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Reducing Energy Consumption in Greek School Buildings through Energy-Efficient Design

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Abstract

In recent years, several regulations have been set to reduce energy consumption in the building sector. The residential and commercial buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions in the European Union. In the Greek territory, rules on the energy performance of new buildings are set that require the issue of the Energy Performance of Buildings Certificate of category B or lower in order the new building to get a planning permission. This certificate ensures that the building is efficient in terms of energy consumption for heating, cooling, air-conditioning, lighting and hot water production and also fulfills certain requirements regarding to the building envelope. In this paper two energy-efficient school buildings are presented; a sixth grade high school complex of 6373 sq.m in the climatic zone B (Athens) and an elementary school of 2505 sq.m in the climatic zone C (Thessaloniki). The building design is focused on bioclimatic architecture, passive design strategies, high performance electrical and mechanical systems, lighting control and automation systems.

Keywords: Energy performance, EPC, Bioclimatic architecture, Passive design

1. Introduction

In recent years, several regulations have been set to reduce energy consumption and prevent energy waste both at national and international level. These regulations concern the transport sector, the industrial sector and the building sector. The residential and commercial buildings together represent almost 40% of the final end use of energy and 36% of CO_2 emissions in the European Union (EC, 2018). Although buildings consume large amounts of energy, their potential of energy savings can be improved when particular measures are implemented. In the Greek territory, the Ministry of Environment and Energy is responsible for the industrial, environmental and energy policy and also for the energy efficiency enhancement of the buildings. The requirements and specifications for the calculation of the energy efficiency of buildings are provided by the Rules of the Energy Performance of Buildings (Government Gazette 2367B, 2017) and the corresponding Technical Guidelines of the Technical Chamber of Greece (Government Gazette 4003B, 2017). These regulations concern both new buildings and fully renovated existing buildings (Government Gazette 42, 2013) and are in compliance with relevant EU regulations (Directive 2010/31/EU, Directive 2012/27/EU). In the case of a new building, an energy performance assessment must be performed and an Energy Performance of Buildings Certificate (EPC) of category B or lower must be issued in order the building to get a planning permission.

2. Building Energy Performance Requirements

The energy performance assessment of a building is conducted by experts during the design procedure. It intends to estimate the primary energy consumption of a building according to its systems and classify it according to its energy performance.

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The information to be collected during the assessment regards to the building envelope, building orientation, insulation, heating and cooling systems, air-conditioning, ventilation, lighting, hot water production, systems for renewable energy, automation systems, and bioclimatic parameters that provide a good quality of indoor comforts (Government Gazette 4003B, 2017).

First of all, during the design procedure, there must be a proper selection of the orientation of the building taking into account the existing climatic conditions. The openings should be designed in such a way as to take advantage of sunlight and good ventilation. Techniques that protect the building from the sun and the north winds, natural ventilation methods, passive solar systems and optical comfort via natural lighting must be incorporated. Figure 1 shows the graphic representation of the angle α which forms an obstacle (near building) to calculate the shading it causes in a vertical opaque building element and in a transparent structural element (door or window). Figure 2 shows the graphic representation of the angle β, which forms a cantilever and a tent with the vertical surface, to calculate the shading it causes in a wall, door or window.

Apart from the classification of the building as category B or lower, certain requirements that concern the building envelope and the electro-mechanical installations must be fulfilled, such as:

a) The maximum permissible thermal conductivity values for the different structural elements (walls, ceilings, floors, windows).
b) Maximum allowable mean coefficient of thermal conductivity as the ratio of the area of the external walls of the building to its volume.
c) All distribution systems (central heating pipes, cooling system pipes and air ducts) must have thermal insulation, especially where parts are outdoors.
d) At least 60% of the needs for hot water must be covered by solar thermal systems.
e) Each central air conditioning unit providing more that 60% of fresh air should be able to regain >50% of the heat of the outgoing air.
f) Minimum requirements of fresh air supply for classrooms and gathering areas are 11m^3/h and 27.50m^3/h respectively.
g) Referring to lighting, the existing natural light in areas of the building must be adequate as to decrease use of light lamps by 50%.

