Πανεπιστήμιο Κύπρου

ΕΤΑΣ

Διατμηματικό Μεταπτυχιακό Πρόγραμμα
Ενεργειακές Τεχνολογίες και Αειφόρος Σχεδιασμός
Πολυτεχνική Σχολή Πανεπιστήμιο Κύπρου

FINAL GROUP PROJECT
COURSE POL 604-704-804

ENERGY PERFORMANCE EVALUATION OF LEFKARA PRIMARY SCHOOL

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2024-2025

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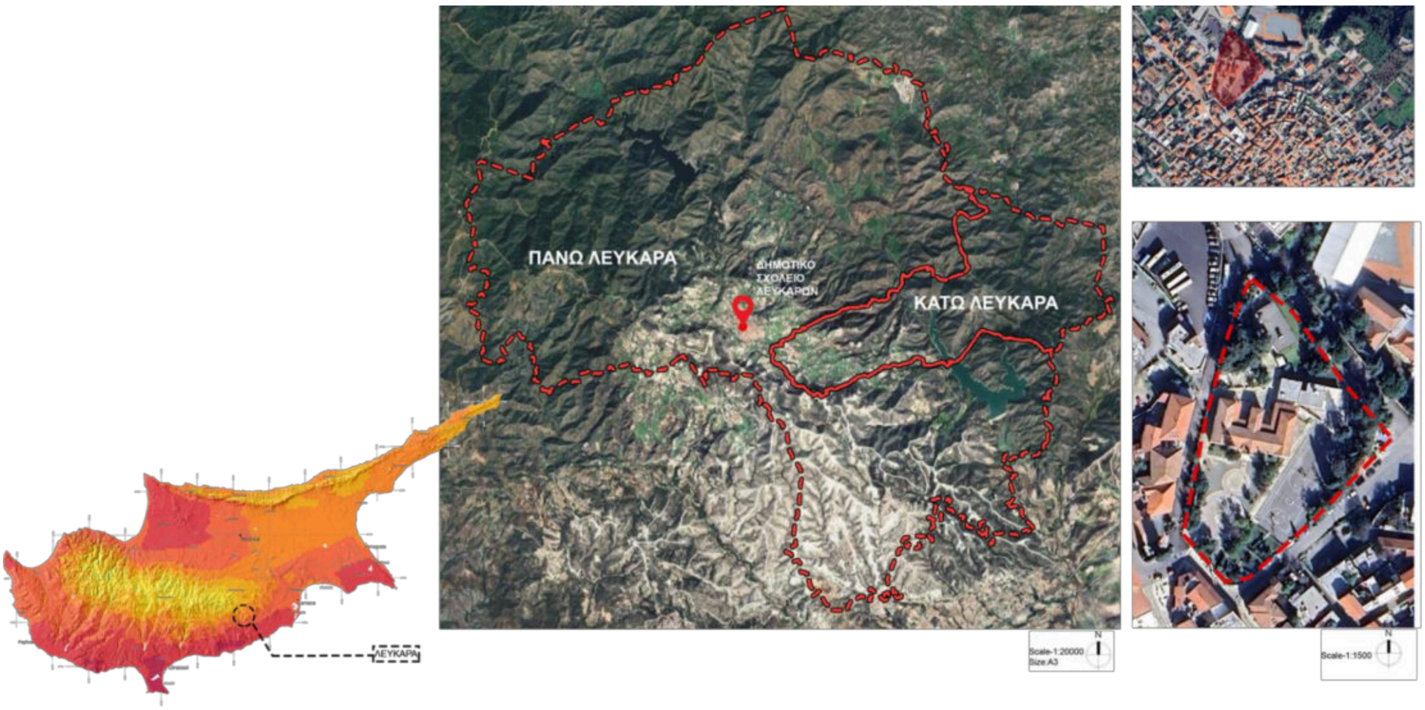
1. INTRODUCTION

The main objective of this study is to evaluate the energy performance of the Lefkara Primary School in order to identify factors that require improvement and propose solutions to achieve net-zero energy consumption. The need for a sustainable approach to energy management in buildings is more urgent than ever, especially when these buildings incorporate traditional elements and have historical and cultural value. In the case of the Lefkara Primary School, the research focuses on analyzing the existing energy needs and challenges of the building, as well as identifying areas that could benefit from upgrades to make them more efficient and environmentally friendly.

This study will analyze various factors such as the type and quality of construction materials, temperature management, lighting control, thermal losses, and the efficiency of heating, ventilation, and air conditioning systems. Additionally, the potential for applying new technologies and improvement solutions that could reduce energy consumption and promote the sustainability of the building will be examined, without compromising its traditional character.

The final goal of the research is to highlight strategies for the energy upgrade of the Lefkara Primary School, with the ultimate aim of achieving net-zero energy consumption, while ensuring the protection of its cultural and historical identity.



Boundaries Area - Plot

2. BUILDING INFORMATION

The building under study, located in the village of Pano Lefkara, is an important architectural and cultural element for the area, as it incorporates the history of the place and combines traditional and modern construction elements. The construction of the Primary School in 1920, in the center of the village, reflects the educational needs of the time, as well as the desire for development and modernization of the area, under the influence of British colonial rule. The Lefkara Primary School is a neoclassical building, belonging to the second period of British colonial rule (1878-1960), a period during which significant public and educational buildings were developed in Cyprus.

The use of Lefkara stone as the main material for the building's structure is characteristic of the local architectural tradition. The natural materials of the area are utilized to create structural solutions adapted to the local climate and conditions. Lefkara stone, with its unique texture and durability, gives the building a sense of stability and continuity, while simultaneously contributing to its aesthetic, ensuring a connection with the traditional building stock.

As a listed building, the Lefkara Primary School is protected by laws governing the preservation of cultural heritage. Its recognition as a listed building means that any renovation or upgrading work must respect its original form and architectural identity. However, it is also necessary to consider the building's energy upgrade to meet modern requirements for sustainable and efficient energy use, without altering its traditional character.

The architectural and cultural heritage of the building, combined with modern needs for sustainability and energy efficiency, presents an interesting challenge for researchers and engineers, who are tasked with combining the preservation of traditional architecture with the modern upgrading of the building.

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Photographic depiction of a building

3. ANALYSIS OF ARCHITECTURAL DRAWINGS

The building plans and sections of Lefkara Primary School give a clear view of the building structure and its functional arrangement, along with the plan of the surrounding space. Specifically:

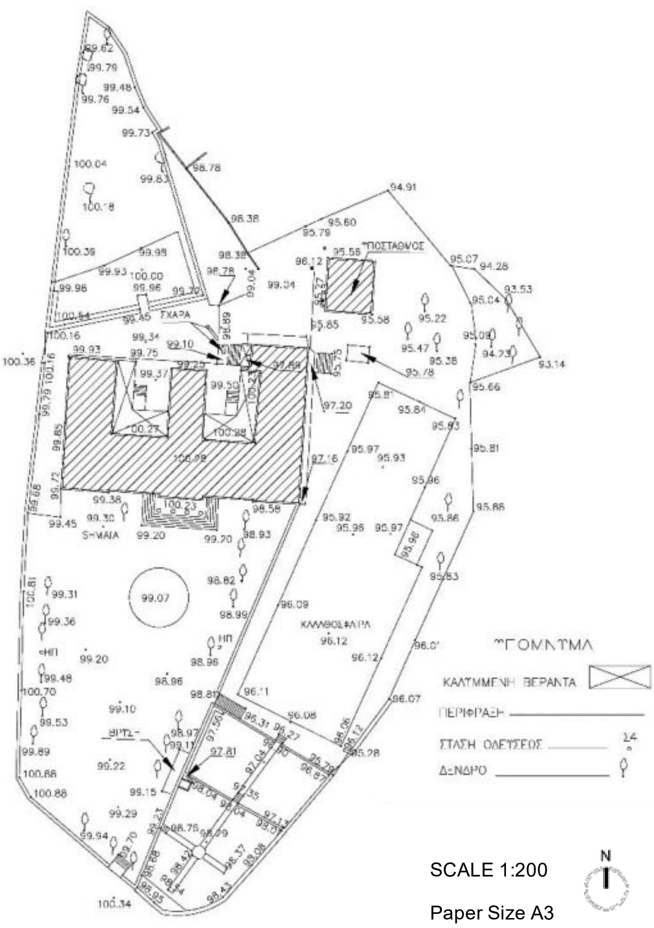
3.1 Spatial Plans

The more general spatial plans show how the land is arranged and how the structure is interconnected to its environment. They include:

<u>Placement of Building:</u> Define where the building will be placed on the plot relative to the sides, entrances, and routes.

<u>Outdoor Spaces:</u> Highlight outdoor areas like courtyards, green spaces, sports facilities, planting zones, and well-labelled functional spaces.

<u>Access and Circulation:</u> Provide main and side gates, pedestrian/car routes.



GENERAL SPATIAL PLAN

3.2 Floor Plan

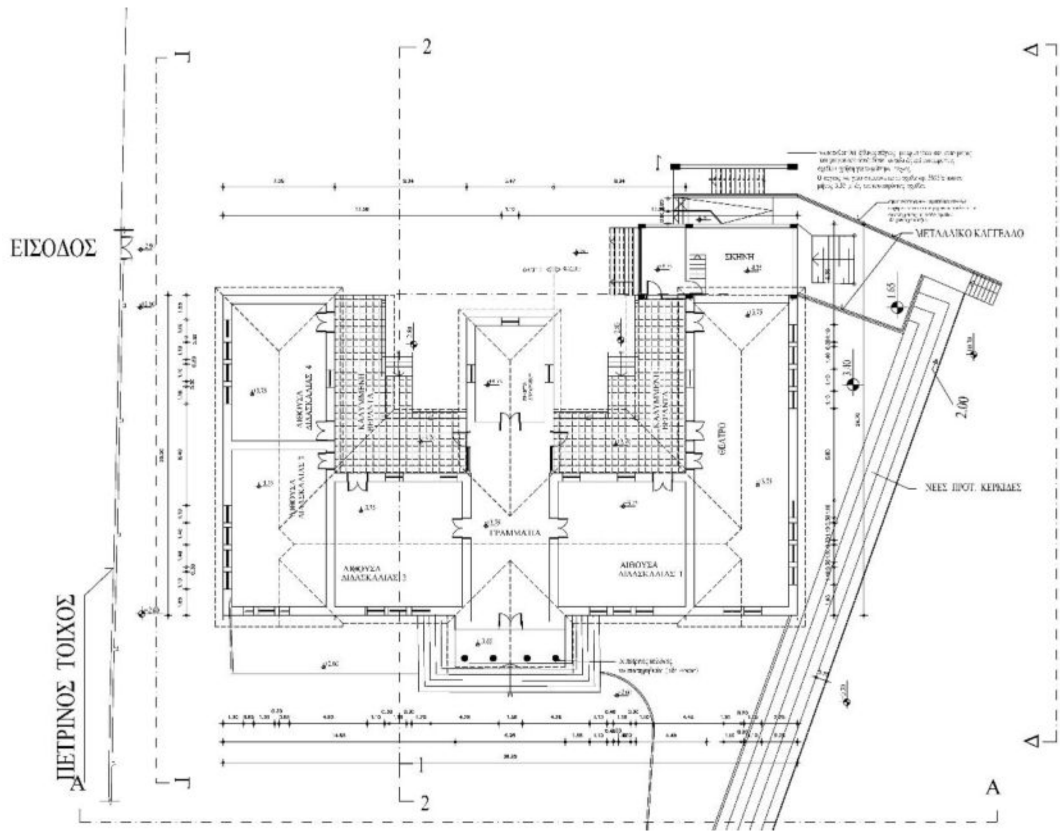
Lefkara Primary School Floor Plan A rendering of the internal layout of the building, showing the space and its function. It includes:

<u>Internal Layout</u>: The floor plan describes the arrangement of the classrooms, offices, utility rooms, and common areas. It identifies the functional relations between rooms (corridors, doorways).

<u>Dimensions and Details:</u> The exact dimensions of every room are noted so it can be rated to see if the space is appropriate for the purpose it was designed for. It is also notated for specific details like furniture or installations inside.

<u>Access and Circulation:</u> The floor plan depicts where the building is opened and how spaces are designed to allow users to move around. It reveals stairs, hallways, and building openings.

<u>Room Functions:</u> The different rooms are tagged, for example, classroom, teachers' offices, storage, or sanitary facilities to make sure we know exactly what the building is used for.



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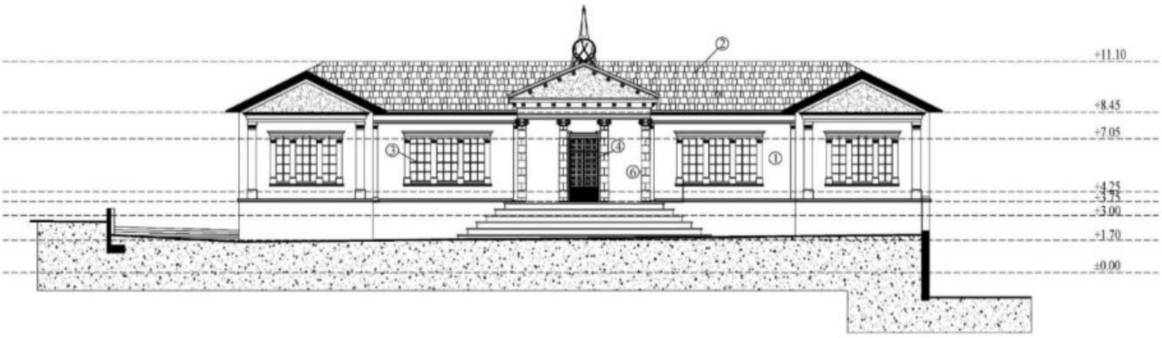
BUILDING FLOOR PLAN

3.3 Elevations (East, West, North, South)

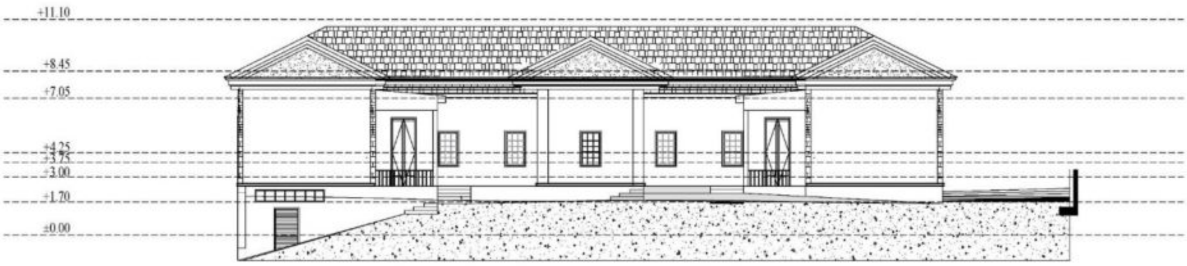
The elevations are an external view of the school building and detail details of its architecture and construction.

<u>Architectural Features:</u> Demonstrative windows, doors, geometry of the roof and morphological characteristics (porcelain and ornamentation).
<u>Construction Materials:</u> Describe materials, e.g., stone, tiles, metal.
<u>Facade Details:</u>

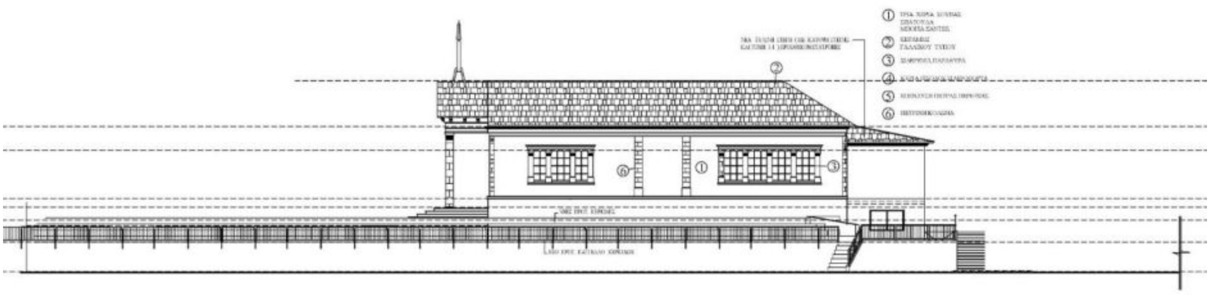
Look closely at the entrance door and how it is symmetrical or asymmetrical in opening layout.



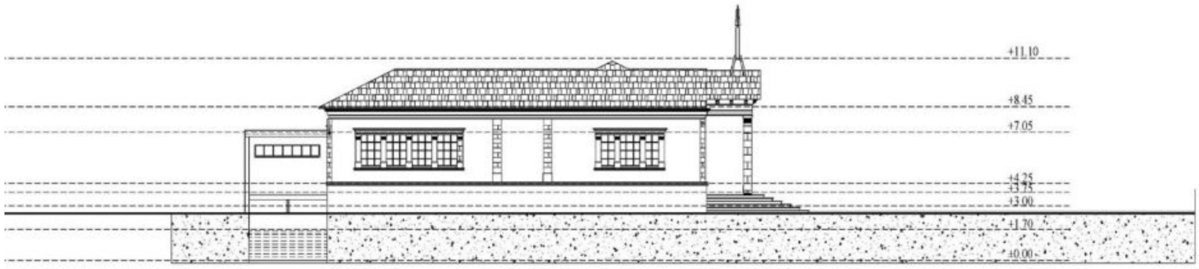
SOUTH ELEVATION



NORTH ELEVATION



EAST ELEVATION



WEST ELEVATION

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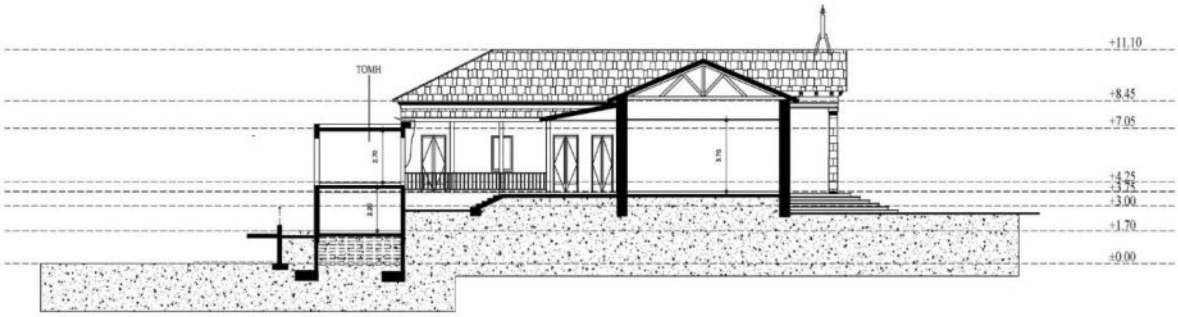
3.4 Sections

These part tell us a lot about the vertical arrangement of the building:

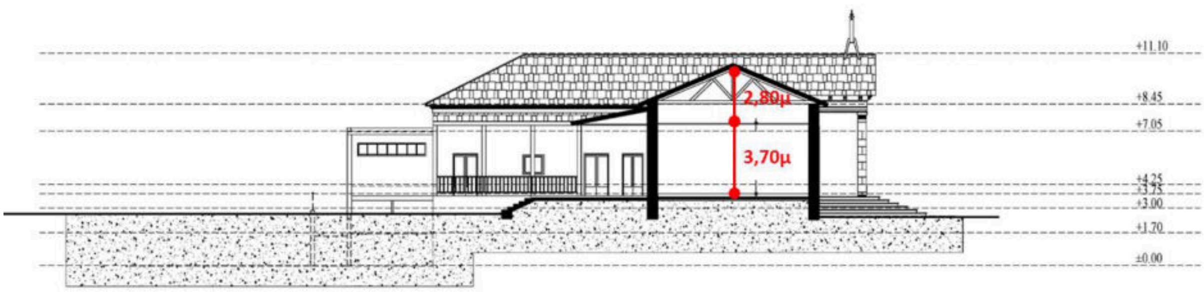
Building Structure: List foundations, slabs, columns, and walls.

Height References: Detail the room height, the shape of the roof, and the connections to the surrounding space.

Design in Interior: Draw vertical variations of the rooms, like the height of rooms or staircases.



SECTION 1-1



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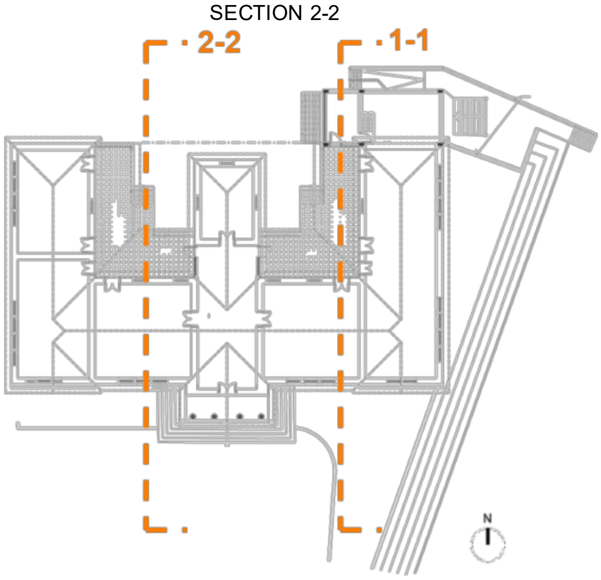
SECTION 2-2

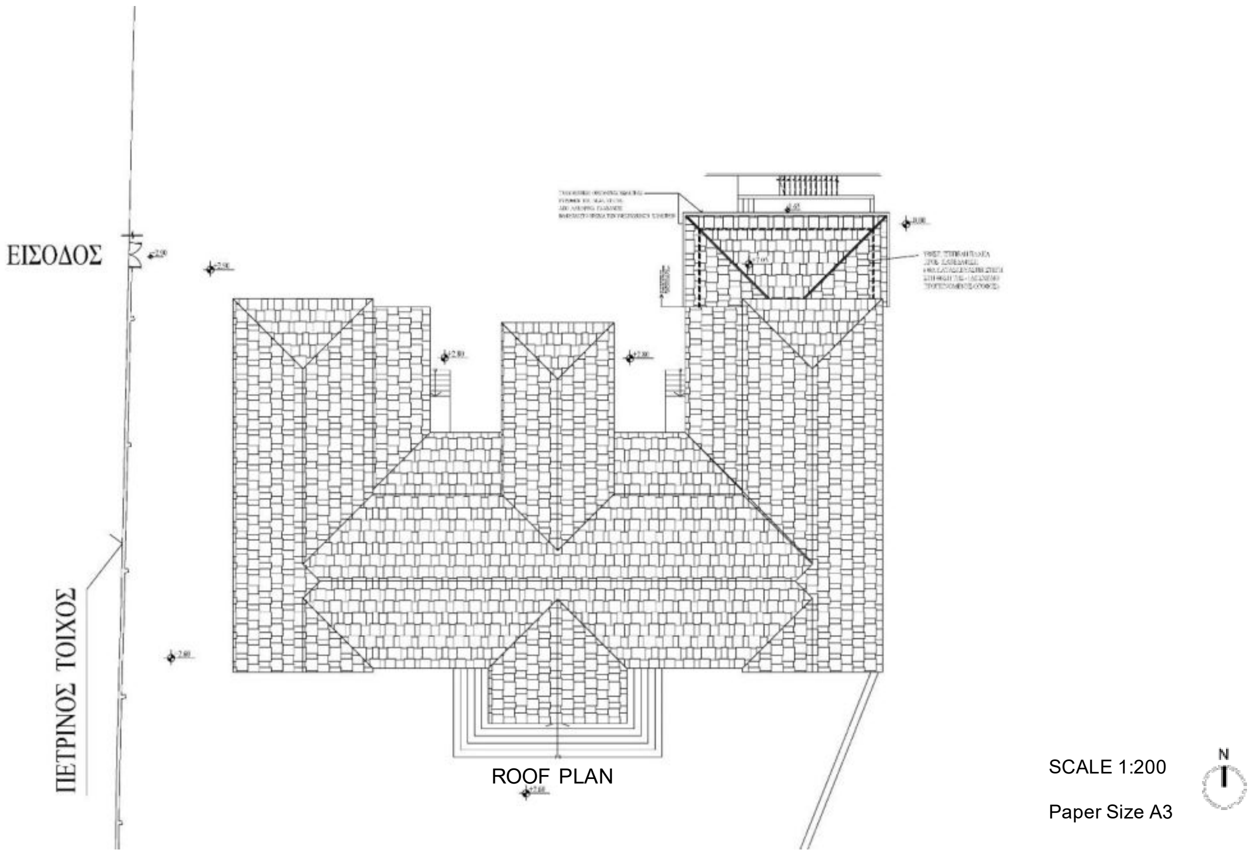


3.5 Roof Plan

The roof plan describes the layout and arrangement of the roof coverings, and includes information on:

Roof Configuration: Defines slopes, coverings (tiling) and drainage spaces.

Avant and Post Expansion: Track changes to dimensions, heights, and incorporation of new components.

