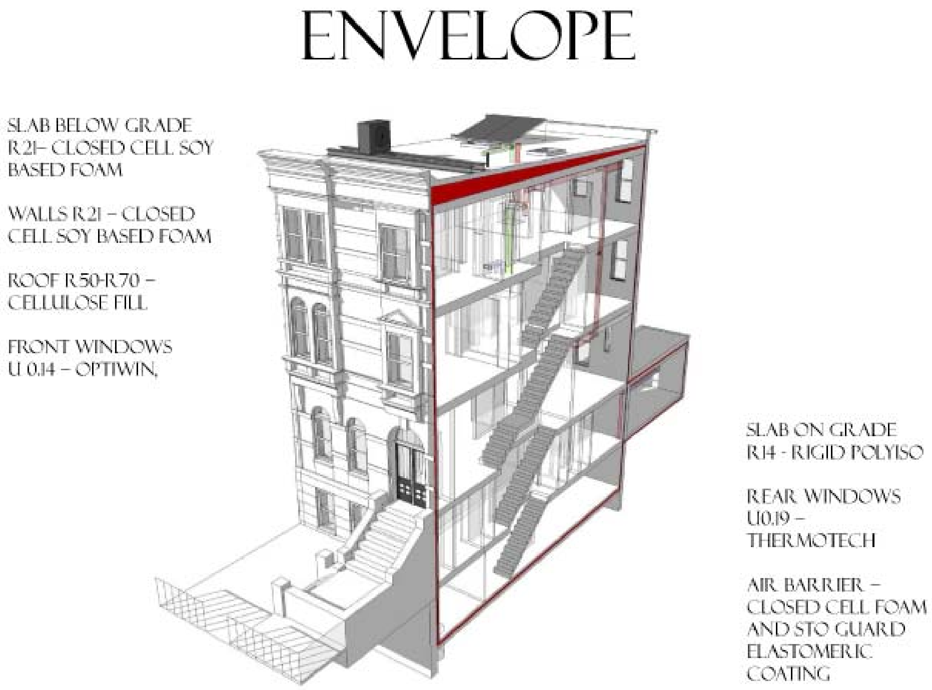
On the same time , the thermal insulation of the buildings envelope the risk of superficial condensation to be manifested is limited and thus the structures are protected against moisture phenomena in the building's interior.

More generally the consumption of energy is limited and as a result the fuel consumption rate drops and the pollution of the environment due to gas emissions is limited also.

Finally the Greek building energy rating directive (K.Ev.A.K.) imposes the thermal insulation of buildings and on the same time helps towards this goal by evaluating the thermal insulation aptitude of the building in two ways :

- The evaluation of the thermal insulation of each individual structural element
- The evaluation of the thermal insulation of the building envelope as a whole

To evaluate the thermal insulation of the building envelope and that it meets the minimum standards, the building characteristics are needed along with the building's specifications and construction plans. In many cases , the construction plans of a building will not provide the necessary information to the energy auditor in regards of thermal insulation , its type and the thickness, or the window types. This is mostly happening in energy audits in old buildings , due to the fact that as the time passes and more and more variables contribute to the final design of the buildings , the information of construction plans becomes more and more precise. Thus as mentioned above in the building characteristics and building identity sections , the energy auditor must extract information about the building from every source.



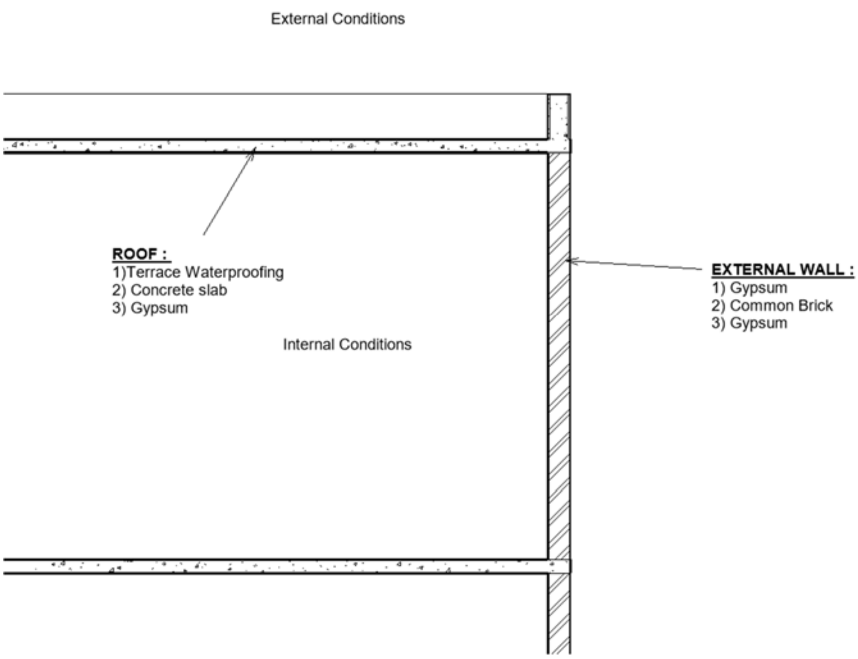
Picture 12 Building Envelope picture provided by (Passive House Brooklyn, n.d.)

In our case , the construction plans of the building provided by (Urban Planning Department) did not contain the information about the thermal insulation of the building. The school building was constructed in 1989 , and at that time the thermal insulation standards were different and thermal insulation was not used in the building. Below follow more detailed analysis about each part of the building envelope and their properties.

Roof Insulation properties

In the past decades in Greece, and specifically 1989's and onwards when the thermal insulation of the buildings began to be implemented, the thermal insulation of the roof was non existent. On that time the thermal insulation of buildings was only limited to the insulation of walls and the materials used where very basic and thin. Due to the construction date of the building we study, the roof was not thermally insulated too. Depending on location and climate , each country has it's own building techniques and principles. While in America and Canada most of the buildings are made from lumber, in Greece all the building's structural elements are constructed from concrete, thus floors and roofs structural material is reinforced concrete.

In the building that we are studying the roof is composed of two parts. The first part is the roof horizontal concrete slab and has a surface area of 750.48 m^2, and above the roof slab is the second part which is terrace sealer in order to make the terrace waterproof. In order to calculate the U value of the roof only the first part of the roof will be taken into consideration. Below will follow a detail of a section plan of the school provided from (Urban Planning Department) to show to the structure of the roof , showing that the insulation is non existent.



Picture 13 Building Terrace Section

The concrete roof slab of the building is where the waterproofing is located along with a gypsum finishing coating. According to data from (Technical Chamber of Greece, 2017) the U values from the materials used in the terrace is as follow. The concrete slab is considered to have a U value of 2.03 Watt/m^2 ^oK and the thickness of the slab is 20 cm according to the section in the construction plans. The gypsum coating has a U value of 0.87 Watt/m^2 ^{o} K and a thickness of 2 cm. Below follows a table of the materials and some of their information , presented in an order from the material on the inside towards the material on the outside.

Material	Thickness	U value	Color
Gypsum	0.02 m	0.87	white
Concrete Slab	0.20 m	2.03	grey

Table 1 Roof Materials list and U values

Having categorized the materials , their U values and their thicknesses , we can now start to calculate the U of the slab roof. According to (Technical Chamber of Greece, 2017) the U value of a multilayered slab composed from different materials is :

$$\frac{1}{U_{total}} = R_{Gypsum} + R_{Concrete} = \frac{0.02}{0.87} + \frac{0.2}{2.03} = 0.121 \frac{m^2 K}{Watts}$$

$$U_{total} = \frac{1}{0.121} = 8.264 \frac{Watts}{m^2 K}$$

Floor Insulation properties

There are two floors on the building if the ground floor is to be taken in mind. The concrete slab on the first floor has not been thermally insulated because it is between two floor that are heated and it is inside of the building envelope. The ground floor is the floor that is part of the building envelope and the one that comes in contact with the ground. The surface area of the ground floor is 705.34 m^2. At the time of the buildings construction , thermal insulation was not added on the ground floor slab, same as the roof and walls. Thus the floor is compromised of three layers of materials that are described below. The first layer that comes in contact with the ground is the concrete slab that is also the structural material and has a thickness of 20 cm and a U value of 2.03 Watts/m^2 ^oK . The second layer of the ground floor is the cement paste that is needed to glue the marble tiles of the floor. The thickness of the paste is 3 cm and the U value according to (Technical Chamber of Greece, 2017) is 0.87 Watts/m^2 ^oK . The final layer of the ground floor is the marble tiles that have been placed over the concrete paste or a cement – gravel mix called Mosaiko. The thickness of the marble tiles is 1,5 cm and the U value of marble is 3.5 Watts/m^2 ^{o} K. Also on the marble layer there has been natural tare of the surface due to usage. Below will follow a table of the materials and their specifications listed in an order from inside towards the outside.

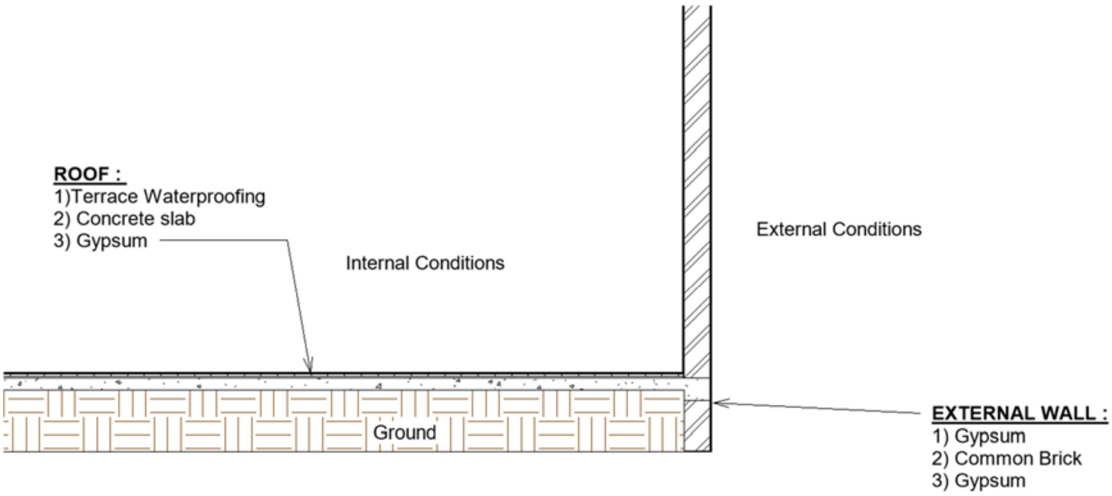
Material	Thickness	U value	Color
Mosaiko - Marble	0.015 m	3.5 Watts/m^2 °K	White
Concrete Paste	0.03 m	0.87 Watts/m^2 °K	Grey
Concrete cast in Site	0.20 m	2.03 Watts/m^2 °K	Grey

Table 2 Floo Materials list and U values

Having categorized the materials that consist the ground floor , we can now calculate the total U value of the floor.

