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Energy performance of primary and secondary educational buildings

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Foreword

This dissertation has been written as part of the MSc in Energy systems at the International Hellenic University. Due to the rising concerns for the impact of the people's activities on the environment, it has become more urgent than ever, to take action towards a more sustainable development, meaning less use of fossil fuels, more use of renewable sources of energy, management of the energy demand and improvement of the system's efficiency, in order to save energy. Major consumers of the world's total energy are the buildings. At the present dissertation the subject is the educational buildings, which as described later on, have an important footprint both to the society's well-being and the energy balance, too. The interest on studying their energy performance has motivated my supervisor and me, to choose this area for my dissertation topic.

In the first chapter an overview of the available literature is included, discussing several issues, related to educational buildings. Afterwards, different criteria of categorizing schools are presented. In the last two chapters, the dissertation becomes more practical, presenting a real case elementary school in the city of Thessaloniki with all its characteristics that could affect its energy performance and then the building is simulated and brings out some relative results. Judging from them, some ESM are presented that would mitigate the factors that deteriorate the energy efficiency. The last chapter, followed by the conclusions, refers to the simulation results of the various scenarios. The choice of the best possible solution is made, according to the beneficial impact on the energy consumption and to the financial evaluation.

For their help and support during the various stages of this effort, I would like to thank my supervisor Professor Agis Papadopoulos and his PhD student Christina Constantinidou. Also, I would like to express my thanks to my friend Socrates Tselepis and Mr Panagiotis Dalpas, lighting consultant of Bright Special Lighting S.A.

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25/10/12

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1 Introduction

"It makes no sense to teach the next generation of California's students in facilities that are relics of the past, powered by energy sources that are out of touch with our state's renewable future. Investing in energy efficiency will help our schools save money - now and over the long run – and show students that we're concerned about the environment and their future."

Superintendent of Public Instruction, Tom Torlakson, 14 January 2011

Educational buildings hold, due to their big number, a big percentage of the total national resources, spent for the supply of energy in public buildings. Therefore, they are very attractive to be audited, in order to assess their energy performance and also because they play an important role in the whole idea of sustainability. These are the places, where the children will hear the main ideas about efficient use of energy, in order to become conscious citizens, who will make wise use of the sources during their future life. Also, regarding the Indoor Environmental Quality, it is very crucial for the teachers and the students to work and learn in a comfortable indoor environment, which will allow them to come up with the demanding learning process. Children, during their school years, spend almost 1/3 of their daytime in the school, so spending this big amount of time into healthy conditions is very crucial, due to their vulnerability and due to the fact that it has been noticed that Indoor Air Quality influences their concentration to a great extend [3].

Unfortunately, when it comes to the Greek educational buildings, they lack many of the necessary features to be regarded as environmental friendly and as the right place for someone to be teached. These features are their envelop, meaning the insulation they are provided with and their openings, the efficiency of their heating and cooling systems and despite these technical aspects, it is also noticed that in many of these buildings an unconscious use of these systems takes place.

2 Literature review

2.1 The climate of Greece

A few things should be said about the climatic conditions in Greece and the climatic zones as well. Greece is characterized by the Mediterranean climate, which has cold and wet winters, while hot and dry summers. Due to the different altitudes and the fact that there is a usual alternation between sea and country, many different climates are encountered in Greece, varying from the very cold villages in Pindos Mountains to the hot and dry countryside of Crete. Also, according to the Insulation Regulation, Greece can be divided into A,B, C and D climatic zones, from the warmest to the coldest, which is presented in Figure 2.1 [5]. In addition and according to the regulation, every building that is located in a place with altitude above 500m, it is considered to belong to the next colder climatic zone.

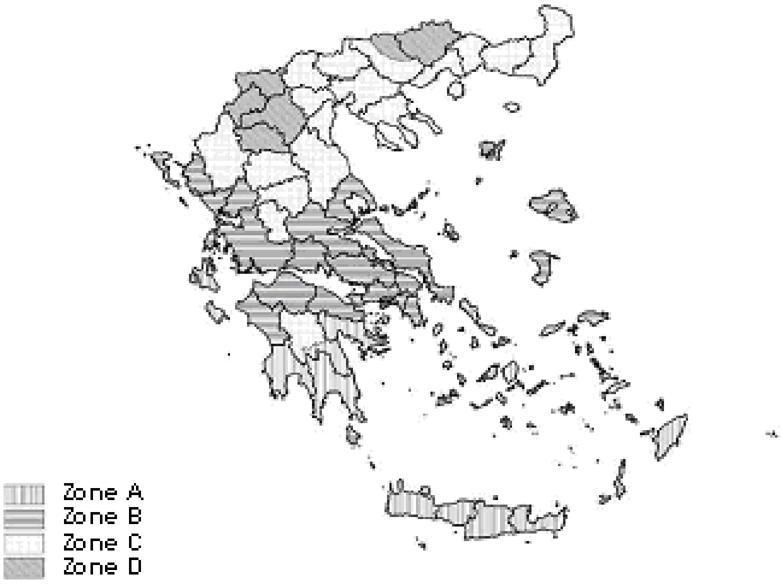

Figure 2.1: The climatic zones of Greece [5]

2.2 Designing an educational building

When designing an educational building, the principle target should be a school that will be energy efficient and which will be a comfortable and healthy environment for the people they will occupy it. In order to mitigate the huge costs of the HVAC systems, it is of vital importance that even from the stage of designing, high attention will be paid on the orientation, the shading, the natural lighting and ventilation of it. All these can be implemented during the design procedure of the building and can be regarded as passive systems. Some of these principles are given with detail in the Handbook for the designing of bioclimatic school buildings, published by the School Buildings Organization in 2008 [5].

2.2.1 Orientation

It is probably the main perquisite, in order to achieve a mitigation of the use and expenses of the technical systems that support the thermal comfort of the building. The piece of land, which the school will be built on, should be located at an appropriate place. If not possible, at least the orientation of the school should be such that will service the operations of the schools with the best way.

More specific, the building should have such an orientation that the classrooms will take advantage of the heat gains from the sun during winter and they will be provided with the most possible daylight throughout the year. The better choice for the orientation of the classrooms would be south; assuring that they will be protected against the direct sunlight, which getting into the classrooms will cause glare or overheating problems. Second choice would be the north orientation that ensures a nice diffuse daylight. In any case, east and west orientation should be avoided.

In addition, when the optimum orientation is desired, it is necessary to know the orbit of the sun during the year, the region and the climate.

2.2.2 Natural lighting

A carefully designed lighting system could take advantage of the daylight and reduce the consumption of electricity to a big extend. In addition, it could reduce also the electricity consumption for the air-conditioning of the room, because less artificial lighting means less internal gains and therefore decrease of the cooling load. Also, having to do with educational buildings, natural light is far more pleasant and helps the children watch the lesson more concentrated than the artificial one.

But not any kind of sunlight is pleasant during the class. Thus, a distinction is made between the light that comes into the room directly, without any intervention and the one that passes through some devices that make it spread into the whole classroom in a diffuse way. The former can be found in the literature as sunlight and is most of the times responsible for glare or overheating problems. The latter is called daylight and can be achieved by placing lighting shelves, venetian blinds, etc.

2.2.3 Shading

Shading is advisable not only for reducing the cooling loads during summer, but also for dealing with the glare problems that might occur during the whole year. Therefore, providing an educational building with the proper shading contributes to the thermal and the optical comfort inside it, as well.

Shading can be achieved either with moveable subjects or with steady ones that are parts of the building's envelop. External shading that stops the sunlight before entering the building, is preferred more than the internal ones.

Openings with south orientation should be shaded with horizontal overhangs, which are dimensioned in that way that they will permit the necessary winter sun enter and heat the room. On the contrary, openings with west or east orientation should be shaded either with moveable vertical features or with deciduous trees that would also improve the optical comfort of the courtyard and would contribute also to the good psychology of the building's users.

2.2.4 Natural ventilation

In order to achieve a satisfactory natural ventilation of the spaces, it is important to design the opening in an appropriate way.

- First of all, the air velocity and direction of the prevailing winds in the area should be studied and the building should be positioned in the direction that the wind mostly blows
- The openings should ideally be positioned opposite to each other, in order for the wind to get into the space from the opening with high pressure and leave the building from the low-pressure one. It is also possible that some external features like trees, windbreaks etc. could be used, in order to create such pressure differences
- Attention should be paid also on the height of the openings, so that the incoming wind can pass through the whole volume of the space and sufficiently ventilate it
- Natural ventilation during night is very important, due to the lower temperature of the wind, so wind conditions during night should be taken into consideration

Additional methods that could contribute to the natural ventilation are also the solar chimneys, the cooling towers, etc.

2.3 Characteristics of school buildings

In 2010, Dascalaki and Sermpetzoglou published a paper [3], where some of the characteristic typologies of school buildings are presented, in relation to the region they are built in. Greek educational buildings were built most of the times many years ago. They may be constituted of a single or two floors, depending on the population density of the place they are constructed. For example, in climatic zones B and C, where most of the big urban centers exist, it is more common to encounter a 2-floored educational building, than in the zone A that is mainly constituted of the Greek islands. The height of the floors varies usually between 3-4 meters, with the exception of some old traditional buildings, mainly built in zone A, where there are heights of 4-5 meters.

As far as the roof is concerning, in climatic zone C there is the the majority of the traditional school buildings, which have a roof constructed with roof tiles (85%). This percentage is lower in zones A and B, where almost 70% of the roofs are like that [3]. Concerning the shape of the buildings, there are the L-, the R- and the Π-shaped buildings, with a dependence existing again on the geographic region. In zone A, the Π-shaped are the most popular, whereas in zones B and C these are the R-shaped ones. It is believed that there is a relationship between the energy consumption and the shape of the school building. Π-shaped buildings are considered as the most environmental friendly ones, whereas the L- and R-shaped come second and third respectively.

The majority of the educational buildings in Greece were constructed before 1964 and this is why there are a lot of those buildings that have no insulation, since the latter has become mandatory in 1979 by the Hellenic Building Thermal Insulation Regulation [3]. In addition there is a percentage of educational buildings, mainly technical lyceums that are poorly insulated (34%).

2.4 Categories of school buildings

Dimoudi and Kostarela have categorized the Greek educational buildings into [4]:

a) Those that were constructed until 1960, using stone for the building envelop and wood for the roof
b) Those that are built after 1960 and follow the standards the national Organization of School Buildings. ATHINA and EREUNA belong to this category and can be encountered either with open or with closed corridors. Moreover, a further separation

of this category can be performed, regarding the Thermal Insulation Regulation that was adopted in 1979. From that date the insulation of the building's envelop and of the roof has become mandatory.

Some further categorization of the school buildings is presented also in the 3rd chapter.

2.5 Energy consumption

The biggest part of the schools' energy consumption holds the energy for heating, then comes the electricity for lighting and operation of the equipment, while very rarely does a school consume energy for hot water. Regarding the cooling of the building, the consumption is too low, because in Greek schools only a few A/C exist to cover just the cooling loads in the teachers' offices, whereas in the classrooms the thermal comfort during the warm months is achieved usually by using ceiling fans. Besides, the Greek schools are closed during summer, so only in May, September and early October they do have cooling demands.

The expenses for the heating are covered by the budget of each school, while the electricity expenses are paid by the public authorities that the school belongs to [4].

Table 2.1: Specific energy consumption for heating per of school classes (KWh/m^2) [4]

School type	Climatic zone A	Climatic zone B	Climatic zone C
Old stone building	10	48	146
Type with open corridor	15	46	122
Type with close corridor	12	41	115
Type ATHINA	5	27	86

2.6 Encountered problems

2.6.1 Heating system

In a paper that was published by Theodosiou and Ordoumpozanis in 2008 [1], many of the problems that can be encountered in a school are mentioned. Starting with the energy consumption for heating, it is noticed that the most used heating systems are equipped with central oil-fired boilers, but there are also some very few buildings that use stoves. Most of the times, the radiators are installed on the wall that is exposed to the environment. Also, the typical formation of the desks in a classroom is in 2-3 rows and therefore the row that is close to the radiators may warm too much, not allowing also the heat to be radiated to the other rows.

Another fact that might not be that contributive to the thermal comfort is that in many cases there is only one thermostat that regulates the starting of the heating system. If this thermostat is located in cold room, for example in front of the central door, that would create thermal discomfort in the classrooms, because it would turn on the heat, even if the temperature in the classrooms is high enough. That would lead to overheating of some rooms, forcing the users (teachers, students) to open the windows to balance that, spending energy unconsciously.

Factors that also affect the heating consumption are the insulation levels of the building envelop, the heating equipment and the attitude of the systems' operators. Most of the times, the heating system is not properly maintained, thus having too small efficiencies. In addition, the modern cities are so densely built, that very rarely has an educational building enough solar exposure, in order to cover some part of the heating loads passively.

2.6.2 Electricity consumption

The electricity consumption of the Greek schools is much lower than the energy consumption for heating. The vast majority of those have no air-conditions and hence they use electricity just for lighting and for their electrical equipment.

Most of the Greek educational buildings are equipped with fluorescent lamps with reflectors or diffusers. Due to the lack of sufficient lighting controls or maintenance, there is usually either a lack of enough lighting or there are glaring problems. A usual fact is also that the lights are on, even if there is enough lighting, which happens when the classrooms have a south orientation.

In addition, schools that are located in smaller cities, which are scarcely built, take advantage of the fact that they do not have any nearby buildings that would obstruct the natural lighting with their shadows, so they consume even less electricity, than the educational buildings that are located in densely built big cities.

2.6.3 Air quality

. Natural ventilation is the common means, which contributes to the maintenance of the air quality at allowable levels. It was found that in most of the schools the openings are not always properly positioned, so they do not contribute as much as they could to the ventilation. Because of the high occupation density (too small area corresponds to each student), there is a strong need for ventilation, in order for the Indoor Air Quality (IAQ) to be kept at satisfactory levels. That is not achieved in the majority of the Greek Schools, due to the lack of sufficient ventilation systems or because of the fact that even if such a system exists, it is very difficult for a school that is built in a city with air pollution, to reach to a point that the indoor air will be healthy enough for the students. Moreover, these conditions are in many cases difficult to be reached, because there are many educational buildings that were built for other purposes, so no sufficient studies were made, regarding their environmental behavior [1].