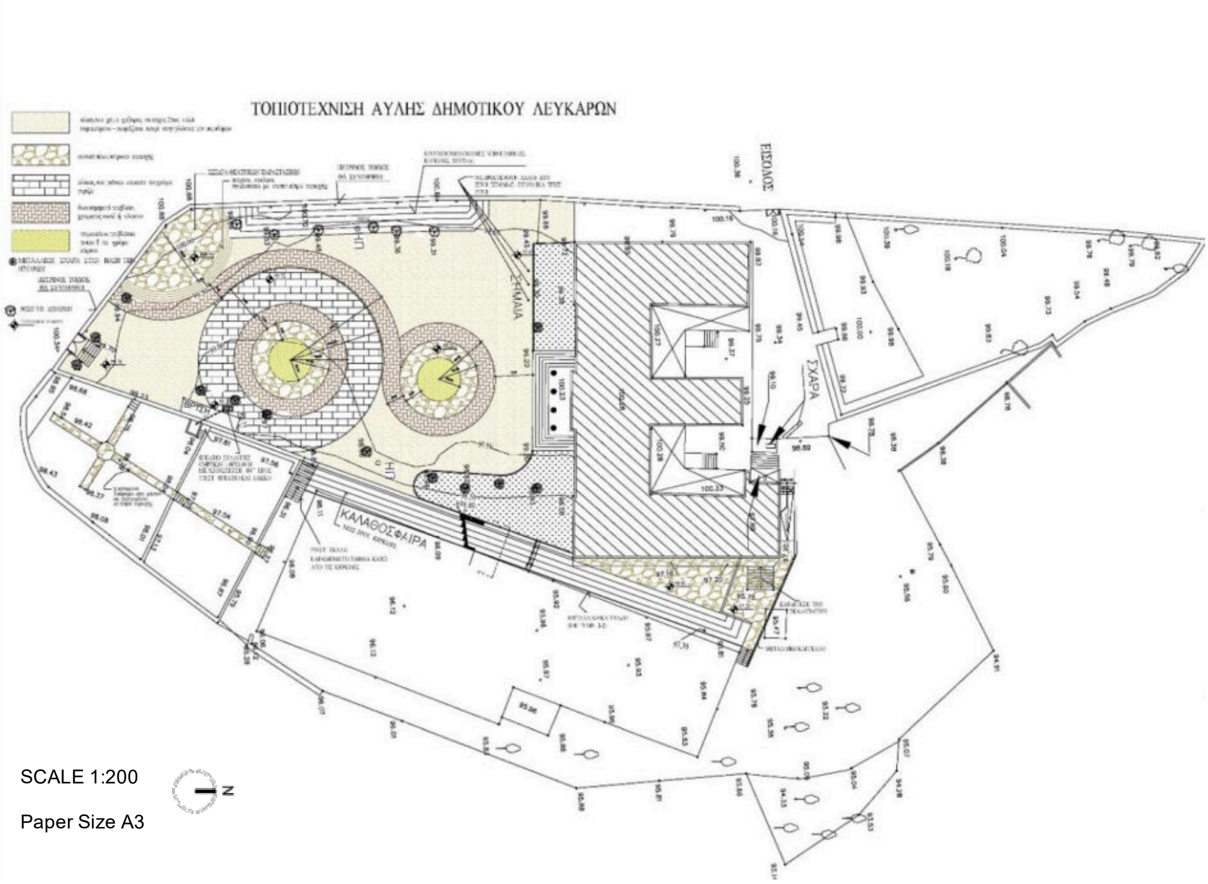


3.6. Landscaping plans

The landscaping specifications describe the plantings and vegetation for the exterior areas, as well as the paving:

Environmental Design: Include plants and plant setup for practical as well as aesthetic purposes.

Space Management: Prioritize the creation of play spaces and outdoor learning areas.



GENERAL SITE PLAN/LANDSCAPE DESIGHN OF THE COURTYARD

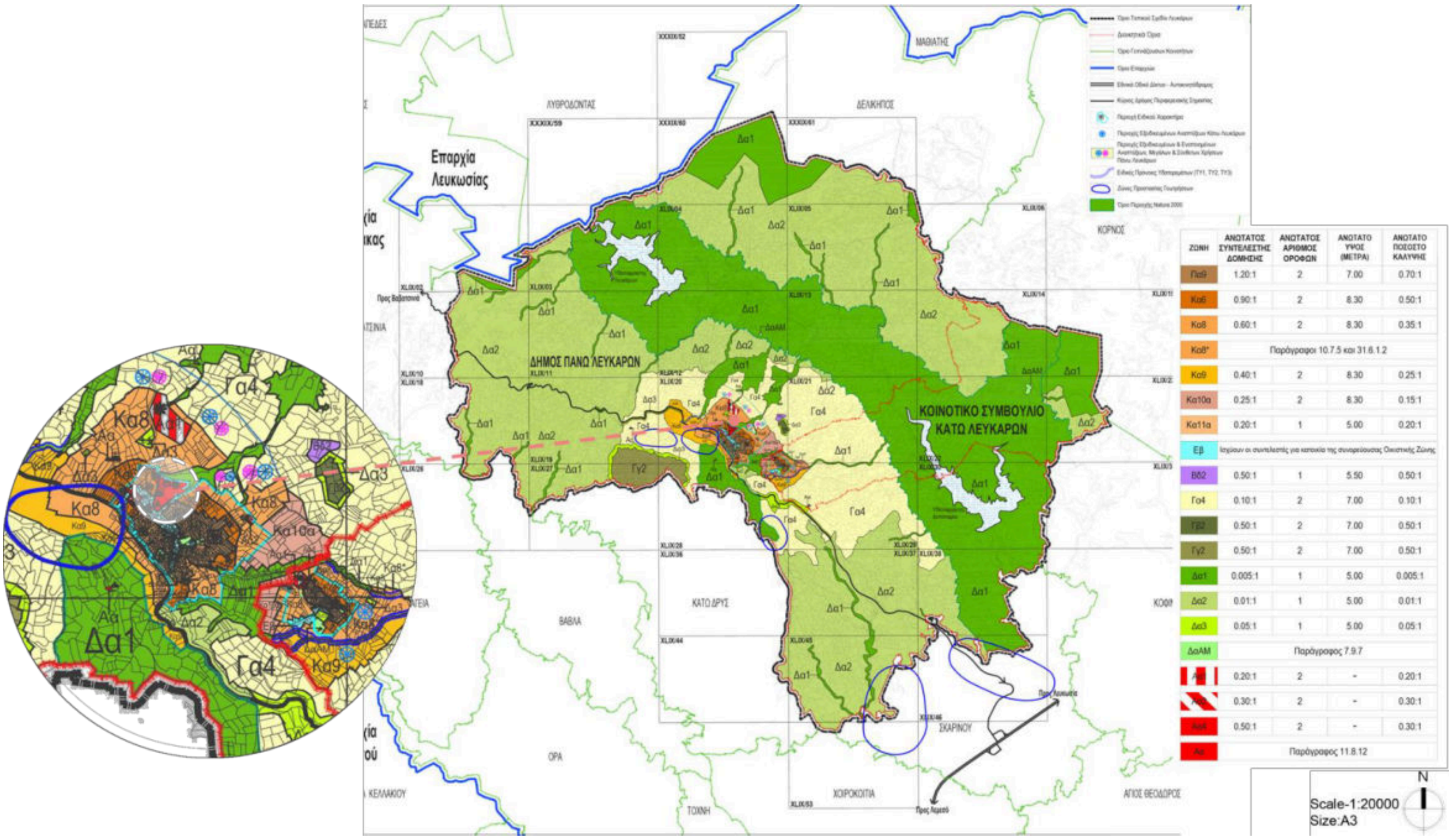
The Lefkara Primary School, presented in its plans and architectural drawings, is a school complex that successfully blends historic and architectural heritage with functionality and contemporary requirements. Spatial, elevational, sectional, and floor plans offer a holistic understanding of the building and site, and technical information assists in its effective management and upgrades. With the unbounded interplay of interior and exterior layouts, the school integrates sustainable, accessible, and safe features to create an academically effective environment rooted in the regional cultural legacy. These plans are important as the basis for planning future interventions and maintaining the school's ability to meet the community's needs while maintaining its own history and navigating future demands.

4. AREA MAPS

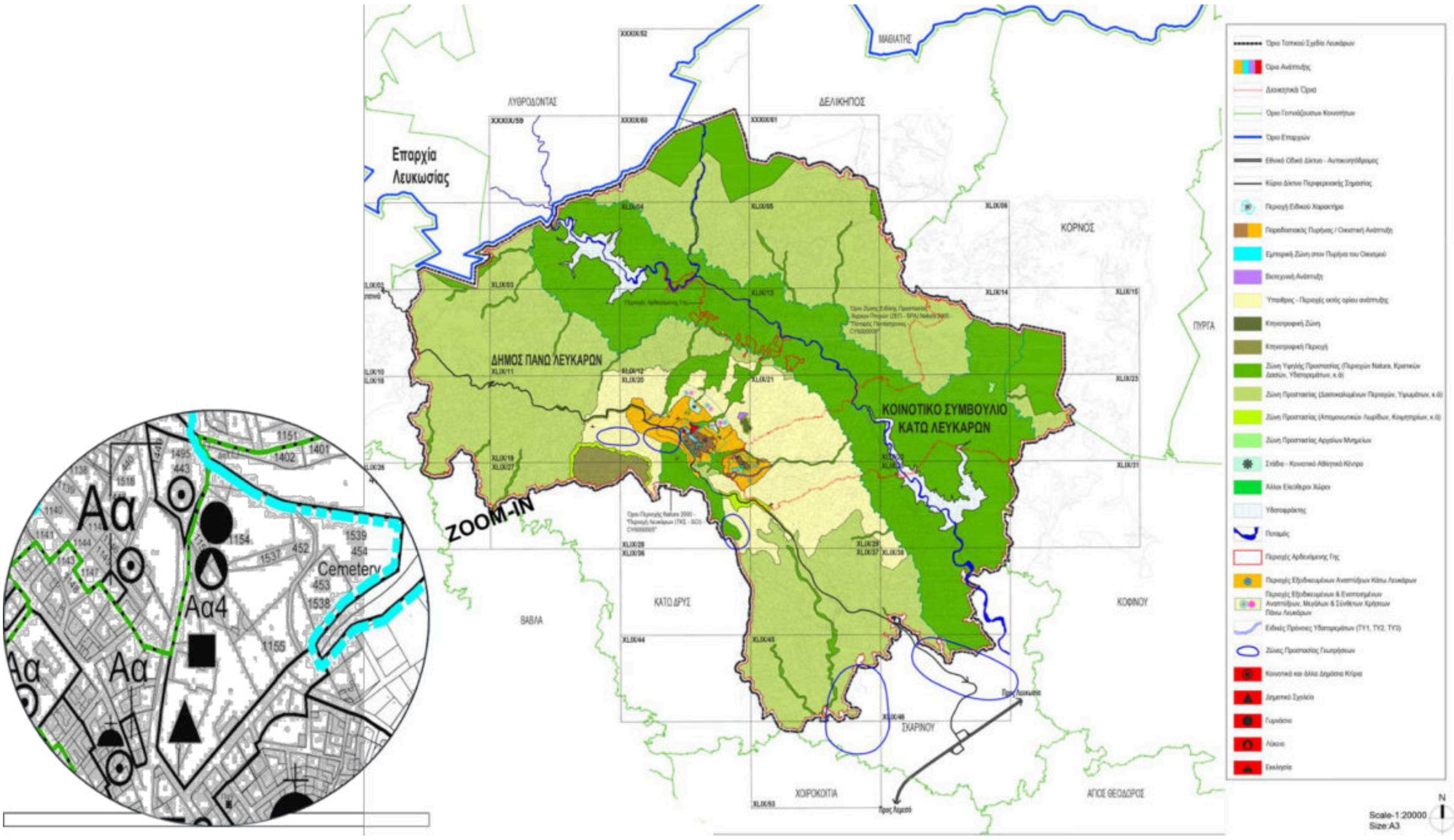
These maps depict the various urban planning zones and uses in the Lefkara neighborhood — particularly the zone where Lefkara Primary School is located. The first map identifies the region's urban areas, including the division into residential, commercial, and public utility zones. The most relevant of these is zone Aa4, which includes public uses like schools and school buildings due to the importance of the school to the local community.

The second map focuses on land uses, and it is obvious how the land was structured for commercial, educational, religious, and other purposes. Lefkara Primary School sits in an area of strategic local importance, close to churches, a gymnasium, and public spaces. These uses also show that the area is being developed equitably with the local community.

Examining these maps is necessary for our analysis of the school. They give a glimpse of the local landscape, accessibility, and the region’s pulse to aid in formulating measures to upgrade the education system according to the needs of the local community.



1.URBAN ZONING MAP-LEFKARA

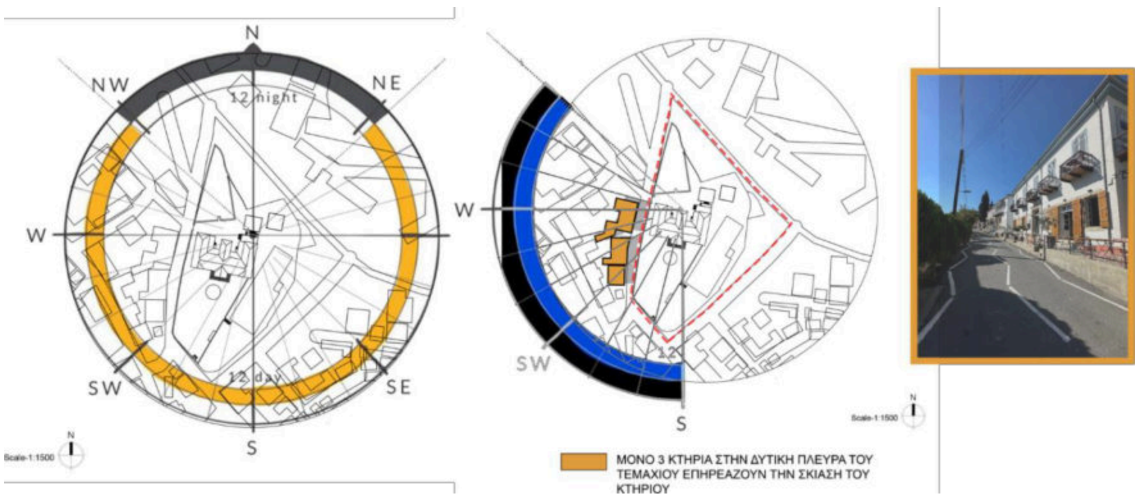


2.LAND USE MAP -LEFKARA

5. METEOROLOGICAL DATA

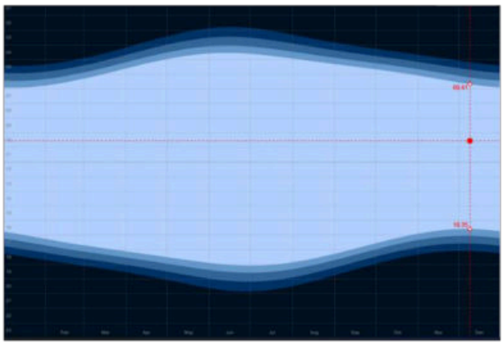
5.1 Solar Light and Shadow Analysis

Solar light analysis for this site examines the direction of the sun and shadows in the space around the school in Lefkara. The first figure plots the solar direction in plan view and how structures on the western edge of the lot influence light and shade. Only three buildings in the zone of interest seem to make a big difference in lighting, depriving direct sunlight during the day.

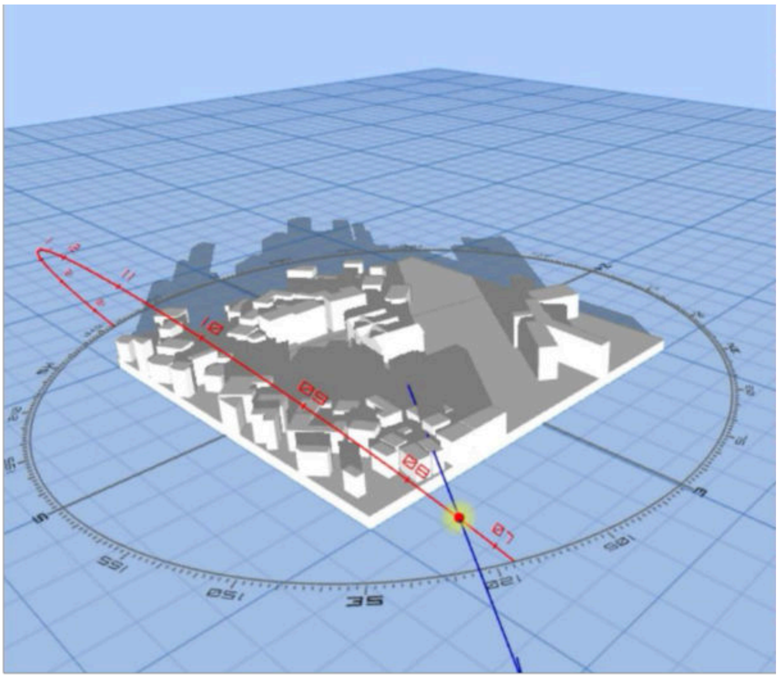


The second graph—a 3D simulation—shows how the building is shaded in daylight. The red circle is the path of the sun on 8 December, and the shading regions (blue and black) show the time of day and night, respectively. The study shows the areas where sunlight is scarce, essential to energy efficiency measures like the deployment of photovoltaic panels or maximizing natural light in the school.

This research will contribute to a better energy design for Lefkara Primary School, which will be more sustainable and energy efficient while keeping the local climate at heart.



Γαλάζιο: διάρκεια της μέρας
Μαύρο: διάρκεια της νύχτας



5.2 Weather

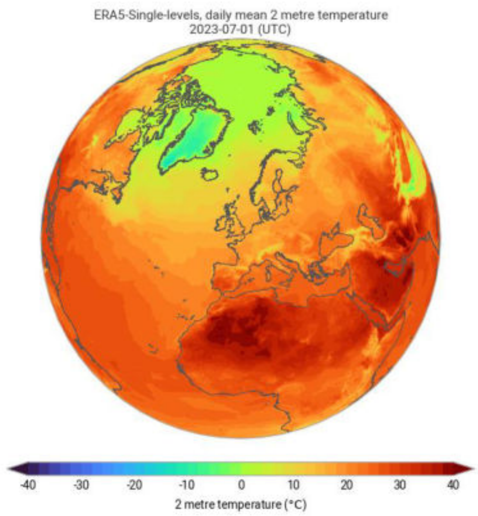


Fig.1 [ERA5 hourly data on single levels from 1940 to present]

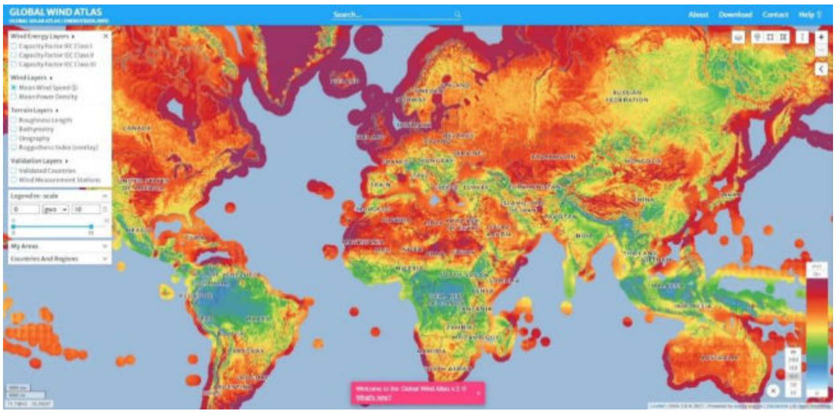


Fig.2 [Global Wind Atlas]

Meteorological data were collected using Copernicus Era5 and Global Wind Atlas sites focusing mostly on 10m wind speed, 2m temperature, surface solar radiation downwards and total precipitation, for the years of 2000 – 2024, all days and months for the hours 07:00 – 16:00, specifically for Lefkara, . From Global Wind Atlas, we collected, for Larnaca, rodograms and wind speed distribution maps for 10m, 50m and 100m above ground. These data were later on processed using tools like spyder anaconda, a python based data optimization program.

5.2.1 Data optimization

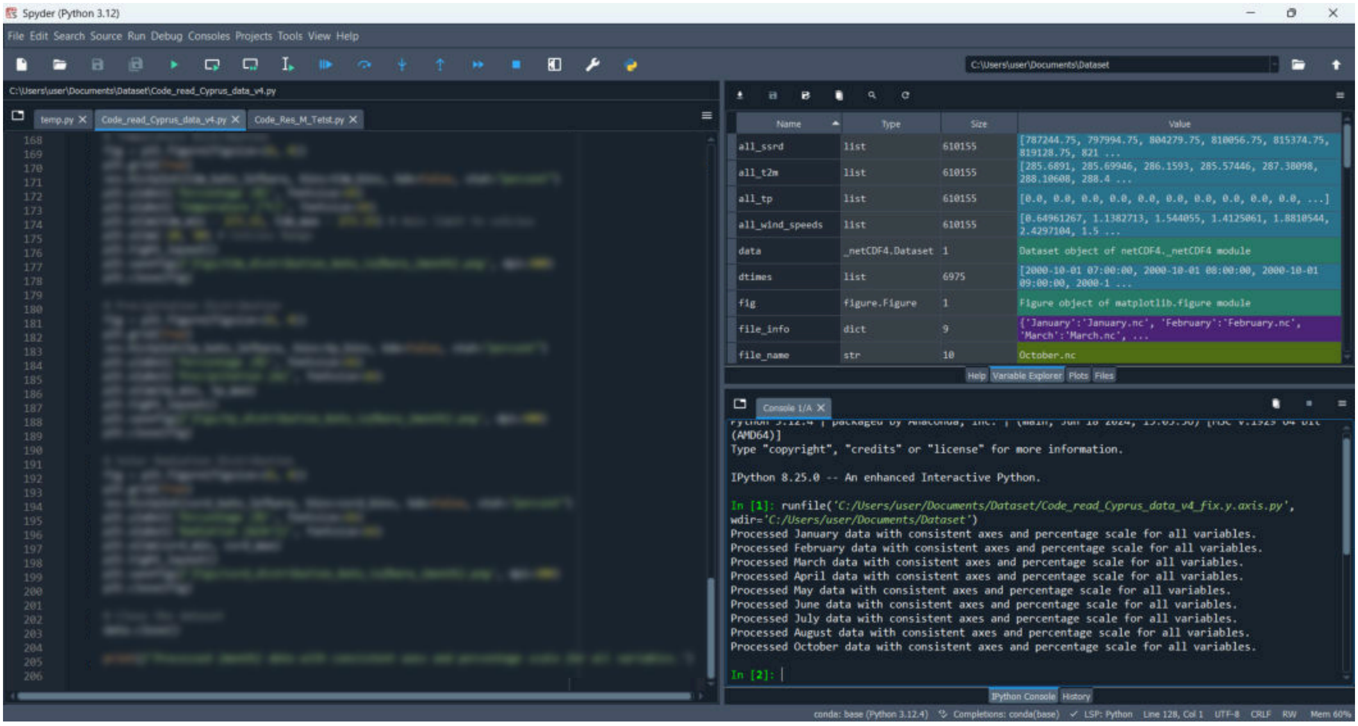
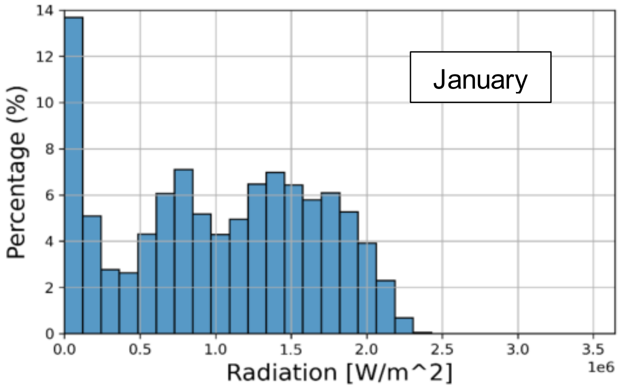
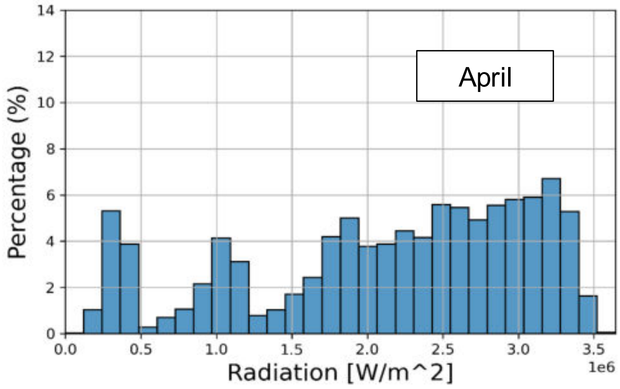


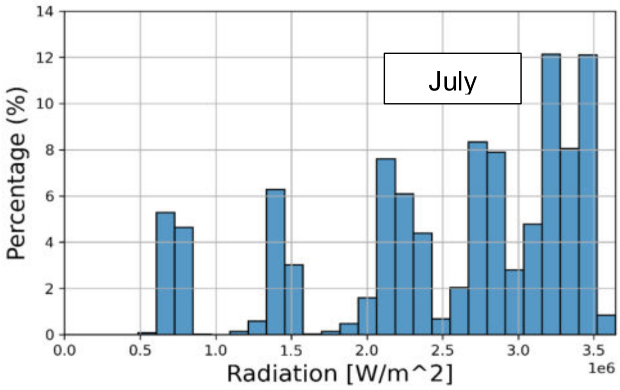
Fig.3 python code made by Dr. Lily Oikonomou

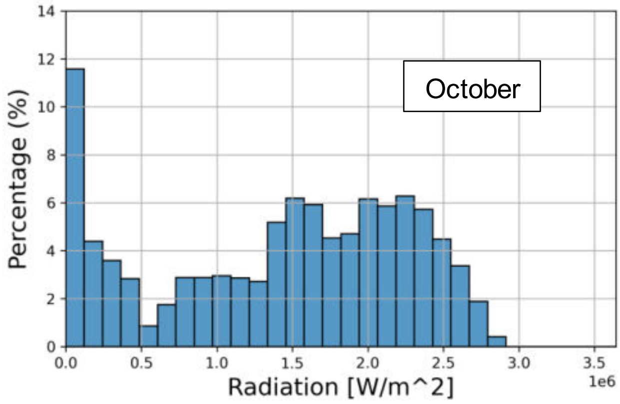
Data from Era5 are downloaded in NetCDF4 file form that can not be analyzed as there is. Using a python code, written by Dr. Lily Oikonomu, we can create graphs for each parameter, solar radiation, temperature, wind speed and precipitation specifically for Lefkara, area of interest, aprox. 2528.34 km^2. These graphs will be later on selected based on the representative months of each season, January, April, August and October.