$$\frac{1}{U_{total\ floor}} = R_{marble} + R_{paste} + R_{concrete} = \frac{0.015}{3.5} + \frac{0.03}{0.87} + \frac{0.2}{2.03} = 0.137\ \frac{m^2K}{Watts}$$

$$U_{total\ floor} = 7.283\ \frac{Watts}{m^2K}$$



Picture 14 Ground floor material section

Wall Insulation Properties

The walls of the building can be assigned in two categories, the external walls and the internal walls. The internal walls are less thick and have no insulation , with a thickness of 11 cm , with a three layers of materials. The three layers are composed of the two external coatings of gypsum that have a thickness of 1 cm each and the core structural material which is brick and has a thickness of 9 cm. The external walls are part of the buildings envelope and have a thickness of 25 cm and is composed by three layers of materials. The external layers of the wall are composed of gypsum, while on the core of the wall is the 20 cm of common brick. The external surface area of the walls on ground floor excluding the surface area of windows is 330.47 m^2, while on the surface of the external walls on the first floor is 379.52 m^2. Along with the external walls , there are also the concrete wall columns that in some cases have a length of almost 2.5 meters. The concrete walls are also not thermally. The concrete walls are composed from two layers of 1 cm gypsum on both sides , along with 25 to 40 cm of reinforced concrete. The surface area of the concrete walls on each floors are as follows, measuring 60.68 m^2 on first floor and 86.44 m^2 on the second floor. Below the U values for each of the two kinds of wall will be calculated.

$$\frac{1}{U_{total\ brick\ wall}} = R_{gypsum} + R_{brick} + R_{gypsum} = \frac{0.015}{0.87} + \frac{0.22}{0.64} + \frac{0.015}{0.87}$$
$$= 0.378\ \frac{m^2 K}{Watts}$$

$$U_{total\ brick\ wall} = 2.643\ \frac{Watts}{m^2 K}$$

$$\frac{1}{U_{total\ concrete\ wall}} = R_{gypsum} + R_{concrete} + R_{gypsum} = \frac{0.015}{0.87} + \frac{0.25}{2.03} + \frac{0.015}{0.87}$$
$$= 0.157\ \frac{m^2 K}{Watts}$$

$$U_{total\ concrete\ wall} = 6.343\ \frac{Watts}{m^2 K}$$

Now , according to the above since we have the U value of each type of wall and the surface area of each wall, we could calculate the combined U value of each face of the building. This would be required in order to input the combined U values of each face of the building and its orientation on the computer , along with the other U values and surface areas of the other elements of the building envelope. This would lead to the calculation of a total U value of the building. But since there will be no computer interaction in this paper the procedure will stop here.

windows / openings

The windows and openings in the shell of a building is a major reason for energy losses because of the significantly higher U values of the windows and doors. Thus the external window joinery and glass fonts constitute complete structural elements that fill the external wall openings in each face of the building. As parts of the building envelope they must meet the minimum design specs in order to protect the interior spaces from the external conditions (temperature variations, rain, snow, wind , noise, dust) and in addition to ensure the desirable levels of visual comfort, acoustics and easy contact and movement on the building interior and exterior and permit the natural lighting and ventilation of each space. Finally they are an important part of the building's architecture.

The window surface area in the case of our school, is big in both floors. The window surface area of the ground floor is 81.45 m^2 , while the window surface area of the first floor is 98.66 m^2. This means that the windows are an important part of the building envelop of the school and is a possible sector of the school where an upgrade can take place.

The window type that is currently installed on the building is the aluminum windows with single glass with no thermal stop. These windows were installed during the construction of the building and according to (Technical Chamber of Greece, 2017) have a U value of 6.0 Watt/m^2K, which is quite high in today's standards. Below follows a detailed table containing the number of windows, their dimensions , the surface area of each unit and the total surface area for each floor.

Number of Units	Dimensions Width X Height (m)	Unit surface area (m^2)	Total surface area (m^2)
6	3.20 x 1.15	3.68	22.08
6	3.20 x 0.52	1.66	9.96
1	2.20 x 1.05	2.31	2.31
7	0.45 x 0.60	0.27	1.89
1	1.50 x 0.48	0.72	0.72
1	1.10 x 2.30	2.53	2.53
1	1.00 x 2.30	2.30	2.30
11	0.85 x 0.70	0.56	6.16
7	0.88 x 1.75	1.54	10.78
1	1.59 x 2.30	3.66	3.66
1	1.77 x 2.30	4.07	4.07
2	0.40 x 1.80	0.72	1.44
4	1.20 x 1.06	1.27	5.08
1	1.40 x 1.86	2.60	2.60
1	0.96 x 1.86	1.78	1.78
1	1.85 x 2.21	4.09	4.09
First Floor total surface area			81.45

Table 3 1st Floor Openings Surface Area

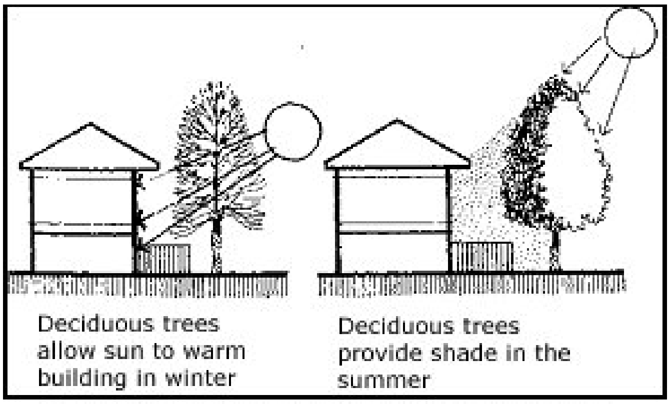
Number of Units	Dimensions Width X Height (m)	Unit surface area (m^2)	Total surface area (m^2)
6	3.15 x 1.15	3.63	21.78
6	3.15 x 0.52	1.64	9.84
1	2.20 x 1.05	2.31	2.31
7	0.45 x 0.66	0.30	2.10
1	1.40 x 2.30	3.22	3.22
4	1.80 x 0.65	1.17	4.68
2	2.03 x 1.75	3.55	7.10
2	1.87 x 1.75	3.27	6.54
2	1.89 x 0.66	1.25	2.50
2	1.91 x 1.76	3.37	6.74
2	1.95 x 0.66	1.29	2.58
1	2.72 x 1.75	4.76	4.76
1	3.15 x 1.75	5.52	5.52
2	2.09 x 1.59	3.33	6.66
2	2.19 x 1.59	3.49	6.98
1	4.65 x 1.15	5.35	5.35
Ground floor total surface area			98.66

Table 4 Ground floor Opening Surface Area

Shading

The existence of shading in the window openings of the building is important, especially in a climatic zone that the summer is hot. Shading is the first energy measure that must be put in use in order to achieve a lower temperature in the interior of the building during summer and thus decrease the cooling needs of the building. The shading system must be designed in such a way , that in summer that the sun is high, shading of the windows can be achieved and in addition on winter that the sun is low , the shading system must allow the sun to heat the interior of the building.

Our building has not shading systems installed on it's windows , but there are tree planted on the southern side of the building. These trees are deciduous , meaning that during winter they drop their leafs leaving the sunlight to warm the interior, but in the summer their leafs provide shade to the building. The height of the trees is not enough to provide shade to the classrooms of both floors, leaving the first floor classrooms unshaded during summer.



Examples of side landscape features that help to conserve energy

Picture 15 Deciduous trees shading

Operation hours

The operation hours of each building is an important factor that adds to the sum of the energy consumption. The operation hours , the number of users of the building and the peak and low hours of use are the factors that contribute to the formulation of the energy consumption of the building. There are many different schools , some of which, operate only in the morning until midday hours and there are others that are open all day and operate as both day and night school. The school that we are currently studying is a morning school only, meaning that it starts its operation from 7:00 and closes at 14:00 each day , with a 5 day each week schedule. Generally, a school operates from Monday to Friday for teaching. The school operates 185 days for that school year, with varying operating days. Finally during the operation hours the number of users reaches a peak number of 282, of which 257 are children aged between 15-18 and the rest are the educational, secretarial and cleaning stuff. The number of users peaks on Wednesday and Thursday during 12:00, that the education program is mostly 7 hours.

Operation Hours	
7:00 – 15:00	
Number of Students	257
Number of Stuff	25
Total Number of Users	282

Table 5 Number of Stuff and Students

Operation Hours of each area of school	
Type of Area	Monday – Friday Usage hours every day
Teachers room	8
Class	6.5
Administrators room	3
Hall	1
Science Laboratory	1
Computer room	1
Gym – Gathering room	1
Toilet	7

Table 6 Operation Hours of SChool

Energy Consumption and Cost

According to the energy audit guide from (Centre For Renewable Energy Sources) during a walk through audit, the energy consumption information and the cost information are supplied by the manager of the building in the form of fuel bills , energy bills and invoices , that will help the energy auditor form an opinion about the energy consumption of the building he is auditing. To properly form his opinion the energy auditor will need bills and invoices of the last five years , in order to know the energy consumption history. To our case the school administrator has provided the power consumption numbers of one year and the oil fuel consumption data of the last year. Below will follow a list of the electrical equipment of the school and their predicted consumptions. The usage hours of the electrical equipment depend on the operating hours of the school.

Equipment type	Quantity	Power rating/ equipement Watts (W)
A/C 9000 Btu	3	1150
A/C 24000 Btu	1	4000
Amplifier	1	250
Desktop computer	5	200
Fax	1	100
Fridge	4	100
kettle	2	1850
Lights (T8 fluorescent lamp , 1200mm)	320	32
Microwave	1	800
Photocopier	2	1300
Printer	5	120
Stand Fan	1	50
Tv	1	150

Table 7 SChool Electric Appliances Record

Energy Consumption last year

According to the invoices by the Public Electricity company provided by the school administrator, the power consumption of the school had an average value of 2531 kWh each month through a 12 month period. Meaning that the total power consumption is calculated at 30372 kWh.

In order to satisfy the heating needs the school uses an old oil boiler constructed in 1995. The fuel consumption values of the school for space heating for the last year have been also provided from the administrator in the form of fuel bills and the refueling dates. The heating system was used for 7 consecutive months last year, starting from 25 of October and finishing in 31 April.

According to the energy data , the oil fuel consumed in these seven months sums up to 9350 liters of Diesel. Having in mind that the lower calorific capacity H_u of Diesel is 10 kWh/liter , we can calculate the kWh of energy consumed from the oil boiler, to almost 93500 kWh. Below will follow tables showing more accurately the energy and power consumption each month according to the data provided.

Monthly Energy Consumption

The energy consumption data are dated from 2017, thus we will use the Diesel oil prices of 2017. In October 2017 , the Diesel heating oil distribution began with a cost of 0.944 Euro / liter, higher in comparison to 2016 that was 0.92 Euro/ liter, and ended at a cost of 1.025 Euro / Liter in April 2018.