IAQ has been related to the CO_2 concentrations. This does not mean that CO_2 is considered as a pollutant, but it has to do much more with the productivity and the concentration levels of the students, which is strongly influenced by the CO_2 levels. Furthermore it is easy to monitor and evaluate. Ventilating only specific rooms would not be a wise solution. In most of the cases, the polluted air from the rest of the classrooms would enter the ventilated one and affect it [1].

Although the principle of the schools is to open the windows during the intervals between the classes, it has been noticed that such a method is not always the appropriate, because the duration of the breaks does not allow the air of the classroom to be enough refreshed. A measure that would foster the natural ventilation even more would be to install opening at the top. It has been noticed that if they stay open at night, they are a safe solution to drop the temperature down during the warm days of the school period and prevent the classroom from being overheated during the day. However, it is not advisable to be installed anywhere, for example at the north side. Instead, they would better be installed at the south or east side, or else an increase of the heating load would occur as a counter-result. Except for the ventilation, they play an important role in the natural lighting, since they allow the light coming into the class [4].

2.7 Possible improvements

In the article mentioned above, written by Dimoudi and Kostarela in 2008 [4], some issues along with possible measures are presented, regarding the performance of the educational buildings in the cold region of Greece and specifically in the prefecture of Grevena, which at that time was included in the climatic zone C of Greece. Nowadays, it has been transferred to the even colder D climatic zone, along with Florina etc. In that study, issues regarding the energy consumption of the schools of that region were developed and a potential for making these buildings more efficient was presented. Furthermore, improving the insulation of the building was proved to be of crucial significance, especially the insulation of the support frame. Also, along with the insulation, providing the school building with modern, more air-tight openings and with movable shading devices would decrease the energy consumption for heating to a big extend. When it comes to the cooling loads of that region, they are too low and only in June exists a little possibility of the classrooms to be overheated. Therefore, a combination of ceiling fans, night ventilation and a satisfactory thermal mass would reduce the cooling loads up to 99%.

There are many possible actions that can be taken in order to improve the energy efficiency of a building. Some of them need just some conscious and not a lot of capital. Santamouris et al. [2] have issued a paper concerning the energy efficiency of school buildings and have proposed a series of measures that could improve it and they are discussed below.

2.7.1 Reducing the heating loads

Heating loads can be significantly reduced by reducing the overall heat transfer coefficient [2]. That could be done by protecting the school building with the proper insulation material and thickness and by placing state-of-the-art windows, double glazed ones and with very low U-value. When a building is provided with high-quality windows, it contributes to its air-tightness, reduces the infiltration. This is very important, especially in the cold areas of Greece. These have been made mandatory from the European directive 2002/91/EC which has to do with the energy performance of the buildings (EPBD). Other feasible measures may be the installation of multiple thermostats, in order not to waste thermal energy in rooms that it is not needed.

Moreover, increasing the efficiency of the heat production system is also a crucial factor. That could be succeeded with the substitution of the very old and high-consuming boilers with modern ones, like gas condensing boilers that have really high efficiencies. If it is not feasible for financial reasons, a solution could be the appropriate maintenance of the system and the insulating of the boiler and the network of pipes.

2.7.2 Reducing the electricity loads

Santamouris et al [2] have also referred to the decrease of electricity consumption. It is easy to install efficient fluorescent lamps that will be accompanied by diffusers, reflectors or lighting shelves. Also, occupancy sensors would really face the problem of leaving an unoccupied room, with the lights on and spending big amounts of energy. Additionally, taking advantage of the natural lighting during the daytime using again reflectors or lighting shelves would really decrease the consumed electricity by a percentage of 80%.

2.7.3 Reducing cooling loads

First thing to do would be reducing the direct heat gains by providing the school building with the appropriate shading, which ideally would be a moveable overhang placed mainly at the south-oriented sides of the building and would close in order to allow the necessary direct solar gains during the winter. That kind of shading would not only reduce the cooling loads, but also face the glare problems, which are common in the classrooms [3].

Another solution would be to reduce the internal gains. Since the equipment, that is a big source of internal gains offers a service and cannot be moved away, it is reasonable to cope with the other sources, like the lights. The fluorescent lights that were mentioned above, emit much smaller amount of heat compared to the incandescent ones [2].

Since the Greek school buildings are closed during the hot summer months, they can overcome the warm weather during May and September by installing ceiling fans, which offer a really comfortable environment, even if the temperature is 30^oC. Moreover, there is a study published by Synnefa et al. [9], where the impact of cool roofs is examined. A case study is presented, in which a school in Athens is simulated by means of the TRNSYS software, giving results regarding its performance with the regular roof material, in comparison with the cool material, which has high solar reflectance value. Installing cool roofs, particularly in Mediterranean countries, brings multiple benefits such as the decrease of the cooling loads, especially in uninsulated buildings. It was recorded that, during summer, the application of cool roofs resulted to a decrease of the indoor air temperature by $1{,}5\text{-}2^oC$, while $0{,}5\ ^oC$ during winter. Another advantage of such a cool roof, with a solar reflectance factor at 0,89, is that the fluctuation of the materials' temperature of the roof is minimized significantly, protecting the roof from the big and harmful temperature differences. The only drawback of such technologies would be the increase of the heating loads, referred as *heating penalty* [9], which however seems to be rather trivial, compared to the reduce of the cooling loads.

2.8 Overview of other relevant literature

However, inappropriate energy performance of educational schools is not only a Greek problem, but concerns also other countries as well. Therefore, some literature concerning the European school buildings is presented, which deals with a variety of issues regarding the improvement of the IEQ of the European schools and at the same time making them more efficient with the scope to minimize the energy consumption.

2.8.1 Schools not fully equipped with HVAC systems

There are many schools that although they have HVAC systems, the spaces equipped with them are restricted, which means that their occupants have to feel comfortable when they change from unconditioned to conditioned spaces and vise versa. Conceicao et al. [6] developed a model, after a study was made in a school of south Portugal, that could be adapted in other Mediterranean countries as well, that are characterized by similar climatic conditions.

That model has as main target to control the temperature in the spaces that are serviced by HVAC in such a way that thermal comfort principles are achieved and at the same time conservation of energy is made, as well. It takes into consideration the different seasons and clothing during the year, the indoor and outdoor temperatures and the humidity. At the same time it regards the fact that the occupants of such semi-conditioned buildings desire not too big differences of the conditions they meet, when they change between spaces. More specific, during winter time the model should set the HVAC system to a temperature not too high, so that when a student or teacher enters an unconditioned space, he will not feel too much uncomfortable by that difference. Respectively, during summer time the temperatures of the conditioned spaces should not be too low.

2.8.2 Modeling and calculation of IEQ

It is widely accepted that even from the designing phase of the educational building, there are some design details that could affect the future performance of the building, like the orientation, the materials, the openings, etc. So it would be really helpful for the constructors to have a model, which would take as input some parameters and would give as an output the expected IEQ of the building. Such a model is presented by Tiberiu Catalina and Vlad Iordache [7], who have developed a regression model using the software TRNSYS. This model takes as input the climate, the heat transfer coefficient, the glazing surface etc. and results in calculating the IEQ of the building. At that kind of modelling another important option is to have a sensitivity analysis tool, in order to speculate how much the output changes, when a single parameter of the inputs fluctuates.

2.8.3 Need for new heating systems

Wim Zeiler and Gert Boxem [8] have studied the problem of overheating of the classrooms not only in summer, but also in winter. That is attributed to the fact that in many cases the ventilation rate is not capable of dumping out the excessive heat, which comes either from winter solar gains or from the internal gains (e.g occupants). The vast majority of the questioned students declared uncomfortable thermal conditions that are responsible for the deterioration of the students' performance to the same extent as the IAQ. Therefore, an alternative heating system is examined and that is the Thermo Active Building System, which takes advantage of the thermal mass, in order to provide the spaces with the suitable amount of heat. One characteristic example of such a system is the Heated Floors. Results of the audit have shown a respective improvement of the thermal comfort, in comparison with the conventional heating systems.

2.8.4 Passivhaus standard educational buildings

Arthur Tatchell published an article [14] about the first ever 'zero carbon' school that was constructed in UK, under the Passivhaus standard. It is the Montgomery Primary School and was built with the initiative of the UK's Department for Children, Schools and Families (DCSF) to comply with the regulation that imposes that all non-residential public buildings should be zero carbon from the year 2016.

A way to construct a zero energy school would be to equip it with biomass burners, instead of natural gas boilers, to install PV systems on its roofs and to emit no carbon at all. But that alternative would not be that realistic and sustainable, since it would make use of precious resources. The main principle to comply with the Passivhaus is first to minimize the demand for energy, with Demand Side Management (DSM) techniques and then apply also renewable energy systems, in order to generate the necessary energy on-site. However, it would make no sense if an educational building was equipped with all the state-of-art infrastructure, while its occupants were unconscious with the use of energy, for example if they left windows open or lights on, without any reason.

The best option to reach the Passivhaus criteria is to provide the building with excellent insulation, maximizing its air-tightness, while at the same time keeping the IAQ to high levels by using Mechanical Ventilation with Heat Recovery system (MVHR). This idea goes against the ‘Sick building syndrome’’ or the ‘Tight building syndrome’ perceptions, which were based on the theory that the more air-tight the building is, fewer are the chances of keeping the IAQ to acceptable levels. On the contrary, Passivhaus idea indicates that the building should not have any leakages of air and therefore energy, it should provide however its spaces with the satisfactory amount of fresh air, after heating him first in the Heat Recovery system.

In order for a building to be regarded as Passivhaus one, it must satisfy the standards that are presented in Table 2.2. More specific, it should in any case comply with the primary energy consumption value, while it is free to decide whether it will catch up with the Heating demand or the cooling demand. Moreover, it is imposed that these buildings, even in the cold winter days, should be able to exceed the temperature of 16^{o}C, even if its heating system is turned off.

Table 2.2: Passivhaus building standards

Specific heating demand	15KWh/m^{2}yr
Specific cooling demand	15KWh/m^{2}yr
Specific primary energy demand	120KWh/m^{2}yr
Airtightness	0,6ach at 50 Pa

Having reached these standards, it is the first Passivhaus school in UK and is believed to be the first in use ‘zero energy’ school in Europe.

2.8.5 PVs on schools roofs

SBO (School buildings Organization) of Greece has taken actions since 2004 to make some improvements at some schools of Greece, which had a bad environmental attitude and the Indoor Environmental Quality was very low [15]. Apart from insulating the buildings, putting some CO_2 sensors and providing shading to them, they were involved into a project, which would study the installation of PV systems on the roof of the 4th High School of Athens, built in 1982. The interest of the teachers and the students was great and except for the improvements that were expected, the whole idea took an educational character. Moreover, the specific building is located at the center of Athens, a very densely built area, so the conclusions of this audit would be a benchmark for other similar situations.

Apart from the SBO, the Centre for Renewable Energy participated also into the project, installing a PV system that would provide the produced electricity to the city’s grid.

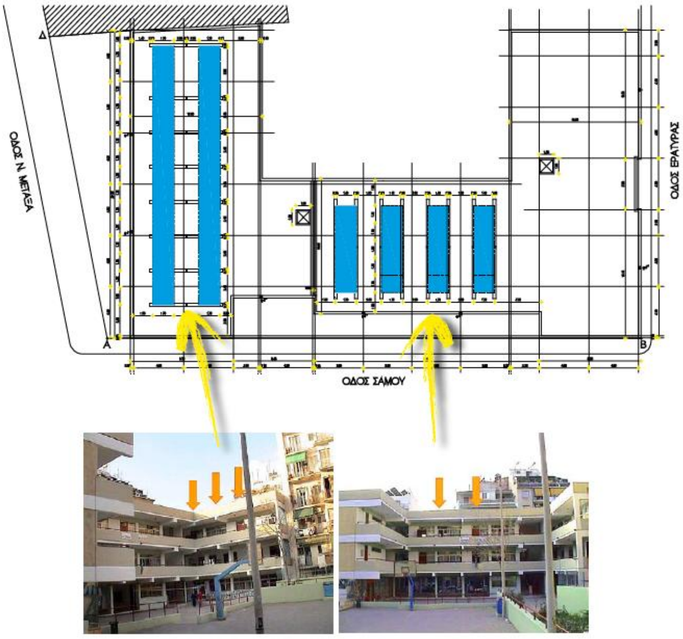

Figure 2.2: Roof plan depicting the photovoltaic panels [15]

The installed PV system has a nominal output of 15,75KWp and is presented in Figure 2.2 above. It consists of 50 panels of 315 Wp each and five inverters. The capacity of this system is such that it could provide the grid with 22447 KWh annually. The annual earnings of the school, through selling the electricity to the grid, count up to 10 000 Euro, while the required by the school electricity costs 3 000 Euro. The project was scheduled to have been finished by 2007 and the total cost of it was calculated at 138 000 Euro, with a payback period of about ten years. Ending, the environment benefit can be realised by considering the amount of fossil fuels that would have been consumed over a year, if it had not been for the PV system. This is 6 083 kg of fuels and 19 711kg of emissions.

2.8.6 Heat pumps in schools

Euiyoug Kim et al. have recently published a paper [16], discussing what effect could a Ground Source Heat Pump (GSHP) have on a school’s energy performance. More specific, a GSHP system installed in the Pusan National University of Korea was studied. Fist of all, it is stated that this kind of heat pump is more efficient than an air source heat pump (ASHP), due to the fact that it exchanges heat with a far more stable heat source/sink than the air, the ground. That means that during the heating period it takes heat from the ground, which has much higher temperature than the outdoor air, while during cooling period it dumps heat to it easier, as it is colder than the warm summer air.

The GSHP that was installed in the university is a water-to-refrigerant type, fact that makes it more efficient than a water-to-water one. A circulating pump is not needed and also it is not burdened by maintenance costs, that would be needed in the case of water-to-water, because corrosion possibilities would exist. As seen in Figure 2.3, the whole system consists of a ground heat exchanger (GHE), which reaches a depth of 175 m. Some thermocouples measure the impact of the exchanger at the ground temperature. At the indoor part of the system, another heat exchanger exists, transferring heat from the water to the refrigerant and vise versa. Also, there are two kinds of compressors, one inverter and the other one fixed, so the electricity consumption is reduced when the system is not working in full load. Apart from the temperature variation of the ground, measured with the thermocouples, the temperature volatility of the air is also measured and also the electricity consumption for the circulating pump for the water inside the underground tubes, the compressors and the fan coils.