5.2.2 Radiation



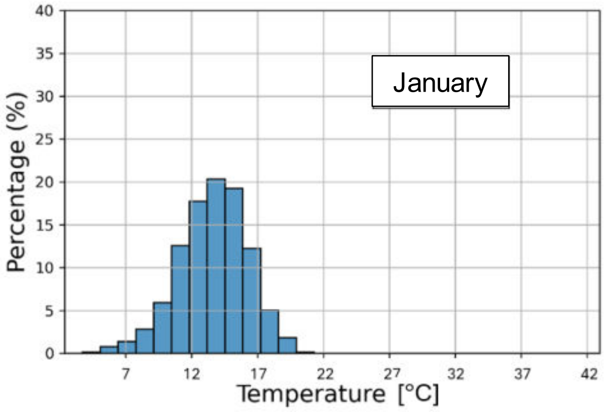


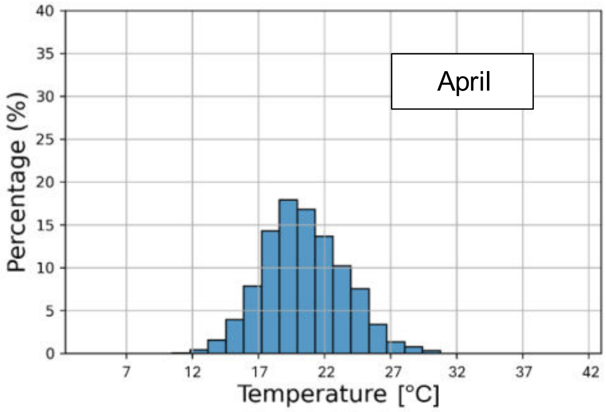


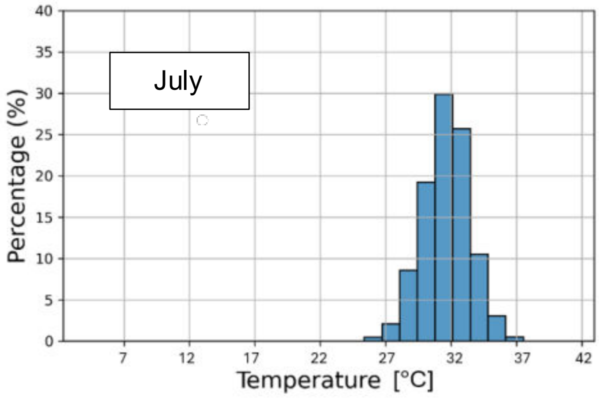


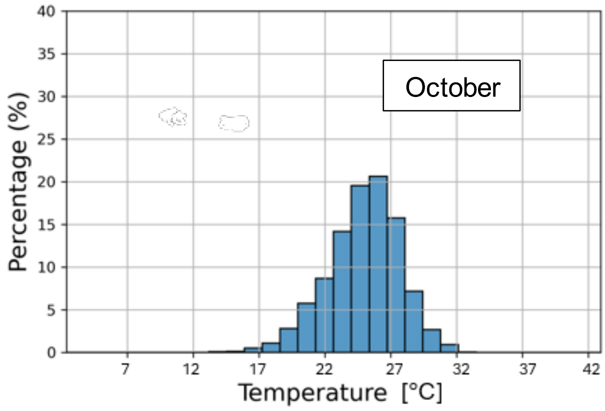
Note: we observe that the months with the highest and lowest radiation rates are July and January respectively. This as we will see next aligns with the temperature graphs.

5.2.3 Temperature

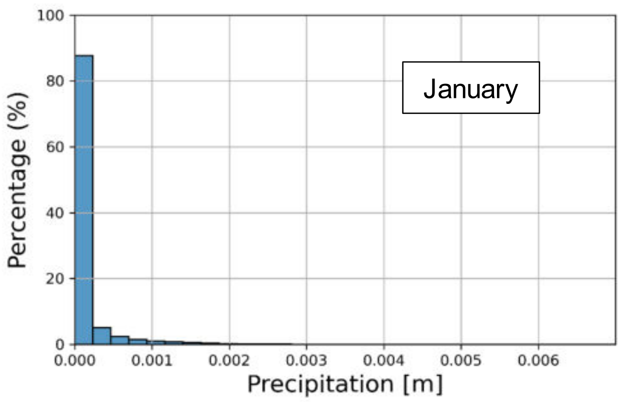


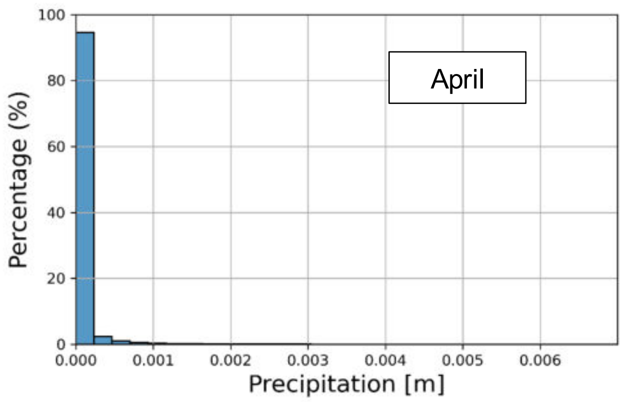


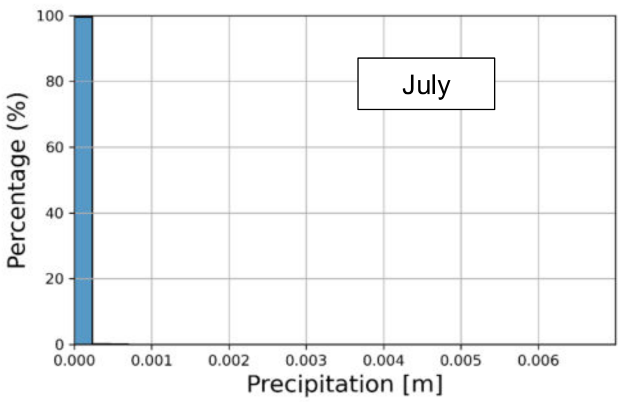


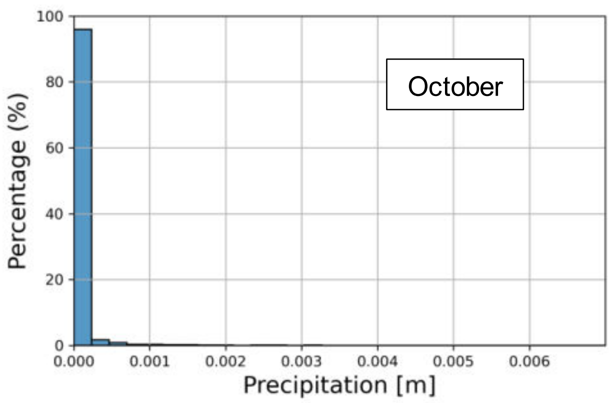


5.2.4 Precipitation



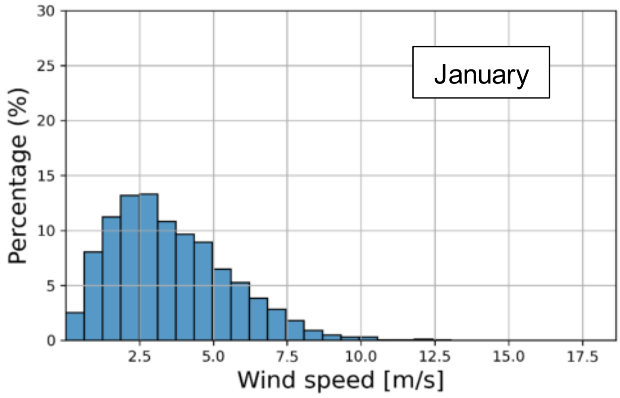


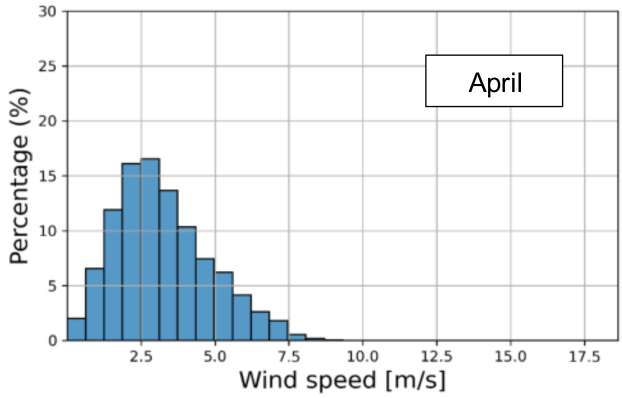


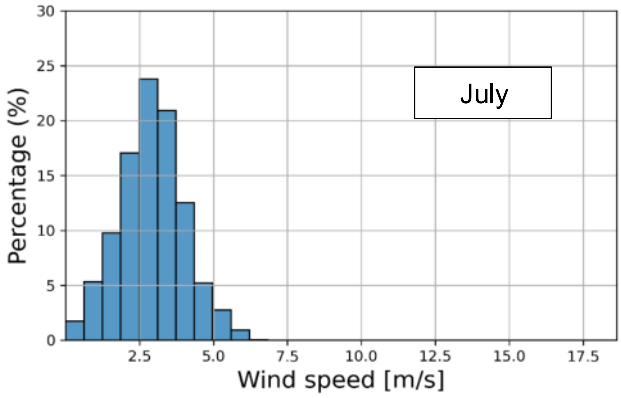


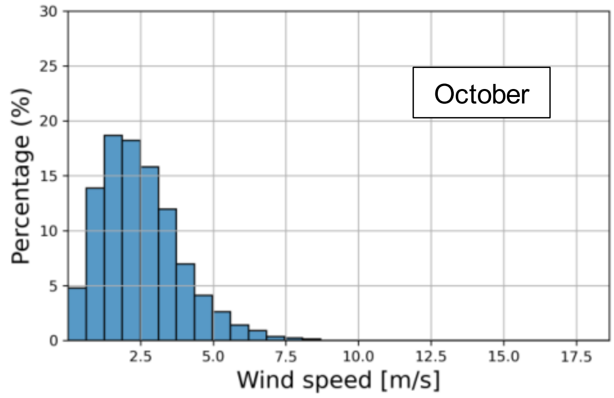
Note: On the opposite, we see that July has the lowest precipitation rates and January the highest.

5.2.5 Wind Speed









Note: January has the highest rates on wind speed measurements.

5.2.6 Global Wind Atlas Maps

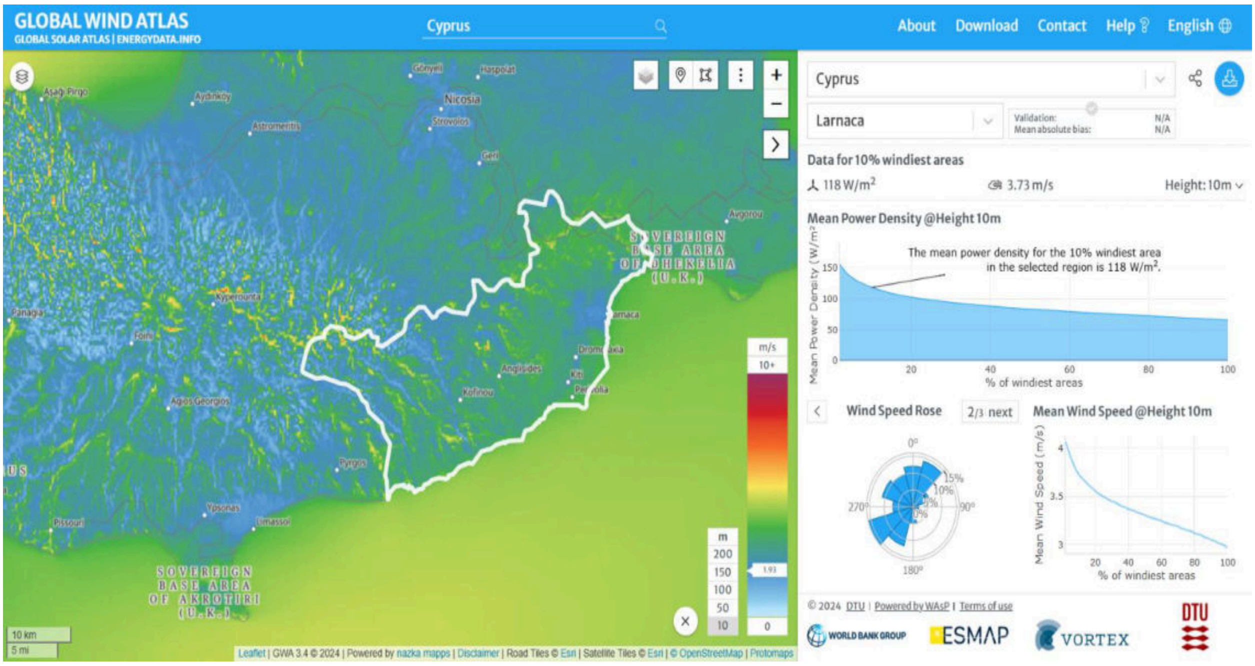
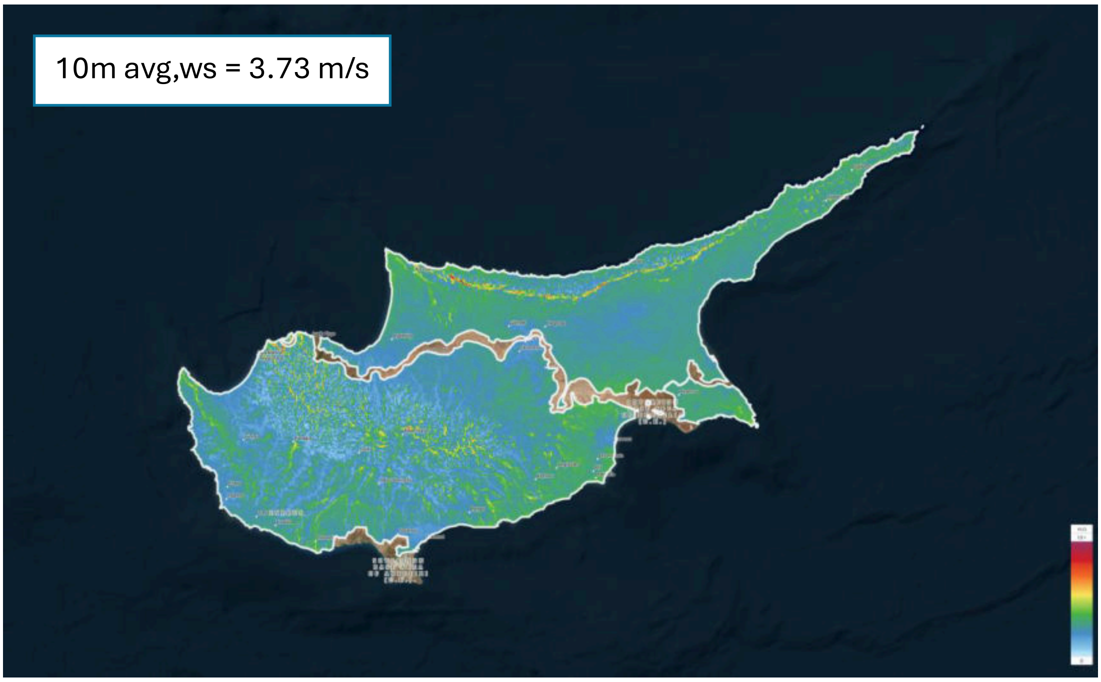
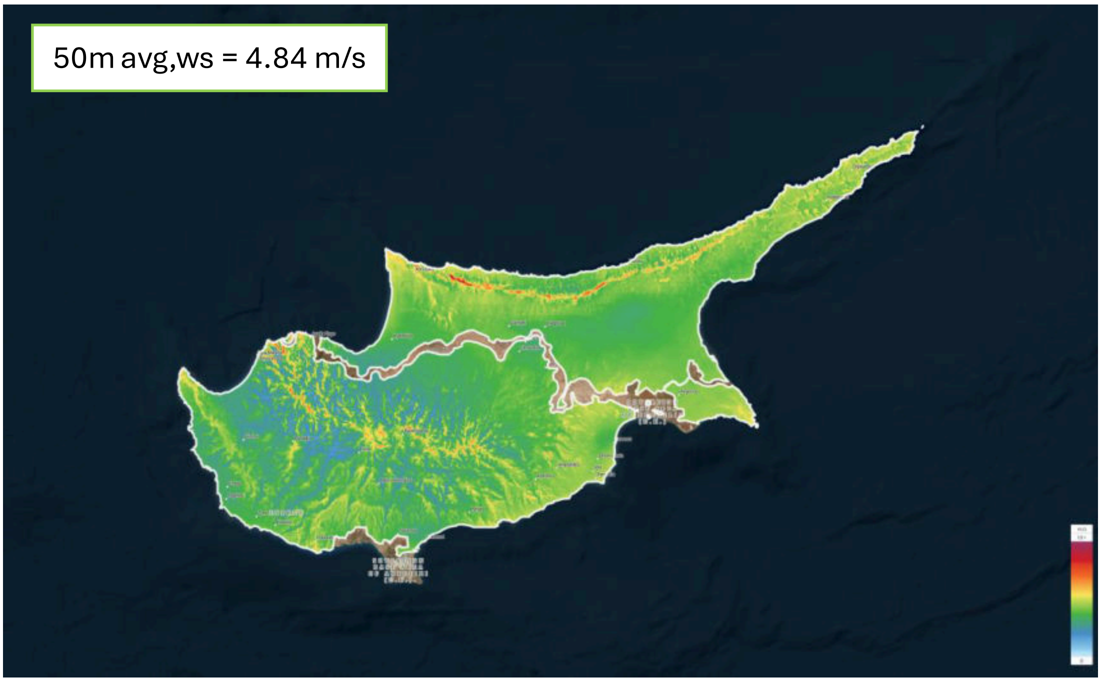


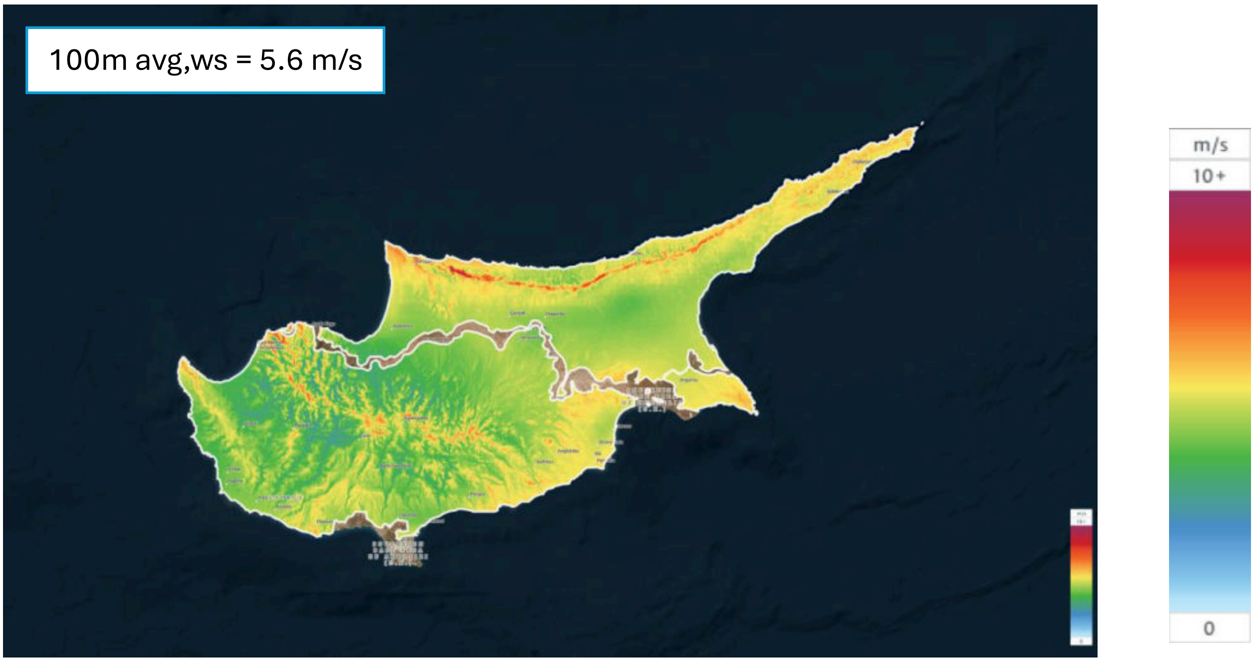
Fig.4 Global Wind Atlas for Larnaca.

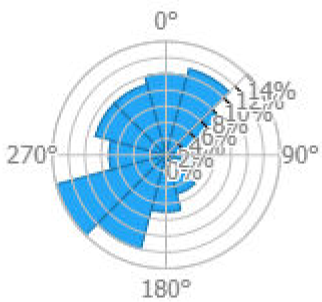
From Global Wind Atlas we focus on Larnaca, the site can't get more specific for Lefkara, this model fits our purposes, to see the wind distribution on a map and to understand the prevalent wind direction.

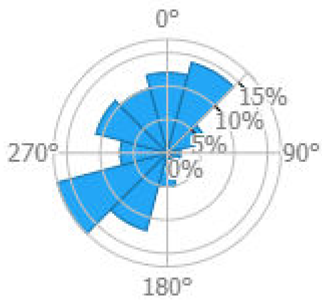

10m avg,ws = 3.73 m/s


50m avg,ws = 4.84 m/s


m/s
10+
0







Wind Frequency Rose

Wind Speed Rose

Note: The wind speed increases with altitude and the winds main direction Northeast and Southwest.

5.2.7 Weather Observations

Unique Solar Radiation Pattern:

- Lefkara's high solar radiation levels during summer, coupled with its elevation could mean clearer skies and less atmospheric interference than lower-lying or coastal areas. This may enhance solar energy efficiency uniquely in this region compared to other parts of Cyprus or the Mediterranean.
- The high levels of solar radiation in Lefkara during the summer, combined with the altitude of the area and the low precipitation rates on the summer months can improve the unique performance of solar energy in the area compared to other areas of Cyprus and/or the Mediterranean.

Localized Wind Patterns:

- The slight increase in wind speed during the summer months could point to local topographical effects such as mountain-valley breezes or thermal winds specific to Lefkara’s geographic setting.

October Transition:

- The noticeable October cooling and slight uptick in precipitation might be more pronounced compared to coastal areas, where the sea moderates temperature and delays the onset of autumn rains.

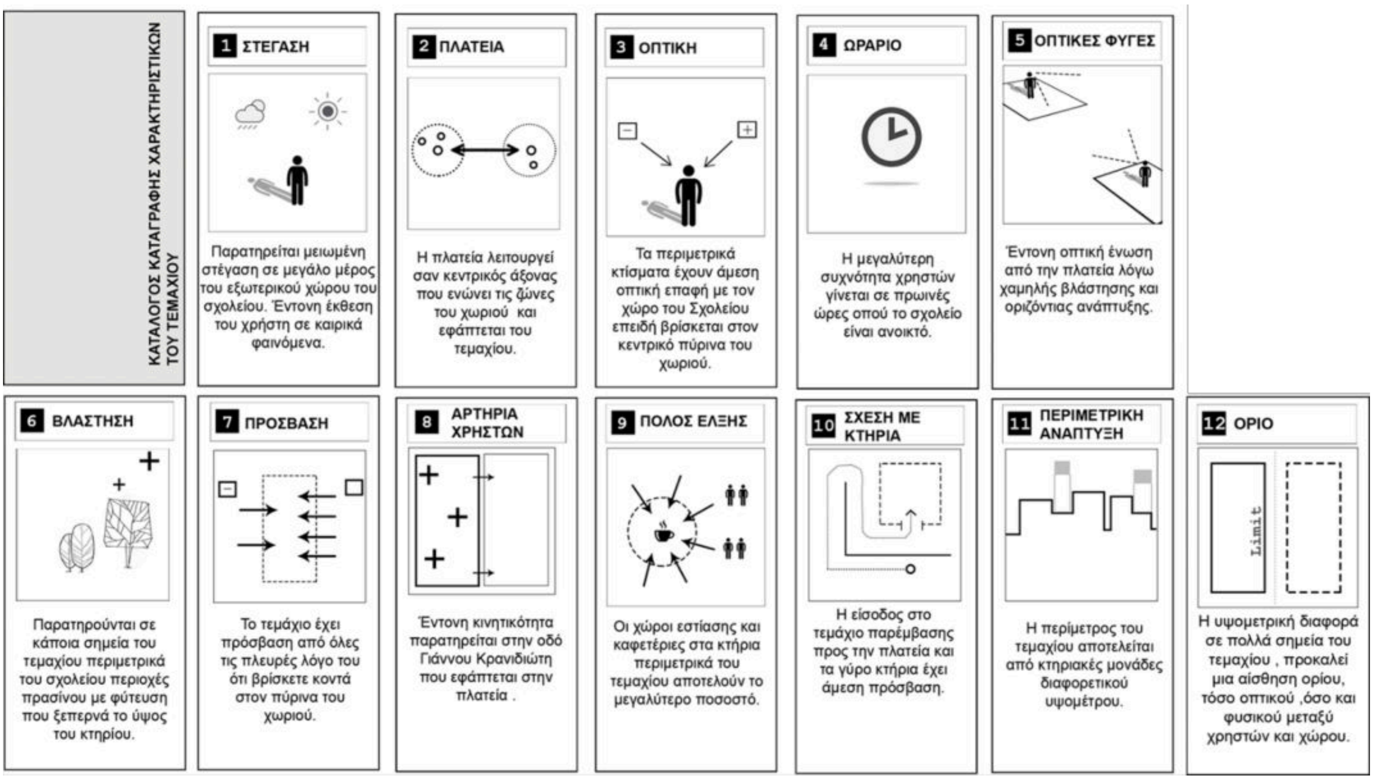
These observations, if consistent across multiple years, could imply that Lefkara’s weather patterns, especially its solar and wind dynamics, offer advantages for renewable energy projects or specific agricultural practices better suited to slightly cooler and windier conditions compared to coastal regions.

6. SITE ANALYSIS

6.1 Site Characteristics Documentation

This particular analysis of the site around the Lefkara Primary School is one of the important sections of the site analysis, which is used to get an idea of what the area is like and make technical recommendations for improvement. The central square is an interface that links the different zones of the room and strengthens the social and practical interaction with the school. Meanwhile, the lack of suitable shelter in the outdoor environment points towards users' need to be kept out of the weather. The visual axes, underpinned by the low vegetation and the horizon, establish a solid sense of relationship to the land. At the same time, the adjacent buildings form a direct visual and functional interface with the site.

Moreover, convenient connectivity from both sides of the complex and high mobility on the main road becomes an interchange point for multiple applications. There are adjacent restaurants and bars, which create a scene of color in the city. The boundaries of the plot, defined by the natural terrain and the variation of the boundary development, give it a great sense of separation and provide possibilities for the emergence of a defined and organized urban form. It is an analysis that can be used to inform the design of interventions in ways that are both empathetic to Lefkara's history and natural context, as well as to transform it for better function and long-term sustainability.