Month (Refuel date)	Fuel Quantity (liters)	Energy (kWh)	Cost (Euro)
September 2017	-	-	-
October 2017	1200	12000	1132.8
November 2017 (25/10/2017)	1900	19000	1793.60
December 2017 (4 /12/2017)	1800	18000	1710
January 2018 (27/12/2017)	1750	17500	1680
February 2018 (23/01/2018)	1900	19000	1922.80
March 2018 (20/02/2018)	2000	20000	2050
April 2018	1150	11500	1178.75
May 2018	-	-	-
June 2018	-	-	-
July 2018	-	-	-
August 2018	-	-	-
Total Sum	11700	117000	11467.95

Table 8 Fuel Consumption Records of 2017 Winter

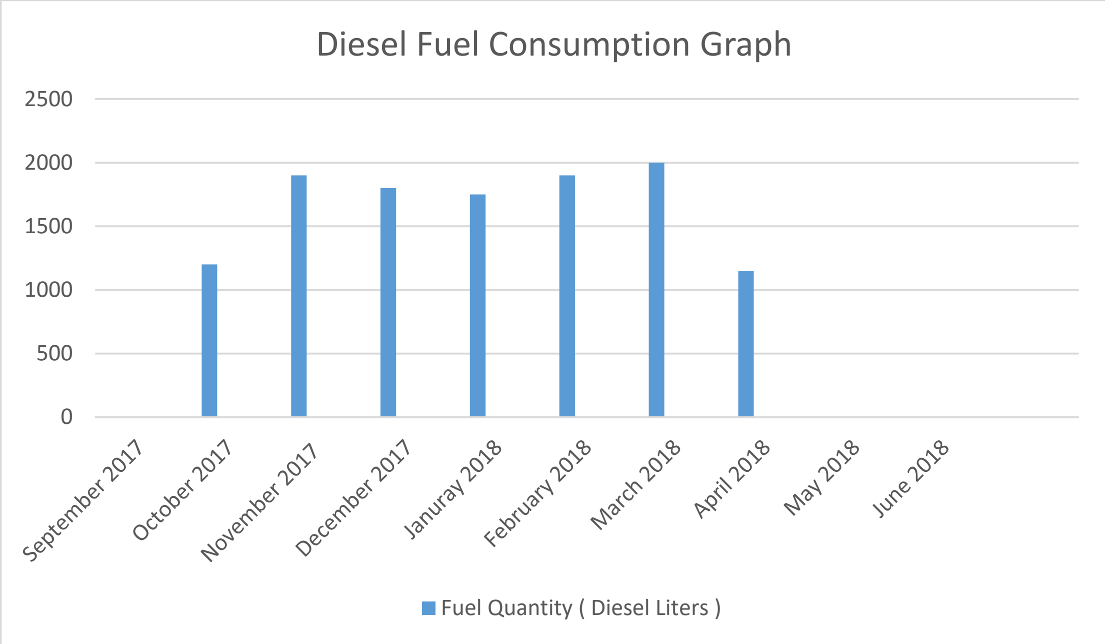


Table 9 Heating Fuel Consumption Graph Winter 2017

From the table and graph presented above featuring the diesel fuel consumption for space heating the year 2017-2017, we can see that the heating systems are mostly used during a period of 7 months , usually from October to April , with an average refuel quantity of 1671.42 liters and an average cost of refueling of 1638.27 €.

Monthly Power consumption

The monthly power consumption data are from the year 2017 , thus we will use the power consumption rates of 2017 according to the Public Power distribution Company. Below will follow a table with the tariffs depending on the scale of usage according to Public Power distribution Company.

kWh	€ / kWh
0 – 800	0.08436
801 – 1000	0.10404
1001 – 1200	0.10644
1201 – 1600	0.10814
1601 - 2000	0.11423
2001 – 3000	0.14347
3000+	0.14798

Table 10 Power Consumption pricing list

A table with the power consumptions of 2017 and their cost each month will follow, calculated according to the price rates mentioned above.

Month	Power Consumption (kWh)	Cost
January	2680	295.61
February	2903	327.60
March	2860.3	321.477
April	2851.78	320.255
May	2990.45	340.150
June	3150.66	363.810
July	374.25	31.571
August	257.11	21.689
September	1854.54	181.577
October	2546.21	233.374
November	2756.31	306.558
December	3413.32	402.683
Fixed Maintenance Costs		9.24
Total Cost of Power for 2017		2532.384

Table 11 Power Consumption Record for 2017

From the table and the power consumption graph of the school building for the year 2017, we can see that the consumption peaks mostly at December, May and June, where the energy needs for space heating and cooling are at their peaks. The monthly cost of power averages at 211.03 € and the total annual cost is almost 2535 €.

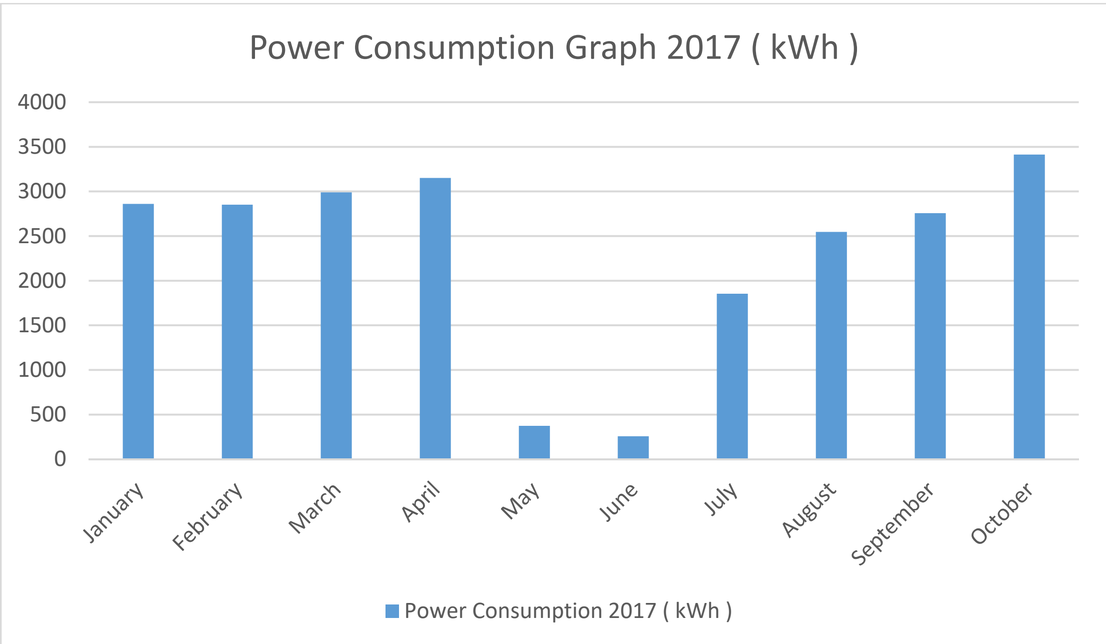
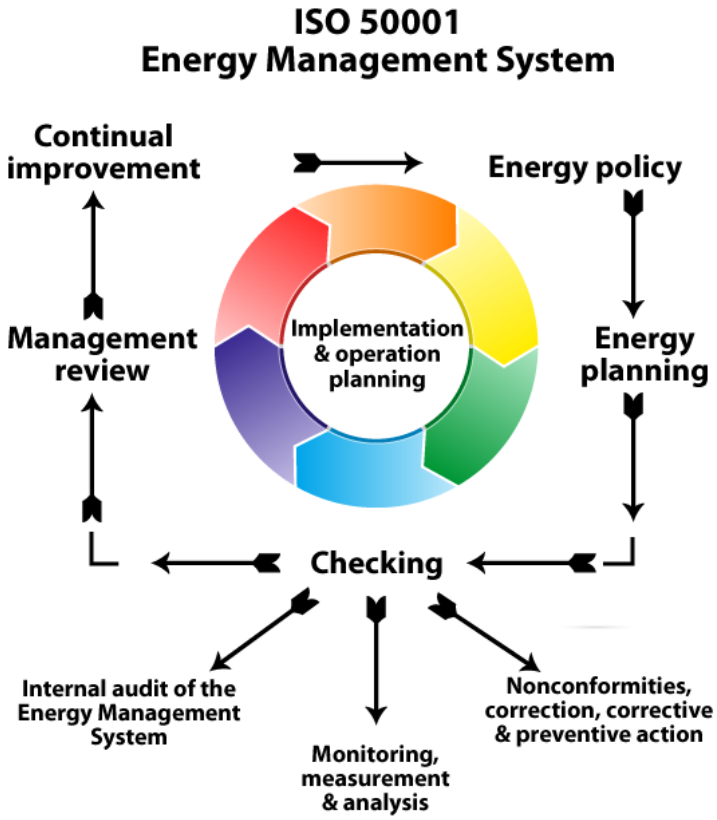


Table 12 Power Consumption Graph 2017

Energy Management

The energy management of the building is an important and potentially big energy saving measure, that helps in the proper maintenance of the buildings systems and ensures that they work as efficiently as possible , through the process of energy consumptions records and maintenance records. Also the energy management as a process involves the building users training in order to know simple energy saving measures and implement them to their daily use of the building and its systems.

To implement the energy management on buildings some international standards have been issued. According to (Energy Management Handbook BSR, April 2012) the China's Standard Certification Center (CSC) began research into improving energy management systems and upgrading national standards in 2002. In 2009, the government implemented its newly developed research GB/T 23331-2009, "Requirements for Energy Management Systems." Since then, China has made regular updates to its systems to match national standards with those of the International Organization for Standardization (ISO), which published its latest international energy management standards, the ISO 50001, in June 2011. Organizations across the world face energy-related challenges, including those related to energy supply, reliability and climate change matters. The ISO 50001 is a framework that helps companies and public buildings manage their energy systems and plan better to save energy and to reduce pollution as well as costs. ISO estimates these standards can reduce global energy consumption by 60 percent. Both ISO50001 and GB/T23331-2009 are based on the same model which applies the "Plan, Do, Check and Action" cycle (PDCA). (Energy Management Handbook BSR, April 2012)



Picture 16 Energy Management System ISO50001

In the case of our school building , there has been no energy management in the past, thus leaving room for big improvements. According to the schools administrator there have been no energy consumption records of any kind, and haven't been fuel consumptions records for space heating, or power consumption records. In addition to the above the heating installations of the school haven't been maintained from the construction of the school in 1989. The efficiency of the boiler and its heat delivery systems has not been evaluated by any means. Thus there is no implementation of the ISO50001 in any way, even after its publication in 2011 and the more active stance of the Greek state towards the energy saving measures in the building sector.

HVAC systems

According to (Walter Grondzik) HVAC, is an acronym that stands for "heating, ventilating and air conditioning" and generally includes a variety of active mechanical/electrical systems employed to provide thermal control in buildings. Control of the thermal environment is a key objective for virtually all occupied buildings. While a heating system (H) is designed to add thermal energy to a building in order to maintain a selected indoor temperature that would otherwise not be achieved due to the heat loss of the building to the exterior environment, a ventilating system (V) is intended to circulate new air and to remove air from a building. Finally the design purpose of a cooling system (C) on a building is to remove thermal energy from the building to maintain a selected temperature and the purpose of the air-conditioning system is to achieve all four previous goals at the same time. In our case, the school building that we will study has some small air conditioning units that play a minus role in the cooling of the building during summer, and a general heating system for the satisfaction of the thermal needs of the building. Below will follow a more detailed description of each system along with their specifications, all gathered from the brief walk through audit to the school building.

Heating system

There are many types of heating systems depending on the use and purpose, the type of fuel and distribution and the type of emission. A heating system is divided into three main parts , which are the Production system, the Distribution system and the Emission system and a minor part of the system that is the auxiliary equipment such as circulation pumps. The Production system is the boiler or the source of the thermal load. There are many production system types depending on the fuel such as oil-fired boilers, gas-fired boilers, heat pumps and others. The second part of a heating system is the Distribution system, which has the job of distributing the thermal power provided from the production system to the building and is in the form of a pipes network or duct work. The third and last part of the heating system is the emission system that is the final delivery device of thermal loads to each space of the building. Each part of the system must be as efficient as possible and according to ISO50001 that we mentioned above there must be a repeated maintenance and efficiency evaluation of each system , in order to achieve the minimization of the energy loss. Thus below will follow an estimation of the efficiency of each of the three parts of the heating system in the school building.