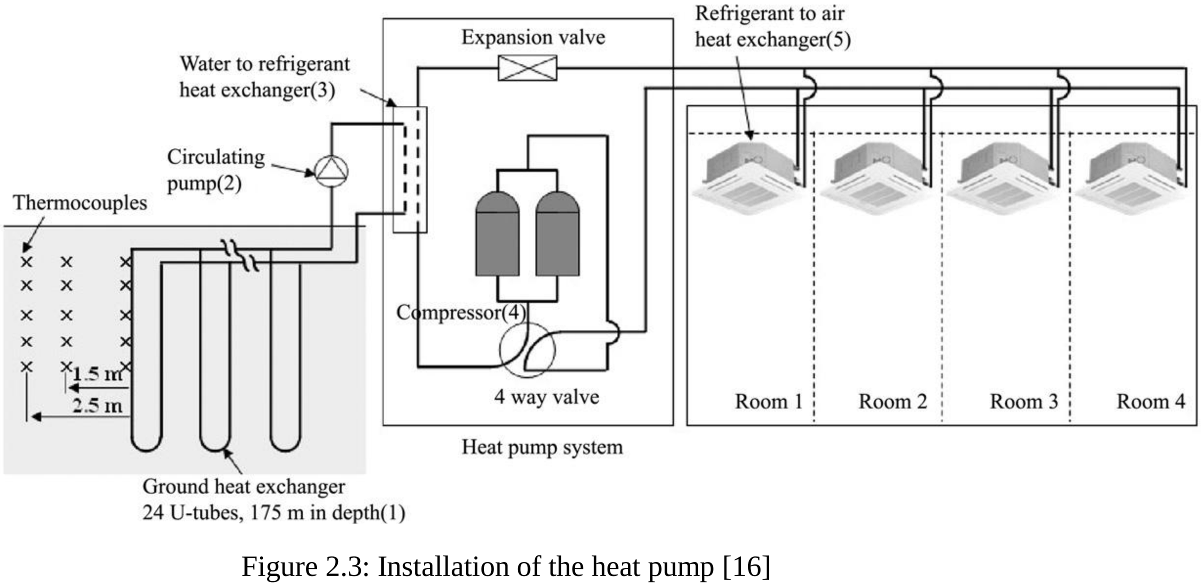

Figure 2.3: Installation of the heat pump [16]

The paper is concluded with some results that are produced by comparing the GSHP with an ASHP of the same capacity. Realized from the Table 2.3 that depicts the results for a heating period day, when a GSHP is used, a COP of almost 37% higher could be accomplished. This could be explained by the fact that although the outside temperature is almost the same, the evaporator of the GSHP works under much bigger temperatures (15,4 ^{o}C) than the ASHP. This has as a result that the suction pressure is much higher for the GSHP and therefore the compressor does not need to rise it too much, saving electricity. However, the difference of the COPs' could be even higher, but it does not do so, because the electricity input for the pump of the GHE is also calculated. Equivalent results are taken also for the cooling period, having there somehow higher improvement, at the level of 45% average, again for the same reason that condenser gives heat to a sink that is far cooler than the outside warm air. In terms of energy savings per day, almost 51 KWh/day are saved during cooling period, while almost 44 KWh/day during heating period.

Table 2.3: Comparison between GSHP and ASHP for the same outdoor temperature during heating period

		GSHP	ASHP
Evaporator	Average circulatin water temperature (^{o}C)	15,4	-
	Outdoor air temperature (^{o}C)	6,7	7
Compressor	Discharge pressure (kPa)	2839	2892
	Suction pressure (kPa)	1045	634
Heating performance	COP of heat pump	6,1-6,6	3,8
	COP (overall)	5-5,2	3,2

2.8.7 Condensing boilers

A study was published in 2004 by Defu Che, Yanhua Liu and Chunyang Gao [17], a team from Xi' an Jiaotong University of China. That article was a result of a continuously rising worry about the big amount of energy consumption of the heating systems of China. More specific, it compares the condensing boiler with a conventional one, presents the beneficial impact of the condensing one on the energy consumption, while at the same time the feasibility of such a technology is examined.

Conventional boilers have the flue gases leaving them at very high temperatures of 150-200oC, which means that all the water that is included in the products of the combustion exits the chamber in the form of vapor. Consequently, large amounts of heat are lost in the environment, in the form of latent heat, fact that deteriorates the efficiency of the boiler. That is the existence reason of condensing boilers. As imposed by their name, they are able to capture the latent heat of the vapors, by condensing them into water. For this to be achieved, it does not require any fundamental changes on the existing natural gas fired boilers. Instead, a surface type condensing heat exchanger made of stainless steel is installed at the conventional boiler, which uses as a cooling medium the returning water. By this way, the temperature of the flue gases drops at 55-60 ^{o}C and the vapors condense at that temperature, due to the high pressures. An extra advantage of these boilers is that some or the total of the harmfull substances of the flue gases like SO_x and NO_x are not allowed to be emitted to the environment, they are dissolved to the contrary in the condensed water.

The figure below represents the operation of a condensing boiler, regarding its efficiency in relation to the temperatures of the flue gases. Two regions are distinguished at the graph, with the dew point of almost 60^{o}C separating one another. The condensation of the vapors is accomplished below that temperature, where there is an impressive increase of the efficiency, even greater than 100%, until 107,4%. This can be attributed to the fact that the efficiencies below are calculated with base the low heating value.

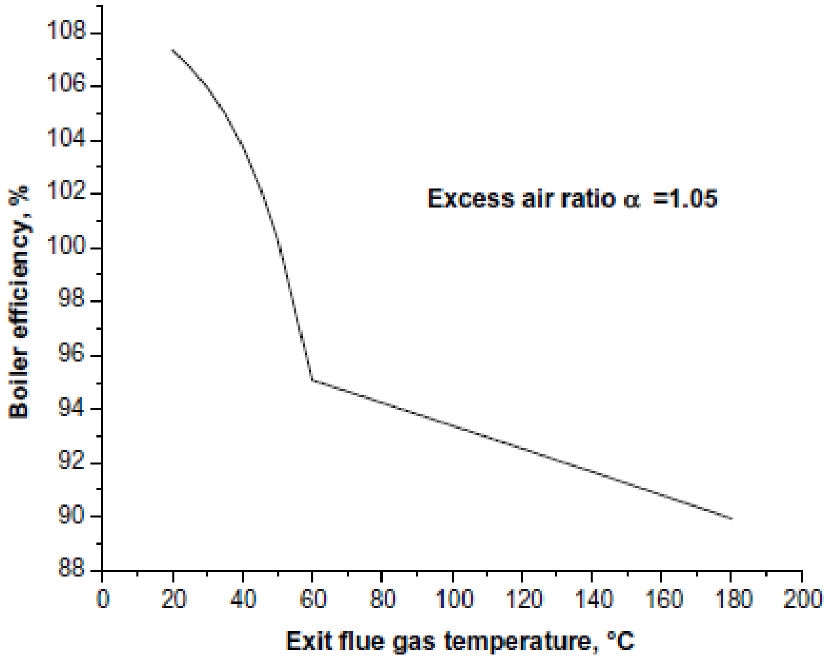

Figure 2.4: Efficiency of the boiler according to the flue gases temperature [17]

In that article a feasibility study is also performed, calculating the payback period. It is noticed that a payback period of 3-4,5 years is expected, depending on the materials of the devices that are to be purchased (Figure 2.5).

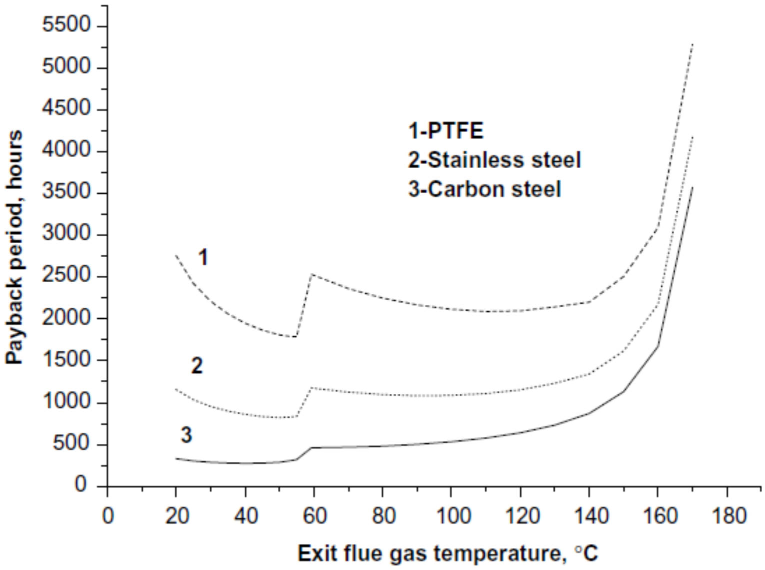

Figure 2.5: Payback periods according to flue gas temperatures[17]

This dependence can be noticed into the above figure. Heat exchangers are usually constructed either with carbon steel or stainless steel or PTFE (polytetrafluoroethylene), from the cheapest to the most expensive one. Representative of this cost variation is as expected the payback period of the retrofitting investment, which depends not only on the material of the heat exchanger, but also on the temperature of the flue gases. The lower the temperature is, the bigger is the amount of latent heat that is recovered and therefore, the savings shorten the payback period. This shortening is even steeper at the region of the dew point, close to 55-60^{o}C.

In the article it is concluded that the stainless steel is preferred to the other two materials, because on the one hand the cheap carbon steel is very likely to be corroded by the acid environment of the condensation, whereas the PTFE material is too expensive and has big payback periods, despite the fact that it is very resistant to corrosion.

2.8.8 Green roof systems on buildings

Santamouris et al. published an article in 2007, regarding the installation of a green roof system on a building of Athens, where a nursery school is hosted [18]. The necessity of green areas and reflecting materials has been noted, mainly in densely built cities, where the heat island is a very common problem. Therefore, installing green roof systems is the only way to achieve enough green area in an already built environment, where there is no other space to plant trees on.

Moreover, it is stated that these system provide insulation, shading and they are able to drop down the indoor air temperatures to a great extend, with the evapotranspiration effect taken also into account. The results are even more impressive when the building has no insulation and also if the floor under the green roof is examined, regardless of if the building is insulated or not. Also, it is pointed that the benefits of a green roof installation are more related to the cooling loads, during the warm summer periods of the year, when a reduction on the cooling loads in the range of 6-49% occur for the whole building and 12-87% for the floor lying underneath the green roof.

Representative of those mentioned above is Figure 2.6, which presents the frequency distribution of the indoor air temperatures encountered in a building without insulation and for both cases, with or with no green roof installed. It is realized that the temperate temperatures, the ones that are desired to retain thermal comfort are more frequently encountered in the case of the green roof system, whereas the extreme and unwanted temperatures are more usual, if no green roof system is installed.

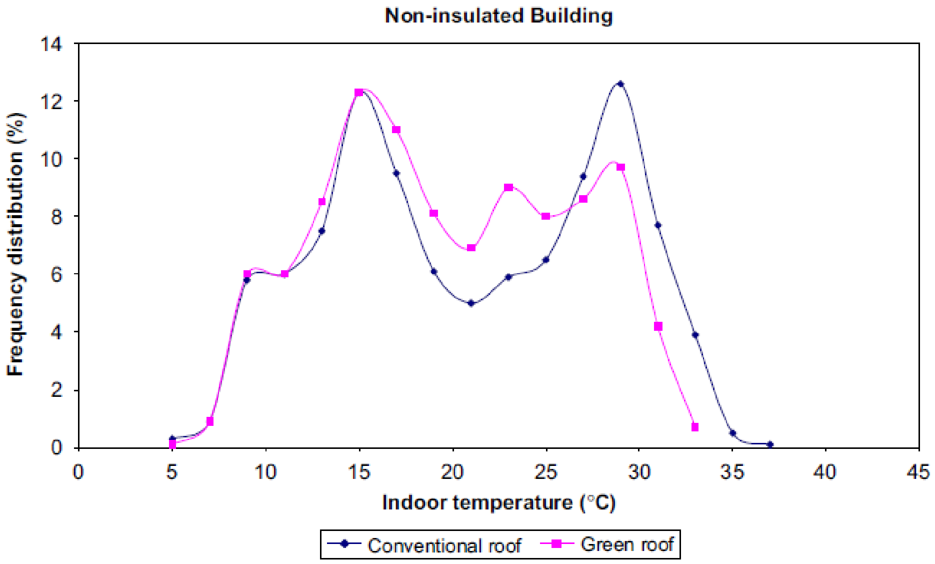

Figure 2.6: Frequency distribution of indoor air temperatures for the non-insulated building, with and without a green roof installed [18]

2.8.9 High school in Perugia, Italy

Umberto Desider and Stefania Proietti have published in 2002 a paper, regarding the energy consumption of high school in Perugia, a province which is located in central Italy [22]. This study was made in the frame of a European Union project, named TEACH and supported also from Energy and Environment Agency of the province of Perugia. The main purpose of it was to examine school buildings, regarding their construction materials, their supportive technical systems and suggest some Energy Saving Measures (ESM) that would be also applicable to other European schools.

In Italy generally, school building are proved to present many variations, regarding their building construction, the technical systems they use and due to the fact that they are many, can be considered as a priority, should it be attempted to improve the efficiency of the public buildings. In Italy, there are the old schools constructed mainly in the historic city centers, consisted of bearing walls with high thermal inertia, having though very old openings. In addition and most times in the outskirts of the cities, more modern educational buildings are encountered, which are most of the times prefabricated, having though high energy consumptions due to some problems that are discussed later.

Desider and Proietti are referring to some issues, they have noticed during their study. First, concerning the daylight, only the modern school buildings are equipped with bigger windows that allow the natural light to enter the classrooms. Also, the importance of high-efficiency lamps is stated. When it comes to the energy consumption, 80% accounts for heating, using mainly natural gas and oil. The majority of the heating systems are old, have low efficiencies and lack the necessary controls.