6.2 Land Survey and Parcel Division of Lefkara Primary School

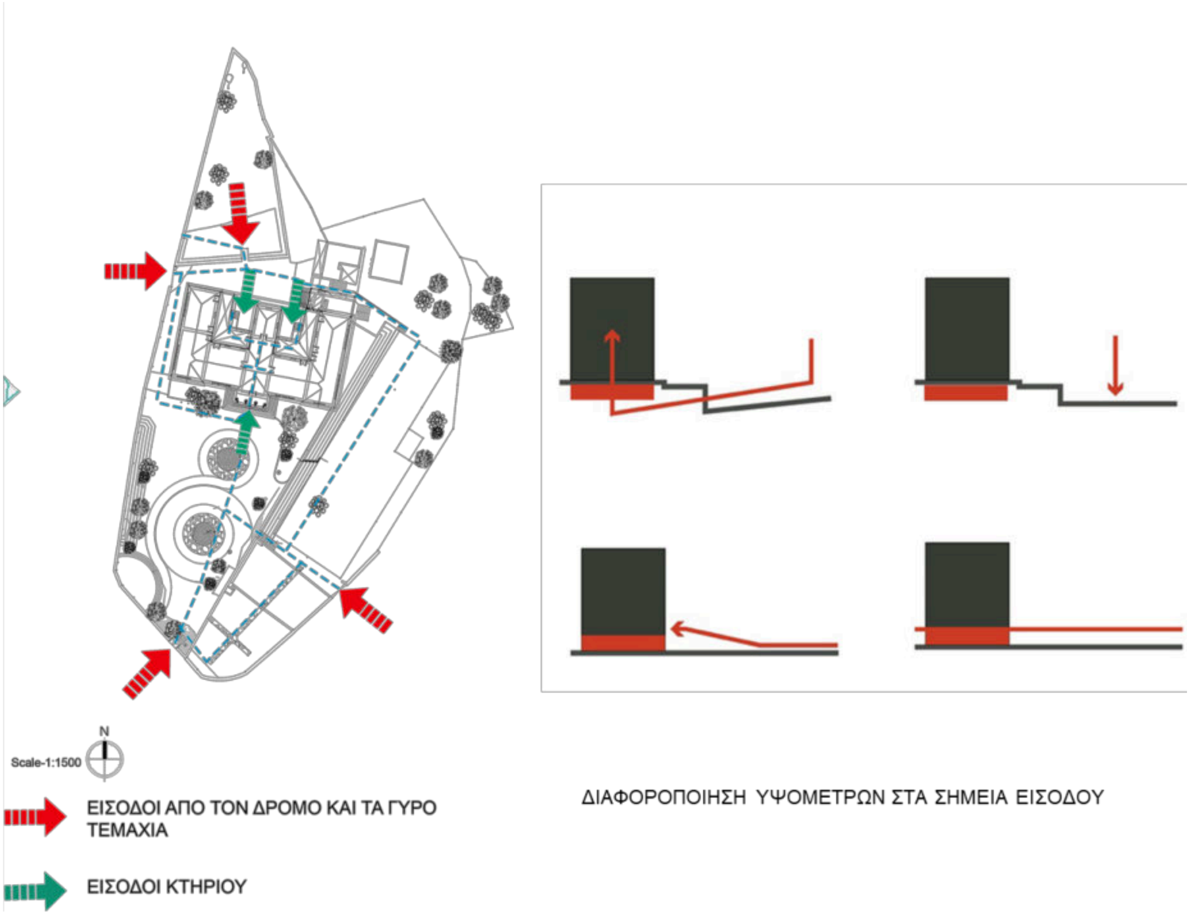
The plots offer a high-level view of the intervention area, capturing the spatial distribution of the Lefkara Primary School and its surrounding area. The first map shows the overland landscape, describing the intervention parcel (red dashed line) and primary (yellow) and secondary road systems (blue). This depiction aims to make sense of the relationship between the school complex and the fabric of Lefkara, a traditional village with strong cultural influences.

The second diagram goes deeper, describing the parcel's functional areas. It features the school's main hall, wing, gymnasium (open courts), schoolyard, and commons. The easy-to-read color-coded display helps identify distinct uses and analyze their relation to the landscape.

The third diagram gives a view from the sky that helps visualize all of the above at scale. This three-part presentation enables the production of a technical report to measure the site's performance and motion and, therefore, guide the implementation of interventions in keeping with Lefkara's historic nature.

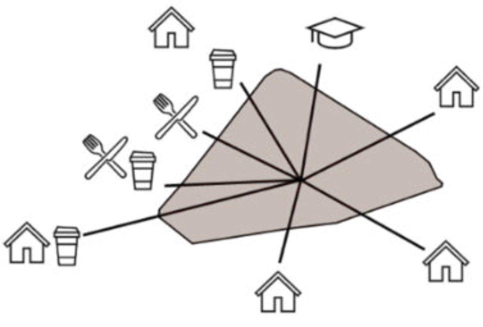
6.3 Analysis of Site Accessibility and Connection to The Surrounding Environment

The first diagram investigates the pathways of access and the relationship of the Lefkara Primary School to its surrounding neighborhood. The first diagram depicts the entrances from the road, the surrounding areas, and the building entrances. Its special focus is on the level design of the entry points to allow easy access for all users. The elevation differences at the entrances are compensated for by ramps and steps that integrate the structure with the local terrain.

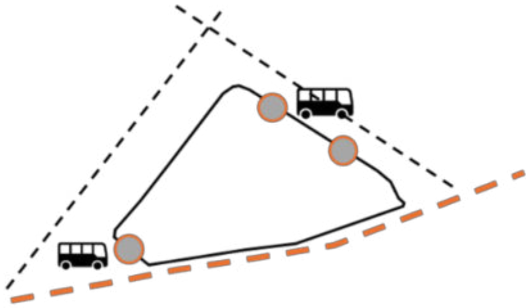


The second diagram also reveals the school's strategic alignment with Lefkara's broader community program. The school stands as a hub with linear links showing that it is within close proximity to homes, restaurants, schools, and recreational areas. This ensures that the school is not siloed but embedded organically in the local social and cultural landscape.

This study supports the project's technical design, which incorporates the school into the natural and urban landscape while encouraging eco-friendly and accessible design.



ΚΑΛΑ ΣΥΝΔΕΔΕΜΕΝΟ ΜΕ ΤΟ ΠΕΡΙΒΑΛΛΟΝ ΠΡΟΓΡΑΜΜΑ



ΚΑΛΑ ΠΡΟΣΒΑΣΙΜΟ ΑΠΟ ΤΡΟΠΟΥΣ ΜΕΤΑΦΟΡΑΣ

6.4 Planting and Shading Analysis for The Lefkara Primary School

These diagrams show plantation and shading at Lefkara Primary School, where trees are arranged along their spatial location and how they interact with the structure. The green outlines mark the boundaries of trees on the plot; the orange marks the trees that shade the building.

In the sectional elevation, we see the tree-building height relation, where trees directly affect the shading of particular facades. Such a study is essential to developing an eco-friendly and efficient school space, with the proper shade to cool and conserve energy while maintaining the visual and architectural integrity of the space.

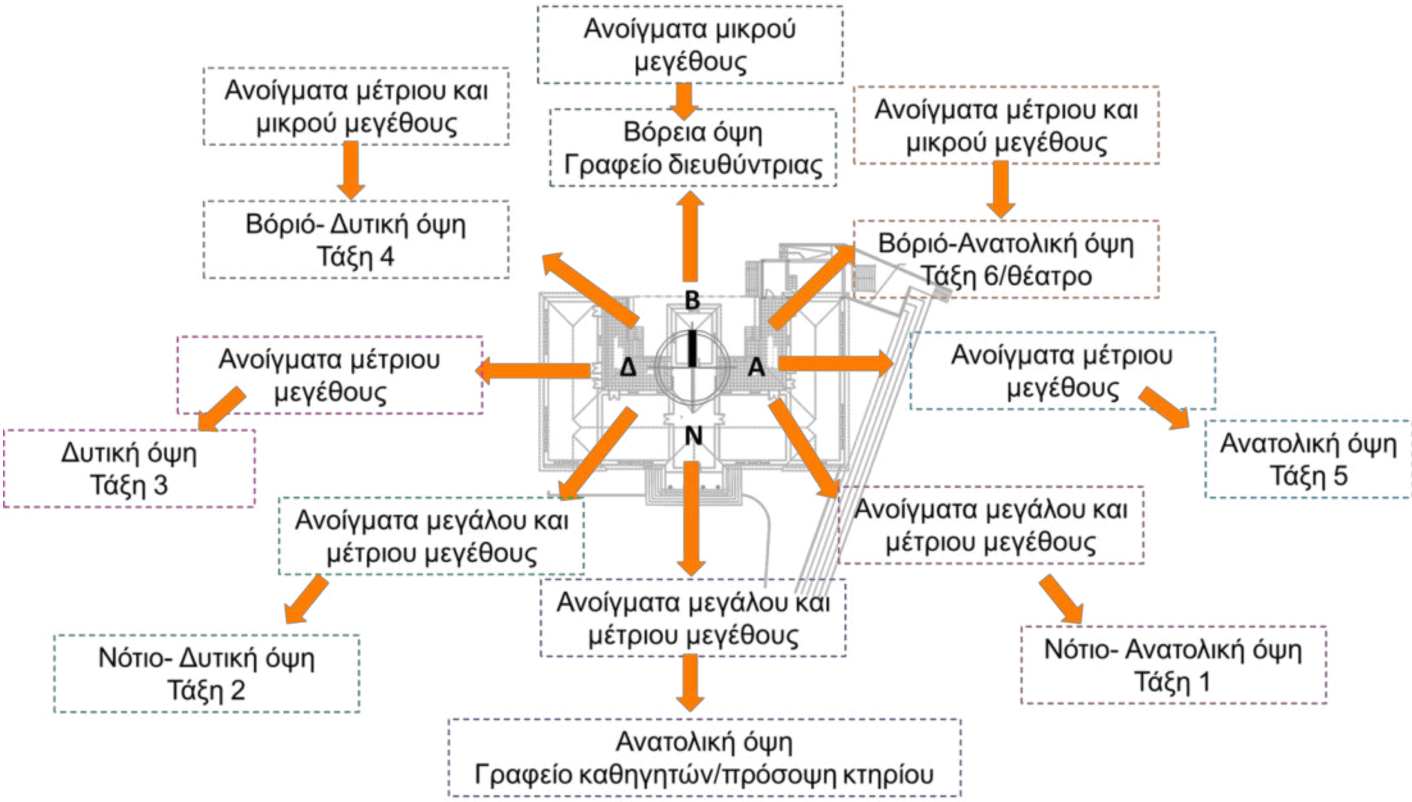
Lefkara is a heritage-rich and tradition-oriented city, so any technical project requires care. Sustainable designs must reconcile respect for the cultural heritage to keep the place as natural as possible.

6.5 Analysis of Functional Space Organization and Orientation of Openings in Lefkara Primary School

This diagram shows how the space is functionally arranged and openings are positioned so that Lefkara Primary School can benefit from natural light and ventilation and create a safe and sustainable learning space. What really matters is how openings (windows and doors) are placed in accordance with each space's function and direction.

The rooms are set up to maximize solar radiation. Classrooms are separated by orientation (north, south, east, west), and different opening sizes and types depend on how they are used for light and ventilation. Small to medium openings are preferred on the north and western façades to reduce overheating. In contrast, larger openings on the south and eastern facades are coupled with shading mechanisms to capture most of the winter sun and reduce summer heat.

This research is crucial for the technical report on the project because it allows us to show how the design assists in sustainability, energy conservation, and functional aspects of the school while also preserving the Lefkara region's character.



6.6 Building User Analysis

A Building Users Analysis of the Lefkara Primary School is integral to the site analysis and technical report. Diagrams show the three main user populations: students, teachers, and school employees.

Students: There are 60 children ages 6-12. This is the biggest user base and covers the whole block. The interpretation considers what can be done to support child learning and play and how it might be safer and more accessible.

Teachers: Ten teachers are 30-60 years old and the primary facilitators of education. Their facilities include classrooms, offices, and break rooms.

School Employees: There are three staff, mostly 40-60 years old women. They do administrative and support work in the school. Offices and support spaces are what they use.

This data is also included in the technical report, and it gives us information to help us create functional spaces for each user group so that Lefkara Primary School becomes more efficient and functional.

ΜΑΘΗΤΕΣ

ΑΡΙΘΜΟΣ ΑΤΟΜΩΝ: 60 ΑΤΟΜΑ
ΗΛΙΚΙΑ: ΑΠΟ 6 ΜΕΧΡΙ 12 ΧΡΟΝΩΝ
ΦΥΛΟ: ΑΝΤΡΕΣ -ΓΥΝΑΙΚΕΣ

ΔΑΣΚΑΛΟΙ

ΑΡΙΘΜΟΣ ΑΤΟΜΩΝ: 10 ΑΤΟΜΑ
ΗΛΙΚΙΑ: ΑΠΟ 30 ΜΕΧΡΙ 60 ΧΡΟΝΩΝ
ΦΥΛΟ: ΑΝΤΡΕΣ -ΓΥΝΑΙΚΕΣ

ΠΡΟΣΩΠΙΚΟ ΣΧΟΛΕΙΟΥ

ΑΡΙΘΜΟΣ ΑΤΟΜΩΝ: 3 ΑΤΟΜΑ
ΗΛΙΚΙΑ: ΑΠΟ 40 ΜΕΧΡΙ 60 ΧΡΟΝΩΝ
ΦΥΛΟ: ΓΥΝΑΙΚΕΣ

7. REGULATIONS FOR LISTED BUILDINGS

As previously mentioned, our building is in the heart of the village, classified under urban planning zone Aa4 (Public Uses, Education, etc.), and is considered a listed building.

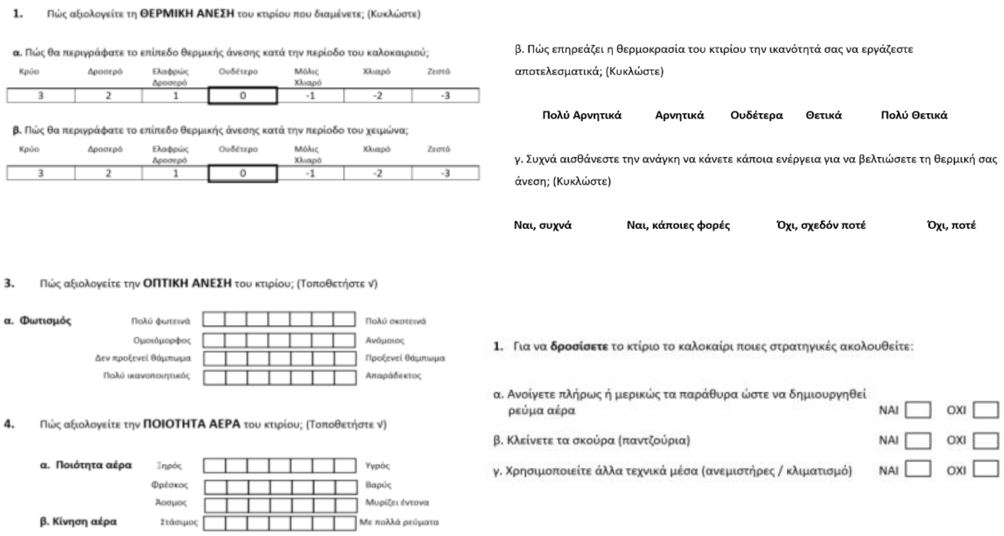
A listed building is a structure or property designated by the relevant authorities as having historical, architectural, cultural, or aesthetic significance and is protected by legislation. This designation aims to preserve and safeguard cultural heritage while highlighting the history and unique character of a place.

Listed buildings are subject to specific regulations that restrict, or guide repair, renovation, or alteration works. Therefore, we face this beautiful challenge of ensuring compliance. Practically, any intervention required for the building under study must receive special approval from the Department of Urban Planning or other relevant authorities.

Based on research we conducted, the main restrictions include the discreet installation of photovoltaic systems to avoid altering the building's appearance, the prohibition of replacing metal window and door frames, and the preservation of the original form and slope of the roof. Additionally, any modifications must respect the authentic form and materials of the structure.

8. QUESTIONNAIRE

As part of this study, a questionnaire was distributed to a total of 7 individuals associated with the Primary School, including teachers and students from Grades 3, 4, and 5. Although the total number of stakeholders was 52, only 7 responses were collected. This low response rate (13.5%) was due to delays in obtaining the necessary approvals from the Ministry of Education and the school principal, which prevented wider distribution of the questionnaire within the intended timeframe. Despite the small sample size, the results provide indicative insights into the prevailing indoor conditions within the school building.



1. Πώς αξιολογείτε τη **ΘΕΡΜΙΚΗ ΑΝΕΣΗ** του κτιρίου που διαμένετε; (Κυκλώστε)

α. Πώς θα περιγράφατε το επίπεδο θερμικής άνεσης κατά την περίοδο του καλοκαιριού;

Κρύο	Δροσερό	Ελαφρώς Δροσερό	Ουδέτερο	Μόλις Χλιαρό	Χλιαρό	Ζεστό
3	2	1	0	-1	-2	-3

β. Πώς θα περιγράφατε το επίπεδο θερμικής άνεσης κατά την περίοδο του χειμώνα;

Κρύο	Δροσερό	Ελαφρώς Δροσερό	Ουδέτερο	Μόλις Χλιαρό	Χλιαρό	Ζεστό
3	2	1	0	-1	-2	-3

β. Πώς επηρεάζει η θερμοκρασία του κτιρίου την ικανότητά σας να εργάζεστε αποτελεσματικά; (Κυκλώστε)

Πολύ Αρνητικά **Αρνητικά** **Ουδέτερα** **Θετικά** **Πολύ Θετικά**

γ. Συχνά αισθάνεστε την ανάγκη να κάνετε κάποια ενέργεια για να βελτιώσετε τη θερμική σας άνεση; (Κυκλώστε)

Ναι, συχνά **Ναι, κάποιες φορές** **Όχι, σχεδόν ποτέ** **Όχι, ποτέ**

3. Πώς αξιολογείτε την **ΟΠΤΙΚΗ ΑΝΕΣΗ** του κτιρίου; (Τοποθετήστε √)

α. Φωτισμός
Πολύ φωτεινά — Πολύ σκοτεινά
Ομοιόμορφος — Ανόμοιος
Δεν προξενεί θάμπωμα — Προξενεί θάμπωμα
Πολύ ικανοποιητικός — Απαράδεκτος

4. Πώς αξιολογείτε την **ΠΟΙΟΤΗΤΑ ΑΕΡΑ** του κτιρίου; (Τοποθετήστε √)

α. Ποιότητα αέρα
Ξηρός — Υγρός
Φρέσκος — Βαρύς
Άοσμος — Μυρίζει έντονα

β. Κίνηση αέρα
Στάσιμος — Με πολλά ρεύματα

1. Για να **δροσίσετε** το κτίριο το καλοκαίρι ποιες στρατηγικές ακολουθείτε:

α. Ανοίγετε πλήρως ή μερικώς τα παράθυρα ώστε να δημιουργηθεί ρεύμα αέρα — ΝΑΙ ☐ ΟΧΙ ☐
β. Κλείνετε τα σκούρα (παντζούρια) — ΝΑΙ ☐ ΟΧΙ ☐
γ. Χρησιμοποιείτε άλλα τεχνικά μέσα (ανεμιστήρες / κλιματισμό) — ΝΑΙ ☐ ΟΧΙ ☐

Results Analysis

The results revealed that the most prominent issue is the insufficient thermal comfort during the winter months, as initially expected. All respondents reported that classrooms are excessively cold in winter, which negatively impacts both comfort and performance during lessons. In contrast, responses for the other seasons (summer, spring, and autumn) were more balanced, with many participants indicating that the temperatures felt either neutral or slightly cool. This suggests that thermal comfort improves during periods with milder weather conditions.

Additionally, it is worth noting that no significant overheating issues were reported during the summer months when the school is in operation. This may be attributed to the local geography, the architectural form of the building, or shading provided by the surrounding environment.

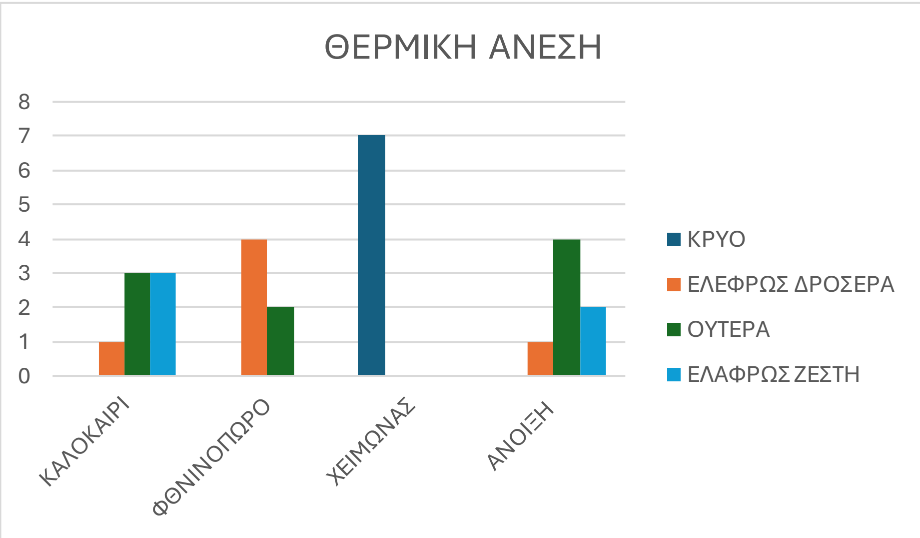
Artificial lighting usage is notably higher during the morning hours (07:00–11:00), especially in winter and autumn. This is likely due to limited natural daylight during early hours, as well as generally cloudy weather and reduced solar radiation in these seasons. As the day progresses, the use of artificial lighting decreases, with summer showing the least demand for artificial lighting, primarily limited to specific rooms such as the teachers’ office.

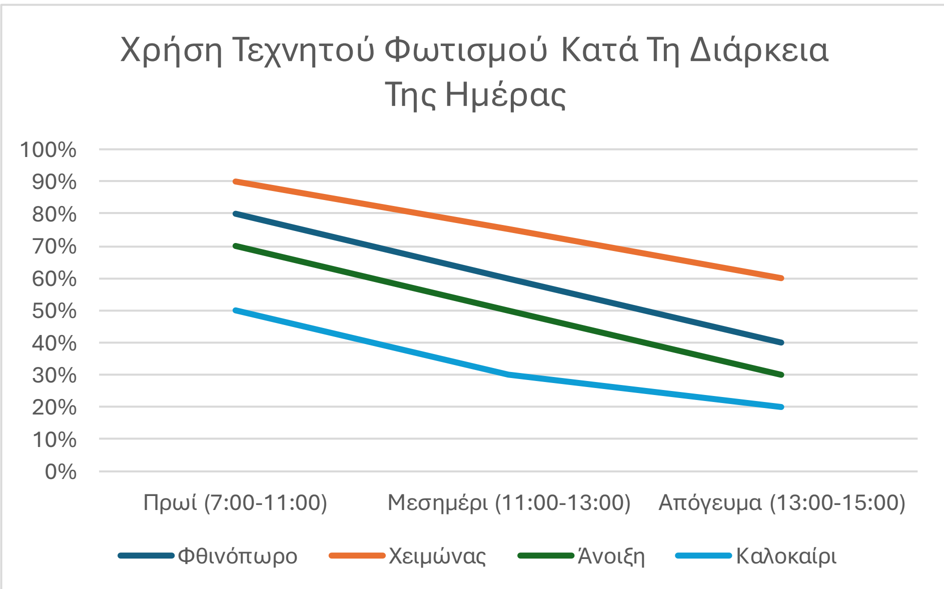
Key Findings

The analysis of the responses highlights two major issues:

- The primary thermal comfort problem occurs during the winter months, indicating the need for improved heating or energy-efficient upgrades to the building envelope.
- Artificial lighting is used most intensively during the early morning hours, especially in winter and autumn, reinforcing the need for enhanced natural daylight access or the implementation of high-efficiency lighting systems.

These findings should be carefully considered in the overall energy retrofit planning of the school premises, aiming to improve indoor environmental quality and achieve greater energy efficiency.





9. MEASUREMENTS

On November 23, 2024, between 10:00 and 10:30 in the morning, we conducted thermal camera measurements both inside and outside the Lefkara Primary School. The measurements were taken on the interior and exterior walls of each room, as well as on the internal and external metal frames of the windows. In the image below (Figure 1), the points where measurements were taken are indicated. Red marks represent the walls, while blue marks indicate the metal frames of the windows.

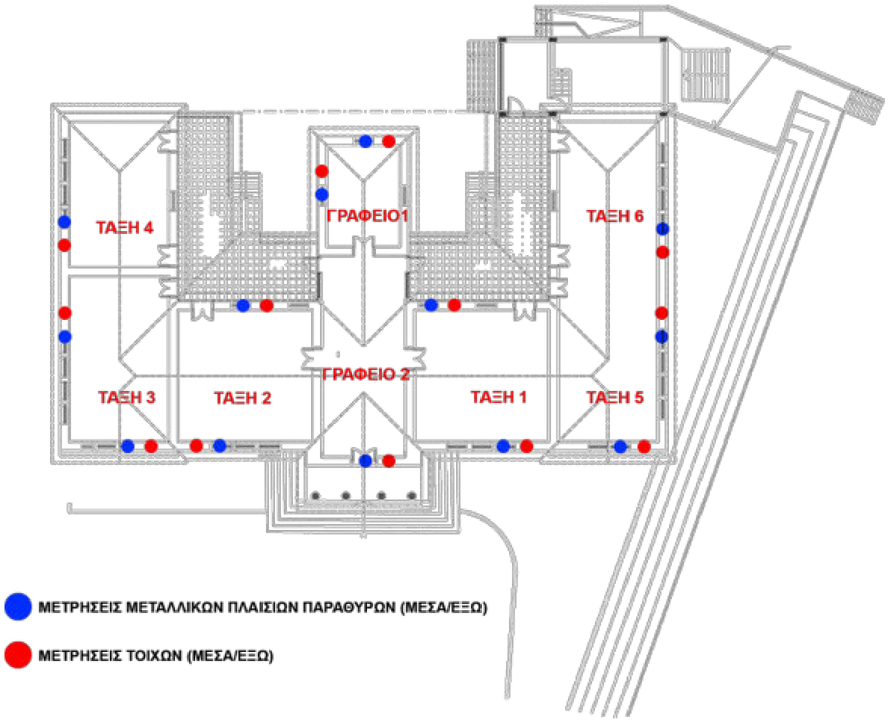
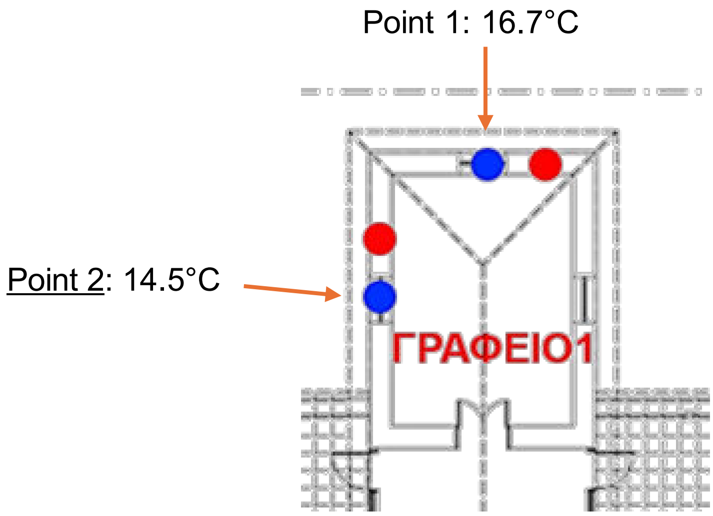


Figure 1: Indication of Measurement Points

ΤΑΞΗΣ	ΕΣΩΤΕΡΙΚΟΣ ΤΟΙΧΟΣ	ΕΣΩΤΕΡΙΚΟ ΜΕΤΑΛΛΙΚΟ ΠΛΑΙΣΙΟ	ΕΞΩΤΕΡΙΚΟΣ ΤΟΙΧΟΣ	ΕΞΩΤΕΡΙΚΟ ΜΕΤΑΛΛΙΚΟ ΠΛΑΙΣΙΟ
ΓΡΑΦΕΙΟ 1	17,1	17	13,1 / 13,1	16,7 / 14,5
ΓΡΑΦΕΙΟ 2	18,8	20,9	18,9	18,3
ΤΑΞΗ 1	18,8	36,3	14,8 / 15,8	18,5 / 25,3
ΤΑΞΗ 2	15,4	31,9	14,8 / 22,2	18,5 / 38,7
ΤΑΞΗ 3	15,7	18,5	16,4 / 22,2	21 / 38,7
ΤΑΞΗ 4	16,1	17,7	16,7	20,7
ΤΑΞΗ 5	19,5	34,3	18,7 / 15,8	29,5 / 23,5
ΤΑΞΗ 6	19,2	40,5	19,1	41,1

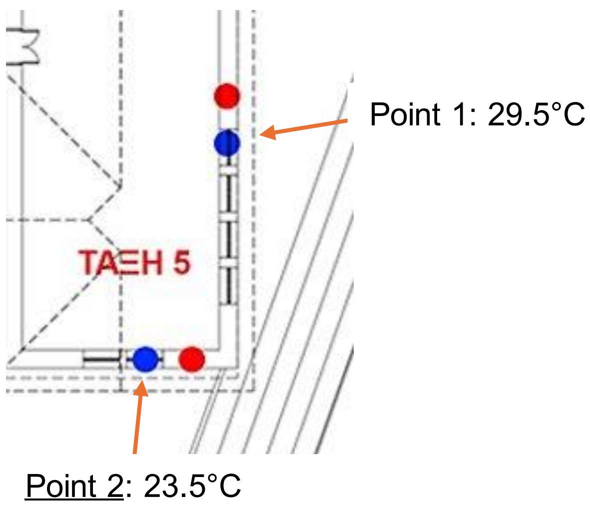
Table 1: Temperature Measurements in °C

It is noteworthy to observe the following results:
In Office 1, we recorded two different temperatures on the external metal frames.