In the case of our building, the school was constructed in 1989 and the heating system has not been renovated or maintained since. The system is a central heating system, meaning that a central boiler is supplying the building with the thermal loads it needs, and the fuel of the boiler is diesel heating oil. Depending on the use of each space, a building is divided into thermal zones for heating, with each zone having more or less or none heating needs. In the school building though, the need for heating is the same to all the departments of the school with an exception of the toilets in our case, according to the school administrator. Thus there is no need to divide the building in thermal zones as it is one big thermal zone.

The central oil boiler was constructed the year 1990 according to the label that is located on it. The label also provided us with the output power of the boiler, that is 350000 kcal/hour which is almost 406.7 kW of power. The efficiency of such a boiler can be calculated through the table below.

Boiler type	Efficiency
Common	$= 84 + 2*\log(P_n)$ (for $4 < P_n < 400$ kW)
Low temperature or condensing (oil)	$= 87 + 2*\log(P_n)$ (for $4 < P_n < 400$ kW)
Low temperature or condensing (gas)	$= 91 + 2*\log(P_n)$ (for $4 < P_n < 400$ kW)

Table 13 Boiler Type Efficiency

The existing boiler is not a low temperature or condensing oil boiler, thus the calculation of its nominal efficiency will be according to the first formula of the table. With the power output of the boiler at 406.7 kW, we will use the maximum value of P_n of 400 kW and have an accurate estimation of the nominal efficiency.

Nominal efficiency of the boiler :

$$N_{gm} = 84 + 2 \times \log P_n = 84 + 2 \ \times \log 400 = 89.2\ \%\ or\ 0.892$$

To calculate the overall efficiency of the boiler, two correction factors must be first calculated. The first correction factor (N_{g1}) provides a measure value of the system's efficiency depending on how oversized is the boiler, with the oversized meaning that the boiler has higher actual output power than the nominal power that is calculated based on the design load calculations according to relative standards. The second correction factor (N_{g2}) provides a measure value of the system's efficiency according to the insulation level of the boiler.

Thus to calculate the correction factor N_{g1} , the nominal power that is needed based on the design load calculations must me calculated. The proper power output P_{gen} in order to size a boiler is calculated as follows.

$$P_{gen} = A_{building} \times U_m \times \Delta T \ \times 2.5 = 61100.373\ Watts\ or\ 61.10\ kW$$

Where the $A_{building}$ is the external surface of the building in square meters and has a value of 1118.54 m^2 for our building. The U_m is the mean thermal transmittance factor of the building (W/m^2K) that is calculated through the calculation of U value of each of the buildings elements and their surface area. Though in our case because the calculation of the total U value of the building is a calculation that needs computing power and software, we will use assigned values of U depending on the climate zone of the building and their year of construction. Thus for a building that was constructed after 1980 and before 2010, and for Climatic Zone C the U_m is 0.95 Watts / m^2 K and for the Climatic Zone C the mean difference ΔT between the internal and the external air is 23 K.

As we can see from above, the installed boiler power output is more than double the nominal power output (P_n/P_{gen} = 6.54 times higher). Thus providing us with a correction factor of n_{g1} of 0.75.

Finally the n_{g2} correction factor for an oil boiler with power output greater than 400 kW and without or in bad condition insulation is 0.952. According to the above we can calculate the overall efficiency of the installed production system :

$$N_{gen} = N_{gm} \times N_{g1} \times N_{g2} = 0.892 \ \times 0.75 \ \times 0.952 = 0.632\ or\ 63.2\%$$

The resulting overall efficiency of the production system is at 63.2% and according to the needed nominal power output, the production system is oversized by more than 250%.

The Distribution system is a network of pipes that runs through the internal spaces of the building that according to the inspection made during the walk through audit have no insulation. The network is composed usually by two pipes, one to supply the heating media and the other to return it, and also from the media, which is usually water, that transfers the heat from the boiler to the emission system. The supply temperature of the heating system is greater than 60°C because the distribution system is big and there must be high enough temperature in order to reach even the most distant parts of the school. According to the data from above, a 406.7 kW boiler with a piping system routing through internal spaces with no insulation has a very low efficiency leading to energy losses of almost 7%.

Finally the Emission system is the final part of the heating system and is the system that will transfer the heat stored in the distributing media (water) to the space. The emission system can be wall mounted, installed on the floor or on the ceiling. In the school the emission system is composed from radiators attached to external walls with a supply temperature greater than 60°C (Supply – Return temperature 90-70°C). The efficiency of such a system is close to 89%.

Hot water system

The domestic hot water systems are important parts of the heating systems and their power is calculated from the maximum daily domestic hot water thermal load. In our case the school building has no hot water system installed , because of the unnecessity of the hot water in a public building like that operates only on the morning and has no domestic hot water needs, such as showering and dish washing.

Air-conditioning system

Air-Conditioning as mentioned above is called the system that does all four things describing the HVAC systems, such as heating, cooling and ventilating. In some countries, for example US, the popularity of an all-in-one system as the air- conditioning system for a build is great and as a fact they are used in a great percentage of the building sector. On the other side, in Greece, all-in-one systems for the satisfaction of the heating and cooling loads of a whole building is limited. The air conditioning notion in Greece is limited to the use of small air conditioning units, usually for the cooling or heating of small spaces or rooms due to the inefficiency and cost of the old central heating systems.

In our case, the school uses a total of 4 air conditioning units that are located in the gathering room, the halls and the teacher's room. Below will follow a table with the locations of each unit and the cooling loads according to the specifications label of each unit.

Number of Units	Location	EER	Cooling Capacity (Btu)	Colling Capacity (kW)
1	Gathering room	1.7	24000	7.04
3	Teacher's room, Halls	1.7	9000	2.637

The overall Energy Efficiency Ratio (EER) is provided from the manufacturer and is calculated based on the following equation, EER = Cooling Capacity / Input Power for Cooling, and is usually measured under a specific condition (35 degrees °C, outdoor temperature 27 degrees °C indoor temperature and 50% relative humidity). The higher level of EER on an air conditioning unit , the better the efficiency. According to (Technical Chamber of Greece, 2017) the energy efficiency ratio for old air conditioning units is taken 1.5 for units that are almost

20 years old and 2.0 for 10 year old units. In our case, the air conditioning units were installed in 2000, thus they are almost 18 years old and are taken with an EER of 1.7, and the resulting SEER for cooling is SEER = 1.56.

Assuming the air conditioning units run 7 hours per day during the hot months, May and June, and that on average throughout the cooling season, the units run at two thirds of its capacity we have a cooling load :

$$Q_{cooling} = 51000 \frac{Btu}{hour} \times \frac{2}{3} \times 7 \frac{hour}{day} \times 33\ days\ \times \frac{1}{1.56} = 5034.61\ kWh$$

The air conditioning systems are composed by three parts, which are the same as the heating system, the heat pump, the delivery system which is insulated tubing and the internal wall mounted emission system. In our case the emission system is inverter, which means that it has an overall efficiency of 96% and when the space reaches the desired temperature, the system goes into standby mode and thus saves energy, starting again when the temperature rises.

Ventilation system - Indoor Air Quality

The indoor air quality is the 4th largest childhood problem according to EPA. The ongoing design of air tighter buildings in order to achieve energy savings, along with other factors such as the presence of an increasingly complex array of chemicals used in building materials and the increase in the average time spent by children indoors, have contributed to the awareness of the indoor air quality in public buildings and especially in school buildings. The high amount of time that the children spent on schools during the day along with the absence of proper ventilation, is a problem many schools face in Greece. While the indoor air quality had more attention to other countries, in Greece ,most of the policies involving ventilation in public buildings have been issued after 2010.

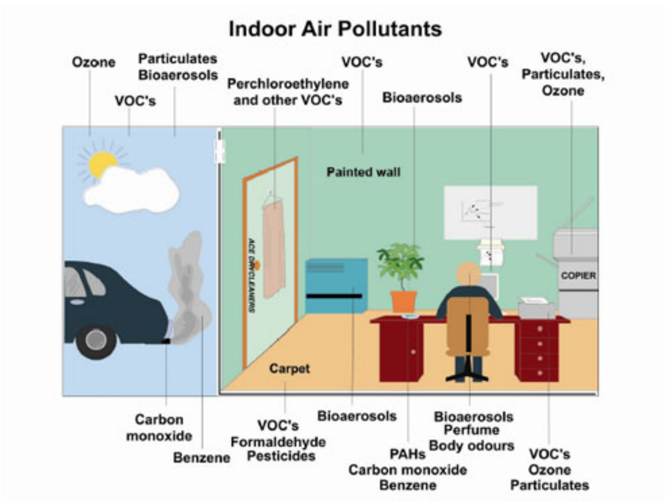


Figure 1 Primary sources of indoor air pollution

Picture 1 (CRC for Construction Innovation)

The minimum ventilation needs of a school building according to (Technical chamber of Greece, 2017) and the specifications of ELOT EN 15251:2007 and ASHRAE 62.1-2010 are valued by the number of users per 100 square meters of building surface, the minimum fresh air per person (m^3/hour/person) and the minimum fresh air per surface value (m^3/hour/m^2). According to the above regulation, the minimum values ,that are described above, for an elementary school building are 50 people/100 m^2, 22 m^3/hour/person of fresh air and 11 m^3/hour/m^2 of fresh air.

In our case the school building uses natural ventilation, due to the fact that it was constructed in 1989. The natural ventilation is achieved through the crevices of the window systems and the door openings. In the past natural ventilation was a fact for all buildings, though at the present natural ventilation is only implemented in residential buildings and all commercial and public buildings must have forced ventilation.

Lighting systems and visual comfort

In each space of a building there must be provided lighting that ensures the visual comfort of the users, in other words an environment with the needed quantity and quality of light , that permits the pleasant stay and the practice of the planned activities, without phenomena that lead to visual discomfort. According to the ELOT EN 12464.1:2002 standard, detailed levels of luminance are specified depending on the use of space. Below will follow a table showing the luminance levels of different spaces of school.

Area usage	Luminance level (Lm / m^2)	Power for Building of Reference (W/m^2)
Multiple use space – gathering room	300	9.6
Corridors – auxiliary spaces	200	6.4
School classrooms	500	16
Offices	500	16
Bathrooms (common)	200	6.4

To calculated the needed power for the building of reference, we must have the surface area of each of the above uses of space presented in the table. According to the floor plans provided by (Urban Planning Department) the surface area of each space and the needed watts to provide the proper luminance level is :

- Gathering room : A = 151.11 m^2 and needs 1450.65 Watt or 1.450 kW
- Corridors – Auxiliary spaces : A = 349.74 m^2 and needs 2238.33 Watt or 2.238 kW
- Classrooms : A = 466.08 m^2 and needs 7457.28 Watt or 7.457 kW
- Offices : A = 32.17 m^2 and need 514.72 Watt or 0.514 kW
- Common Bathrooms : A = 72 m^2 and need 460.8 Watt or 0.460 kW

Thus the sum of the total power of the lighting system needs to be 12.119 kW.