Afterwards, they include some possible interventions that should be taken into consideration, when attempting to improve the performance of a building:

- Electrical infrastructure
    - Substitution of the Incandescent lamp with efficient fluorescent ones
    - Improvement of the power factor
- Heating system
    - Dealing with the oversizing problem
    - Insulation of the pipes exposed to the environment
- Installation of thermostatic valves

- Thermal losses
    - Insulation of the building envelop
    - Installation of low U-Value, double-glazed openings

Some few things are also mentioned, regarding the economic feasibility of these interventions. Using financial indexes such as NPV and DPB, one could make an estimation, which is the best to be implemented.

They proceed then to a comparison between some schools that have been studied and they examine their consumption by using some specific consumption indexes, such as Specific Consumption per unit of volume or specific consumption per student etc. This is helpful, since it contributes to the evaluation of different school that neither have the same size, nor do they have the same number of students.

They have found that the highest thermal energy consumption accounts for the schools constructed with reinforced concrete and plugging of several material, which are built in 70s and 80s. It seems strange that the historical buildings that were constructed many years ago with masonry and have mostly old systems, have medium thermal energy consumptions, because of the high thermal inertia, they are characterized of. Modern schools though, constructed during 90s, have the lowest thermal consumption. An expected correlation between the kind studies is also mentioned, with the industrial technical schools holding the lowest consumption per volume, since they are equipped with more infrastructures, which results in internal gains.

Regarding the electricity consumption, it was found that the very old buildings with the small windows and the old lighting systems, are very high consumers. However, the highest ones turned out to be the industrial-technical schools, because they are burdened with the biggest electricity loads, needed to service their electrical equipment.

Concluding the article, some extreme cases of schools were presented that have very high consumptions related to other schools of the same type. These deviations were attributed to some encountered problems such as huge electricity consumptions for electrical heaters, oversizing of the heating systems etc.

2.8.10 Feasibility study of ESMs

Although there has been much literature written about Energy Saving Measures (ESM), only a little of it has referred extensively to the economic evaluation of the interventions, by using some necessary financial indicators. Yiannis Nikolaidis et al. [20] and Agis M. Papadopoulos et al. [21] have tried to cover this gap with the articles they published in 2009 and 2002, respectively.

Regarding [20], some ESM are proposed that intend to improve the energy performance of a residential building in central Greece. Despite the irrelevance of this building with the educational buildings studied in this dissertation, it is interesting to see what criteria are followed, in order to pick the best solution.

The proposed interventions are the insulation, the provision of double-glazed openings, the substitution of the current oil-fired boiler with a gas-fired one, the introduction of solar thermal systems, since in Greece the sun is available almost the whole year, and the installation of new A/C units with relative higher efficiency than the old ones. The financial indicators that are used are the Net Present Value (NPV), Internal Rate of Return (IRR), Savings to Investment Ratio (SIR) and Dipreciated Payback period (DPP).

The NPV adds all the cashflows that are expected in the future, as a benefit from the measure, discounted back in the present with a discount factor reflected by the cost of capital:

$$NPV = -C_0 + \sum_{t=1}^{n} \frac{F_t}{(1+p)^t} \qquad (1)$$

Where: Co the initial investment, Ft the future cashflow in year t, p the cost of capital and n the period for which the NPV is calculated.

In order for an intervention to be regarded as acceptable, the NPV should be greater than 0 (NPV>0). When comparing though two different investments, the one with the higher NPV is prefered.

The IRR gives the discount rate, for which the discounted cashflows are equal to the initial investment, meaning that the NPV is set equal to zero:

$$NPV = -C_0 + \sum_{t=1}^{n} \frac{F_t}{(1+p^*)^t} = 0 \qquad (2)$$

The resulted discount rate is the maximum interest an investor could afford, when financing the investment using debt. An investment with an IRR greater than the interest is considered acceptable. Between two different independent investments, the one with the higher IRR is preferred.

The Savings to Investment Ratio (SIR) compares the present values of the future inflows with the present values of the future outflows:

$$SIR = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+p)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+p)^t}} \qquad (3)$$

If an ESM yields a SIR greater than one (SIR>1), it is acceptable, since that means that the NPV>0. When comparing two independent investment, the one with the higher SIR is chosen.

At last, the DPP is analyzed, which expresses the years needed for the initial investment to be recovered, through the cashflows Ft that are initiated by the investment:

$$DPP = \frac{-\ln\left(1-\frac{p \cdot C_0}{F_t}\right)}{\ln(1+p)} \qquad (4)$$

where the future cashflows are assumed to remain constant

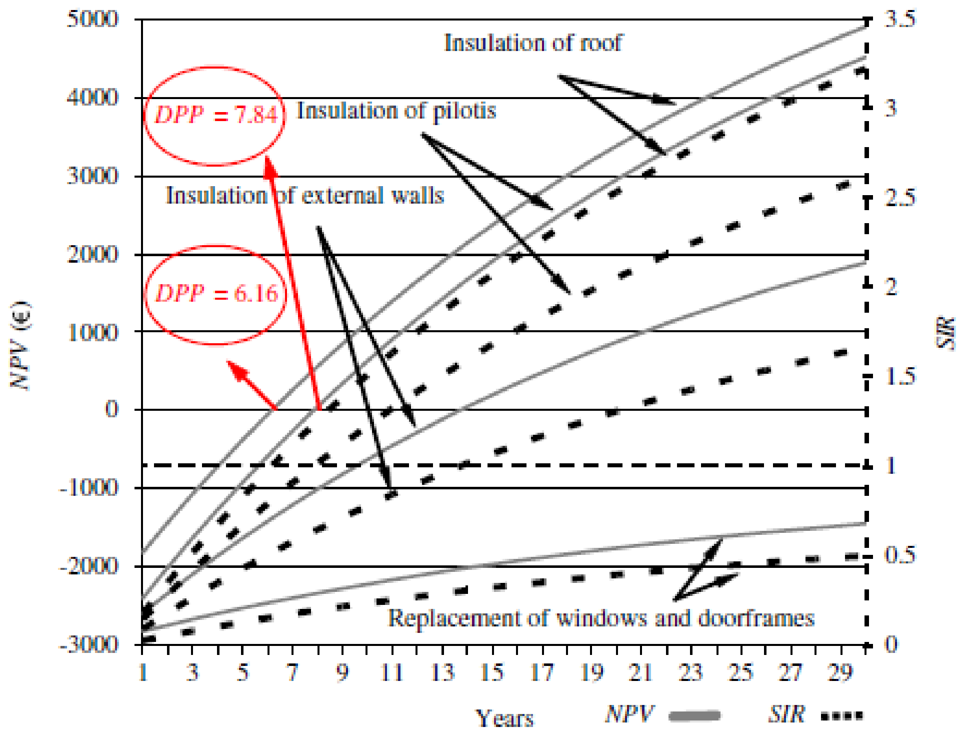

Figure 2.7: NPV, SIR and DPP for the interventions with cost of capital=4% [20]

The above figure is also included in the paper and depicts the fluctuation of the aforementioned financial indicators, assuming a cost of capital equal to 4%. It is noticed that although the replacement of old windows with modern double glazed ones is a very common ESM, it does not recover its initial investment during its life-time. On the contrary, the insulation of the roof seems to be more beneficial with the bigger NPVs and SIRs and with a DPP of 6,16 years. These indicators are also included in the paper published by A. M. Papadopoulos et al.[21], proceeding however further and taking also into consideration the life-time of the investment and of the building.

The study starts with some issues that are encountered in the Greek building sector and concern its energy consumption. It is mentioned that due to the fact that energy prices remained had been remaining low until 2000, there was little concern about taking energy saving measures. The only priority was to cope with the increasing cooling demands, because at that time the market of A/C units was developing rapidly. However, in 2001 the retail price of oil and electricity increased from 0,031 €/KWh and 0,082 €/KWh to 0,053 €/KWh and 0,091 €/KWh, respectively. The first reaction was that a majority of households started using heat pumps not only for cooling, but also for heating purposes. That solution was a reasonable reaction of the consumers, because it saved money for them. However, regarding the national sources needed to produce electricity and the impact they have on the environment, it was considered not to be such an efficient solution.

Afterwards, a series of buildings were audited, the problems regarding their energy performance were investigated and then some possible solutions were proposed, such as insulation, upgrading of the heating systems etc.

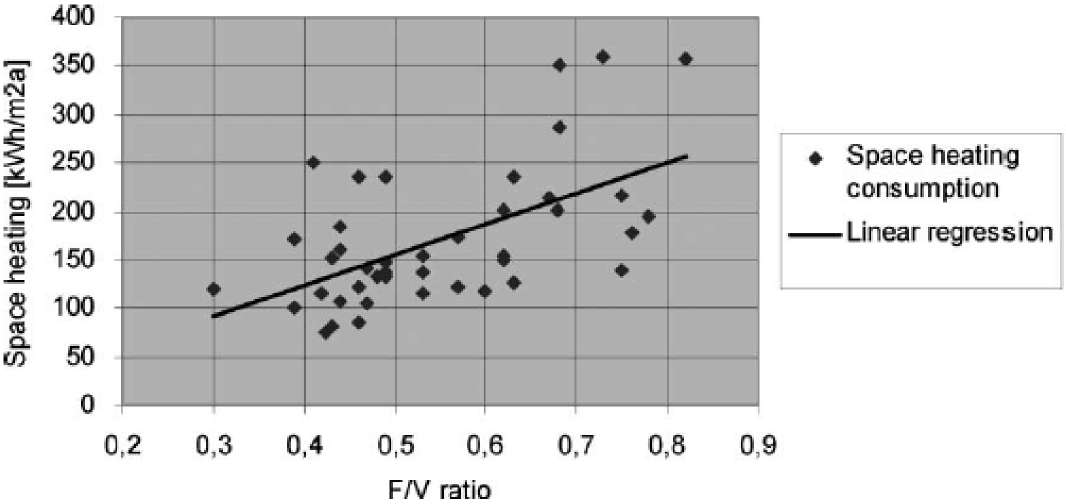

Figure 2.8: Correlation between heating consumption and F/V ratio [21]

Furthermore, some factors that affect the energy performance are included. These are the size of the building, the surface to heated volume ratio (F/V), the insulation level of the building's shell and the heating system. The correlation of F/V ratio with the energy consumption can be noticed in the Figure 2.8.

Regarding the feasibility of the proposed ESM, it is pointed out that two factors shoulb be taken into consideration. The remaining life-time of the buildings and the cost of energy carriers. Moreover, despite the fact that a 20-year old building starts to depreciate, it is still considered to have a great potential for energy savings. Furthermore, accepting that the average lifetime of a building is about 70-80 years, it seems irrational to proceed to investments for upgrading the energy performance of a 50 years old building. Though, because of the increasing demand for buildings, even old ones are tending to be target of energy efficiency upgrading.

The article is concluded with the presentation the financial indicators that were aforementioned. With respect to the DPP, it is determined that this period should not exceed the one-third of the remaining life-time of the building. In addition, DPP should be studied, because it could reject investments that have a slight bigger payback period, but they yield though higher annual savings during their life-time.

3 Categories of school buildings

An attempt to share the European educational buildings into categories has been made by Alessandro Rigolon, who wrote an article [11] during his PhD at the University of Bologna. He published this article in the journal of OECD, which deals with issues of educational buildings, where he notes down the big variety of school types. The choice of a specific one should take into consideration the number of students, the level of the education and also the climatic conditions and location where the school is going to be build (urban, suburban, rural). Moreover, he refers to a tendency of the modern times that the circulation spaces within the schools, where the children spend their time during breaks, tend to be constructed bigger and in such a way that they could host teaching activities, if needed.

3.1 Courtyard, Block, Cluster and Town-like type

Rigolon categorized the educational buildings according to their shape and the way the internal spaces are formed. So, he distinguishes between the Courtyard, the Block, the Cluster and the Town-like type that are presented in Figure 3.1.

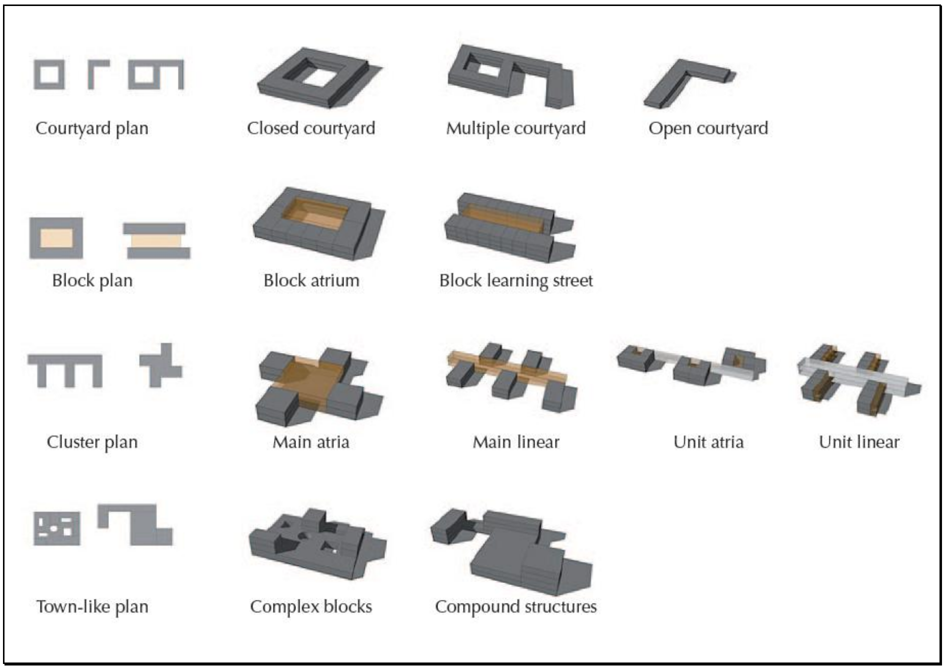

Figure 3.1: Rigolon’s types of educational buildings [11]

3.1.1 The Courtyard type

This is the traditional type of schools that are very popular nowadays also, having as the main characteristic the total or the partial enclosure of the courtyard by the building modules. An advantage of it is that it provides a secure place for the children to spend their time during breaks or perform the class of sport. In urban environments, where the dangers are more usual, the total enclosure sub-type is the ideal one (Figure 3.2). But there are also the U- and the Γ shaped sub-type, which are more popular in rural or suburban areas, where issues like dangers discussed before and spatial limits do not exist (Figure 3.3).