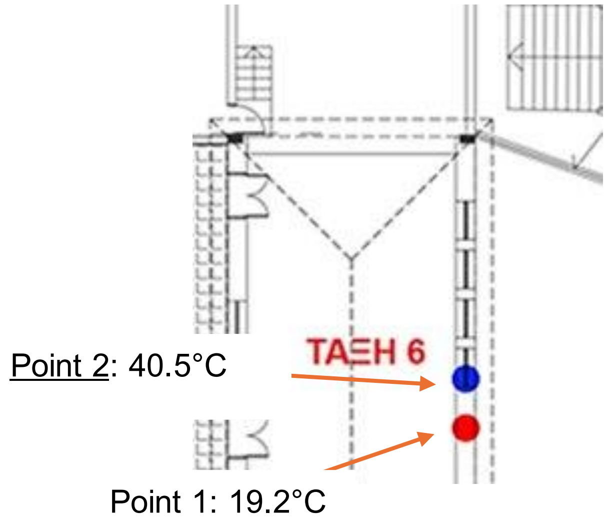
At point 1, we observed a higher temperature (16.7°C) due to prolonged exposure to sunlight. In contrast, point 2 (14.5°C) is shaded by a part of the building.

In Classroom 5, we also observed two different temperatures on the external metal frames.



At Point 1, we observed a higher temperature (29.5°C) because this side of the building is constantly exposed to sunlight. In contrast, Point 2 (23.5°C) is shaded by the vegetation directly in front of it

In Classroom 6, we observed a significant temperature difference between the interior wall and the internal metal frames.



At Point 1, we observed a lower temperature (19.2°C) compared to Point 2 (40.5°C). This side of the room is also constantly exposed to sunlight.

10. BUILDING ANALYSIS

10.1 Building Materials

Due to the fact that the school was built about 100 years ago, finding information and data about the building's materials was quite difficult. However, after discussions with villagers and teachers who were students at the time, we came to some conclusions about the structure of the school's walls. First of all, the school's main structural material is ‘Lefkara’ stone, which is a trademark of the village and its cultural character. The main frame, the columns, the external and internal walls, and the frames of the building are all made of 50 cm thick ‘Lefkara’ stone (hypothesis). There is also a cement coating of approximately 2 cm on the inside and outside surfaces of the building and a 1 cm plaster render on the outside. Following an intervention made to the building at a later stage since its construction, spritz has been applied to all external walls except for the front of the building.

Regarding the roof construction, no information was found about what it contains, only the plans for the school's stage extension, which indicate the exact materials that were installed due to the fact that they are more recent. Furthermore, the plans indicate that the rest of the existing roof had been repaired recently, so the entire roof of the building will be approached based on the building materials that were installed in the school's stage extension. Starting from the outside, the roof consists of French tile, 2" x 1" tile planed timbers, 3mm bituminous waterproofing, 1.2cm MDF plywood, and 3" x 6" planed timbers every 45cm. Under the sloping roof there is a gap-air, and at a distance of approximately 2.8m from the highest point of the roof, there is a 1.2cm thick (60x60cm2) plasterboard ceiling (60x60cm2) which is suspended on a metal horizontal frame.

The openings of the building (windows, doors, and main entrance) are made of steel metal frames and single glazing. Without some study, it is understood that the thermal gains/losses from the openings will be too large due to the single layer of glass and the metal frames. There are two types of windows in the building: large ones that consist of three columns of glass and small ones consisting of two. The dimensions of the windows are shown in the figure 1.

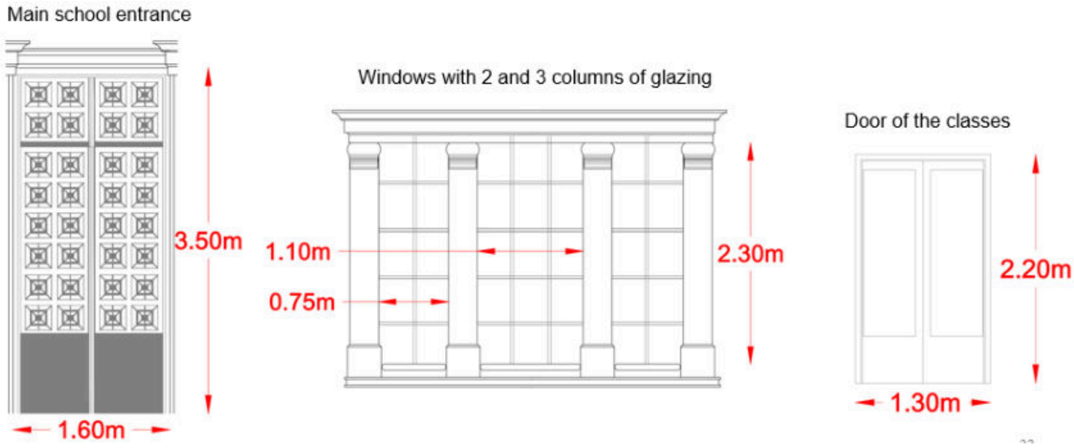


Figure 1: Dimensions of the openings of the building

10.2 Thermal Coefficient U-values

Below are the tables for calculating the thermal coefficient for the various structures of the building. The materials are always shown from the inside to the outside of the building. The tables show the thickness of each material, its characteristic thermal conductivity, and its thermal resistance. Also indicated are the direction of heat flow in the structure and the corresponding internal and external thermal resistances of the air, selected from the Building Thermal Insulation Guide.

The calculations were based on the following equations:

Thermal Resistance: $R = \frac{d}{\lambda} \quad \left[\frac{m^2K}{W}\right]$

Thermal Coefficient: $U = \frac{1}{R_{total}} \quad \left[\frac{W}{m^2K}\right]$

Table 1: External front wall

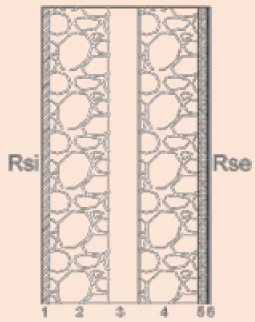
Structure Type		External wall with double stone 20cm (front wall)			
A/A	Name of Material	Thickness of Material d [m]	Thermal Conductivity of Materials λ [W/mK]	Thermal Resistance of Materials R [m²K/W]	Typical Design Detail
1	Coating (cement)	0.020	1.000	0.020	
2	Lefkara Stone	0.200	1.700	0.118	
3	Air gap	0.100	-	0.180	
4	Lefkara Stone	0.200	1.700	0.118	
5	Coating (cement)	0.020	1.000	0.020	
6	Plaster	0.010	0.180	0.056	
Heat Flow		R_{si} [m²K/W]	R_{so} [m²K/W]	Thermal Coefficient [W/m²K]	
Horizontal		0.130	0.040	1.466	
Note		The requirement of U≤0.4 W/m2K as defined in the relevant decree is not met.			

Table 2: External wall

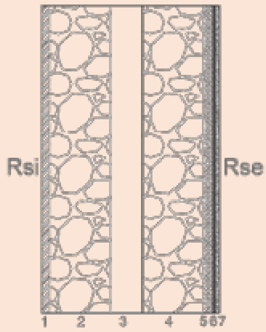
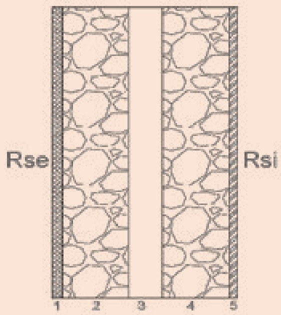
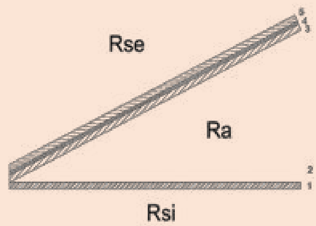
Structure Type		External wall with double stone 20cm and spritz 1cm			
A/A	**Name of Material**	**Thickness of Material** **d** **[m]**	**Thermal Conductivity of Materials** **λ** **[W/mK]**	**Thermal Resistance of Materials** **R** **[m²K/W]**	**Typical Design Detail**
1	Coating (cement)	0.020	1.000	0.020	
2	Lefkara Stone	0.200	1.700	0.118	
3	Air gap	0.100	-	0.180	
4	Lefkara Stone	0.200	1.700	0.118	
5	Coating (cement)	0.020	1.000	0.020	
6	Plaster	0.010	0.180	0.056	
7	Spritz	0.010	1.200	0.008	
Heat Flow		**R_{si}** **[m²K/W]**	**R_{so}** **[m²K/W]**	**Thermal Coefficient** **[W/m²K]**	
Horizontal		0.130	0.040	1.449	
Note		The requirement of U≤0.4 W/m2K as defined in the relevant decree is not met.			

Table 3: Internal wall

Structure type		Internal wall with double stone 20cm			
A/A	**Name of Material**	**Thickness of Material** **d** **[m]**	**Thermal Conductivity of Materials** **λ** **[W/mK]**	**Thermal Resistance of Materials** **R** **[m²K/W]**	**Typical Design Detail**
1	Coating (cement)	0.025	1.000	0.025	
2	Lefkara Stone	0.200	1.700	0.118	
3	Air gap	0.100	-	0.180	
4	Lefkara Stone	0.200	1.700	0.118	
5	Coating (cement)	0.025	1.000	0.025	
Heat Flow		**R_{si}** **[m²K/W]**	**R_{so}** **[m²K/W]**	**Thermal Coefficient** **[W/m²K]**	
Horizontal		0.130	0.130	1.377	

The results of the thermal coefficients for external walls are quite close in both cases (~1.7 $\frac{W}{m^2K}$), but do not satisfy the relevant decree requiring U ≤ 0.4 $\frac{W}{m^2K}$). Thus, some interventions should be made to reduce the coefficient (e.g. the installation of thermal insulation). As far as the internal walls are concerned, there is no limit to the thermal transmittance coefficient.

Table 4: Sloping roof with air gap and plasterboard ceiling

Structure type		**Sloping roof with air gap and plasterboard ceiling**			
A/A	**Name of Material**	**Thickness of Material** **d** **[m]**	**Thermal Conductivity of Materials** **λ** **[W/mK]**	**Thermal Resistance of Materials** **R** **[m²K/W]**	**Typical Design Detail**
1	Plasterboard	0.012	0.210	0.057	
2	Thermal resistance of air gap	-	-	0.300	
3	Plywood MDF	0.012	0.070	0.171	
4	Bituminous Waterproofing	0.003	0.230	0.013	
5	French Tile	0.020	1.000	0.020	
Heat Flow		**R_{si}** **[m²K/W]**	**R_{so}** **[m²K/W]**	**Thermal Coefficient** **[W/m²K]**	
Vertically - upwards		0.10	0.04	1.425	

The sloping roof of the school has a slope of less than 30°, so based on the thermal insulation guide, it is considered horizontal, and the heat flow is vertical upwards. From the results, it can be seen that the requirement U ≤ 0.4 $\frac{W}{m^2K}$ of the relevant ordinance is not met. So, some changes should be made to the school roof to improve the thermal coefficient.

Table 5: Thermal coefficient for openings

Structure Type	Windows - Doors		
Structure	**Frame (Steel)**	**Glazing (Single)**	**Total Coefficient**
Thermal Coefficient U [W/m²K]	Uf = 7.0	Ug = 5.6	U = 6.1
Note	Based on Table 6.13 of the "Building Insulation Guide"		

The thermal coefficient of openings refers to all windows and doors in the building, because their characteristics are the same, since all doors include glass in their construction. The above data have been selected from the thermal insulation guide.

Figure 2: Window with 3 columns of glazing and main entrance

From Table 6.6 of the "Building Insulation Guide", due to the fact that the building is in contact with the land and the land type is not known, λ=2,0 $\frac{W}{mK}$ and p_c= 2,0*10^3 $\frac{W}{mK}$.

According to calculate the U-value of the floor the above equations were used:

- $B' = \frac{A}{0.5*P}$, where the A = 1174.5m^2 is the area of the floor and P = 171.6m is the perimeter of the building. So, B' = 13.69m^2
- $dt = w + \lambda(R_{si} + R_f + R_{se})$, *where* the w = 0.55m (the thickness of the wall) and R_{si} = 0.17 $\frac{m^2K}{W}$, R_f = 0 (no insulation) and R_{se} = 0.04 $\frac{m^2K}{W}$, the thermal resistance of the inner surface, of the insulation and of the outer surface*. So, dt = 0.97m.*
- Cause dt < B', the U-value is equal to*:* $U_o = \frac{2\lambda}{\pi*B'+dt}\ln\left(\frac{\pi*B'}{dt}+1\right) = 0.347\ \frac{W}{m^2K}$

10.3 Mechanical and Electrical Equipment

For heating the interior of the school, central heating is used with an oil boiler located in the engine room. For cooling, wall-mounted fans are used in each room. Also, for the lighting of the school, old-style fluorescent ceiling luminaires are used. Each classroom in the school contains approximately two fans, two radiators, and 8-10 fluorescent fixtures, depending on the room. The electrical drawings show specifically in each classroom how many are contained (Figure). As for the large main room (teachers' office), it contains two fans, two radiators, and 12 fluorescent luminaires. Also in the principal's office, there is a split unit installed along with a radiator and 6 fluorescent luminaires.

Basic Equipment Specifications

Fluorescent ceiling light (old type):

It consists of 4 fluorescent lamps of 18W each, so each luminaire has a power of 72W.

Wall-mounted fan:

It has an operating power of 55W.

Split unit (AC):

It's only in the director's office and has an output of 12000btu.

Radiator:

Each radiator has dimensions of 2.00m x 0.60m x 0.10m. It is of double type, i.e. it contains two columns and has a thermal power of 3440W.

Oil boiler:

The boiler has a thermal input of about 245.30kW and delivers a thermal output of 222.10kW. The figure 3 shows the other characteristics of the boiler.

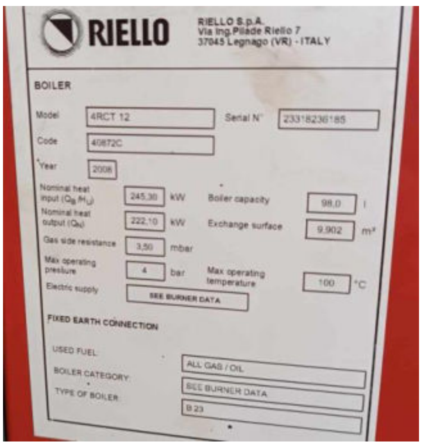


Figure 3: Specifications of the boiler

10.4 Electrical plans

Below in figure 4 are the electrical drawings of the school, which show the various electrical connections between the electronic components. Also shown are the lighting fixtures in each room and some extra spotlights in the school stage.

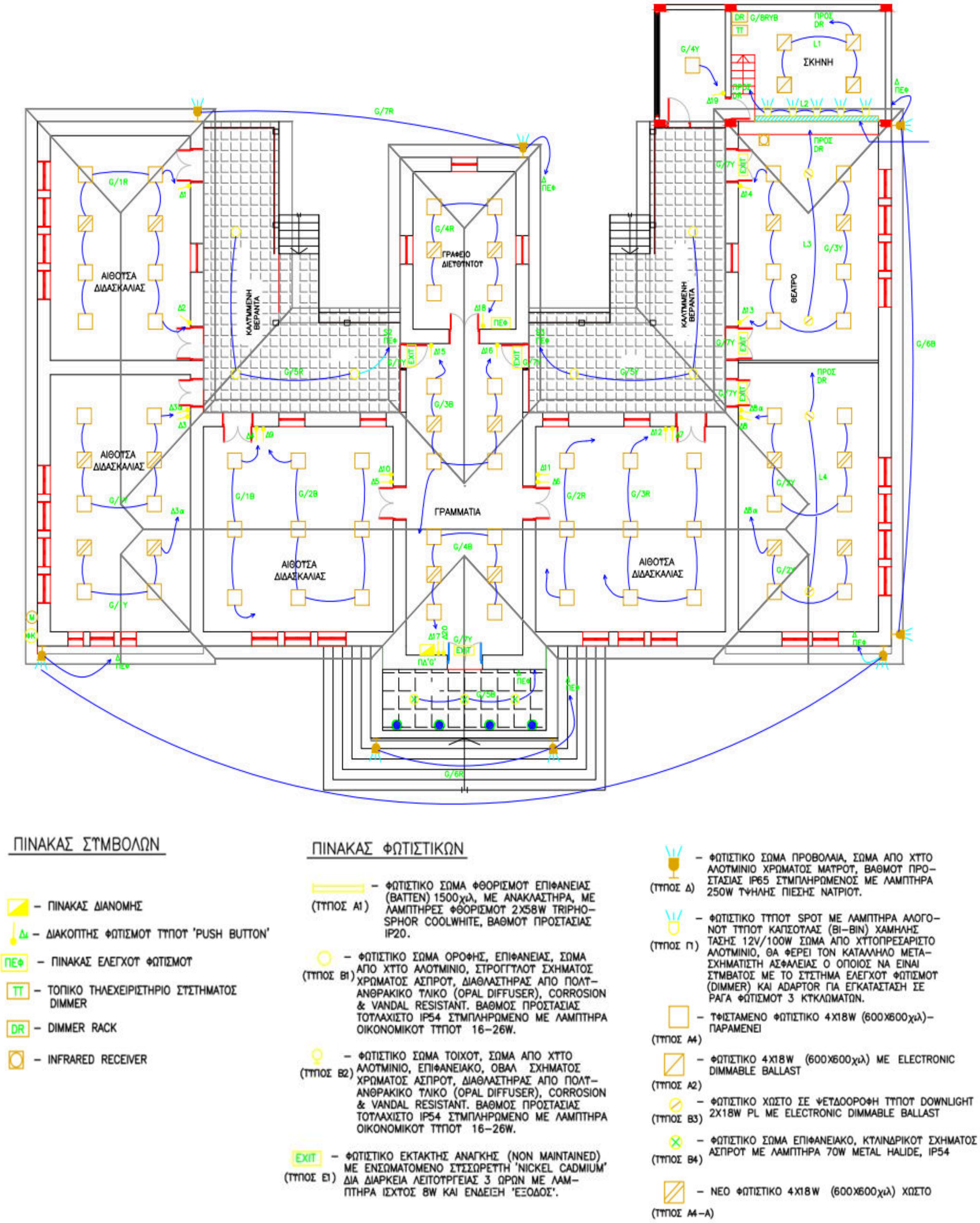
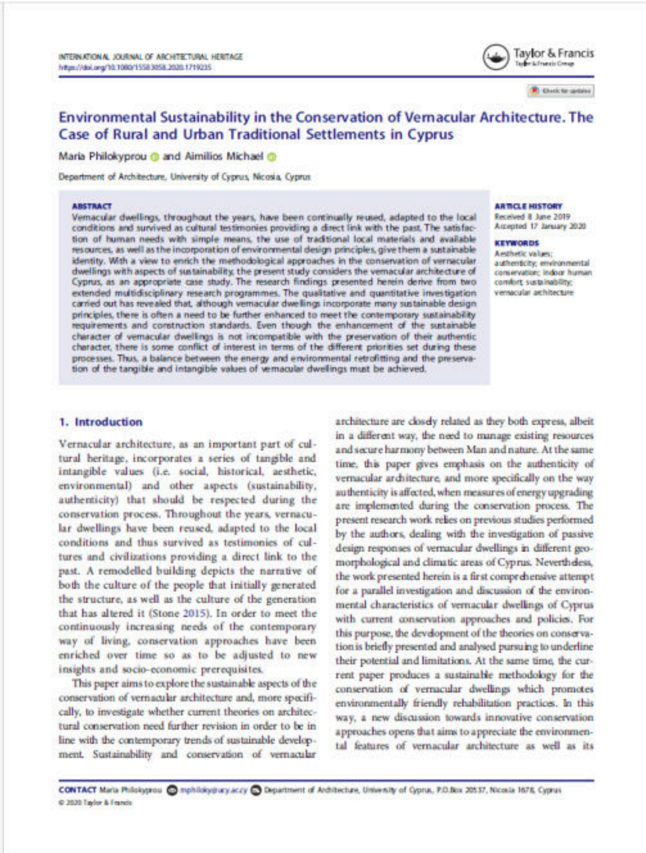


Figure 4: Ηλεκτρολογικά σχέδια του σχολείου

11. LEFKARA, SOLUTIONS FOR ENERGY UPGRADING / MAIN PROBLEMS

The building under consideration, Lefkara Primary School, built in 1920 and classified as a listed building, presents significant challenges in terms of its energy upgrade, mainly due to the restrictions imposed by the relevant legislation for the protection of architectural heritage. These restrictions often conflict with modern energy efficiency requirements, making it difficult to implement extensive interventions in the building envelope and systems. It is therefore important to take into account Study Guides for corresponding cases in order to properly document the problems and solutions that can be identified.



INTERNATIONAL JOURNAL OF ARCHITECTURAL HERITAGE
https://doi.org/10.1080/15583058.2020.1719235

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Environmental Sustainability in the Conservation of Vernacular Architecture. The Case of Rural and Urban Traditional Settlements in Cyprus

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ABSTRACT

Vernacular dwellings, throughout the years, have been continually reused, adapted to the local conditions and survived as cultural testimonies providing a direct link with the past. The satisfaction of human needs with simple means, the use of traditional local materials and available resources, as well as the incorporation of environmental design principles, give them a sustainable identity. With a view to enrich the methodological approaches in the conservation of vernacular dwellings with aspects of sustainability, the present study considers the vernacular architecture of Cyprus, as an appropriate case study. The research findings presented herein derive from two extended multidisciplinary research programmes. The qualitative and quantitative investigation carried out has revealed that, although vernacular dwellings incorporate many sustainable design principles, there is often a need to be further enhanced to meet the contemporary sustainability requirements and construction standards. Even though the enhancement of the sustainable character of vernacular dwellings is not incompatible with the preservation of their authentic character, there is some conflict of interest in terms of the different priorities set during these processes. Thus, a balance between the energy and environmental retrofitting and the preservation of the tangible and intangible values of vernacular dwellings must be achieved.

ARTICLE HISTORY
Received 8 June 2019
Accepted 17 January 2020

KEYWORDS
Aesthetic values; authenticity; environmental conservation; indoor human comfort; sustainability; vernacular architecture

1. Introduction

Vernacular architecture, as an important part of cultural heritage, incorporates a series of tangible and intangible values (i.e. social, historical, aesthetic, environmental) and other aspects (sustainability, authenticity) that should be respected during the conservation process. Throughout the years, vernacular dwellings have been reused, adapted to the local conditions and thus survived as testimonies of cultures and civilizations providing a direct link to the past. A remodelled building depicts the narrative of both the culture of the people that initially generated the structure, as well as the culture of the generation that has altered it (Stone 2015). In order to meet the continuously increasing needs of the contemporary way of living, conservation approaches have been enriched over time so as to be adjusted to new insights and socio-economic prerequisites.

This paper aims to explore the sustainable aspects of the conservation of vernacular architecture and, more specifically, to investigate whether current theories on architectural conservation need further revision in order to be in line with the contemporary trends of sustainable development. Sustainability and conservation of vernacular architecture are closely related as they both express, albeit in a different way, the need to manage existing resources and secure harmony between Man and nature. At the same time, this paper gives emphasis on the authenticity of vernacular architecture, and more specifically on the way authenticity is affected, when measures of energy upgrading are implemented during the conservation process. The present research work relies on previous studies performed by the authors, dealing with the investigation of passive design responses of vernacular dwellings in different geomorphological and climatic areas of Cyprus. Nevertheless, the work presented herein is a first comprehensive attempt for a parallel investigation and discussion of the environmental characteristics of vernacular dwellings of Cyprus with current conservation approaches and policies. For this purpose, the development of the theories on conservation is briefly presented and analysed pursuing to underline their potential and limitations. At the same time, the current paper produces a sustainable methodology for the conservation of vernacular dwellings which promotes environmentally friendly rehabilitation practices. In this way, a new discussion towards innovative conservation approaches opens that aims to appreciate the environmental features of vernacular architecture as well as its

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11.1 Poor Thermal Performance of Windows

Existing windows, with traditional glazing, show significant heat loss, increasing the need for heating in winter and cooling in summer. According to "Environmental Sustainability in Conservation", old frames are among the weakest points of the shell in terms of thermal insulation. The manual for the energy upgrading of architectural heritage buildings points out that improving airtightness and replacing or reinforcing glazing with modern, energy-efficient materials is a basic requirement for compliance with minimum energy performance standards, without altering the character of the building.