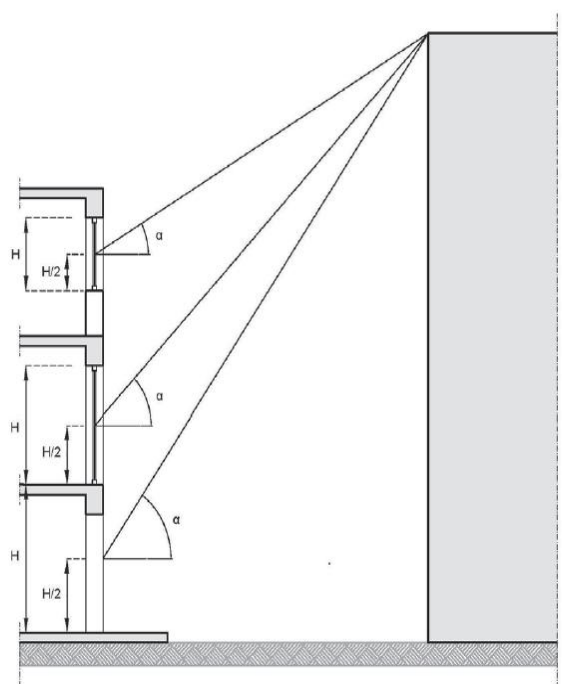

Figure 1. Shading calculations for obstacles

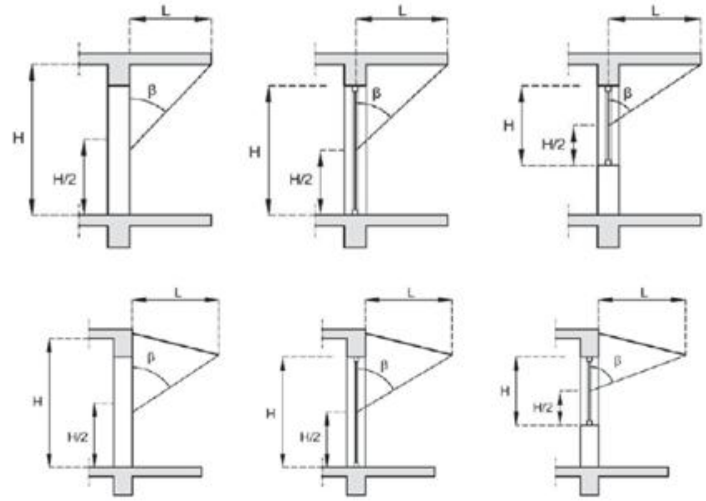

Figure 2. Shading calculations for cantilevers and tents

The calculation methodology of the energy performance of buildings takes into account the division of the Greek territory into four climatic zones, A to D, based on their degree days. The maximum permissible thermal conductivity values for the different structural elements differs among these four climatic zones, with the lowest values specified for the most demanding zone in terms of heating, zone D.

3. Case Study 1

3.1. The Building Envelope - Bioclimatic Architecture

The first study concerns a complex of two school buildings, 3200sq.m and 3173sq.m respectively, that belongs to climatic zone B (Athens) and will operate as a sixth grade high school, Figure 3. The building is at the construction stage and is expected to operate at the school year 2019-2020. Each building has a capacity of 360 students and consists of a basement, ground floor, first and second floor. The basement includes storage rooms, a parking area of 10 cars and electro-mechanical facilities rooms as engine room, pumping station and boiler room. The floors includes classrooms, two computer laboratories, laboratory of physical sciences, technology-design laboratory, arts laboratory, offices, administration rooms, a multipurpose hall of approximately 320sq.m, library, medical room and sanitary facilities. The indicative budget of the study is 10.775.000 €.

The free space extending between the two buildings is landscaped in such a way that hosts playfields, passages, rest areas, gathering areas and green areas. A chimney of an earlier industrial use of about 30 meters height is included in the study as an architectural element of the surrounding area.

Figure 3. 3D model of the school buildings and the surrounding area

The architectural bioclimatic design includes the optimum orientation in such a way as to take advantage of the climate and environmental conditions for natural lighting and ventilation, (Dimitrellou et al, 2018), such as:

- Larger openings at the two largest facades of the building extending north and south.
- Cantilevers and architectural protrusions along the southern side of the building to provide sun protection to the openings, Figure 4.
- Horizontal exterior shades with fixed blinds in the openings of the southern facades to enhance the shading.
- Vertical exterior shades with fixed horizontal blinds in the openings of the western and eastern facades and plexiglas panels to the areas that are exposed to the north, Figure 5.
- Evergreen trees and bushes on the north side of the surrounding area for protection from the north wind.
- High and dense planting on the west and east side of the surrounding area for protection from sunlight especially in the summer months.
- Thermal insulation of expanded polystyrene with low coefficient of thermal conductivity and thickness 7cm for walls, roof and floor and external insulation to avoid thermal bridges.
- Double glazing units with low emissivity glass and argon inert gas to improve thermal comfort.
- Green roofs of total 316sq.m to reduce the temperature of the roof of the underlying areas and also to maintain the microclimate, as the complex is in a densely populated area.