Figure 3.2: 4th gymnasium, Amsterdam [13]

Figure 3.3: Preschool in rural area, Chaource, France [13]

3.1.2 The Block type

The characteristics of the school buildings that belong to that type are: they have compact volumes and instead of courtyards they have only one socializing space which in many cases is a central atrium or a ‘learning street’, as it is called. These socializing areas are formed in such way that they are offered for informal teaching purposes, whereas there are also some that have few or no classrooms at all, like the Orestad College, located in Copenhagen (Figure 3.4). Building of such type would turn out to be really useful in northern countries, where the weather does not allow open courtyards to serve as socializing places. Instead, enclosed atria or 'learning streets' are considered as good solutions.

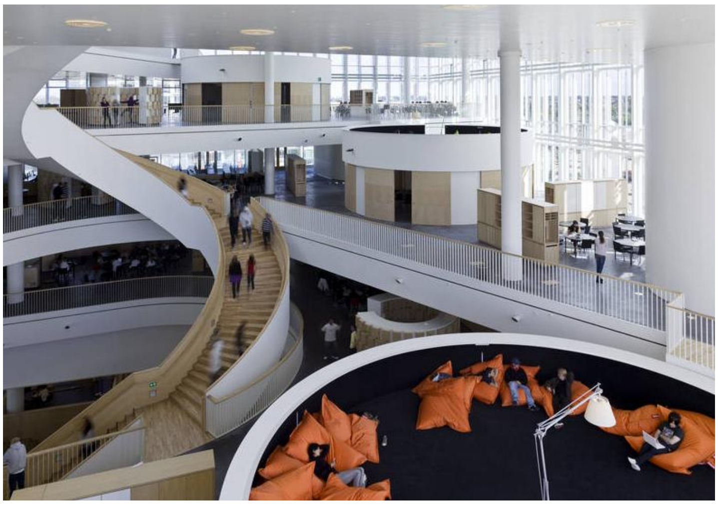

Figure 3.4: Orestad College, an almost classroom-free building in Copenhagen [13]

3.1.3 Cluster type

The main characteristic of that type is that the schools belonging to it, consist of many modules, which can be regarded as separate 'Small Learning Communities'', as in many cases they have except for classrooms some other spaces like a canteen, an atrium, etc, giving them an independent role. They are further shared into sub-categories according to the circulation pattern they follow (Figure 3.1).

Figure 3.5: Cluster type Nordbyskolen in Denmark [13]

3.1.4 Town-like type

School building that belong to that type, give some kind of a notion that the occupant stands in the center of a city. This is created by the fact that there is a central square the 'Town Hall Square'', which is surrounded by the facilities that are more used like the library, the canteen or the auditorium. Starting from this central square, there is a circulation pattern consisted of many paths which are leading to the learning places. Also, some sub-types are presented in Figure 3.1, while a typical Town-like school is depicted in Figure 3.6.

Figure 3.6: The compound structure Aurinkolahti Comprehensive School, Helsinki [13]

3.2 Construction period

One classification that has already been done in the previous chapter is according to the construction year of the school building and was described by Dimoudi and Kostarela [4]:

a) Those that were constructed until 1960, using stone for the building envelop and wood for the roof. The classrooms are positioned in a linear formation at the one side of the building, while at the other side there is the corridor. These are the neoclassic buildings and the buildings holding from the interwar period which have thick walls.

b) Those that are built after 1960 and follow the standards the national Organization of School Buildings. They have thinner walls, constructed with reinforced concrete and bricks, while their openings are single-glazed with metal frames. Moreover, a further separation of this category can be performed, regarding the Thermal Insulation Regulation that was adopted in 1979. From that date the insulation of the building's envelop and of the roof has become mandatory.

3.3 Climate

Another type of categorization could be made regarding the climatic conditions. Therefore, they are distinguished as:

a) The northern (mountainous) type which is characterized by the linear formation of the classrooms. The lighting is one-side one, appropriate in cold climates

b) The meridian (lowland) type which has again linear formation of the classrooms, which are positioned with south orientation. At that type the light is coming mainly from the openings that are positioned at the southern façade of the building, but there are also cases with either-side lighting, both from northern and southern openings

3.4 Shape of the building

Taking into consideration the shape of the school building, it is noticed that since the late 70s’ the educational buildings are constructed linearly or in a Γ shape, with the classrooms lying towards the south and with a closed corridor lying at the northern side of the building. However, at the end of 70s’ starts the trend towards buildings that are not constructed with the traditional linear formation, but they follow other modern ones, like Π or the cross.

‘Athina’ type school buildings, firstly introduced in 1978, are the main representatives of this formation variation. These are educational buildings with 6-30 classrooms, hosted from modules that are connected together with intermittent places, with each module having 3 classrooms. In case there is a need for expansion, the school does not need to stop functioning, since this type of school consists of many independent modules, forming T, Γ, linear or cross shaped buildings (see Figures 3.7 and 3.9).

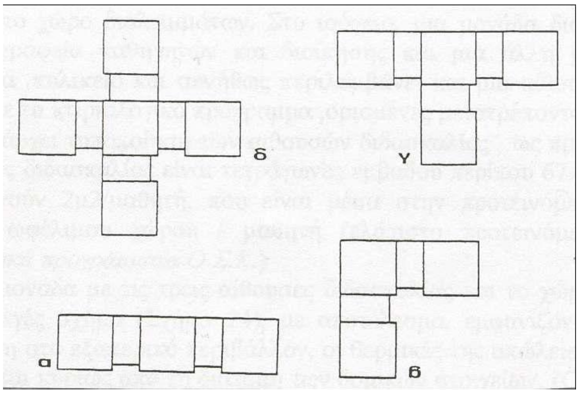

Figure 3.7: Configurations of ATHINA school buildings (10)

In 1983, a new type of school building was introduced the ‘EREUNA’ type. This is characterized by the linear positioning of the classrooms either at the one or both sides of a corridor, while space for library and a room for multiple uses have been designed and also laboratories.

Both ‘ATHINA’ and ‘EREUNA’ together with ‘PALAMAS’, ‘KALVOS’, etc. have little variations, so it could be said that they all derive from the ‘PSYCHARIS’ educational building (figure 3.8).

Figure 3.8: PSYCHARIS type

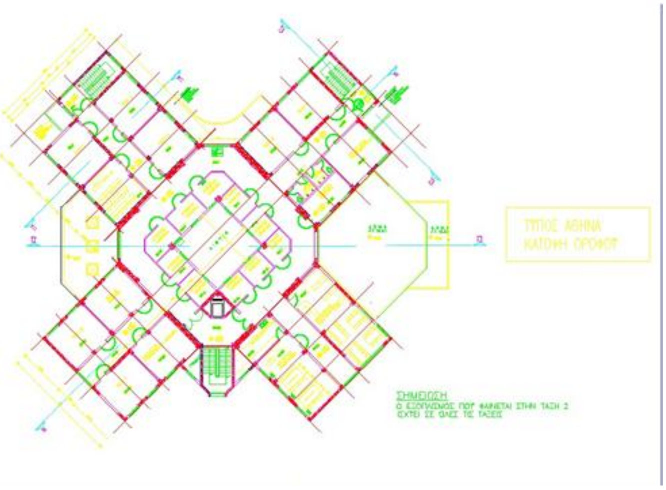

Figure 3.9: ATHINA type floor plan

4 Energy performance case study

In this chapter, the 11th elementary school of Thessaloniki is being studied, in order to calculate its thermal and cooling loads, at its current form and after some interventions that are made.

4.1 Methodology

This is an educational building constructed in 1979 with no insulation, since no such a regulation existed that time. In addition to that, it is considered representative of the many schools buildings that are built in densely constructed urban areas of Greece. First, the current operation of the school is modeled and simulated, in order to acquire some data and evaluate its current energy performance. Afterwards, an effort is made to intervene and find solutions that would improve the energy efficient of the building. Each solution is regarded as a separate scenario, which in turn is also simulated, to examine how feasible the recommended intervention is and to check if its feasibility.

For the modeling and the simulation of the school performance the software that has been used is the EnergyPlus. It is software for modeling various buildings, with all their heating, cooling, ventilating equipment. At first, it was introduced to be part of a system of programs that would assist each other providing input and outputs. However, EnergyPlus can be also executed alone.

EnergyPlus has derived from two programs that were developed in early 70s and early 80s, the BLAST and DOE-2. They were programs intending to provide that time’s designers and engineers with the needed tools and help them size or retrofit the HVAC systems and the buildings. As many of the simulating programs, it could have various inputs, such the design of the building and its surroundings, climatic data etc and at the same way it can give a variety of outputs, some of which need further processing, in order for someone to be able to interpret them. Some possible outputs are the energy loads of buildings, the energy consumption and the primary energy consumption, too.

4.2 Description of the building

As aforementioned, the educational building that has been chosen is the 11th elementary school of Thessaloniki, which was constructed in 1979. It is positioned at the block of Amalias, Paraskevopoulou and Vyzantiou str, whereas its official address is Amalias 60 (Figure 4.1). Although it lies in a very densely built area of Thessaloniki, it has no other building attached to it. Until now, the building has not undergone any refurbishment works, except the regular maintenance procedures and furthermore it is not insulated.

Figure 4.1: Panoramic view of the school

The building was constructed under the No: 643/16.3.79 construction permission of the Organization of School Buildings and has a southwest orientation. It consists of two modules with common staircase; the one that lies by Vyzantiou street (northern) has three floors, covering an area of 437 m^2, while the other one (eastern) lies by the Amalias street, has two floors and covers an area of 365 m^2. The two modules form the building into a Γ shape, which leaves an available courtyard of 982m^2, protected from the northern air currents.

The conditioned volume of the building is V=6.147,8 m^3, while the conditioned area is F=1.808.17 m^2 and their fraction gives the ratio F/V=0,294. The total area of the building, including the unconditioned spaces is 1.973,17 m^2. The total openings area is 407,36 m^2 , holding the 22,53% of the total building area. The building's operation profile, together with the number of occupants is depicted below.

Table 4.1: Operation schedule and number of occupants

Hours	**Staff**	**Students**	**Visitors**
07.00’-07.50′	4	18	-
07.50’-08.20′	35	272	120
08.20’-14.00′	35	272	
14.00’-16.00′	14	105	35
16.00’-18.00′	2	20	20

As all Greek schools, it stays closed for 15 days during the Christmas and Easter vacations, for 3 months during the summer vacations and furthermore for the national days of 26th , 28th October, 25 March, 17th November and 1st May.

4.2.1 Thermal zones

In order to make the simulation of the building as real as possible, it has been separated into various thermal zones. One thermal zone is the basement, which is an unconditioned space. Each of the other thermal zones consists of all the classrooms that are located in each floor, whereas two more zones are discussed later, when examining the ‘Green roof’ scenario. All these zones are summarized below.

Table 4.2: Code and description of the thermal zones

Thermal zone name	Space in the building
Z0	Basement-Unconditioned space
Z1	Classrooms
Z1A	Classrooms
Z2	Classrooms
Z2FYT	Classrooms
Z3FYT	Classrooms

Table 4.3**:** Operation details of thermal zone for a primary educational building for climatic zone C (TOTEE 20701-1)

Operation schedule	8 hours
Operation days	5
Operation months	9 (Sep-May)
Heating period	15/10 - 30/4
Cooling period	1/6 - 31/8
Heating set-point temperature(°C)	20
Cooling set-point temperature (°C)	26
Average indoor relative humidity during winter (%)	35
Average indoor relative humidity during summer (%)	45
Fresh air demand (m^3/h/person)	22.00
Fresh air demand (m3/h/m2)	11,00
Lighting levels (lux)	300
Lighting power per unit of area for reference building (W/m2)	5,5
Annual DHW consumption (m3/m2/year)	0.68
Average desired temperature of DHW (°C)	50
Average annual temperature of the network water (°C)	16.4
Heat gains from thermal zone occupants per unit of area (W/m2)	40
Average factor of occupants presence	0.18
Heat gains from devices per unit of (W/m2)	5.00
Average factor of the devices’ operation	0.18

The pictures below are taken from Google SketchUp software and present the position of the various thermal zones into the building. The arrow indicates the northern direction.