The building has currently installed in all the spaces, evenly spaced luminance systems with 4 1200 mm High performance T8 fluorescent lamps in each ballast. In each classroom there are 4 lighting systems with ballast and each system has 4 lamps, leading to a total of 16 lamps in each classroom. The total number of lamps installed in the building is 316. The high performance T8 1200mm fluorescent lamp, according to (Brian Liebel P.E.) has a system efficiency (Lumens/Watts) of 101.8 percent and the lamp wattage is 32 watts. Thus the installed total power of the lighting system on the school building is 13312 kW. In each classroom there are a total of 16 T8 high performance fluorescent lamps, each with an efficiency of 101.8 lumens per watt, meaning that in the classroom we have 16 X 32 X 101.8 = 52121.6 lumens for a space of 45.24 m^2, leading to a number of 1152.11 Lumens / m^2 which is more than the required luminance levels. For the bathrooms there are 8 T8 lamps for each 36 m^2 of space, leading to 1422.22 Lumens / m^2. To the offices there are 20 lamps in a total surface of 144.17 m^2 leading to 451.91 Lumens / m^2. In the gathering room there are 32 lamps in a total surface of 151.11 m^2 leading to 689.84 Lumens/m^2.Finally in the corridors and .auxiliary spaces there are 72 T8 fluorescent lamps in a total surface of 349.74 m^2, leading to 670.63 Lumens / m^2.

Picture 19 High efficiency T8 fluorescent Lamp with instant start ballast

Energy Upgrade Proposals

The sole purpose of an energy audit on a building is to examine the present status of the building and the status of its systems, HVAC , Lighting and more and calculate the current energy performance rating of the building. To calculate the energy rating of the building, there are many steps to be taken, with the first being the evaluation of the building envelope and its materials, which will lead to the final calculation of the buildings total U_m value that will help to calculate the thermal loads of the building. Concerning this step of the process , this paper has successfully evaluated and calculated the U values of the buildings sub elements, such as the external walls, concrete walls, windows and roof, but the calculation of the U_m value of the building is a process that involves the precise calculation of all the thermal bridges of the building, their length and U values. Thus the need for special software to calculate the thermal bridges, is an obstacle that has not permitted the exact calculation of the $U_{m.}$ The next step of the energy audit is the evaluation of the heating, cooling and ventilation systems of the building. The existing systems have been evaluated to an extent, according to the specifications labels of the parts of the systems, their manufacturing date and consumption. As a result we have an efficiency rating of the parts of the heating system, cooling system and lighting system.

The final step of each energy audit is the assignment of an energy rating on the building along with proposed possible energy saving measures that will help the building ascend in the energy rating ladder. As mentioned again in the previous chapters the calculation of the energy rating of the school building is not possible, because we lack the software. Therefore in this chapter we will make some energy saving proposals according to the evaluation of the buildings elements and systems, in order to increase its efficiency and energy and power consumption. These proposals will try to be realistic and as much as possible cost effective.

Building Envelope - Window refurbishment

From the walk through inspection of the building that was performed, the necessary information, about the quality and energy efficiency of the building envelope, were acquired. The assessment of the building elements has shown that there is non existent thermal insulation in the external walls and structural elements, according to current standards. The thickness of the thermal insulation must be 8 cm, which according to (Technical Chamber of Greece, 2017) is the essential thickness to achieve the energy rating of a new building. Since there is no form of thermal insulation on the buildings external walls and structural elements, it is proposed to upgrade this sector of the building envelope, due to the fact that the upgrade will be the most cost effective way to bring down the energy drain of the building and will lead to decreased energy bills.

According to the current trend in thermal insulation materials, and the «Εξ'Οικονομω κατ' Οικον II» program of Greece with the budget provided from the European Union, the thermal insulation that is currently in use is extruded polystyrene with a λ factor of 0.032 W/m K . The cost per square meter of extruded polystyrene is 6 € , while the cost of the rest materials , such as the gypsum, grid mesh and nails is another 10 €/m^2, bringing the total cost of materials to 20€ / m^2. To this cost is the cost of installation that depends on the contractor, but a realistic cost for the installation is 10€/m^2, which brings the total cost of the insulation upgrade to 30€/m^2. Below will follow a table showing the surface area of the walls and structural elements of the building along with the total cost.

Total surface area of the building (m^2)	New insulation thickness (cm)	λ value (W/m*K)	Total Cost €
1607.59	8	0.032	48227.7

Picture 2 Insulation Surface Area and Cost

The thickness of the new insulation will be 8 cm , as there is non existent thermal insulation. The new insulation will lead to new U value of the external walls and structural elements, which will be calculated below.

$$\frac{1}{U_{total\ Roof}} = R_{Gypsum} + R_{Concrete} + R_{Insulation} = \frac{0.02}{0.87} + \frac{0.2}{2.03} + \frac{0.08}{0.032} = 2.621\ \frac{m^2K}{Watts}$$

$$U_{total} = \frac{1}{2.621} = 0.3814\frac{Watts}{m^2\ K}$$

$$U_{external\ wall\ new} = \frac{1}{\frac{d_{gypsum}}{\lambda_{gypsum}} + \frac{d_{brick}}{\lambda_{brick}} + \frac{d_{new\ insulation}}{\lambda_{ne\ insulation}} + \frac{d_{gypsum}}{\lambda_{gypsum}}} = \frac{1}{\frac{0.015}{0.87} + \frac{0.22}{0.64} + + \frac{0.08}{0.032} + \frac{0.015}{0.87}} = 0.3474\frac{W}{m^2K}$$

$$U_{concrete\ wall\ new} = \frac{1}{\frac{d_{gypsum}}{\lambda_{gypsum}} + \frac{d_{brick}}{\lambda_{brick}} + \frac{d_{new\ insulation}}{\lambda_{ne\ insulation}} + \frac{d_{gypsum}}{\lambda_{gypsum}}} = \frac{1}{\frac{0.015}{0.87} + \frac{0.25}{2.03} + \frac{0.08}{0.032} + \frac{0.015}{0.87}} = 0.3762\frac{W}{m^2K}$$

Thus with the above calculations we can see that we achieve a 94.07% percent improvement of the U value for the external brick walls, and a 86.85% for the concrete elements.

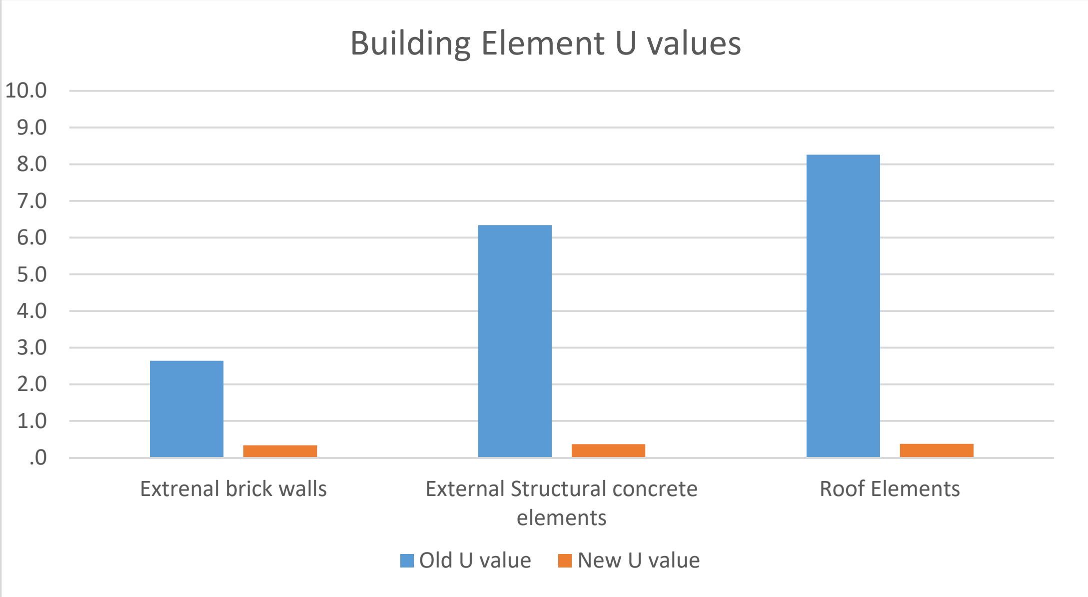


Table 14 Building Element U Values

With an estimation of (1790 DD_h(18° C)) the Degree-days for the city of Trikala according to (Centre For Renewable Energy Sources) we can roughly calculate the kWh of energy that will be saved due to this upgrade.

$$\ddot{A}E = \left(7\ hours\ \times 147.12\ m^2\ \times \left[6.343 - 0.376\frac{W}{m^2K}\right] \times 1790\ ^\circ\frac{Cday}{year}\right)$$
$$+ \left(7\ hours\ \times 709.99\ \ m^2\ \times \left[2.643 - 0.3474\frac{W}{m^2K}\right] \times 1790\ ^\circ\frac{Cday}{year}\right)$$
$$+ \left(7\ hours\ \times 750.48\ \ m^2\ \times \left[8.264 - 0.3814\frac{W}{m^2K}\right] \times 1790\ ^\circ\frac{Cday}{year}\right)$$
$$= 10999.648\ kWh + 20422.058\ kWh + 41410.13 = 72831.84\ \frac{kWh}{year}$$

Which in turn, assuming a price of 0.95 €/ liter for the diesel fuel oil for heating , we have payback period of :

$$Payback = \frac{1607.59\ m^2 \times 30\ €/m^2}{\left(72831.84\frac{Kwh}{year} \div 10\frac{kWh}{Liter}\right) \times 0.95\frac{€}{Liter}} = 6.97\ years$$

Thus the payback period is reasonable and shows the effectiveness of the proposed upgrade in cases that there is not a pre-existing thermal insulation.

Another proposition concerning the upgrade of the building envelope is the refurbishment of the old window systems with new. The old window systems as described in the chapter of the building envelope, are metallic with a 20% frame to glass panel surface with single glass. They have no thermal stop and they are old technology , which leads to a high U value of 6.0 W/m^2K , in comparison with the U value of new energy efficient windows. The new energy efficient windows, that we will propose to install in the building, have aluminum frame with the same percent of frame to glass panel surface, with thermal stop and double glass panels with low emission membrane and 24mm gap. The U value of the proposed window systems is 2.3 W/m^2K , which is an improvement of 61.66% over the old U value. The cost of installment of such windows, according to maximum costs that the the «Εξ'Οικονομω κατ' Οικον ΙΙ» program of Greece justifies, is almost 250 – 280 €/m^2 , which is the cost of the most expensive windows. Thus in our calculations we will assume a cost of 260 €/m^2 in order to calculate the payback period.