(Environmental Sustainability in Conservation.pdf, σελ. 2), (egcheiridio… Copy.pdf, p. 56).

11.2 Thermal inefficiency of ceiling (false ceiling)

The school roof, as is often the case in old buildings, lacks adequate thermal insulation. The absence or insufficient insulation leads to significant heat losses, especially during the winter months, while in the summer it allows the interior spaces to overheat. The manuals suggest insulation techniques that respect the historicity of the building, such as adding insulating layers above the existing ceiling or using reversible solutions, in order to preserve the authenticity of the interior spaces.

(Environmental Sustainability in Conservation.pdf, σελ. 3). (egcheiridio… Copy.pdf, σελ. 60).

12. DESIGN BUILDER

For the energy analysis of the building, it was decided to use the Design Builder program, which is a building energy simulation software. Design Builder is based on the computational tool EnergyPlus, which is one of the best-known tools for energy simulation. Furthermore, it estimates the energy performance based on real climate data, where in this case the data of the airport in Larnaca was used. More specifically, it analyses the thermal behaviour of buildings by calculating heat losses and gains while supporting studies for the installation of thermal insulation. It also examines the natural and artificial lighting performance of the building, evaluates different HVAC (heating, ventilation, and air conditioning) systems, and calculates the carbon footprint of a building.

12.1 Design of the Model

Initially, some basic information was entered, such as the computational tool that will be used for the analysis - EnergyPlus and the location from which the meteorological data will be used - Larnaca Airport (Figure 5).

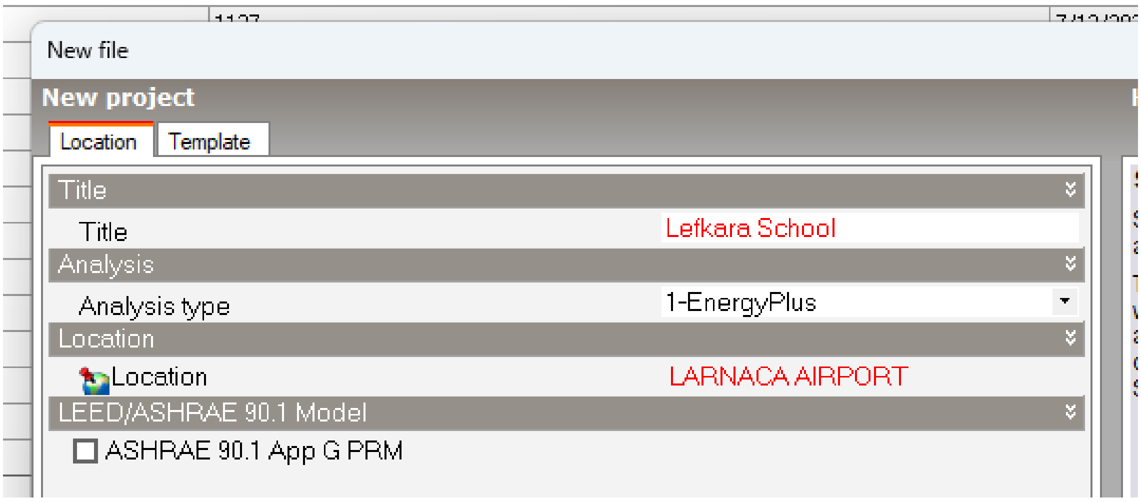


Figure 5: Insert Analysis type and location

Then, the floor plan of the building was imported in two-dimensional form to make it easier to design the building in the program. Next, the main part of the building was drawn in 3D, divided into zones and some openings were placed. The building is shown below in Design Builder but note that it is not the final result since the project is still being worked on.

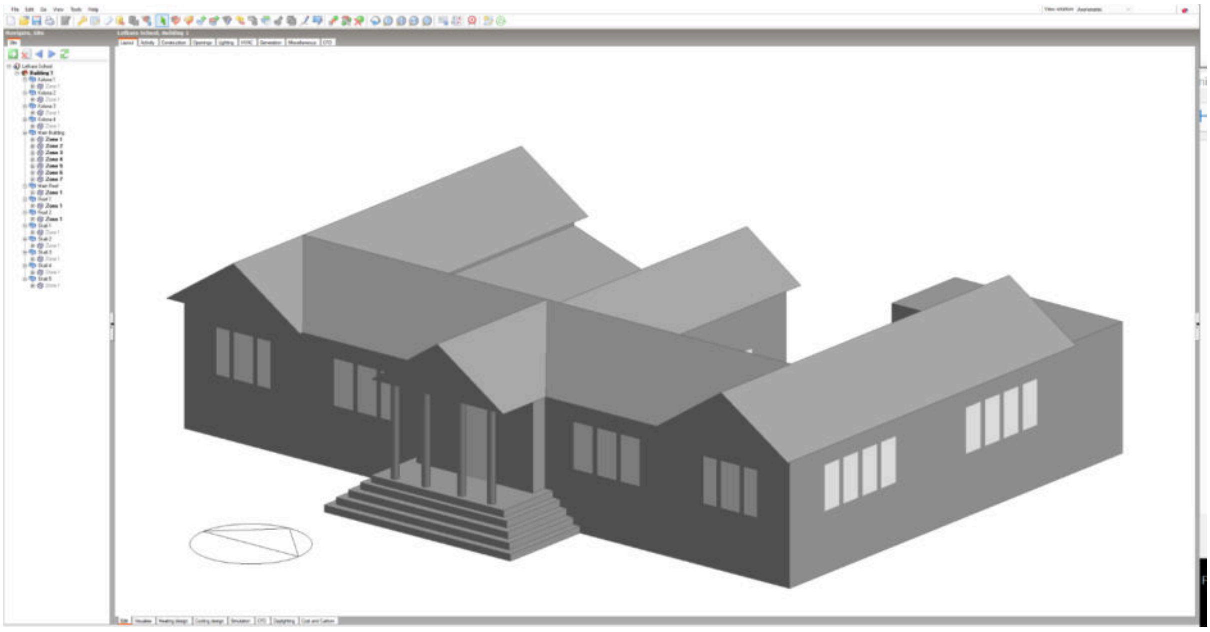


Figure 8: Isometric view of the building

Figure 7: Front view of the building

Figure 6: Back view of the building

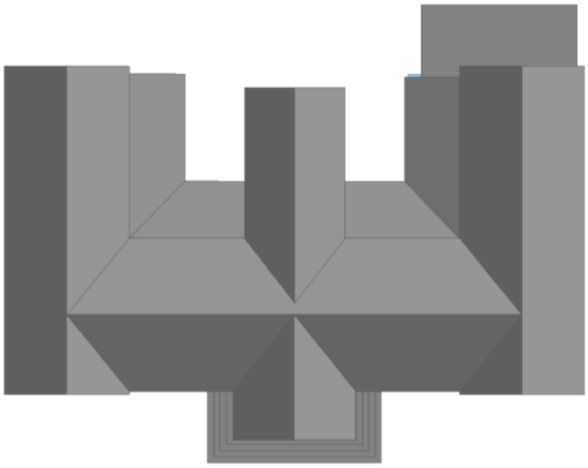


Figure 9: Top view of the building

Figure 10: East – Right view of the building

Figure 11: West – Left view of the building

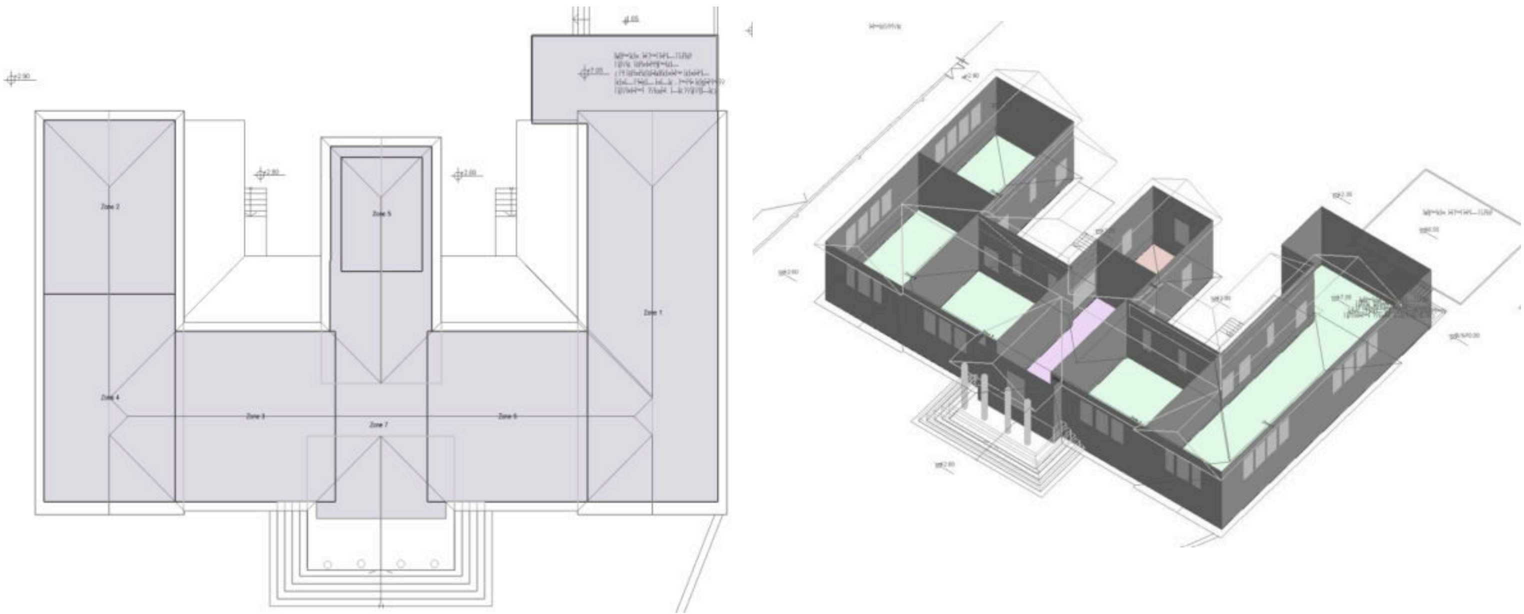
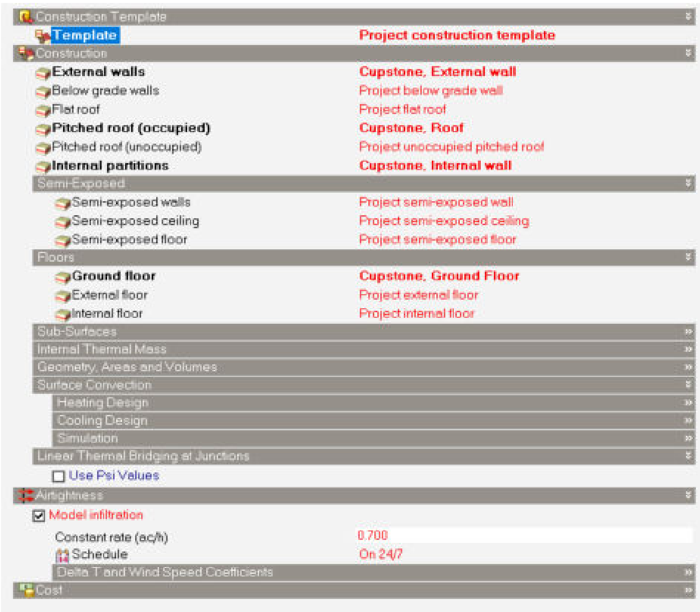
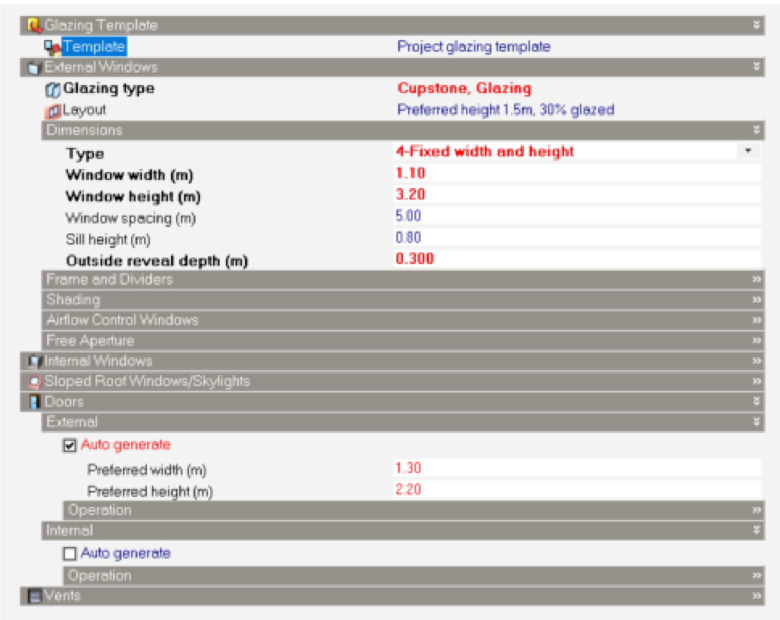


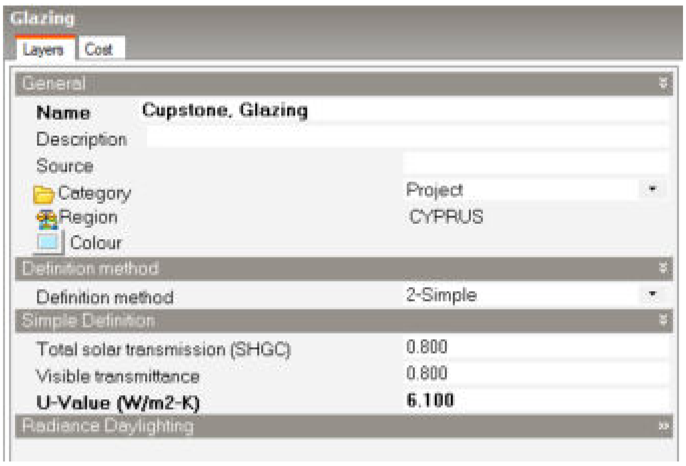
Figure 12: Separation of the building into zones

12.2 Import of construction elements

After the geometry of the building was completed, the structural elements were introduced. All the masonry layers have been created based on the u-value tables calculated above, placing each structural element layer one by one individually. In particular, the external walls, internal partitions, pitched roof, ground floor and openings have been imported. The dimensions of the windows and shutters were recorded for the openings. The dimensions of the windows and the outside reveal depth were entered for the openings.

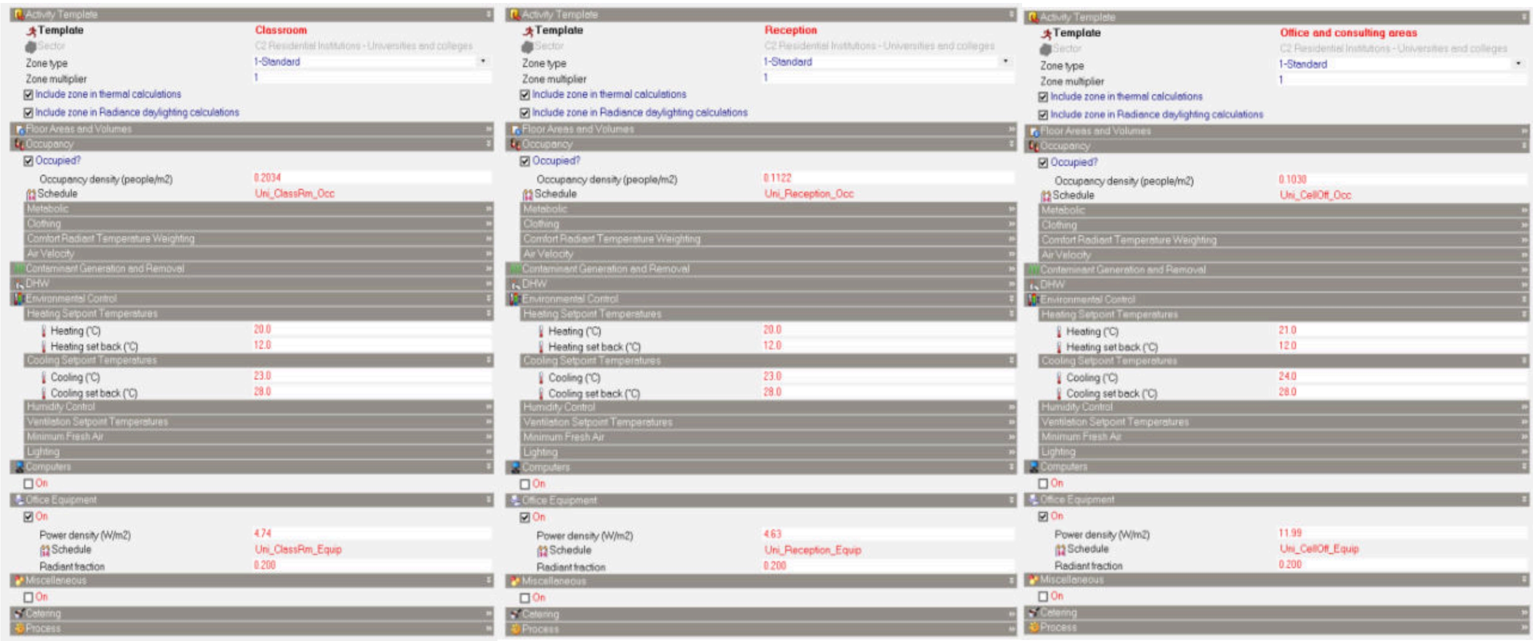






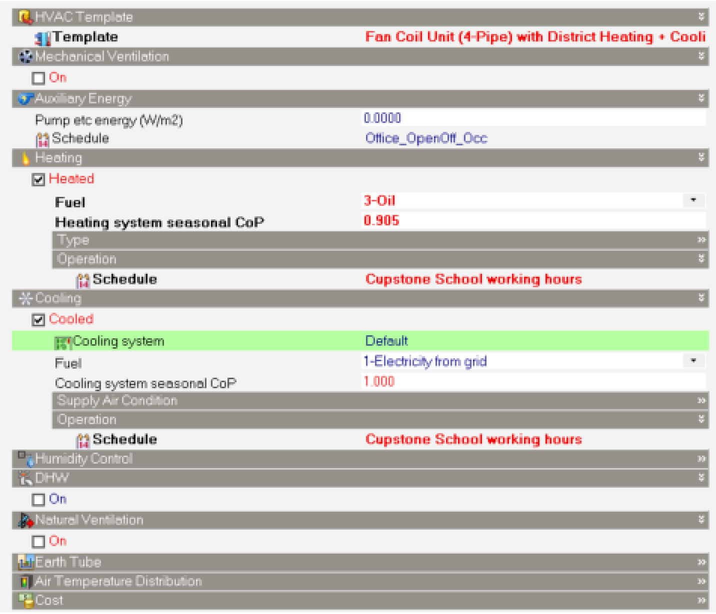
12.3 Zones Activity

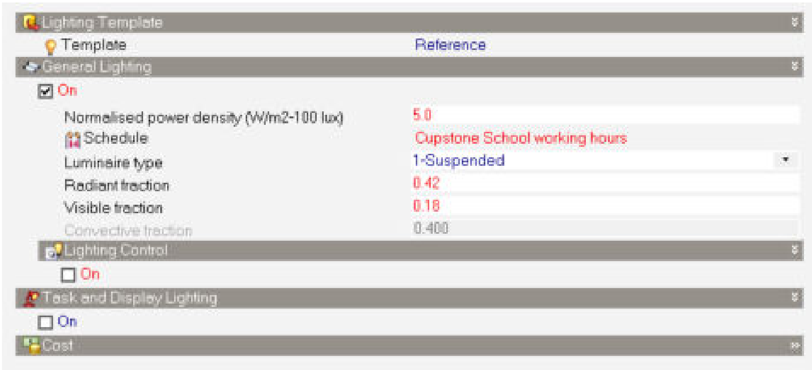
Next, an input was given on the activity of each zone of the building. The building is divided into 7 zones, 5 of which are the classrooms of the school, one is the large teachers' office (reception of the school) and the other is the school principal's office. The activities used were existing software data, where they had heating setpoint temperature 20 °C and cooling setpoint temperature 23-24 °C.

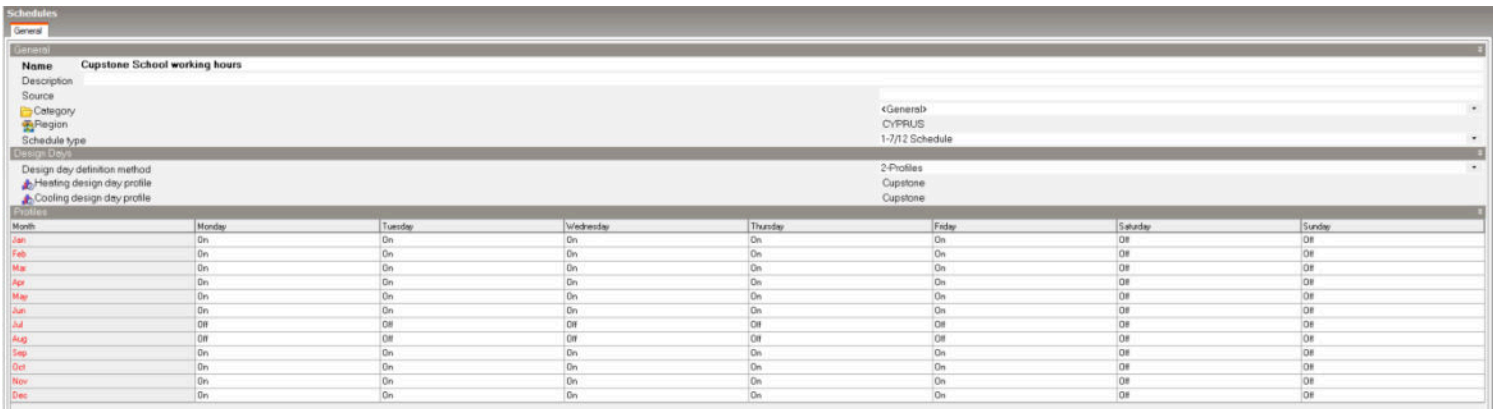


12.4 HVAC Systems and Lightning Equipment

Also, for the HVAC systems of the building, an oil boiler with an efficiency of 0.905 was installed and is used for heating the school. Apart from that, for the cooling of the school there are wall fans that need electricity from the grid. For the lighting equipment of the school was used a normalised power density of 5,0 $\frac{W}{m^2}$ (500 lux), radiant fraction of 0,42 and a visible fraction of 0,18. Continuously, a schedule was created about the working hours of the school, that means also the hours that these systems are activated. The school hours are from 7 a.m. until 1 p.m. every day apart from weekends and for the months of July and August that the school is closed.







12.5 Validation

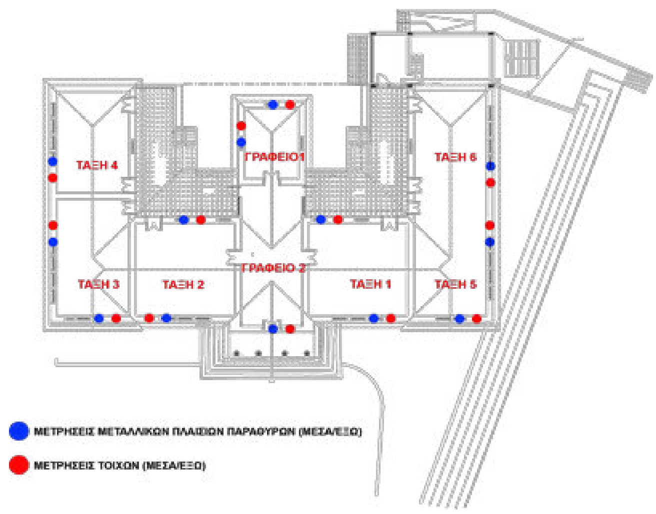
As part of the validation of the thermal model developed in the Design Builder software, the simulation temperatures were compared with the temperature measurements taken with a thermocamera on 23/11/2024 at 9:00 am. The measurements were taken on internal and external walls of different rooms (offices and classrooms) and compared with the simulation results. In general, the model showed good agreement with the actual measurements, confirming its reliability. The deviation between measured and simulated wall temperatures ranges from 2% to 26%. Some discrepancies were mainly recorded in Classrooms 1, 2, 3 and Office 1, which are located at the front of the building. This may be attributed to external factors such as tree shading, which were not included in the geometry or model parameters. Therefore, the model is considered adequate for studying the thermal conditions of the building, with room for improvement in areas where they are strongly influenced by external conditions.

Measurements - Thermocamera

ΑΙΘΟΥΣΕΣ	ΕΣΩΤΕΡΙΚΟΣ ΤΟΙΧΟΣ [°C]	ΕΞΩΤΕΡΙΚΟΣ ΤΟΙΧΟΣ [°C]
ΓΡΑΦΕΙΟ 1	17,1	13,1 / 13,1
ΓΡΑΦΕΙΟ 2	18,8	18,9
ΤΑΞΗ 1	18,8	14,8 / 15,8
ΤΑΞΗ 2	15,4	14,8 / 22,2
ΤΑΞΗ 3	15,7	16,4 / 22,2
ΤΑΞΗ 4	16,1	16,7
ΤΑΞΗ 5	19,5	18,7 / 15,8
ΤΑΞΗ 6	19,2	19,1

Simulation – Design Builder

ΑΙΘΟΥΣΕΣ	ΕΣΩΤΕΡΙΚΟΣ ΤΟΙΧΟΣ [°C]	ΕΞΩΤΕΡΙΚΟΣ ΤΟΙΧΟΣ [°C]
ΓΡΑΦΕΙΟ 1	18,1	17,8
ΓΡΑΦΕΙΟ 2	19,7	18,5
ΤΑΞΗ 1	19,1	18,7
ΤΑΞΗ 2	18,9	19,2
ΤΑΞΗ 3	19,0	19,3
ΤΑΞΗ 4	17,2	17,3
ΤΑΞΗ 5	18,6	18,3
ΤΑΞΗ 6	18,7	18,5



12.6 Simulations

Daylight Factor

During the design of the building, a simulation was carried out to simulate the Daylight Factor in the interior of the building. It is observed that the central and southern rooms with large openings (windows) have the highest illumination values (shades of red and yellow), indicating sufficient access to natural light.