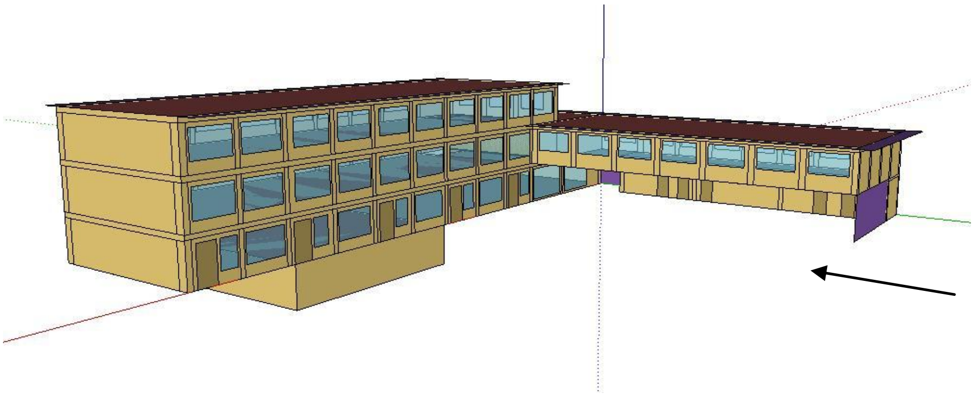

Figure 4.2: View from Paraskevopoulou street

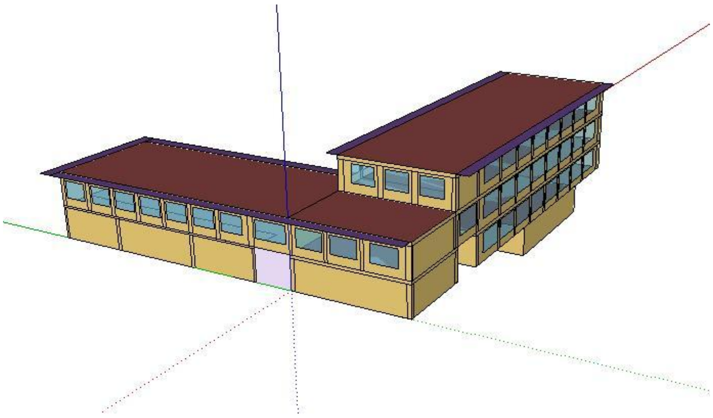

Figure 4.3: View from Amalias street

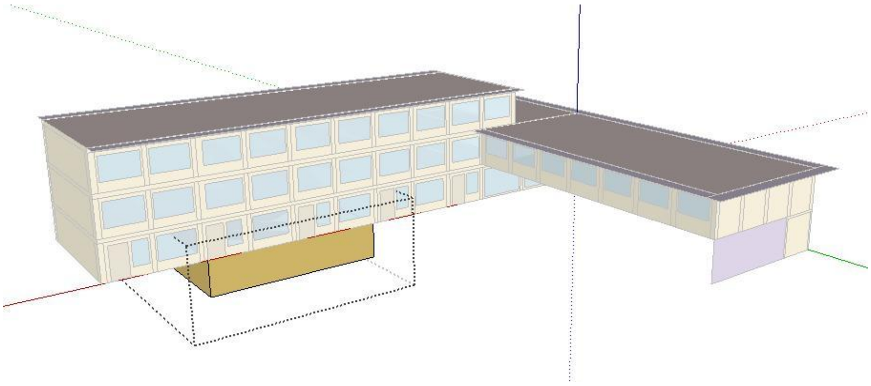

Figure 4.4: Zone ZO

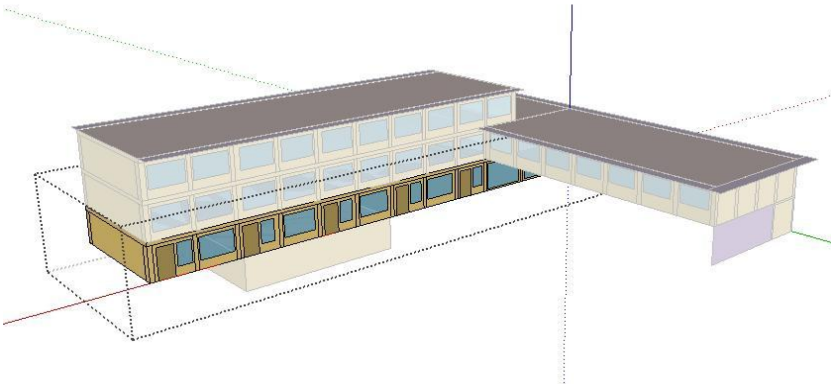

Figure 4.5: Zone Z1

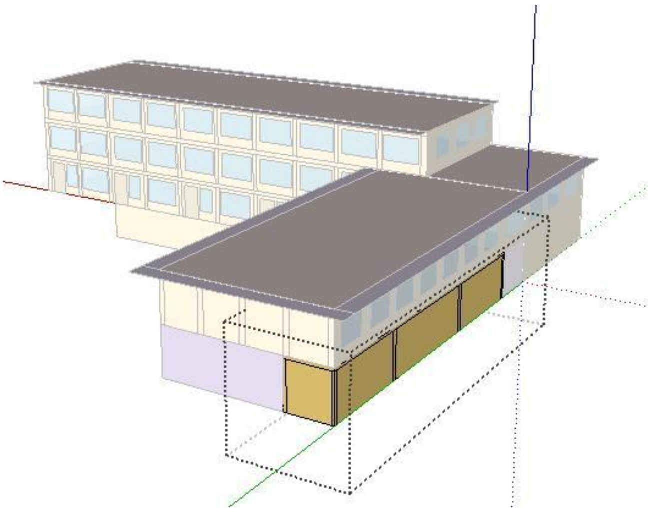

Figure 4.6: Zone Z1A

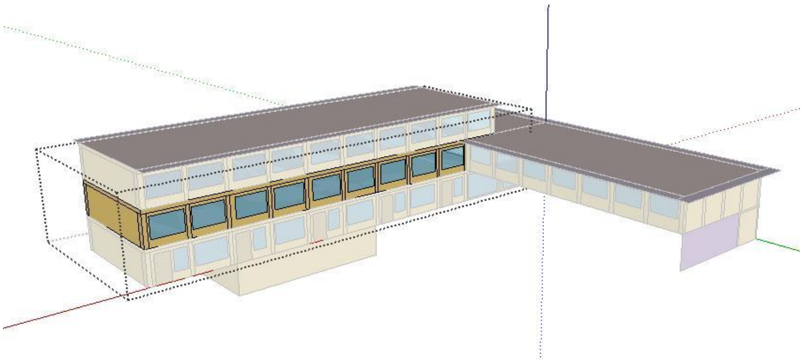

Figure 4.7: Zone Z2

4.2.2 Climatic data

The climatic data that are given as input in the EnergyPlus software refer to an annual climatic period for the calculation of the energy consumption all over the year. They are in the form of IWEC (International Weather for Energy Calculations), which is a result of the ASHRAE Research Project 1015.

Thessaloniki is characterized by the Mediterranean climate with a lot of humidity, due to the sea. The climatic data of the city have been taken from the meteorological station that is positioned at the area of Mikra, which is a suburb of Thessaloniki (WMO 166220, latitude 40° 31', longitude 22° 58', altitude 4 m). Below some tables have been given, regarding the heating degree days and the cooling degree hours of Thessaloniki.

Table 4.4: HDD (Heat Degree Days) of Thessaloniki at setpoint temperature: 18 ^{o}C

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
HDH	394	314	254	111	-	-	-	-	-	53	207	344

Table 4.5: Cooling Degree Hours of Thessaloniki at set-point temperature: 26 ^{o}C

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
CDH	-	-	-	-	-	526	1211	1058	-	-	-	-

4.2.3 The building envelop

As aforementioned, due to the fact that the school was constructed in 1979, it is not provided with any insulation. That fact, as expected, deteriorates its energy performance to a big extend and increases the thermal and cooling loads needed to keep the thermal comfort at satisfactory levels. The actual thermal transmittance factors are given in the following table, compared with the values that are prescribed by the KENAK regulation.

Table 4.6: U-values of the opaque building elements

Building element	U [W/m^{2}K]	$U_{max\ (KENAK)}$ [W/m^{2}K]
Roof	3.05	0,40
Floor over the ground	3.05	0,75
External walls (reinforced concrete)	3.40	0,45
External walls (brick walls)	2.20	0,45

As for the openings of the school, they are all single glazed windows with metal frame. The thickness of them is 3mm, while the thermal transmittance factor is U= 6 W/m^{2}K, according to the technical directive T.O.T.E.E 20701-1/2010 (table 3.12).

4.2.4 Operation profile

As the U-values are prescribed by the KENAK regulation, the same happens also with other functional properties of the building, as the internal heat gains from its occupants and its technological equipment, the level of ventilation and lighting etc. All these values are given in the table below, taken from the KENAK technical directive.

Table 4.7: Operational characteristics of the case study school building

Set-point temperatures	**Heating period[^{o}C]**	**Cooling period [^{o}C]**
	21	26
Ventilation of the classrooms	**Persons per area**	**Natural ventilation [m^{3}/h/person]**
	0.18	22
Ventilation of the offices	**Persons per area**	**Natural ventilation [m^{3}/h/person]**
	0.3	30
Internal heat gains (classrooms)	**Occupants [W/person]**	**Average presence factor**
	80	0.18
Internal heat gains (offices)	**Occupants[W/person]**	**Average presence factor**
	80	0.30
Internal heat gains	**Equipment [W/m^{2}]**	**Average presence factor**
	0.75	0.18
Lighting of the classrooms	**Intensity [lux]**	**Nominal power [W/m^{2}]**
	300	5.5
Lighting of the offices	**Intensity [lux]**	**Nominal power[W/m^{2}]**
	500	9.1

4.2.5 Heating, cooling and DHW systems

The school building is equipped with a natural gas fired central heating system, with a power of 400000 kcal/h or 465,2 KW and efficiency of about 80%. The main problem of this system is that it has not the appropriate thermostatic control, since there is only one thermostat in the whole buildings and as a result, an irrational use of energy could appear frequently. The building is not provided with Domestic Hot Water system.

In order for the total efficiency of the heating system to be checked, the efficiency of the boiler, the losses of the distribution system and how much oversized the whole system is, should all be taken into consideration.

4.2.6 Shading

When simulating the energy performance of a building, it is necessary to take into consideration all the nearby buildings that might cast their shadows onto the building under study. Therefore, all the neighbouring buildings have been taken into account, as seen at the following figures, and have been given as an input to EnergyPlus.

The existence of the shadows affects greatly the heating and mainly the cooling loads, because during summer they obstruct the solar radiation from falling onto the building, which would lead to uncomfortable thermal conditions, due to overheating during the months of summer that the school is open. Moreover, it should be checked whether the trees throw their leaves during winter, so that the studied school building could have access to the important winter solar gains, contributing to the passive heating of the building.

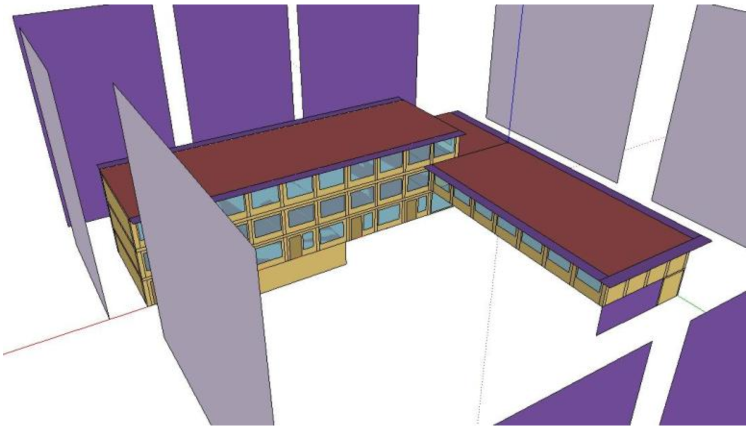

Figure 4.8: The neighbouring buildings (Google SketchUp)

4.3 Simulation scenarios

The first simulation that will be made is to model the current situation and draw conclusions regarding the current energy consumption and how much energy efficient the building is. After the modelling of the current situation, some actions will be proposed that will be in the direction of improving the energy performance.

As already said, it is considered important to provide the building envelop with the proper insulation and also substitute the old one-glazed openings with modern ones double-glazed with aluminium frame. The other intervention that will be simulated is the installation of a green roof on both modules of the building. That would lead to the reduction of the cooling loads, especially at the thermal zones located underneath the green roof. The issue is to examine if such an installation would be reasonable, provided that the school building stays closed during the hot summer months.

4.3.1 Current situation

The results of the building simulation for one year (8760 hours) are presented in this section. Table 4.8 gathers all the data, regarding loads, final and primary consumption and CO2 emissions for heating, cooling and lighting. As presented in this table, the building's total primary energy consumption reaches 145,35 kWh/m^2; 98,32 kWh/m^2 consists the primary energy consumption for heating, 13,22 kWh/m^2 the respective energy for cooling, while the respective one for lighting reaches 33,81 kWh/m^2. Hence, the highest consumption accounts by far for heating, due to the lack of insulation, second comes lighting and third the cooling of the building, due to the fact that, as already mentioned, it stays closed during the warm summer period and only some split A/C units of the offices are in operation. It is therefore evident from these results that minimizing the required energy for heating is more critical.

Table 4.8: Current situation

	Total	per area (m2)
Heating loads (W)	277402,73	152,72
Cooling loads (W)	81141,79	44,67
Heating consumption(KWh)	170448,76	93,84
Cooling consumption(KWh)	8281,53	4,56
Lighting consumption (KWh)	21179,98	11,66
Heating primary consumption (KWh)	178971,20	98,53
Cooling primary consumption (KWh)	24016,44	13,22
Lighting primary consumption(KWh)	61421,95	33,81
	Total (Kg)	per area (Kg/m2)
CO2 emissions-heating	35078,35	19,31
CO2 emissions-cooling	23752,26	13,08

It should be noticed that the primary energy consumption data derive from the final energy consumption, by multiplying with the relative factors, which are 1,05 for heating and 2,9 for cooling and lighting, since they both use electricity. These factors derive by inversing the efficiencies of producing the final energy carriers. For example, regarding the number 2,9, which counts for the electricity consumption, it can be interpreted that producing 1KWh of electricity is not that efficient. Therefore, it requires to burn 2,9 KWh of coal, because all the efficiencies are taken into consideration, from the combustion of the coal at the power plant until the distribution of the electricity.

As a first conclusion, it could be drawn that these are the points that need intervention, in order to improve the energy efficiency of the school. So, it is needed to reduce first the thermal loses of the building, by insulating it and by replacing all its openings with double-glazed ones. Then, the efficiency of the heating system should be taken into consideration and afterwards, actions should be proposed that would reduce the electricity consumption for lighting and cooling. The share of the electricity consumption is depicted in Figure 4.9, where we see that cooling and interior lighting hold the biggest share, with the rest small percentage accounting for the pumps, fans and other interior equipment. Therefore, coping with the consumption for cooling and lighting is quite enough for achieving a smaller electricity consumption.