Total Building Window surface (m^2)	U value (W/m^2K)	Total Cost €
180.11	2.3	46828.60

Table 15 Windows Surface Area and Cost

The total energy savings from the installation of new windows will be as follow :

$$\ddot{A}E = \left(10\ hours\ \times 180.11\ m^2\ \times \left[6.0 - 2.3\frac{W}{m^2K}\right] \times 1790\ ^{\circ}\frac{Cday}{year}\right) = 11928.68\frac{kWh}{year}$$

$$Payback = \frac{180.11\ m^2 \times 260\ €/m^2}{\left(11928.68\frac{Kwh}{year} \div 10\frac{kWh}{Liter}\right) \times 0.95\frac{€}{Liter}} = 41.32\ \ years$$

According to the energy consumption data provided, last year 11700 liters of diesel fuel were consumed to satisfy the energy needs, thus providing us with a realistic estimation of the thermal loads of the building. These thermal loads of the building are calculated as shown below :

$$Q_{heating} = \left(11700 liters\ \times\ 10\frac{kWh}{liter}\right) \times 0.892\ boiler\ efficiency = 104364\ kWh$$

Thus, with the window refurbishment we have a 11.42 % energy savings with the addition of CO_2 emissions decrease from the use of Diesel, and with the building envelope thermally insulated we have 30.10% energy savings.

HVAC systems

The HVAC systems is a sector of the school building that has no maintenance and where there has been no change since the construction of the building in 1989. As a result the technology of both heating and cooling systems is obsolete, and regarding ventilation is non existent. For this reason, some proposition will be made for the upgrade of the systems to improve the efficiency and provide heating and cooling needs in a more "green" way.

Heating system upgrade

The heating system is the first important part that must be upgraded, because it is both inefficient and energy consuming, but also environment polluting through the use of Diesel oil. In addition to the above the boiler is extremely oversized, to almost 7 times bigger, leading to more power consumption and inefficiency.

The proper power output of the boiler is calculated in the chapter of the present heating system presentation, in order to calculate the efficiency of the production system, and is 61.10 kW.

The proposed system upgrades is the installation of a new natural gas burner that will be of the proper power output and more efficient than the last. The proposed model of natural gas burner is the MAX GAS 70 P 70Kw 60.200Kcal/h model from Ecoflam which according to (Boiler maintenance union of Greece, n.d.) has a power output of 34,0 – 70,0 kW or 29310 – 60200 kCal /hour , which is perfectly suited for the power output of 61.10 kW that we need for the school building. According to pricing values from a boiler and heating systems supplier in Trikala, the cost of the new gas burner is 1900 – 2500 € , and the cost of installation is 900 €. The cost of installation includes the fees of the plumber and the cost of plumbing and other materials that will be used. Due to the fact that the building has a central heating system it may be difficult and far most costly to install two smaller gas burners to improve the energy efficiency of the building, because the distribution system in central heating systems will run through all of the floors of the building , and such an installation would have the extra cost of installing a separate distribution system. Thus, the most cost effective proposal is the installation of one big gas burner instead of two smaller ones. The efficiency of the proposed burner is nearly 93% which is higher than the current system and is exactly the power output we need thus minimizing the oversize factor. The proposed boiler will improve up on the correction factor n_{g1} , as the new boiler will have 25% -50% higher output power , and a correction factor of n_{g1} = 0.95. This will lead to an improved efficiency of the production system that is :

$$n_{gen} = n_{gm} \times n_{g1} \times n_{g2} = \ 0.932 \ \times 0.95 \ \times 1 = 0.8854 \ \ or \ 88.54\ \%$$

The efficiency will increase by 25.34% providing with a more efficient production system. The new gas burner will also be more clean in terms of emission ratings and more cost efficient. According to the (Natural Gas Company of Thessaloniki, n.d.) the school building that we study is in the T3 consumption category, in which the natural gas provided is for commercial use and central heating use. The price of the natural gas differs from month to month according to the table below.

Month(	T3 Consumption Category		
	Natural Gas Cost (€ / kWh)	Thermal loads (kWh)	Monthly Cost (€)
October 2017	0,039813300	10624.8	423.00
November 2017	0,039853609	16822.6	670.44
December 2017	0,040118922	15937.2	639.38
January 2018	0,040856936	15494.5	633.05
February 2018	0,039877584	16822.6	670.84
March 2018	0,038878204	17708	688.45
April 2018	0,037546644	10182.1	382.30
Yearly Heating cost			4107.46

Table 16 Natural Gas Pricing (Natural Gas Company of Thessaloniki, n.d.)

The cost of heating the school each year with the old oil boiler is 11467.95 €, while the new natural gas burner will heat the school with 4107.46 € each year. That is a saving of 7360.48 € / year. Thus the payback period will be :

$$Payback\ period = \frac{3400\ €}{7360.48 \frac{€}{year}} = 0.461\ years\ or\ 5\ months\ and\ 20\ days$$

Cooling system upgrade

The cooling system of the building in study is composed by 4 air- conditioning units (heat pump) that are almost 16 year old and all four have an Energy Efficiency Rating of 1.7. The best solution to this problem is the installation of new air - conditioning units that will be much more efficient and will decrease the cooling loads of the building. The three units will be 9000 Btu and the fourth of 24000 Btu capacity. The units that are proposed to be installed were selected with according to their energy class for cooling, and they will be A^{+++}. Below will follow a table with their specifications and prices :

	LG Prestige H09AK	Finlux FDCI-24LK46GFH
Cooling Energy Class	A^{+++}	A^{+++}
Heating Energy Class	A^{+++}	A^{++}
SEER	9.1 W / W	8.5 W / W
SCOP	5.2 W / W	4.6 W / W
Inverter	Yes	Yes
Pricing	869 €	700 €
Number of Units	3	1
Total Cost (100 € / unit installation cost)		3707 €

Table 17 Proposed Cooling Units Specifications

As we can see the new units proposed are more than 4.94 times efficient than the old units, thus the new cooling load will be :

$$Q_{cooling} = \left(27000\frac{Btu}{hour} \times \frac{2}{3} \times 8\frac{hour}{day} \times 33\ days \times \frac{1}{9.1}\right) + \left(24000\frac{Btu}{hour} \times \frac{2}{3} \times 8\frac{hour}{day} \times 33\ days \times \frac{1}{8.5}\right) = 1019.138\ kWh$$

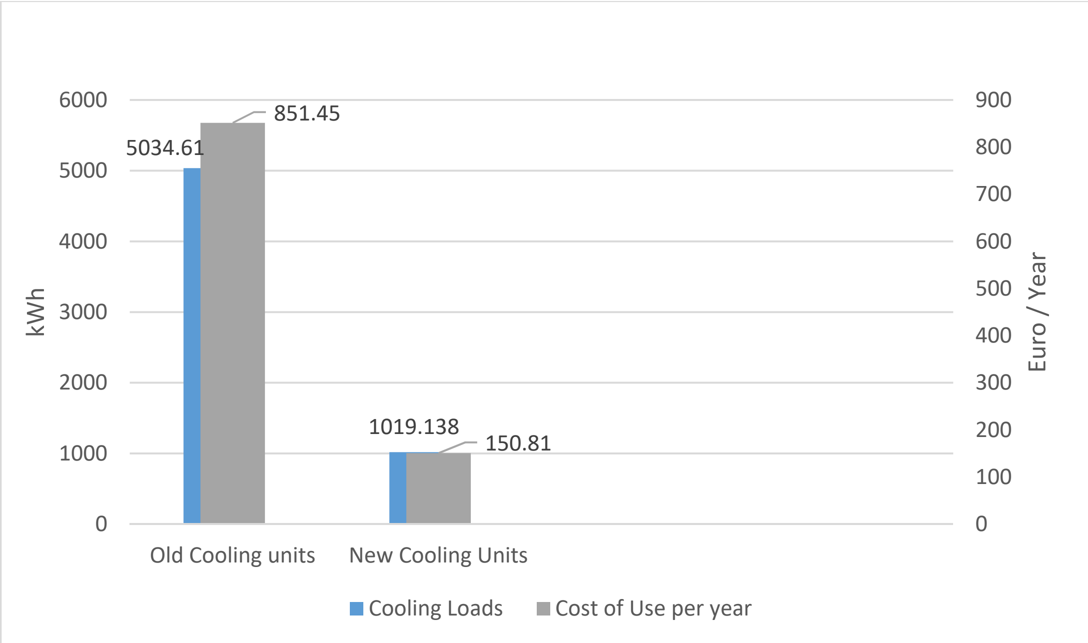


Table 18 Cooling Loads / Costs Comparison

With the new cooling units the cooling loads have been reduced by 4015.47 kWh, which is more than 79.75% of energy saving. Thus the yearly cost of cooling on the building with the new units is 150.81 €, down from 745.01 €. The payback period of the cooling system upgrade will be :

$$Payback\ Period = \frac{Cost\ of\ installment}{Energy\ Savings\ cost} = \frac{3707\ €}{594.20\frac{€}{year}} = 6.23\ years$$

Ventilation

The ventilation system in a public system is a mandatory system, that ensures the good indoor air quality in a building that has over 282 users daily. The building sick building syndrome that has been found to be caused by the poor indoor air quality in public and commercial buildings is an important problem that must be addressed in our case, because the users of the building is in the majority children, and thus the indoor air quality of the building must meet the required standards of ventilation.

At the current state, the school building has only natural ventilation through the window crevices when the windows are closed, but also through open windows and doors during summer.

The minimum ventilation needs of a school building according to (Technical chamber of Greece, 2017) and the specifications of ELOT EN 15251:2007 and ASHRAE 62.1-2010 are 50 people/100 m^2, 22 m^3/hour/person of fresh air and 11 m^3/hour/m^2 of fresh air. The number of users differs every day and time, but peaks at 258 users, thus the ventilation system must be achieve the minimum ventilation required for this number of people and square meter surface of the school. The minimum ventilation required is :

- 285 users X 22 m^3/hour/person = 6270 m^3/ hour
- 1455.83 m^2 X 11 m^3/hour/ m^2 = 16014.13 m^3 / hour

According to (Technical chamber of Greece, 2017) the penetration of air through crevices on the window frames and door frames, for the aluminum sliding windows with single glass and no certification for air tightness, is 6.2 m^3/hour/m^2. Therefore the natural ventilation for our case is estimated to 6.2 m^3/hour/m^2 X 180.11 m^2 = 1116.68 m^3/hour. Thus the resulting remaining ventilation volume is 14897.45 m^3/hour , which will be achieved through mechanical ventilation. Below will follow a table with the proposed number and type of roof ventilators that need to be installed to assure the proper ventilation of the building.

	Roof ventilator type	
	SCHNEIDER ELECTRIC HIMMEL	SCHNEIDER ELECTRIC HIMMEL
Ventilation load	575 m^3/ hour	300 m^3/ hour
Number of units	18	24
Location	1 ventilator / classroom 7 ventilators in gathering room	18 ventilators evenly spaced at halls 1 ventilator / bathroom (total 6)
Unit price	256.33 €	73.33 €
Total Price (plus installation)	6373.86€	

Table 19 New Roof Ventilator Specifications

Picture 20 SCHNEIDER ELECTRICHIMMEL Roof Ventilator

In each classroom the maximum number of students is 30 , meaning that the needed ventilation on the room is 660 m^3/hour. The natural ventilation from the windows is calculated at 75 m^3/hour, leaving the need for mechanical ventilation at 575 m^3/hour. So in each classroom a roof ventilator of 575 m^3/hour will be installed. For the bathrooms , a roof ventilator of 300 m^3/hour in each bathroom will be installed, to a total of 6 ventilators. To the halls there will be 18 roof ventilators of 300 m^3 /hour installed, that will be evenly distributed on the ground and first floor ceilings. Finally the gathering room , is a place where has a lot of surface area and where a lot of users will gather, meaning that there will be 7 ventilators of 575 m^3 / hour installed. The total sum of the ventilation load on the school building after these upgrades, will be :

$$\begin{aligned} Ventilation\ load &= Natural\ ventilation + Mechanical\ ventilation \\ &= 1116.68\frac{m^3}{hour} + 16\ \times 575\frac{m^3}{hour} + 24\ \times 300\frac{m^3}{hour} \\ &= 17516.68\frac{m^3}{hour}\ \cong 16014.13\frac{m^3}{hour}\ \ regulation\ standards \end{aligned}$$

The new ventilation system will provide the exact necessary ventilation on the building, and since it is a new addition to the buildings systems, in each classroom an on/off switch will be installed to save energy if the class is not in use.