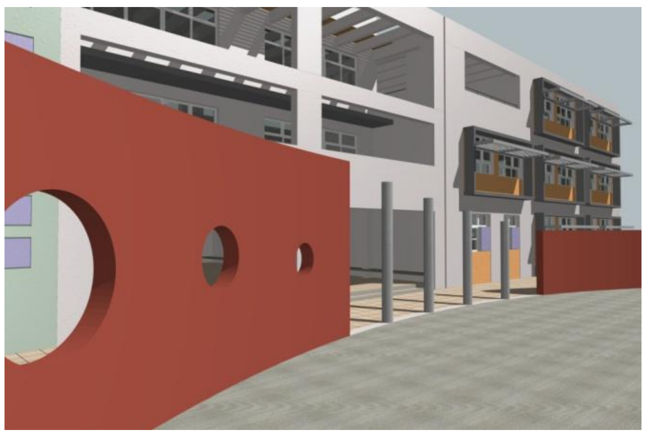

Figure 4. Shading techniques: cantilevers and horizontal blinds

Figure 5. Shading techniques in the northern facades of the complex

3.2. Heating – Cooling – Air conditioning Systems

The electro-mechanical installations regarding heating, cooling, air conditioning of the interior areas, production of hot water and lighting were designed in accordance with the national standards and focused on energy conservation. Each building of the complex includes:

- Heating of the school main areas with a high-efficiency natural gas boiler of 200KW, panel radiators, three-way control valve and actuator system, and room thermostats.
- Cooling of the library, administration offices and computer laboratories with a multi-split air conditioning unit of 50000 BTU/h (15KW).
- Ventilation of the school main areas with three air handling units of 4500m^3/h, 3500m^3/h and 3500m^3/h air supply and air ducts, Figure 6. The heat recovery unit includes a plate type heat exchanger with efficiency > 60%. Air capacity control is based on CO_2 concentration of interior areas that results to an efficient energy saving solution.
- Heating, cooling and air conditioning of the multipurpose hall with a compact heat pump and central air conditioning unit of 30KW/38KW heating/cooling load, 6000m^3/h air supply and air ducts, Figure 7.
- Solar thermal collectors of 20sq.m for hot water production, oriented to 45^o in the south.