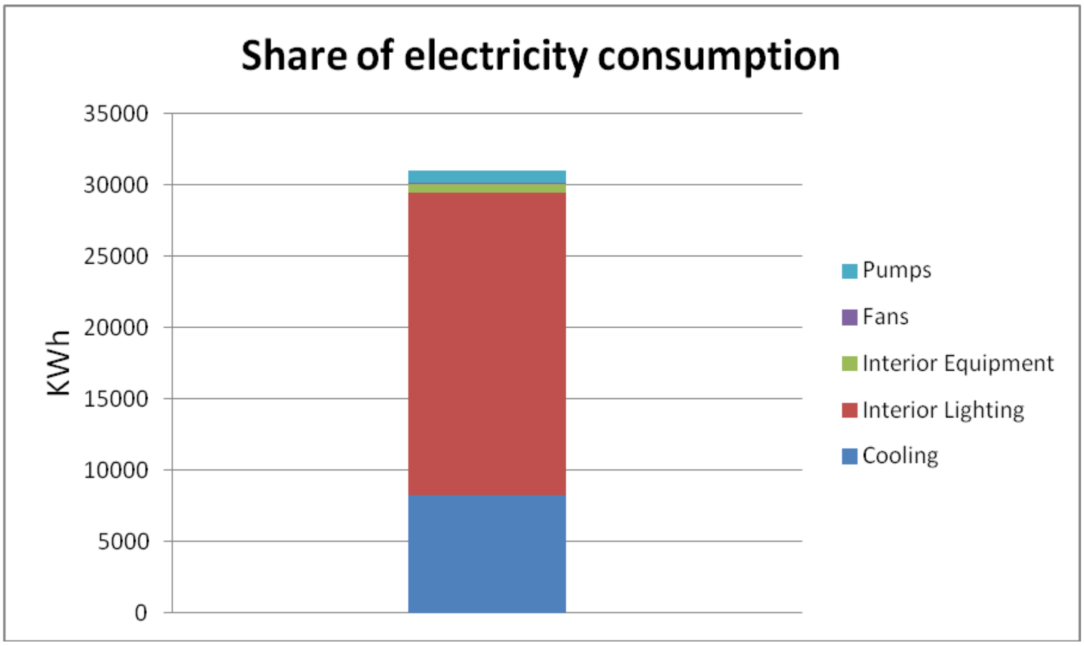

Figure 4.9: Energy consumption by usage

4.3.2 Insulating the building

Constructed in 1979 as already said, the building lacks insulation, so the first intervention is to insulate it according to the KENAK standards. The insulation that is used in this scenario, is applied on the external facades of the building and covers all its elements.

The external insulation of the buildings is a very good solution for the buildings that have already been constructed with no insulation. It is suitable for insulating all the building elements, without any gaps at their junctions. Already from 1960, this type of insulation was used in western and central Europe and during the last years it has started operating successfully in Greece, too. The appropriate materials are expanded and extruded polystyrene and the stonewool [19].

While in the cold areas of Europe, the appropriate material is the expanded polystyrene, in Greece where the climate is more temperate and there are little chances for the appearance of humidity on the building elements, all three types of materials are appropriate. The material that has been chosen is extruded polystyrene type ETICS GF, with rough surface for better application of plaster and adhesive substances. It is suitable for insulating the building's envelope externally and has a thermal conductivity of λ=0,036W/mK.

Table 4.6 presents the U-values of the building elements, at their current situation. In Table 4.9 below, the U-values, prescribed by the KENAK regulation are presented, according to the climatic zone of the region. Thessaloniki belongs to zone C, so these are the values that should be reached, in order to comply with the regulation.

Table 4.9: KENAK regulation for different climatic zones

Minimum Requirements according to the new regulation	**U – value [W/m^2.K]**			
	A	B	C	D
Roofs	0,5	0,45	0,40	0,35
External Walls	0,6	0,50	0,45	0,40
External Floors	0,5	0,45	0,40	0,35
Floor over ground	1,2	0,90	0,75	0,70
External walls in contact with the ground	1,5	1	0,80	0,70
Openings	3,2	3	2,80	2,60
Glass Facades	2,2	2	1,80	1,80

Table 4.10 depicts the current U-values and thermal resistances, together with the desired ones, that should be reached. Also, the thermal resistance and the thickness of the necessary insulation are presented. Thererfore, in order to reach the prescribed values, it is necessary to insulate the roof with 8cm of inulation, the floor over ground with 4cm and the walls attached to external air with 7cm of insulation.

Table 4.10: U-values of the building and needed insulation

Building element	**U [W/m^{2}K]**	**$R_{current}$ [m^{2}K/W]**	**U_{max} (KENAK) [W/m^{2}K]**	**R_{KENAK}[m^{2}K/W]**	**R_{insul} (R_{KENAK}-$R_{current}$) [m^{2}K/W]**	**d (m)**
Roof	3,05	0,33	0,4	2,50	2,17	0,08
Floor over the ground	3,05	0,33	0,75	1,33	1,01	0,04
External walls (reinforced concrete)	3,4	0,29	0,45	2,22	1,93	0,07
External walls (brick walls)	2,2	0,45	0,45	2,22	1,77	0,07

4.3.3 Providing the insulated building with a green roof

Having already insulated the building, the impact of a green roof system is simulated, which is installed on the roof of the both modules of the school building. The “green roof” system consists of different components that should comply with various international standards and should be compatible to each other, in order to avoid malfunctions and to take full advantage of the beneficial results during the whole life-time of the green roof [12]. The green roof system that will be simulated consists of the following layers, starting from the insulated surface of the building’s roof:

1) Waterproofing the construction, using bituminous or plastic membranes, in combination with emulsions. This layer covers the whole surface of the roof, reaching also its vertical elements, such as the parapets up to a height of at least 20cm above the final layer.
2) Protection against the plants’ roots. It consists of a synthetic-thermoplastic membrane and covers also the whole roof, reaching at least 10cm above final layer.
3) Layer for the protection of the anti-roots membrane, preventing the humidity from reaching it. It is a sheet of 9mm made of HDPE (High Density PolyEthylene) membrane and polyester fibers.
4) Drainage system consisting of HDPE, of total thickness of at least 22mm.
5) Filtering layer that prevents the plants substrate from entering the draining system

6) Substrate for the development of the plants, according to the FLL instructions[1], meaning standardized values of water permeability, PH, salinity, etc. It will cover the whole roof, except for the zone of a specific width, that lies on the perimeter and which is positioned to protect the construction, in case of overflow
7) Overflow protection zone is the one mentioned before, between the plants substrate and the parapets or other vertical surfaces.
8) Piping system for watering the plants, according to their species and in accordance with the applying standards.

This specific green roof system is known widely as 'eco-roof' and is characterized by the simplicity of its installation and the low maintenance needs. It does not burden the roof with big static loads, so it is recommended also for inclined roofs. The plants, it is consisted of, need small amounts or no water at all and they can adapt easily at the regional climate. This turns up to be very crucial for climates like the Mediterranean, because in summer, when the climate is dry and hot, they would need enormous amounts of water to remain green and operational. In the following table, the main parameters of the three basic types of green roofs are gathered.

Table 4.11: Types and characteristics of green-roof systems (Source: IGPA 2008)

Type	**Extensive**	**Semi-extensive**	**Intensive**
Maintenance	Rare	Periodical	Often
Irrigation	No	Periodical	Often
Height of plants	60 – 200 mm	120 – 250 mm	>1000 mm
Weight	60 – 150 kg/m^2	120 – 200 kg/m^2	180 – 500 kg/m^2
Installation cost	Low	Medium	High
Usage	Ecological protection	Periodical access	Full use

Generally, the installation of green roof systems has a beneficial impact on the energy performance of the buildings and especially for those with little or no insulation at all. It improves the thermal comfort, mainly of the top floor of the buildings and reduces the heating

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[1] FLL instructions: It is a German guideline for green roofs (http://www.greenrooftechnology.com/fll-green-roof-guideline)

and cooling loads. Moreover, it ameliorates the urban microclimate, having a nice optical impact and lowering the temperatures of the buildings surfaces.

4.3.4 Substitution of the boiler

As aforementioned, the currently used boiler is a simple gas-fired one of 465 KW with an efficiency of almost 65%. This is considered a low one, compared to the efficiencies that could be reached, in case that a state-of-art technology is used and namely condensing gas boilers. That technology, as described in detail in sub-chapter 2.8.7, takes advantage of the latent heat that is contained in the vapors of the flue gases, by condensing them, thus reaching an efficiency of 106%.

In order to reach the required output, a series of Radiant boilers is used, which is found in the literature as a cascade system. So, four RK 100 (100 kW each) and one RK 50 (50 KW) are put together. The whole installation resembles the one depicted in the following figure, where we can see the interconnected boilers. The system can automatically impose how many boilers will function each time, in accordance to the load to be covered.

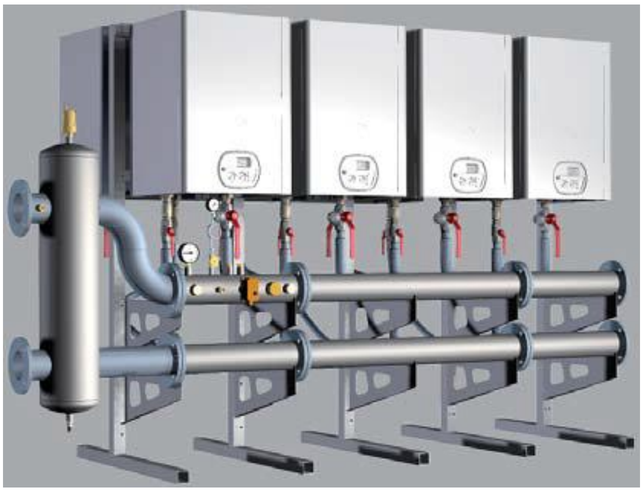

Figure 4.10: A similar cascade system installation

4.3.5 Defining the scenarios

All the possible interventions described above, have been simulated into some combinations that are encoded in the table below. It should be noticed that the insulation of the building has been involved in all scenarios, since it is considered the basic intervention to minimize the energy demand and it would make no sense to proceed to further measures, without having first insulated the building envelop and having substituted the old openings with new double-glazed ones. Therefore, after having provided the needed insulation to the building, the installation of a condensing gas boiler is simulated, encoded with INS+BOIL. Additionally, there is the INS+BOIL+GF scenario, which goes further and examines the installation of the green roof, together with the insulation and the condensing boiler.

Code	**Scenario**
CUR	Current
INS	Insulation
INS+BOIL	Insulation + cond. Boiler
INS+BOIL+GF	Insulation+Cond. Boiler+Green roof

5 Simulation results

Having simulated the performance of the building on an hourly base (8760 values for one year) for all the different scenarios, it is now necessary to present their results, so that it can be examined which one is more worthwhile to be implemented, taking also into consideration its feasibility.

5.1 Energy savings

Studying the Table 5.1 below, all the relevant results from the simulated scenarios are presented. The first sector includes the loads, the second one the final energy consumption and the improvement percentage, compared with the current situation, while the other two sections present the data for primary energy consumption and CO_2 emissions. Judging from a first look of this table and taking into consideration only the energy reduction, it could be deduced that the best case to be implemented would be the last scenario, which combines all of the interventions, since it results in savings of about 42,73%. However, it is clear that the installation of the green roof, on the already insulated and provided with a new boiler building has just a slight higher energy reduction, compared to the INS+BOIL case. Moreover, it is clear that the biggest contribution to the reduction of the consumption characterizes the first scenario (INS) with almost 35%, while the other 2 provide a further reduction of only 7%. This seems reasonable, provided that it is the insulating of the building that yields the maximum reduction on the loads, as it can be seen in the first sector of the table. Namely, heating and cooling loads are dropped down to 105,73 W and 28,55 W respectively, in the INS scenario. Moreover, it is noticed that INS+BOIL does not reduce the loads, since the substitution of the boiler does not influence the energy loads needed to retain the thermal comfort at acceptable levels. However, it reduces the energy consumption for heating, because it makes the operation more efficient. Lastly, examining the last scenario with the green roof, it is realized that neither does it have a significant impact on the loads of the whole building, nor on the reduction of the specific energy consumption. The specific energy consumption of all cases is depicted by Figure 5.1.

Table 5.1: Comparison of the scenarios

	Loads (W)		Final energy consumption (KWh/m^2)					Primary energy consumption (KWh/m^2)				CO2 emissions (Kg/m^2)	
Code	**Heating**	**Cooling**	**Heating**	**Cooling**	**Lighting**	**Total**	**Diff from current(%)**	**Heating**	**Cooling**	**Lighting**	**Total**	**Heating**	**Cooling**
CUR	152,72	44,67	93,84	4,56	11,66	110,05		98,53	13,22	33,81	145,56	17,05	13,08
INS	105,73	28,55	56,52	3,46	11,66	71,64	-34,91	59,34	10,03	33,81	103,19	11,63	9,92
INS+BOIL	105,73	28,55	48,04	3,46	11,66	63,16	-42,61	50,44	10,03	33,81	94,29	9,89	9,92
INS+BOIL+GF	100,44	25,65	48,35	3,02	11,66	63,03	-42,73	50,77	8,75	33,81	93,33	9,95	8,65

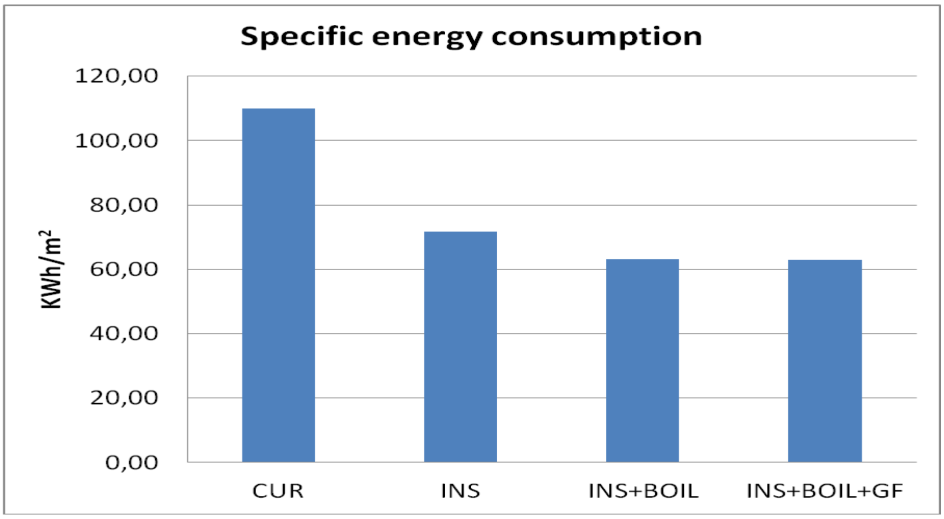

Figure 5.1: Specific energy consumption

The benefit of the installation of the green roof could be realized though, when looking at some relative data that are derived from the thermal zones underneath the green roofs (ZUGF), since these are the thermal zones that are burdened most by the weather conditions and therefore are characterized by higher specific loads (Table 5.2).