Lighting system improvements

The lighting system of the school building, as presented in the above chapter, is newly partially refurbished with the installment of new high efficiency T8 fluorescent 1200mm lambs that have a 101.8 lumens / watt efficiency. Though the lumen intensity on the classes is higher than the standards of (Technical chamber of Greece, 2017) , which dictate that in classrooms the luminance level must be at 500 lumens / m^2. In our case in classrooms we have a luminance level of 1152.16 lumens / m^2 , which is more than double , unnecessary and inefficient. Thus from the total of 16 lambs in each classroom , the 8 lambs will be removed, leaving each ballast with 2 lambs and the luminance level reduced to 574.40 lumens / m^2 for a new lamb, with the projection that in 1 years use will decrease to 90% efficiency, to a number 516.96 lumens / m^2. This energy saving meter will be implemented on all classrooms, teachers room and administrator room, saving a total of 80 new lambs for storage. Also in the gathering room there are 32 T8 lambs providing with 689.84 lumens / m^2 which is more than 2 times the luminance level proposed. Thus the 16 lambs will be removed evenly from the ceiling surface, decreasing the luminance level of the gathering room to 344.92 lumens/m^2, and saving for storage 16 lambs. Each of the bathrooms have a surface of 16 m^2 and 8 T8 lambs installed, which provide a luminance of 1628.8 lumens / m^2, therefore 6 lambs will be removed from each bathroom, reducing the luminance to 407.20 lumens / m^2 and saving 24 T8 lambs for storage. Finally, the corridors and auxiliary spaces have 84 T8 lambs which provide a luminance level of 782.40 lumens / m^2 for the surface area of 349.74 m^2, thus half of the lambs will be removed providing a reduced luminance level of 391.20 lumens / m^2, and 42 lambs for storage. Below will follow a table , showing the lambs removed and the new and previous luminance levels.

	Old Luminance level (Lumens / m^2)	New Luminance level (Lumens / m^2)	Old number of T8 lambs	New Number of T8 lambs
Classrooms Teachers Administrators room	1152.16 810.09 1176.02	574.40 607.57 588.01	152 8 4	76 2 2
Gathering room	689.84	344.92	32	16
Bathrooms	1628.8	407.20	32	8
Corridors Auxiliary spaces	782.40	391.20	84	42
Lambs for Storage				162
Total number of T8 Lambs in use				154

Table 20 Luminance levels and number of lambs

According to (Lighting Research Center, n.d.) the 1200mm T8 fluorescent lamp of 32 watts , has a rated power is 32.5 watts under standard test conditions (ANSI C78.81-2005). Thus assuming that the lambs are used for an average of 2 hours/day for 175 days / year. We have a yearly power consumption for lighting of 3594.50 kWh, with a cost of 410.59 € / year. With the proposed reduction in the number of lambs, the new assumed power consumption will be 1751.75 kWh , with a yearly cost of 200.09 €. Leading to a reduction of 1842.75 kWh in power consumption for lighting, which is more than 51.26% of energy savings on lighting.

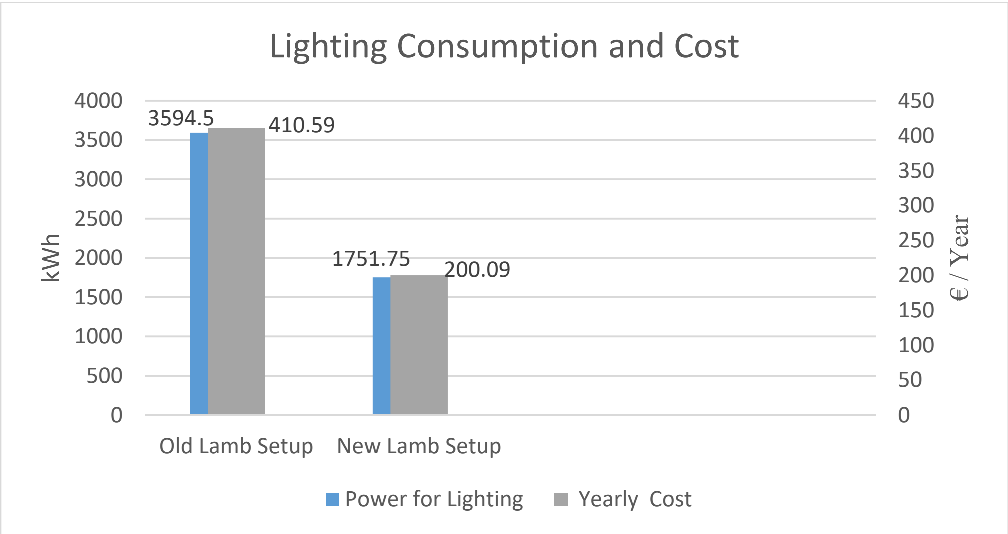


Table 21 Lighting Consumption and Cost Comparison

Edge Energy Efficiency Performance of the Building

What is Edge

EDGE is a green buildings platform that includes a green building standard, a software application, and a certification program for more than 130 countries. The platform is intended for anyone who is interested in the design of a green building, whether an architect, engineer, developer or building owner. EDGE empowers the discovery of technical solutions at the early design stage to reduce operational expenses and environmental impact. Based on the user's information inputs and selection of green measures, EDGE reveals projected operational savings and reduced carbon emissions. This overall picture of performance helps to articulate a compelling business case for building green. The suite of EDGE building types includes Homes, Hotels, Retail, Offices, Health, and Education buildings. EDGE can be used to certify buildings at any stage of their life cycle; this includes new construction, existing buildings, and renovations. EDGE is an innovation of IFC, a member of the World Bank Group. (Edge Application Guide)

The Edge Standard

To achieve the EDGE standard, a building must demonstrate a 20% reduction in projected operational energy consumption, water use and embodied energy in materials as compared to typical local practices. EDGE defines a global standard while contextualizing the base case to the building functions and its location. Only a handful of measures are required for better building performance that result in lower utility costs, extended equipment service life, and less pressure on natural resources. (Edge Application Guide)

Rather than relying on complex simulation software and consultants to predict resource use, EDGE has an easy-to-use interface that runs on a powerful building physics engine with region-specific data. Through user inputs, the data can be further refined to create a nuanced set of calculations that have greater accuracy when predicting future building performance. EDGE focuses intently on resource efficiency and climate change mitigation, recognizing that too wide of a focus leads to disparate results. At the heart of EDGE is a performance calculation engine that harnesses a set of mathematical equations based on the principles of climatology, heat transfer and building physics. Upon receiving design inputs, the calculator charts a building's potential performance i n the areas of energy, water and materials. As markets mature, the underlying data in the calculator will be further sharpened, ensuring EDGE becomes more granular and up-to-date. (Edge Application Guide)

Energy consumption is predicted using a quasi-steady state model. The quasi steady state calculation methodology is based on the European CEN standards and ISO 13790. To determine the base case parameters for efficiency in each of the required areas, EDGE relies on information on typical building practices and national building performance codes, where they are in existence. (Edge Application Guide)

Key Assumptions for the Base Case

The default values shown under the key assumptions are used to calculate the base case performance of a building. EDGE uses the best available information for default values. Since energy and water rates can change with time or location, EDGE provides users with the ability to update the default values for a project. If any of the values are overwritten, justification must be provided in the form of supporting documentation, including a link to any relevant local standards. It should be noted that certain baseline definition values are locked for general users and only accessible to admin users. For example, the baseline value for the hot water boiler efficiency is visible but locked. These values can be updated if a different minimum efficiency is required by the building and energy codes or there are local mandates applicable to the project. In order to adjust these values contact the EDGE Team, with relevant documentation to support the request. (Edge Application Guide) In our case, the Edge software, is used to predict the energy efficiency upgrade of the existing building studied in this paper. Thus while the default key assumptions for the Base Case are above the existent building specifications, we will leave them as it is. For the sake of knowledge, we will refer to the base case assumptions that are different from our case. Below follows a picture of the Key assumptions for the Base Case :

Edge Excellence In Design For Greater Efficiencies — IFC International Finance Corporation, World Bank Group, Creating Markets, Creating Opportunities