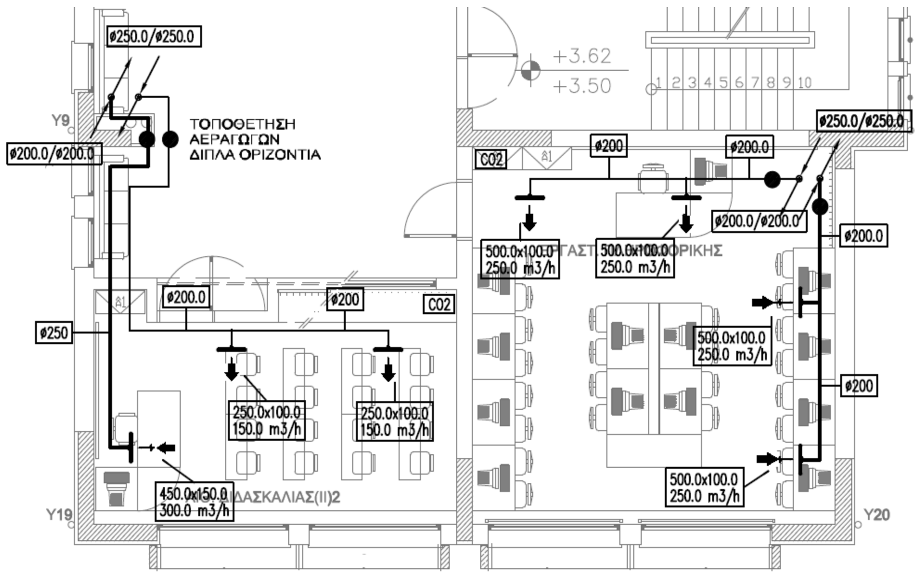

Figure 6. Ventilation drawing of airducts, diffusers and return grilles

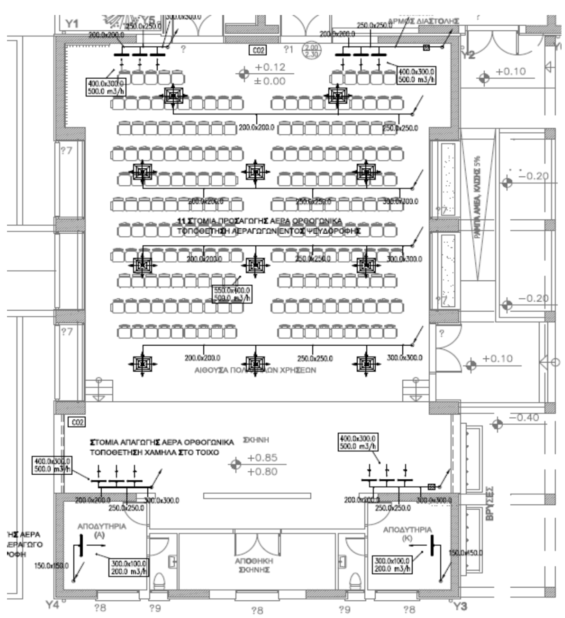

Figure 7. Air conditioning drawing of airducts and diffusers in furred ceiling

3.3. Water Saving Systems

Each building of the complex has a quite large surrounding green area of 3180 sq.m. An automatic rainwater irrigation system will be installed with pop up sprinklers for the lawn areas and bubbler irrigation for the trees and bushes. The system includes an underground network of polyethylene pipes and two submersible pumps of 6.5m^3/h flow rate and 10bar manometric head each. The green area is separated to six regions, each one controlled by a watering valve that operates at predefined evening time and duration. An electronic programmer controls and activates the watering valves. To reduce water consumption for irrigation, the required water will be supplied from an underground rainwater collection tank of 50m^3 of reinforced concrete.

3.4. Energy Performance of Buildings Certificate

For the energy performance assessment, each school building is divided into two parts that have different use and different energy performance requirements; the multipurpose hall and the other areas of the school. The energy performance assessment is conducted for each part and a separate EPC is provided. Table 1 presents the estimated primary energy consumption of the south building according to the systems that have been specified and Table 2 presents the corresponding primary energy consumption and CO_2 emissions per fuel source. The Energy Performance Certificate of the building is classified as category B+.

Systems	Primary Energy Consumption (kWh/m²)	
	School	Hall
Heating	15.4	14.9
Cooling	30.1	55.0
Hot water production	20.0	18.1
Lighting	47.9	46.7
Total	113.4	134.7

Table 1. Estimated primary energy consumption of the south building

Source	Primary Energy Consumption (kWh/m²)		Emissions CO_2 (kg/year/ m²)	
	School	Hall	School	Hall
Electricity	88.0	116.6	87	115
Natural gas	25.4	18.1	5	3.5
Total	113.4	134.7	92	118.5

Table 2. Primary energy consumption and CO_2 emissions per fuel source

4. Case Study 2

4.1. The Building Envelope - Bioclimatic Architecture

The second study concerns a school building of 2505sq.m that belongs to climatic zone C (Thessaloniki), Figure 8. The construction was completed on 2015 and the building operates as a primary school with a capacity of 180 students. The building consists of a basement, ground floor, first floor and includes classrooms, offices, administration rooms, a multipurpose hall of 493sq.m, library, kitchen, dining area, sanitary facilities, storage rooms and electro-mechanical facilities rooms. The indicative budget of the study is 4.045.000 €.

Figure 8. The 3D model of the Primary School

The architectural bioclimatic design incorporates the following techniques, (Dimitrellou et al, 2018):

- Appropriate openings and skylights in all areas for natural lighting and natural ventilation, and passive solar heating system with large windows in the south for most of the classrooms.
- Horizontal exterior shades with automated movable blinds on the southeast and southwest facade of the building. Shading blinds are placed in a vertical metal structure at 1.15m from the facade, Figure 9a. They are connected with daylight sensors that properly illuminate the classrooms, Figure 9b.
- Planting of high evergreen trees on the north side of the surrounding area that protects from the north wind and high planting in the west and south that protects parts of the building and the surrounding area from the sun.
- Lightway sun tunnels installed in classrooms and corridors for natural lighting enhancement, Figure 10 and Figure 12. The sun tunnels consist of Bohemian crystal dome of U-value 0.6W/m²K, inside reflective sun pipe of aluminum with reflection 99.8% and crystal ceiling diffuser.