The assessment was carried out in accordance with the guidelines of the following standards:

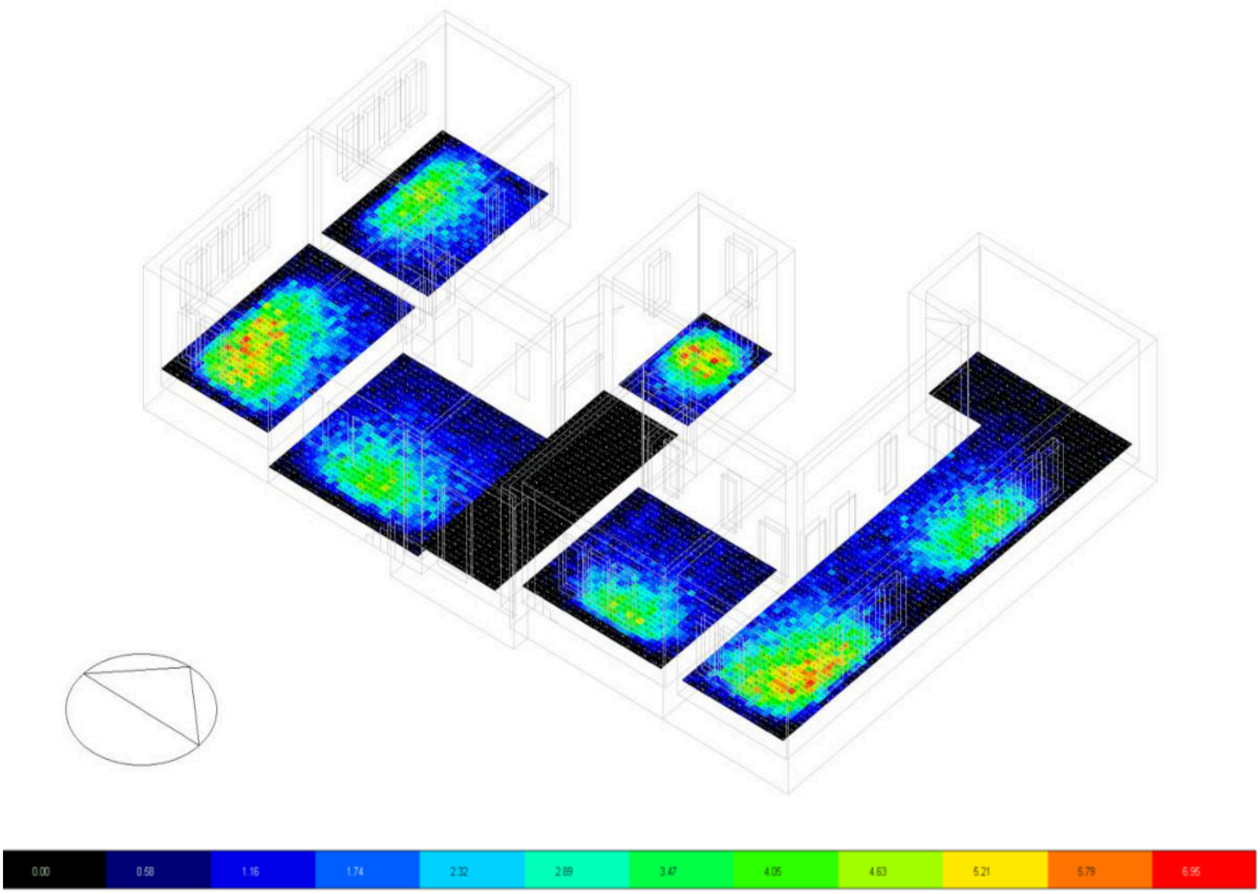
- **EN 17037:2018 – Daylight in Buildings**, which provides recommendations for daylight provision, view out, glare, and sunlight in indoor environments.
- **ISO 15469:2004 / CIE S 011/E:2003 – Spatial distribution of daylight – Luminance distributions of various reference skies**, which defines standardized sky conditions used in daylight simulations.

The simulation yielded the following results:

- South-facing and central areas of the building demonstrate the highest daylight factor values (highlighted in red/yellow tones in the simulation), especially near large window openings. In some locations, DF exceeds 5%, indicating excellent daylight availability. According to EN 17037, DF values above 2% are considered sufficient for general visual tasks during daytime, while values over 5% suggest minimal reliance on artificial lighting.
- Interior zones without direct access to windows exhibit significantly lower daylight levels, with DF values ranging between 0.58% and 2.32%. These figures are on the lower end of acceptable thresholds and imply the need for supplementary artificial lighting to meet visual comfort requirements.
- Rooms with extended depth show insufficient daylight penetration, particularly toward their rear sections, due to distance from window apertures. This behavior is consistent with a decreased *Sky Component* of the DF. Strategies to mitigate this issue may include:
  - ➢ Implementation of light shelves.
  - ➢ Use of high-reflectance interior finishes.
  - ➢ Installation of skylights or clerestory windows to increase daylight penetration.

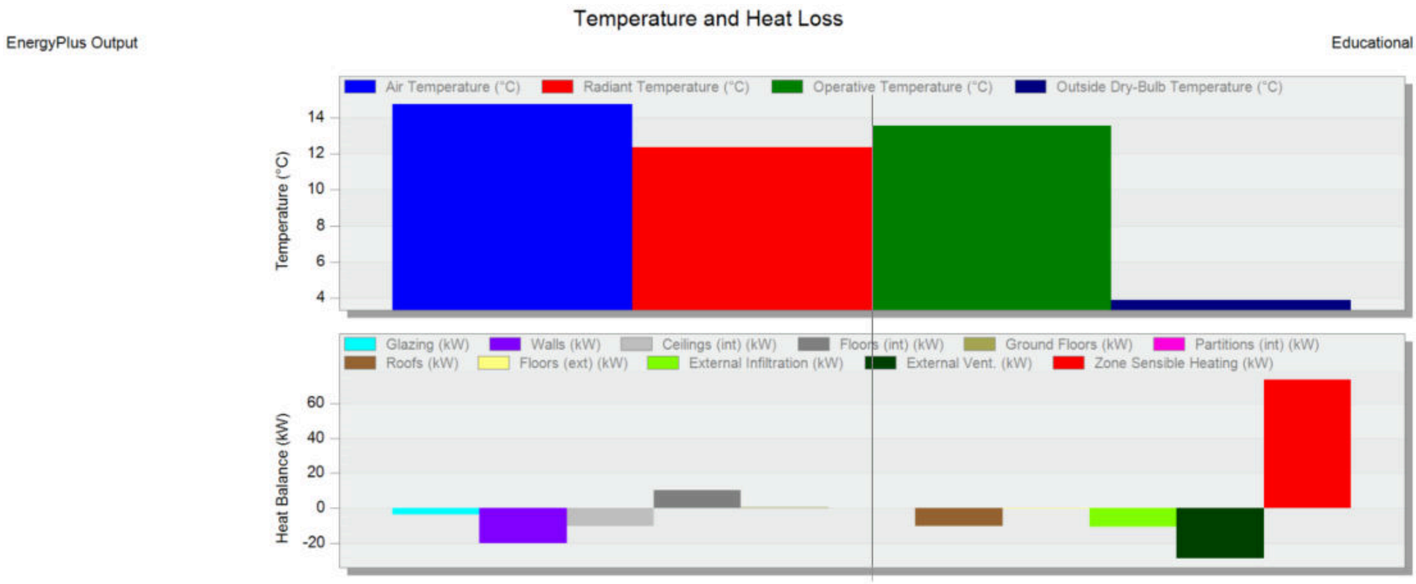
- Dark zones (represented in black in the simulation output) are located in internal corridors or enclosed areas with no access to natural light, showing DF values close to 0%. These zones require constant artificial lighting. To enhance energy efficiency, lighting systems in such areas should incorporate daylight sensors **and occupancy detectors, as recommended** in **EN 12464-1:2021 – Lighting of Work Places – Indoor Work Places**.

This analysis highlights the necessity of both architectural and technological interventions to optimize daylight distribution throughout the school building. The integration of daylighting strategies along with high-efficiency artificial lighting systems can significantly improve visual comfort, support learning performance, and contribute to the building's overall energy efficiency goals.



Heat losses

A simulation was also carried out to study the energy performance of the building. Below are the results of the simulation in Design Builder for the most extreme winter day, focusing on the temperatures and heat losses of the individual elements of the building envelope.



Air Temperature (°C)	14.73
Radiant Temperature (°C)	12.36
Operative Temperature (°C)	13.55
Outside Dry-Bulb Temperature (°C)	3.90
Glazing (kW)	-3.69
Walls (kW)	-20.30
Ceilings (int) (kW)	-10.29
Floors (int) (kW)	10.29
Ground Floors (kW)	0.47
Partitions (int) (kW)	0.00
Roofs (kW)	-10.39
Floors (ext) (kW)	-0.36
External Infiltration (kW)	-10.65
External Vent. (kW)	-28.82
Zone Sensible Heating (kW)	73.75

The results show that the heat losses are particularly high, leading to increased energy requirements for heating (73.75 kW). The largest sources of loss are located in the walls, roof and window frames from 3.69 kW to 20.30 kW, with significant heat fluxes due to air infiltration. The graph also highlights the difference between internal temperatures (air, radiant and operational) and external temperatures, demonstrating the thermal load of the building. These findings highlight the need to upgrade the envelope and improve the thermal insulation capacity of the building elements.

13. BUILDING STOCK

The building stock of any given area comprises both old and new structures that serve residential and public purposes. Renovating older structures such as Lefkara Primary School is essential because these buildings typically do not have adequate insulation and effective heating/cooling systems which results in high energy consumption.

The school maintains its status as a protected heritage site which demonstrates a common challenge since it has historical significance yet delivers poor energy performance. The building's protected status makes demolition or replacement impossible while nationwide renewal would take more than a hundred years and cost too much money. The most practical and environmentally friendly strategy for boosting energy performance involves enhancing current buildings rather than constructing new ones because major alterations are not viable for historically significant structures.

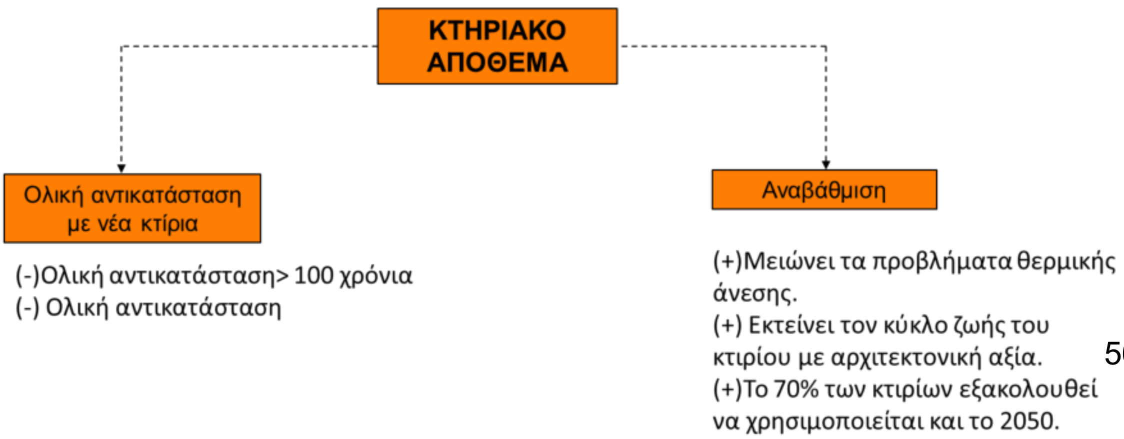
<u>Effective interventions can be implemented through subtle solutions such as:</u>

-Installing new energy-efficient windows and doors.Buildings require either interior or exterior thermal insulation that honors their historical character.
-The application of Renewable Energy Sources (RES) like photovoltaics and geothermal systems.
-Smart energy management technologies enable optimum performance of heating -systems alongside lighting and ventilation controls.

<u>The benefits of energy upgrading are multiple:</u>

-It diminishes thermal comfort issues which enhances students' learning conditions.
-The energy upgrade safeguards the building's architectural identity while prolonging its functional lifespan.
-The fact that 70% of existing buildings will remain operational by 2050 makes their energy efficiency upgrades essential to energy policy plans.

The Lefkara Primary School case shows that upgrading the existing structure is the most efficient, ecological, and economical solution, preserving heritage while ensuring sustainable, future-ready public buildings.

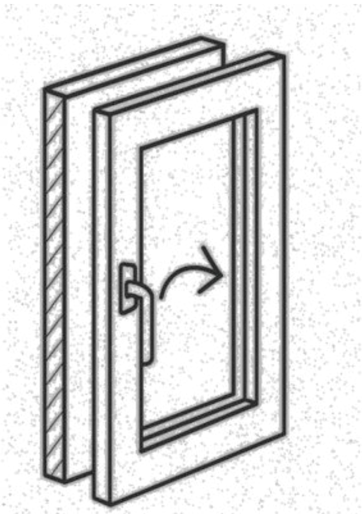


14. BUILDING MODIFICATION CATEGORIES – SOLUTIONS

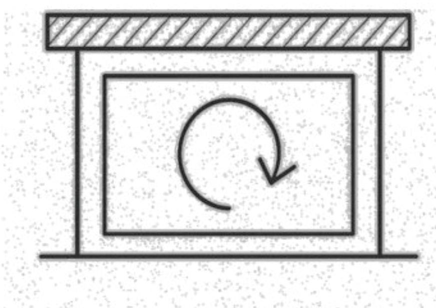
Lefkara Primary School serves as an exemplary model of traditional Cypriot architecture. Since 1920 stands as a historical building under national preservation laws which strictly prohibit any modification to its urban structure. Environmental responsibilities combined with the goals to improve building performance and indoor comfort drive the requirement for energy upgrades. Energy retrofit projects face significant difficulties due to the restrictions imposed by preservation laws.

The DesignBuilder software analysis revealed where energy loss and thermal inefficiency occurred. The selection of three primary intervention categories for further development was guided by recommendations from the "Manual for Energy Efficiency and Retrofit of Heritage Architecture." These interventions focus on enhancing energy efficiency while maintaining the original architectural features.

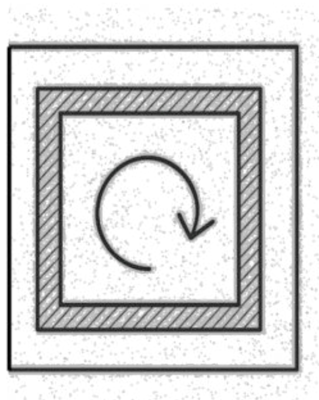
1. Window Upgrade – **Secondary Glazing**
2. Roof Insulation – **Internal Roof Insulation System using Mineral Wool (Rockwool)**
3. Internal Wall Insulation – **Internal Insulation with Mineral Wool**



1. IMPROVED WINDOW FRAMES



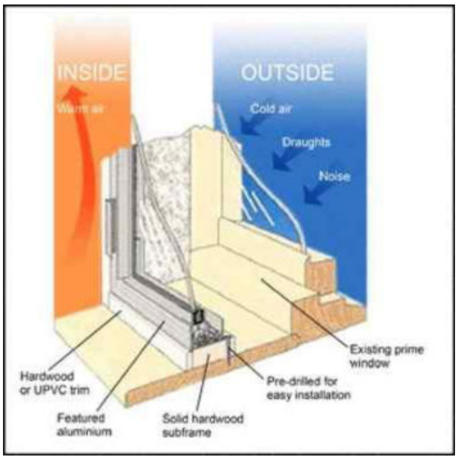
2. ROOF INSULATION



3. WALL INSULATION

14.1 Window Upgrade – Secondary Glazing

The school's original metal window frames serve as a recognizable marker of the era in which it was built. These windows cause substantial heat loss and permit air leaks which results in substandard energy efficiency. The listed status of the building prevents any replacement of the windows.
The ideal solution recommended involves implementing secondary glazing to enhance both thermal and acoustic performance without altering the original windows.



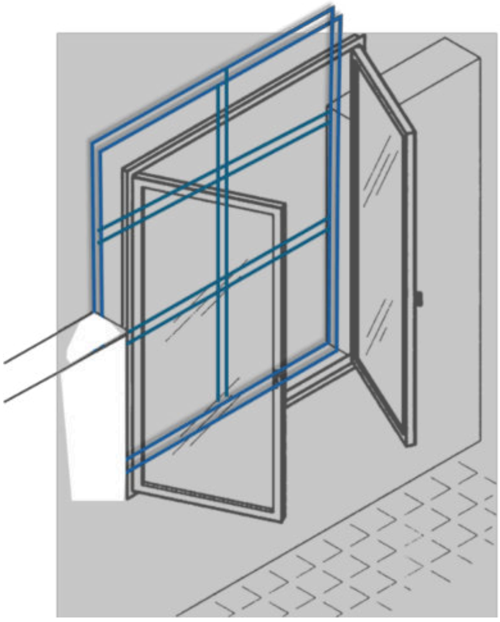
Advantages:

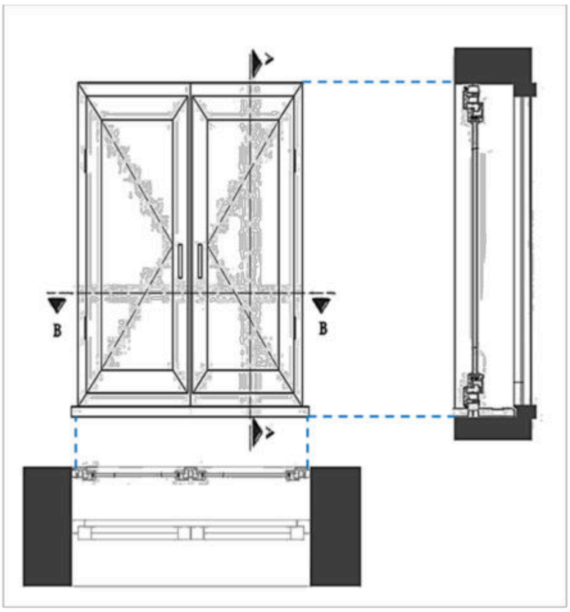
- Reduces thermal losses by creating an air gap that acts as a thermal barrier.
- Enhances sound insulation, particularly beneficial in school environments.
- Low-cost and reversible intervention with no damage to the original structure.
- Maintains the exterior appearance of the building.
- Fully compliant with preservation regulations.

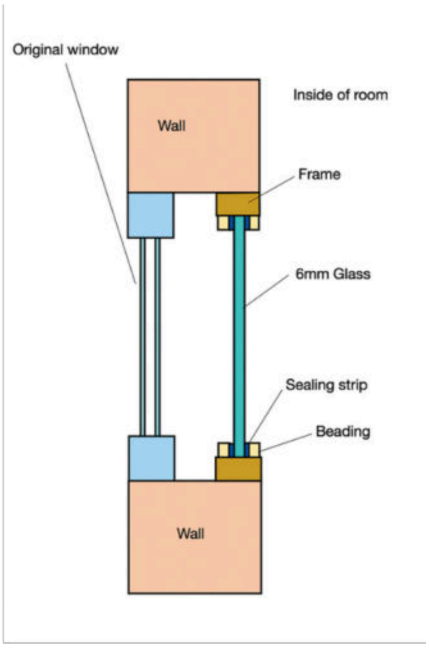
Technical Analysis:

The intervention involves the installation of an additional internal frame with a 6mm glass pane, set approximately 100–150mm in front of the existing window. This air cavity significantly reduces heat transfer and improves comfort.

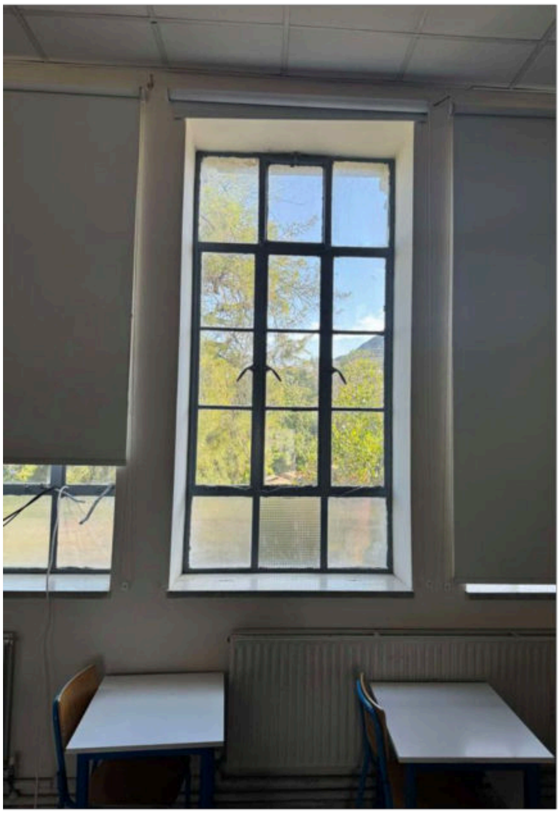
The installation diagrams illustrate the straightforward construction approach, which includes a perimeter sealing strip to prevent air leakage. This solution ensures compatibility with the building's aesthetic character while improving energy performance measurably.







INSTALLATION DIAGRAMS/RENDERS



Window Upgrade
– Secondary Glazing

14.2 Roof Insulation – Internal Roof Insulation System using Mineral Wool

Lefkara Primary School features a pitched roof which consists of timber framing along with wooden paneling inside. The building loses significant heat due to missing insulation which becomes more problematic during winter.

The proposed solution requires placing mineral wool (rockwool) between wooden rafters inside the structure while keeping the exterior tiled roof intact. This solution preserves the building's architectural style and boosts its thermal performance substantially.


Advantages:

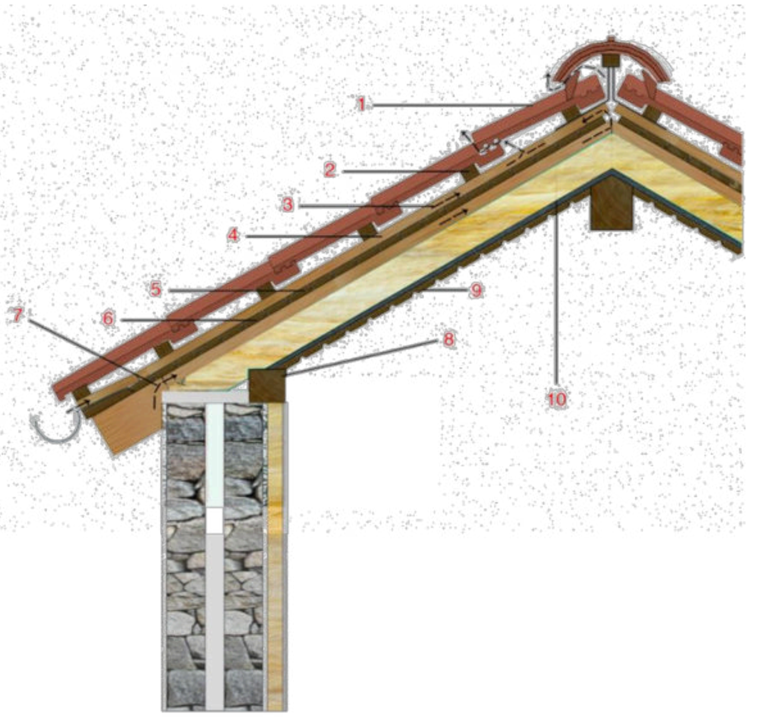
- High thermal resistance (R-value) for effective insulation.
- Allows moisture diffusion, reducing the risk of mold and condensation.
- Long-term durability and fire resistance.
- Easy installation from the interior, without disturbing the exterior envelope.

Technical Analysis:

The construction detail includes:

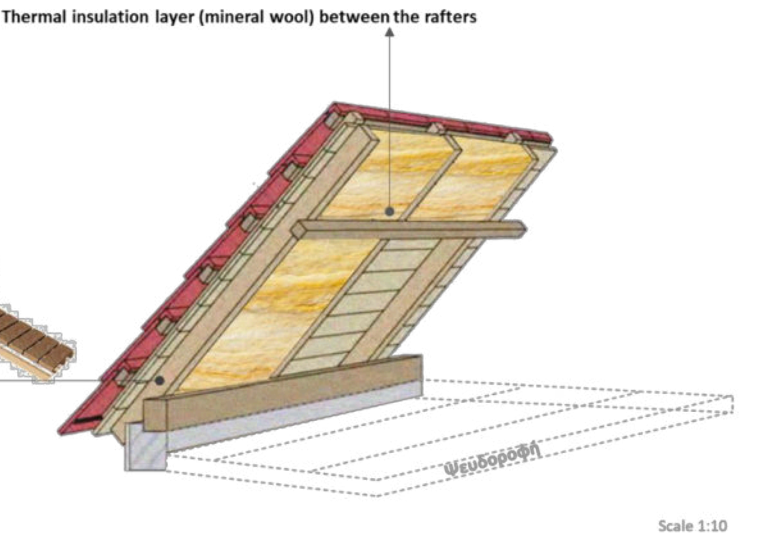
- Placement of mineral wool approximately 100mm thick between the rafters.
- A protective internal wood panel or plasterboard, plus a vapor-permeable membrane.
- Ensured ventilation between the battens and the outer tiles to avoid moisture accumulation.

1. Κεραμίδια
2. Πηχάκια.
3. Αερισμός ανάμεσα στις επιτεγίδες.
4. Επιτεγίδες.
5. Πέτσωμα.
6. Στεγανοποιητική συνθετική υδρατμοδιαπερατή μεμβράνη (διάστρωση επάνω στο πέτσωμα).
7. Αερισμός ανάμεσα στους αμείβοντες.
8. Μηκίδα.
9. Εσωτερικό σανίδωμα. Επ' αυτού τοποθετείται φράγμα υδρατμών, εφόσον κριθεί ότι ο αερισμός ανάμεσα στις τεγίδες δεν επαρκεί για να αποτρέψει τυχόν συμπύκνωση από διάχυση υδρατμών.
10. Θερμομονωτική στρώση ανάμεσα στους αμείβοντες (μορινες).