Key Assumptions for the Base Case

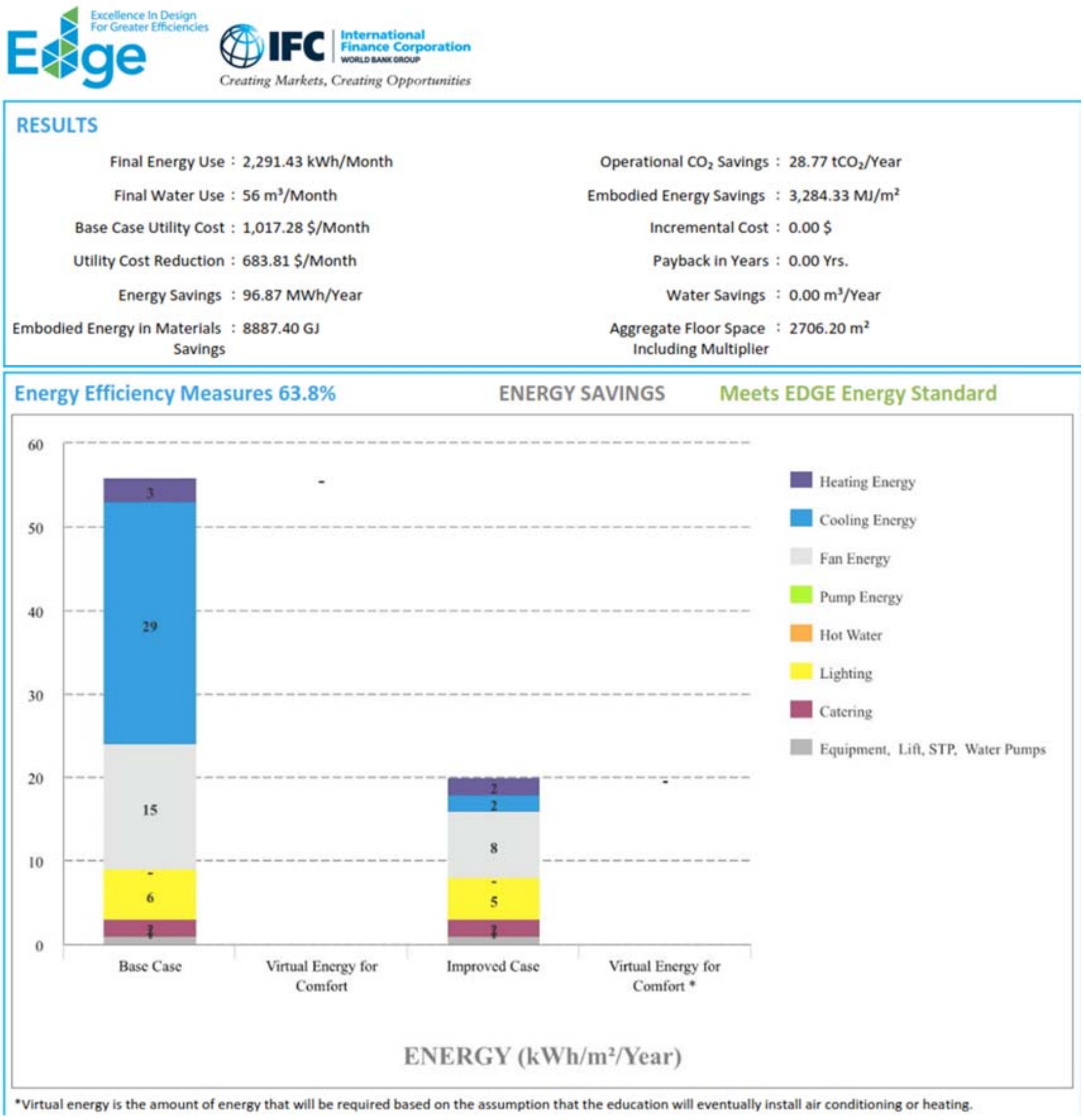
	Default	User Entry	
Fuel Used for Electric Generator :	Diesel	Diesel	
Fuel Used for Hot Water Generation :	Electricity	Electricity	
Fuel Used for Cooking :	Electricity	Electricity	
Fuel Used for Space Heating :	Electricity	Diesel	
% of Electricity Generation Using Diesel :	5.00%	0	% Ave. Yrly
Cost of Electricity :	~~0.2~~	0.1631	$/kWh
Cost of Diesel Fuel :	~~1.6~~	1.1146	$/kWh
Cost of LPG/Natural Gas :	-	0.044	$/kWh
Cost of Water :	~~2.0~~	3.61	$/L
CO_2 Emissions from Electricity Generation :	598.7		g/kWh
Window to Wall Ratio :	40.0%		%
Solar Reflectivity for Paint - Roof :	30.0%		%
Solar Reflectivity for Paint - Wall :	30.0%		%
Roof U-value :	0.50		W/m².K
Wall U-value :	0.70		W/m².K
Glass U-value :	1.40		W/m².K
Glass SHGC :	0.50		Factor
Cooling System :	ASHRAE 90.1.2007	ASHRAE 90.1.2007	
Cooling System Efficiency :	2.77		COP
Heating System :	ASHRAE 90.1.2007	ASHRAE 90.1.2007	
Heating System Efficiency :	0.80		Eff

Table 22 Default Assumptions for the Base Case

As we can see above in the Table 1, the assumptions for the Wall U value (0.70 W / m^{2}K) , Roof U value (0.5 0 W / m^{2}K) and Window to wall ratio (40%) are locked to these values, while the U values of the Wall and Roof of the existing building are calculated to be 2.636 W / m^{2}K and 6.343 W / m^{2}K for the Brick and Concrete Wall parts accordingly, and for the Roof 8.12 W / m^{2}K. Also the Window to wall ratio of our building is 21% while the assumption of the software is 40%.

Energy Efficiency Measures

As a result, the projected energy savings of the software are less than the actual energy savings of the proposed energy upgrades, but nevertheless even with the elevated energy efficiency of the Base Case, the proposed upgrades on the building, are projected to have more than 60% energy efficiency increase. Thus the building achieves the Edge Standard of 20%. Below follows a chart showing the 63.8% increase in Energy Efficiency from the Base Case.


RESULTS

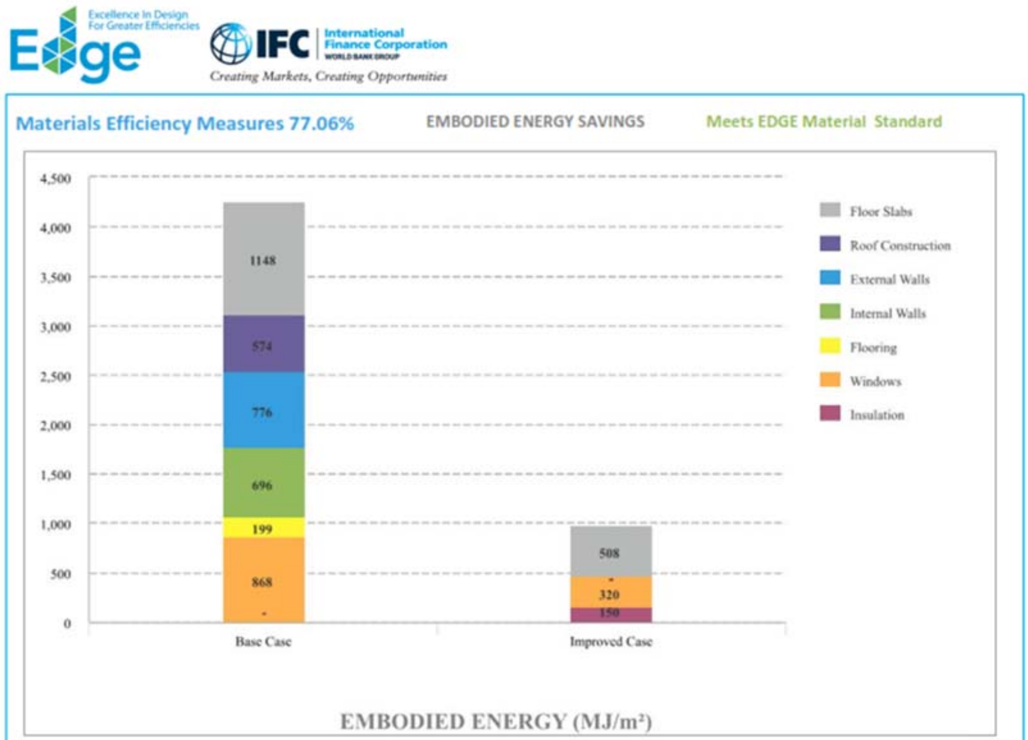
Final Energy Use	2,291.43 kWh/Month	Operational CO_2 Savings	28.77 tCO_2/Year
Final Water Use	56 m^3/Month	Embodied Energy Savings	3,284.33 MJ/m^2
Base Case Utility Cost	1,017.28 $/Month	Incremental Cost	0.00 $
Utility Cost Reduction	683.81 $/Month	Payback in Years	0.00 Yrs.
Energy Savings	96.87 MWh/Year	Water Savings	0.00 m^3/Year
Embodied Energy in Materials Savings	8887.40 GJ	Aggregate Floor Space Including Multiplier	2706.20 m^2

Table 23 Energy Effiency Measures - Energy Savings (Edge Application Guide)

Materials Efficiency Measures

Materials efficiency is one of the three main resource categories that comprise the EDGE standard. To comply for certification purposes, the design and construction team must review the requirements for selected. The Materials section includes Efficiency Measures for the following building elements: floor slabs, roof construction, external walls, internal walls, flooring, window frames, roof insulation and wall insulation. (Edge Application Guide)

In our case , there will be no alteration to the buildings wall and floor materials, but there will be a change in the windows altogether , along with the thermal insulation added on the walls and roof of the building.



				Proportion %	Thickness	Steel Rebar
EDM01	Floor Slabs					
	In-Situ Reinforced Concrete Slab 350mm Steel: 35kg/m2	Re-Use of Existing Floorslab			170 mm	40 kg/m²
EDM02	Roof Construction					
	In-Situ Reinforced Concrete Slab 350mm Steel: 35kg/m2	Type 1	Re-Use of Existing Roof	100 %	mm	kg/m²
EDM03	External Walls					
	Common Brick Wall with Internal & External Plaster 200mm	Type 1	Re-Use of Existing Wall	100 %	mm	

Table 24 Materials Efficiency Measures (Edge Application Guide)

			Proportion %	Thickness
EDM04	Internal Walls			
	Common Brick Wall with Plaster on Both Sides 100mm	Type 1 Re-Use of Existing Wall	100 %	mm
EDM05	Flooring	Type 1 Re-Use of Existing Flooring	100 %	
	Ceramic Tile			
EDM06	Window Frames			
	Aluminium	Type 1 UPVC	100 %	Triple Glazing
	Triple Glazing			
EDM07	Wall Insulation			
	No Insulation	Polystyrene		80 mm
	U: ~1.86 W/m2.k			
EDM08	Roof Insulation			
	No Insulation	Polystyrene		80 mm
	U: ~1.99 W/m2.k			

Table 25 Materials Efficiency Measures (Edge Application Guide)

Finally, while in our case the Base Case building is in some cases different from the assumptions in the Edge applications, we can have a clear picture of the impact of the upgrades in terms of Energy Efficiency. This means that the proposed changes will provide a huge impact on the energy category of the building, and will bring it in agreement with the current minimum standards of new school buildings.

Projected energy savings

As described above, the school building has a lot of room for energy saving. The proposals concerning the building envelope upgrade, provided a 94.07% decrease in the U value of the external walls and a 30.10% decrease in the thermal energy lost through the brick, concrete walls and roof , and as a result they proved an extremely cost effective measure due to the fact that the thermal insulation was non existent. Along with the wall insulation, it was proposed to upgrade the windows of the building. Though the building has an enormous surface of windows, which leads to a high cost of replacement, that has a payback period higher than the life cycle of the entire building (41.32 years), rendering these proposal the last option for an energy saving strategy.

According to the other proposals, of the HVAC system upgrade and the lighting system upgrade, the building can become a building that follows todays standards with a viable payback period that spans from 6 months to 6 years. The new natural gas boiler has a higher efficiency than the old oil boiler and a very low cost of fuel, along with the fact that emits less CO_2. The new air conditioning units with their increased efficiency cooling , decrease the cooling loads by 4015.47 kWh and also have a small payback period of 6 years. Finally the lighting system consisted of highly efficient lamps but they were improperly placed , resulting in high luminance levels. Therefore with some of the lambs removed, the luminance levels were according to the (Technical chamber of Greece, 2017) specification level, saving the school 1751.75 kWh of energy and a yearly cost of 200.09 €.

As a result of the proposed changes, the school that was consuming a total 28637.93 kWh per year, now consumes 22870.71 kWh. Thus the projected energy savings of the building are 5767.22 kWh each year. In addition to the above, the 5767.22 kWh / year decrease, is supplemented by the huge energy savings (20000 + kWh / year) in heating costs due to the thermal insulation on the building envelope.

It is also important to note that from now on, there must be paid more attention to the consumption records and the maintenance of the heating system. It is advised to the building administrator to start following the ISO 50001 protocol, at least in some extend. Therefore the administration of the school building must be commit to :

- Integrate energy policies and regulations into the school operations , such as keeping energy consumption records, maintenance records of all energy systems of the building, and tracking their progress.
- Place energy targets for the school building
- And final but most important : Provide the teaching staff and students with energy management training

The energy management training of the students is a measure that will help a lot in the goal to energy saving for the school building. Students are often unaware of the proper use of equipment and the energy loss through actions, like leaving the lights on while it is not needed or leaving the air condition unit on when it is not needed. Thus the education of the stuff and the students is a measure that has no cost , but will help the school building achieve the energy saving goals it sets and a higher energy efficiency.

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