Figure 9. a) Exterior shading blinds; b) shading enhancement of the classroom

Figure 10. Lightway sun tunnels installed in main entrance and corridors

- Wind chimneys of 1m x 30cm installed in the classrooms to improve natural ventilation and reduce cooling energy demand, Figure 11a and Figure 12.
- Two green roofs of total 563sq.m for bioclimatic building upgrading, Figure 11b.
- Reinforced external thermal insulation of expanded polystyrene and thickness of 10cm that results to a very low coefficient of thermal conductivity of U=0.174 W/m²K, improves thermal comfort and reduces the energy consumption for heating in the demanding climatic zone C.

Figure 11. a) Wind chimneys on the roof; b) green roof

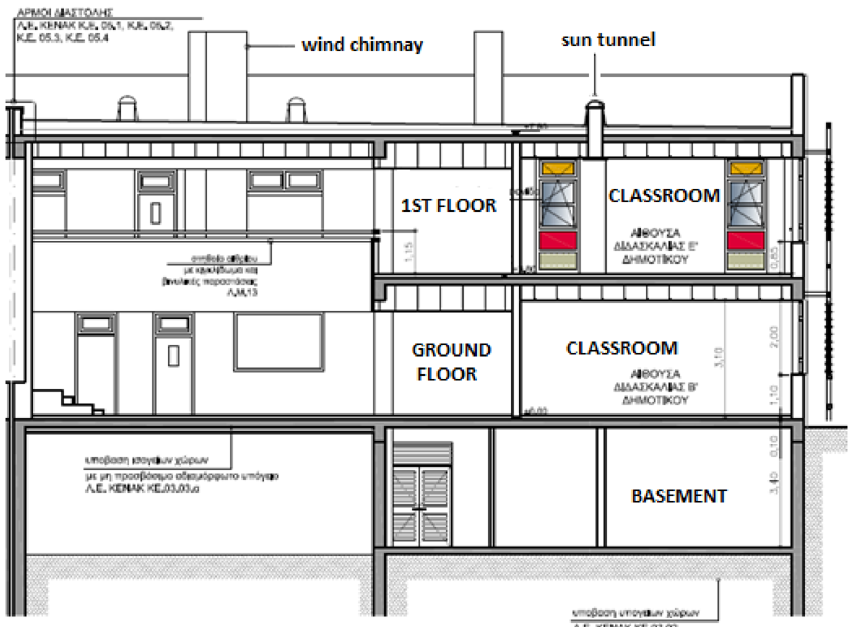

Figure 12. Wind chimneys and sun tunnels on section drawing

4.2. Heating – Cooling – Air conditioning Systems

The design of the electro-mechanical installations of the building was focused on the use of appropriate low-energy systems and high energy efficiency equipment:

- Heating and cooling of the school main areas with an air-cooled heat pump of 102KW/108KW heating/cooling load and fan coil units.
- Ventilation of the school main areas with four air handling units of 9000m^3/h, 3000m^3/h, 2150m^3/h and 2500m^3/h air supply, heat recovery unit with efficiency >60% and CO_2 sensors and air ducts.
- Heating, cooling and air conditioning of the 493sq.m multipurpose hall with a compact heat pump and central air conditioning unit of 32KW/34.5KW heating/cooling load, 6000m^3/h air supply and air ducts.
- Solar thermal collectors of 10sq.m for hot water production, oriented to 45^o in the south.
- Ceiling fans in the classrooms to improve comfort and reduce energy demand for cooling in the summer months.

4.3. Lighting Systems

To control further the electrical energy consumption the following lighting systems are installed. These systems ensure maximum energy savings and provide with proper lighting conditions that are continuously controlled throughout the school areas (Dimitrellou, 2017).