Table 5.2: Loads comparison between all zones and ZUGF

Scenario	Thermal zones	Specific Heating loads (W/m^2)	Specific Cooling loads (W/m^2)
CUR	All zones	152,72	44,67
	ZUG	172,86	66,34
INS	All zones	105,73	28,55
	ZUG	91,11	24,65
INS+BOIL	All zones	105,73	28,55
	ZUG	91,11	24,65
INS+BOIL+GF	All zones	100,44	25,65
	ZUG	80,30	16,73

From this table and from Table 5.3, it is noticed that the impact of all the studied scenarios on the energy loads and consumption of the ZUGF is far more intense, compared to the benefit on the whole building. Namely, taking a look at Table 5.3, the INS and INS+BOIL result in an almost 51% and 58% reduction of the specific heating consumption, respectively. When the green roof is added too (INS+BOIL+GF), a further dicrease is achieved, 61% difference from the current situation. Regarding the respective consumption for the cooling of these zones, it drops by 56%, when the INS and INS+BOIL cases are implemented. The most impressive benefit is noticed though, when adding also the GF, reducing the consumption for cooling by 70%.

Table 5.3: Impact of green roof for ZUGF (zones underneath green roofs)

Scenario	Specific heating consumption(KWh/m^2)	Difference (%)	Specific cooling consumption(KWh/m^2)	Difference (%)
CUR	99,98		6,77	
INS	48,70	-51,29%	2,99	-55,90%
INS+BOIL	41,40	-58,60%	2,99	-55,90%
INS+BOIL+GF	38,65	**-61,34%**	1,97	**-70,93%**

This can be attributed not only to the fact that the green roof works as a kind of insulation to the building, preventing the intense summer solar radiation from reaching the envelope, but it provides also the building with its evapotranspiration function, meaning that the plants absorb heat in order to perform their vital functions, resulting to the cooling down of it. Lastly, they shade also the whole surface of the terrace, preventing the solar heat from reaching the envelope. The results discussed above regarding the ZUGF, are represented graphically in the following two figures.

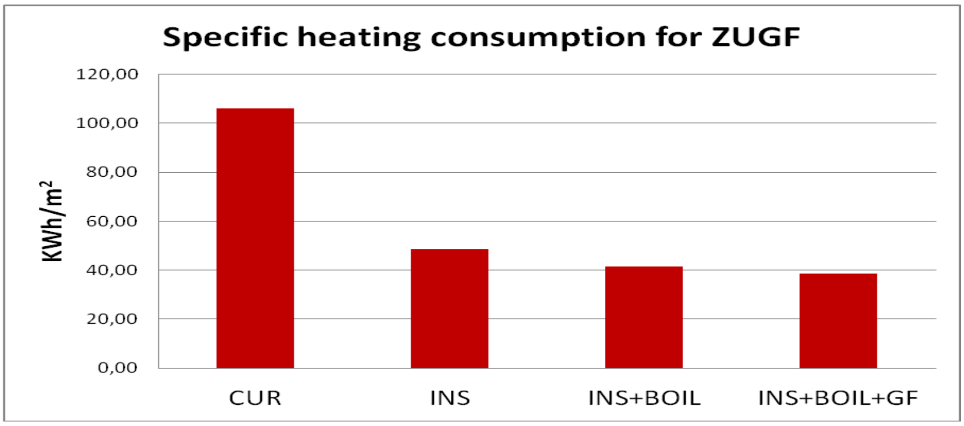

Figure 5.2: Specific heating consumption of ZUG

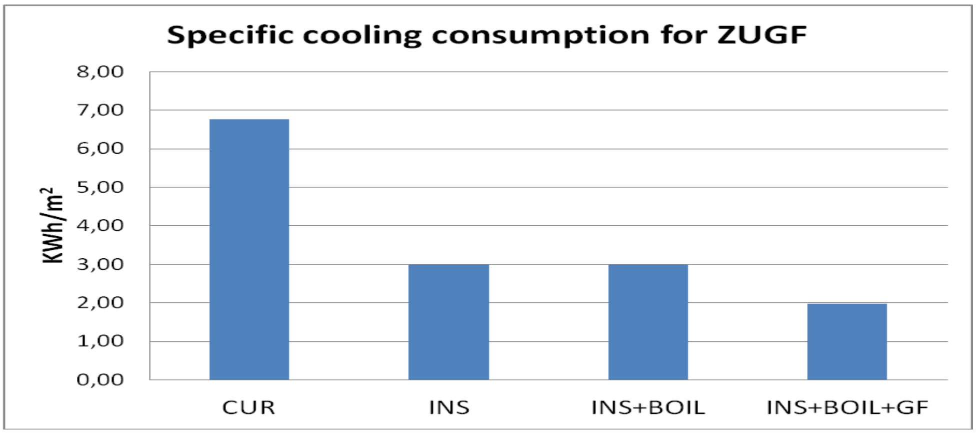

Figure 5.3: Specific cooling consumption of ZUGF

Judging only from the technical results that have been discussed above, one could draw the conclusion to go for the simplest scenario, which is just insulating the building, since it is the one that contributes the most to the reduction of energy consumption and there is no need for further energy saving measures, which would further incur the budget. However, having to do with inteventions that induce heavy costs, it would be reasonable to judge them also from a financial point of view.

5.2 Financial analysis

Generally speaking, energy saving measures (ESM) for a public building are regarded to be costly investments. Most of the times, this seems to be the main discouraging factor for not being implemented. Therefore, it requires a financial analysis of the scenarios that were previously discussed, in order to examine the relative costs, their financial benefits and how quickly each one could pay back.

Below, two tables are included that present the costs of the inteventions, each one separately and the costs of each scenario. The cost data have been acquired from the market.

Table 5.4: Cost data for each energy saving measurement

Intervention	m^2	cost/m^2	units	cost (€)	cost after tax (€)
Insulation	1530	35	1	53550	65866,5
Openings	400	140	1	56000	68880
Green roof	1989	120	1	238680	293576,4
Condensing boiler			1	30000	36900

Table 5.5: Cost of the simulated scenarios

Scenario	Cost after tax (€)
INS	134746,5
INS+BOIL	171646,5
INS+BOIL+GF	465222,9

In order to make a financial evaluation of the scenarios, the Dipreciated Payback Period (DPB) is used as a criterion and the annual savings of each case are also taken into consideration. The formula that is used is given below, where the NPV is equated to zero and this is when the dipreciated payback period occures, expressed by the value of time in years (t).

$$\mathrm{NPV} = -C_{\mathrm{in}} + \sum_{t=1}^{N} \frac{\mathrm{F}_t}{(1+d)^t},$$

Where: C_{in} is the initial investment, F_t the annual savings from the implementation of the measures and d the cost of capital (CoC=6%).

This value of the CoC is taken from other similar investments that are characterized by the same risk. Except for that, the annual increase on the prices of natural gas and electricity are taken also into consideration, setting both at 3%. When it comes to the costs of the energy carriers, the current prices are NG_{price}=0,09 €/KWh and $Electricity_{price}$=0,11€/KWh. The calculations are made in the Excel, are included in the appendix and the yielded results are presented in the following table.

Table 5.6: Comparison data

Scenario	Cost after tax (€)	Energy savings (%)	Annual Benefits (€/y)	DPP
INS	134746,5	-34,91	10324,16	17
INS+BOIL	171646,5	-42,61	12588,02	17
INS+BOIL+GF	465222,9	-42,73	12649,70	33-35

Judging from Table 5.6, it is first realized that although the scenario with the green roof results in the highest annual savings of 12649,7 €/y, it has significantly bigger DPP of about 35 and should be therefore rejected. That was expected, since it requires by far the biggest initial investment of 465222,9 €, it does not yield however a corresponding amount of annual benefits, which are just a little higher than the other two.

Regarding the other two cases, INS and INS+BOIL, the same DPP is noticed, although the latter requires more capital, an initial investment of 171646,5 €. That happens, because INS+BOIL yields higher annual benefits, related to the INS. Thus, the most feasible ESM is to insulate first the school and then provide it with a condensing gas-fired boiler.

This conclusion could also be supported by the financial indicators that have been discussed in the literature review [20,21] and are presented in the following talble. The best case of each column has been bolded. First of all, the results for the last scenario are in line with what has been discussed previously, that INS+BOIL+GF should be rejected. The best NPV accounts for INS+BOIL, which yields almost 195000 € for the studied 30 years. Further more, looking at the last two columns of the table, it can realized that INS yields better results for IRR and SIR. However, this precedence is not that big enough that would make one prefer this scenario.

Table 5.7: Financial indicators of the scenarios

Scenario	NPV (€)	DPP	IRR	SIR
INS	165073,95	**17**	**5,43%**	**2,30**
INS+BOIL	194333,99	**17**	5,10%	2,20
INS+BOIL+GF	-80879,13	33-35	-1,12%	0,82

Figure 5.4 is very representative of all these conclusions. The very little difference of the first two cases can be noticed, though the INS+BOIL seems to increasing the difference from year 25. This is why it has bigger NPV and should be chosen.

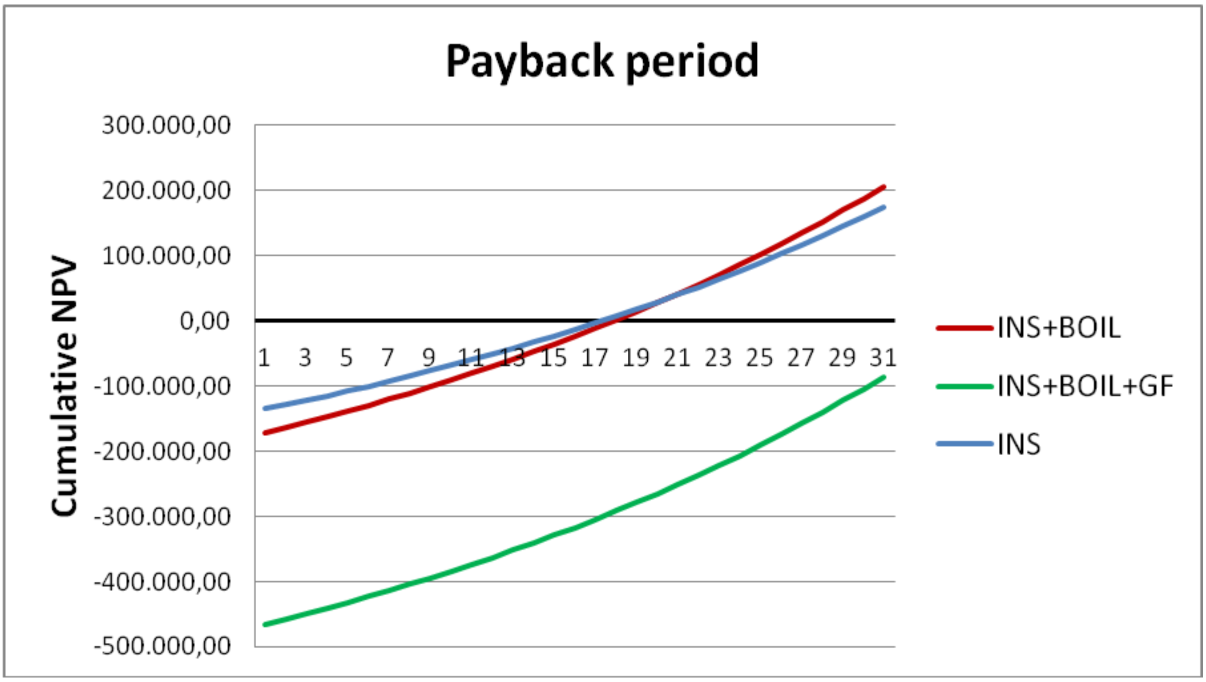

Figure 5.4: The payback period of the scenarios

Conclusions

What should be pointed out from this dissertation, is the significance of the Indoor Environmental Quality (IEQ) in the educational buildings and that at the same time this should be accomplished with the minimum possible resources. In order to succeed this target, the energy demand of the schools should be first minimized, meaning that even from the design phase of the building, the aforementioned technical parameters have to be followed, as tight as possible. Then, it is needed to equip the building with such systems that operate efficiently and therefore consume low amounts of fossil fuels, which tend to become more and more scarce and also polute the environment. Also, taking advantage of some Renewable Energy technologies could have a very beneficial impact on the budget of the school and the enviornment. Constructing green school buildings could have a remarkable impact on the energy consumption of the whole building sector, since they consist a big share of it.

In order to examine within a practical level the issues that have been discussed in the literature review, an elementary school of Thessaloniki was simulated with EnergyPlus software, giving some useful data regarding the current performance of the building. Afterwards, some ESM were developed that were believed to be capable of improving the efficiency of the school. They were in turn simulated and yielded some results that displayed the improvement of the performance. Lastly, all the results were gathered and examined, with the scope of choosing the most beneficial one and the one that is more feasible.

The simulated scenarios included several interventions, combined into various ways, which are the insulation of the building together with positioning of double glazed openings, the substitution of the current boiler with a condensing gas-fired one and the planting of a green roof. Firstly, a technical analysis was attempted and concerned the impact of each case on the energy performance of the building. It was found that the biggest reduction of the loads and the energy consumption of the school is achieved by INS, since the insulation and the state-of-art openings mitigate the thermal loses to a big extend. Concerning the installation of the green roof, the influence of it was too little and only for the zones underneath the roof, does it have significant results.

With regard to the financial analysis, some data regarding the costs of each scenario were presented and also some financial indicators were used such as NPV, IRR etc that have contributed to the selection of the most profitable one. INS+BOIL+GF turned out to be the most costly one and has been rejected, due to the very big payback period. The other two scenarios appeared to be quite identical regarding the IRR and SIR, with INS seeming the most attractive. Judging though from the difference on the NPVs and the annual benefits, INS+BOIL was at last chosen that means that first the school is insulated and provided with low U-value openings and afterwards a high efficiency natural gas condensing boiler is installed.

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