- In the interior areas the location and number of luminaries was selected in accordance with the lighting level limits set by the standard EN 12464: 1.
- Luminaries are energy-efficient LED lamps or metal halide lamps apart from the multipurpose hall that is illuminated with iodine lamps.
- All luminaries except those in storage rooms are integrated with manual dimming control optimizing the energy saving.
- In all classrooms and offices continuous lighting control with presence detection sensors is applied, while in the sanitary facilities lighting is controlled with motion detectors.
- In the case that the lights are forgotten, there will be a timer that will turn all the lights off at a predefined evening time.
- In the complex of case study 1, lighting of the surrounding area and playfields is applied with metal halide lamps of 500-watt and asymmetrical beam. Lighting is controlled via photocell control, timer control and wireless remote control switches.
- In the building of case study 2, lighting of the surrounding area is applied with LED energy-efficient light bulbs and poles with photovoltaic panels.
- For maximum energy saving in lighting, a central lighting control system KNX instabus system is installed for the energy-efficient management of the building's lighting systems (only for case study 2).

4.4. Energy Performance of Buildings Certificate

Figure 13 shows the Energy Performance Certificate of the building that was issued after its construction. All calculations are processed according to the methodology set by the Regulation of Energy Performance of Buildings (Government Gazette 4003B, 2017).

EPC includes the general characteristics of the building, the yearly total primary energy consumption of both the reference building and the building under investigation, the yearly CO_2 emissions and the energy class. The reference building is a fictional building with the same geometrical characteristics, location, orientation and usage as the building under investigation. It is in accordance with the minimum standards and has specific technical characteristics concerning all the structural elements and the electro-mechanical systems.

The Energy Performance Certificate of the building is classified as category B+. The primary energy consumption of the building's systems is 22.7 KWh/m^2 for Heating, 1.9 KWh/m^2 for Cooling, 0.6 KWh/m^2 for Hot water production and 38.8 KWh/m^2 for Lighting.

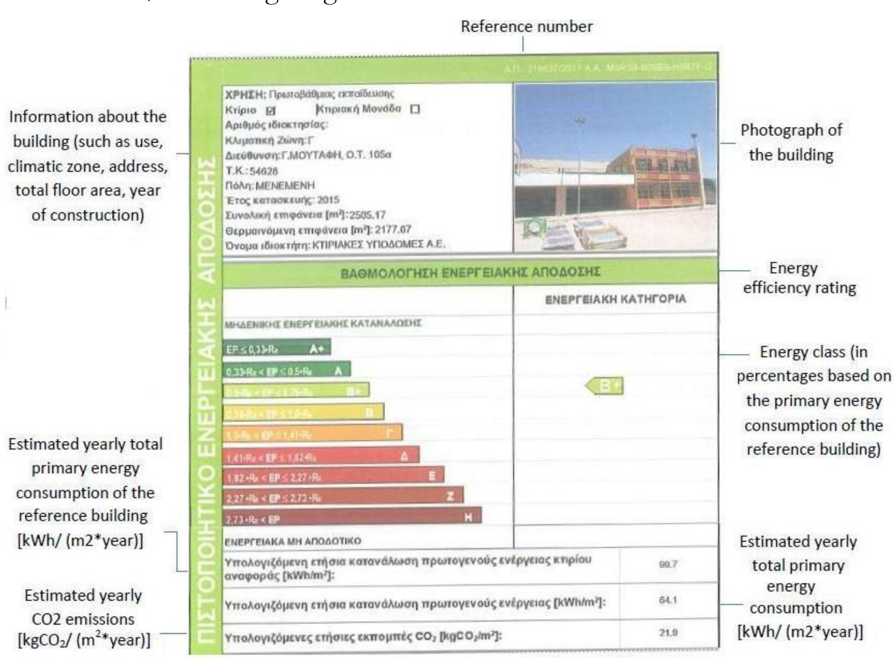

Figure 13. Energy Performance Certificate of the building – Case study 2

5. Conclusions

The aim of the energy-efficient building design is not only the energy and environmental benefits that result from energy savings, but also the improvement of the thermal and visual comfort for buildings' occupants, students and teachers. Energy-efficient design strategies are based on:

1) the principles of bioclimatic architecture design both in the interior and the surrounding area,
2) the exploitation of locally available renewable energy sources, for the partial or total coverage of its energy needs,
3) the use of appropriate low-energy systems and high energy efficiency equipment,
4) the energy management of the building with appropriate control systems,
5) the use of techniques and building materials, based on life-cycle cost, durability and recyclability.

Optimal building design focused on energy conservation and renewable energy is feasible, especially in Mediterranean countries where the climate conditions are ideal. The incorporation of additional systems as photovoltaic, solar chimneys or geothermal heat pumps is an effective way to reduce significantly the energy consumption in school buildings and protect the environment.

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