CONSTRUCTION DETAIL ANALYSIS

Existing Roof Construction



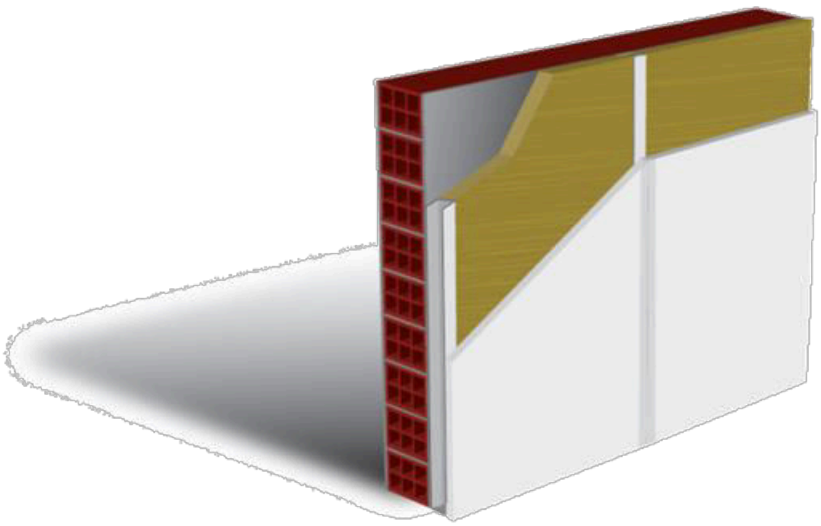
1. Υποστύλωμα.2. Τάκος.3. Μηκίδα.4. Πέλμα - ελκυστήρας.5. Αμείβοντες.6. Ταμπάνι πέλματος.7. Τεγίδες.8. Επιτεγίδες.9. Πέτσωμα, ψευδοστέγη.10. Κεντρικός ορθοστάτης.11. Ελκυστήρας.12. Ορθοστάτες.13. Ταμπάνι, επάνω στο οποίο
πατάει ο ορθοστάτης.14. Ταμπάνι στο φουρούσιγια τη στερέωση της αστρέχας.15. Κεραμίδια.16. Κορυφοτεγίδα.

The use of breathable materials is essential to prevent vapor trapping and ensure the long-term durability of the roof structure.

14.3 Internal Wall Insulation with Mineral Wool

Traditional Lefkara stone forms the construction material for the school's external walls because of its valuable architectural and historical significance. The building's preserved status forbids external insulation which leaves internal wall insulation as the only acceptable solution.

The selected method involves implementing an internal thermal insulation system composed of mineral wool which will then be shielded by layers of plasterboard and interior plaster. The solution follows heritage retrofit standards and enhances the building's internal thermal environment.



Advantages:

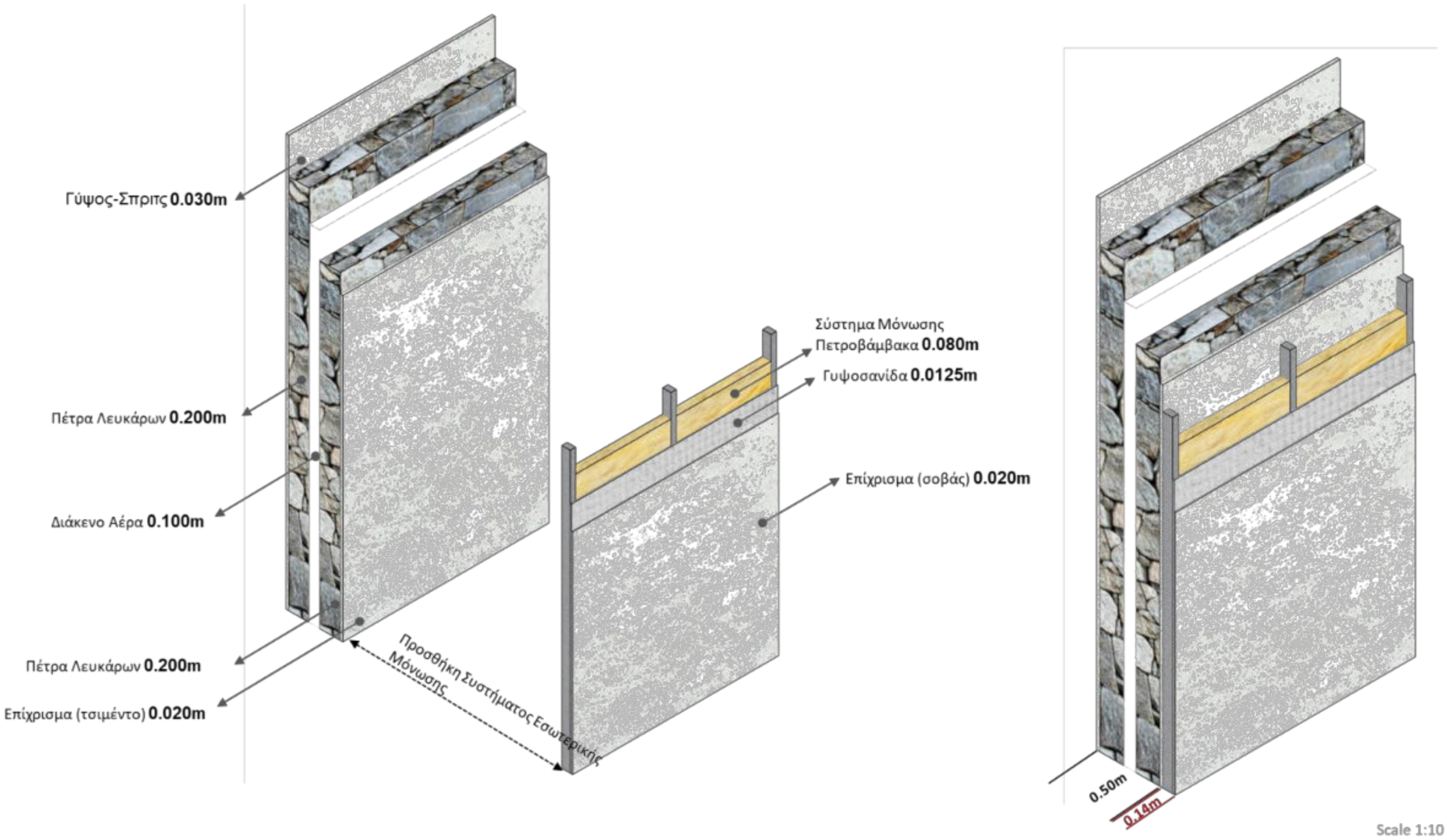
- Significantly reduces heating and cooling energy demands.
- Provides fire protection and improves sound insulation.
- Offers flexibility for architectural finishes (e.g., recessed lighting, hidden cabling).
- Full quality control through defined specifications and certifications.

Technical Analysis:

The wall assembly includes the following layers:

- Existing 0.20m-thick stone wall
- 0.10m air cavity
- Interior stud frame with vertical supports

- 0.08m mineral wool insulation
- 0.0125m plasterboard finish
- 0.02m internal plaster coating



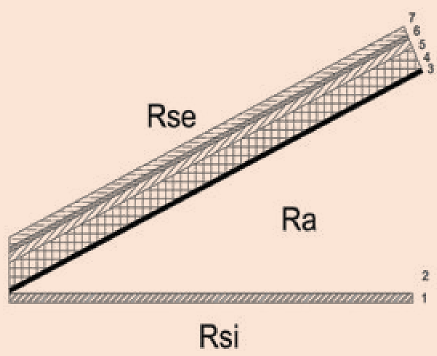
The total additional wall thickness on the interior is approximately 0.14m. This solution preserves the exterior aesthetics while significantly enhancing thermal performance.

14.4 Thermal Coefficient U-values for the Modifications

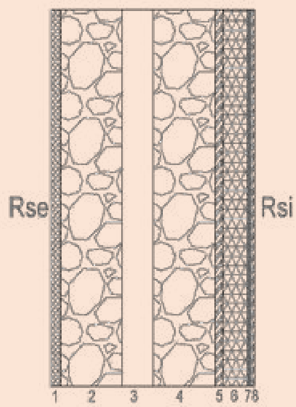
Type of Construction	Windows		
Construction Type	**Frame**	**Glazing**	**Total Window Unit**
Existing Window [W/m^{2}K]	Steel Uf = 7.0	Single Ug = 5.6	U = 6.1
Double Window [W/m^{2}K] (frame-to-window area ratio 30%)	Aluminium Uf = 7.0	Double (4-6-4, air gap) Ug = 3.3	U = 4.5

So, the total U-value of the window is calculated to U = 1.38 W/m^{2}K.

Note: The final U-value calculated is lower than the regulation limit (2.25 W/m²K), considering the air gap between the two windows (R = 0.34 m²K/W).

Structure type		Sloping roof with insulation, air gap and plasterboard ceiling			
A/A	**Name of Material**	**Thickness of Material** **d** **[m]**	**Thermal Conductivity of Materials** **λ** **[W/mK]**	**Thermal Resistance of Materials** **R** **[m²K/W]**	**Typical Design Detail**
1	Plasterboard	0.012	0.210	0.057	
2	Thermal resistance of air gap	-	-	0.300	
3	Plasterboard	0.012	0.210	0.057	
4	Mineral wool	0.080	0.041	1.951	
5	Plywood MDF	0.012	0.070	0.171	
6	Bituminous Waterproofing	0.003	0.230	0.013	
7	French Tile	0.020	1.000	0.020	
Heat Flow		**R_{si}** **[m²K/W]**	**R_{so}** **[m²K/W]**	**Thermal Coefficient** **[W/m²K]**	
Vertically - upwards		0.10	0.04	0.369	

In the optimized cross-section of the roof, layers of mineral wool and drywall were added to reduce thermal losses. The incorporation of these materials led to a significant improvement in the thermal resistance of the structure, resulting in a reduction of the total thermal transmittance (U-value) to 0.369 W/m²K, a value which is within the limits set by the current Building Energy Performance Decree.

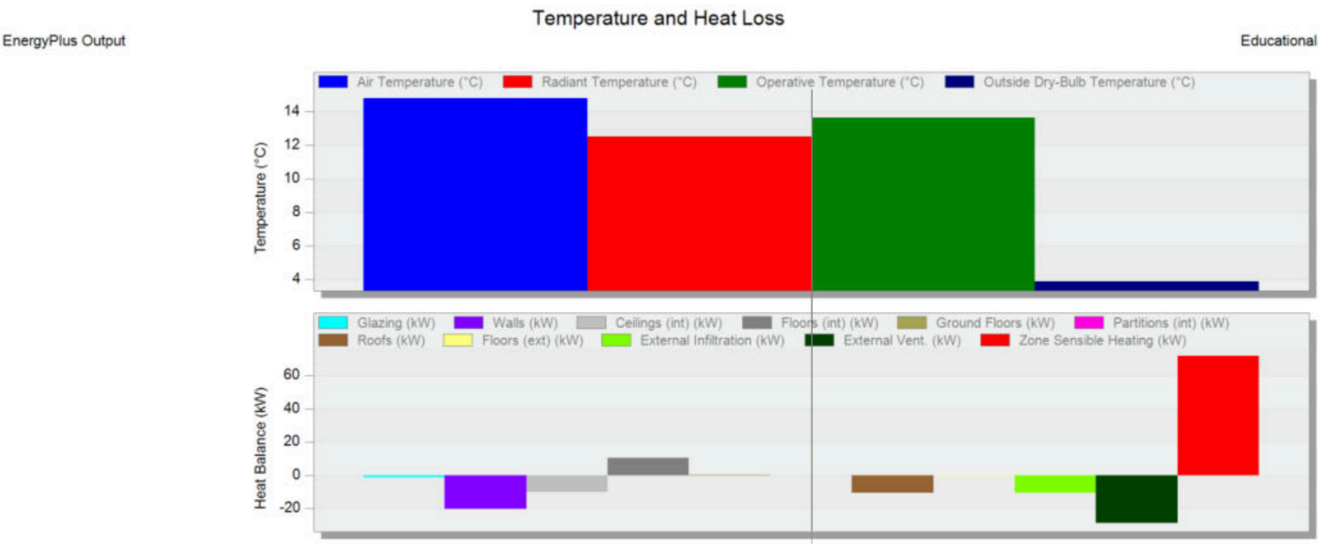
Structure Type		**External wall with double stone 20cm (front wall) and insulation**			
A/A	**Name of Material**	**Thickness of Material d [m]**	**Thermal Conductivity of Materials λ [W/mK]**	**Thermal Resistance of Materials R [m²K/W]**	**Typical Design Detail**
1	Plasterboard	0.012	0.210	0.057	
2	Mineral wool	0.080	0.041	1.951	
3	Coating (cement)	0.020	1.000	0.020	
4	Lefkara Stone	0.200	1.700	0.118	
5	Air gap	0.100	-	0.180	
6	Lefkara Stone	0.200	1.700	0.118	
7	Coating (cement)	0.020	1.000	0.020	
8	Plaster	0.010	0.180	0.056	
Heat Flow		**R_{si} [m²K/W]**	**R_{so} [m²K/W]**	**Thermal Coefficient [W/m²K]**	
Horizontal		0.130	0.040	0.371	

After the intervention in the cross-section of the external masonry, layers of mineral wool and drywall were added on the inner side of the wall, to reduce thermal losses. The addition of these materials led to a significant improvement in the thermal resistance of the structure, resulting in a reduction in the overall thermal transmittance (U-value) to 0.371 W/m²K, a value which is satisfied by the relevant Building Energy Performance Decree.

15. RESULTS COMPARISON

15.1 Secondary Glazing

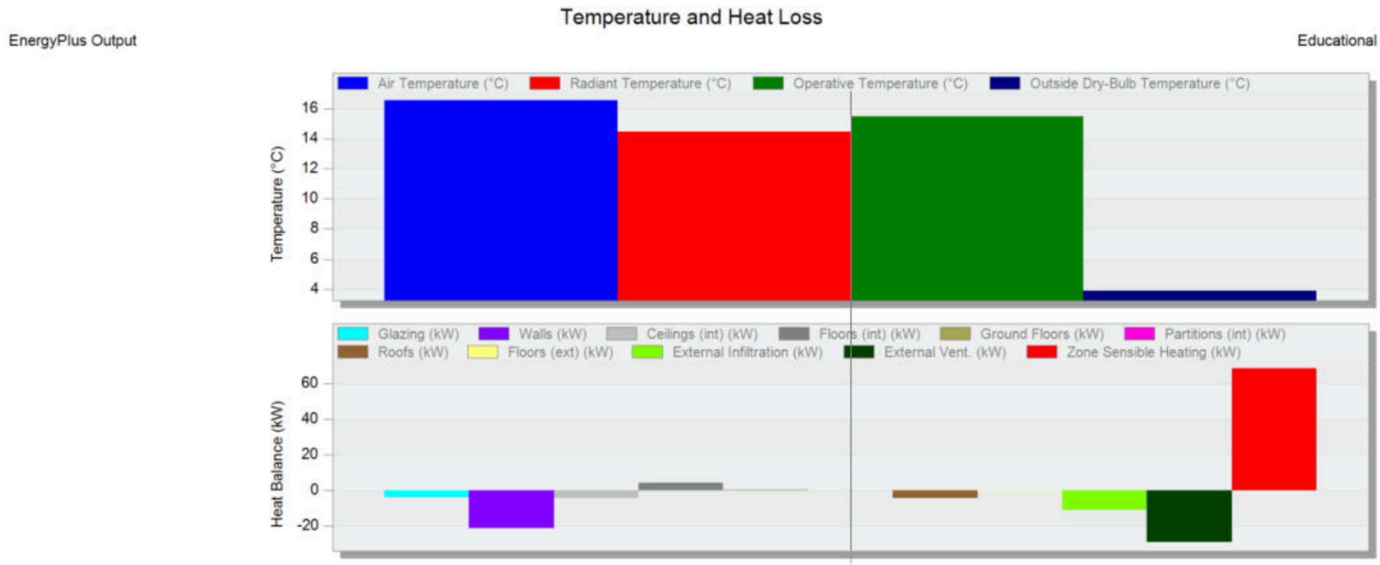
After installing double-glazed windows, the simulation results for a typical winter day demonstrate a significant reduction in heat losses through glazing, falling by **59.3%** from 3.69 kW to 1.50 kW. At 20.46 kW, walls continue to be the largest source of heat loss, followed by the roof at 10.48 kW. Even while glass performance has improved, wall and roof losses continue to have a major impact on the envelope's overall thermal behavior, underscoring the need for more interventions in these areas.



Air Temperature (°C)	14.79
Radiant Temperature (°C)	12.52
Operative Temperature (°C)	13.65
Outside Dry-Bulb Temperature (°C)	3.90
Glazing (kW)	-1.50
Walls (kW)	-20.46
Ceilings (int) (kW)	-10.39
Floors (int) (kW)	10.39
Ground Floors (kW)	0.43
Partitions (int) (kW)	0.00
Roofs (kW)	-10.48
Floors (ext) (kW)	-0.37
External Infiltration (kW)	-10.65
External Vent. (kW)	-28.82
Zone Sensible Heating (kW)	71.87

15.2 Roof Insulation

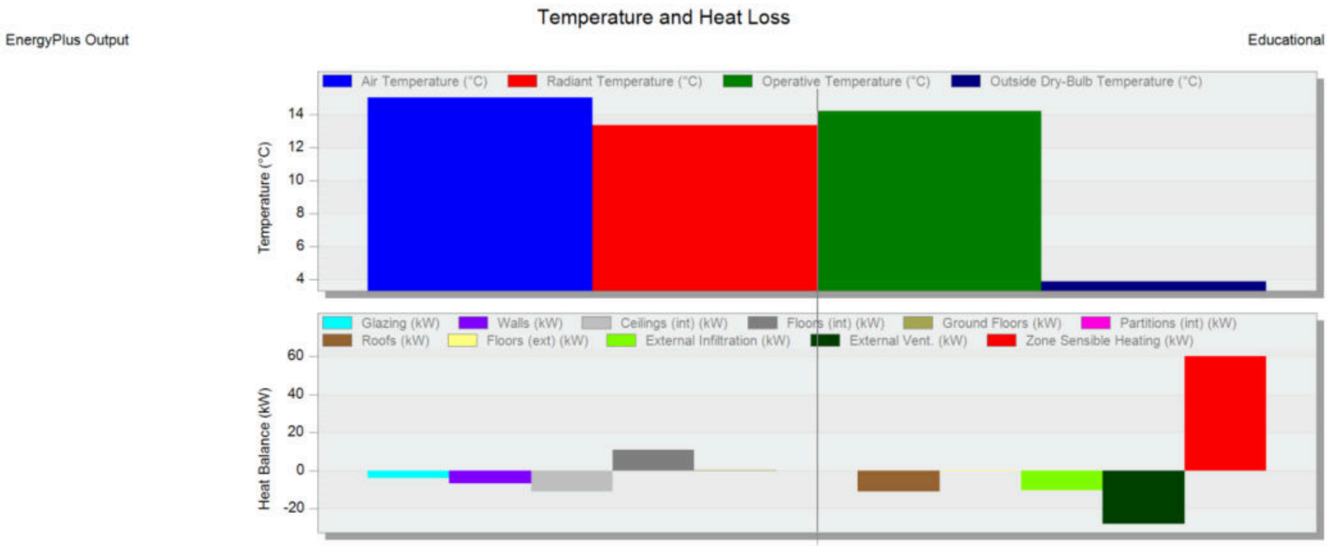
After installing insulation to the roof, the simulation results for a typical winter day demonstrate a significant reduction in heat losses through roof, falling by **59.2%** from 10.39 kW to 4.24 kW. At 20.90 kW, walls continue to be the largest source of heat loss, followed by windows at 3.81 kW. Even while roof performance has improved, wall losses continue to have a major impact on the envelope's overall thermal behavior, underscoring the need for more interventions in these areas. Heating requirements have been reduced compared to double glazing from 71.87 kW to 68.53 kW.



Air Temperature (°C)	16.53
Radiant Temperature (°C)	14.44
Operative Temperature (°C)	15.48
Outside Dry-Bulb Temperature (°C)	3.90
Glazing (kW)	-3.81
Walls (kW)	-20.90
Ceilings (int) (kW)	-4.31
Floors (int) (kW)	4.31
Ground Floors (kW)	0.37
Partitions (int) (kW)	0.00
Roofs (kW)	-4.24
Floors (ext) (kW)	-0.46
External Infiltration (kW)	-10.65
External Vent. (kW)	-28.82
Zone Sensible Heating (kW)	68.53

15.3 Wall Insulation

After installing insulation to the external walls of the school, the simulation results for a typical winter day demonstrate a significant reduction in heat losses through walls, falling by **67.5%** from 20.30 kW to 6.60 kW. At 11.02 kW, roof is the largest source of heat loss, followed by walls and then windows at 3.95 kW. Even while wall performance has improved, wall losses continue to have a major impact on the envelope's overall thermal behavior, underscoring the need for more interventions in these areas. Heating requirements have been reduced compared to roof from 68.53 kW to 60.15 kW.



Air Temperature (°C)	15.01
Radiant Temperature (°C)	13.35
Operative Temperature (°C)	14.18
Outside Dry-Bulb Temperature (°C)	3.90
Glazing (kW)	-3.95
Walls (kW)	-6.60
Ceilings (int) (kW)	-10.93
Floors (int) (kW)	10.93
Ground Floors (kW)	0.21
Partitions (int) (kW)	0.00
Roofs (kW)	-11.02
Floors (ext) (kW)	-0.40
External Infiltration (kW)	-10.36
External Vent. (kW)	-28.03
Zone Sensible Heating (kW)	60.15

External wall insulation was the most successful of the three envelope modifications assessed by simulations, lowering overall heating demand to 60.15 kW and wall heat losses by 67.5%. Although double glazing and roof insulation similarly greatly decreased heat losses (by about 59% each), their effects on overall heating needs were less pronounced. These findings suggest that wall insulation need to be given top priority, with roof and glazing improvements acting as significant secondary improvements.

16. RECOMMENDED SOLUTIONS FOR MECHANICAL EQUIPMENT/ FANS

Installing ceiling fans improves air circulation, reducing the need for mechanical cooling and keeping operating costs low. At the same time, thermal comfort in teaching spaces is enhanced. Fans have low installation and maintenance costs, while they are a reversible intervention, compatible with the requirements for listed buildings.

References

Heracleous C., Michael A, Savvides A., Hayles C., Passive measures for improving thermal comfort and energy performance of educational buildings in Cyprus, SEEP 2019 – 12th International Conference on Sustainable Energy & Environmental Protection, United Arab Emirates- University of Sharjah, 18th- 21st November 2019, pp. 123-128, ISBN: 978-9948-36-625-6.

17. REASONS TO AVOID INSTALLING CONVENTIONAL AIR CONDITIONING SYSTEMS

The installation of conventional air conditioners is not recommended, as:

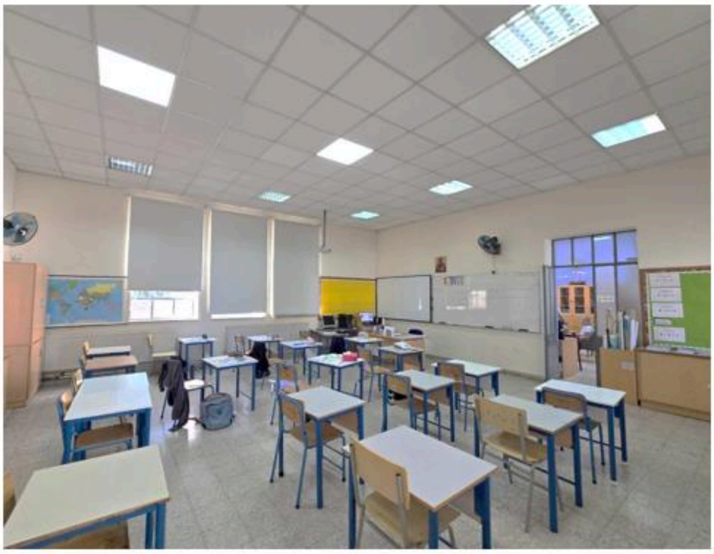
Sufficient air renewal is not ensured, resulting in the accumulation of CO_2 and microparticles.

There is no possibility of regulating humidity, often leading to dry air that affects the comfort of users.

Energy consumption is high, increasing the school's energy footprint and burdening operating costs.

References

Heracleous C., Michael A, Savvides A., Hayles C., Passive measures for improving thermal comfort and energy performance of educational buildings in Cyprus, SEEP 2019 – 12th International Conference on Sustainable Energy & Environmental Protection, United Arab Emirates- University of Sharjah, 18th- 21st November 2019, pp. 123-128, ISBN: 978-9948-36-625-6.



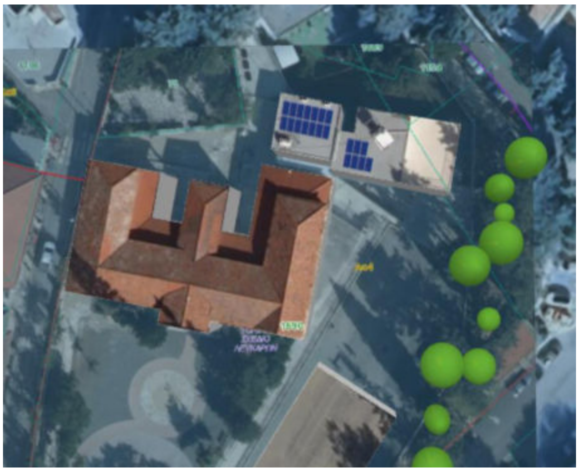
18. RECOMMENDED AREA FOR INSTALLING RES SYSTEMS

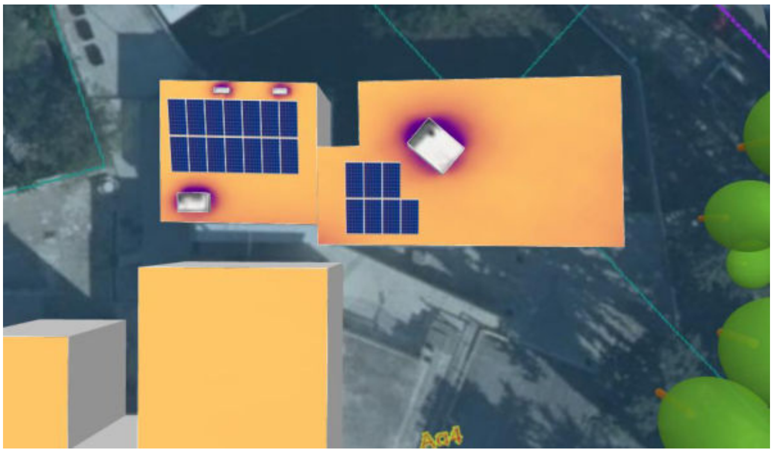
As part of the school's energy upgrade, a photovoltaic system will be installed on the roof of the building extension. Specifically, a 12.18 kW Net Billing system will be implemented. The PV system will consist of 21 EXIOM 580W bifacial panels and a 12 kW Huawei hybrid inverter.

This inverter provides the capability for future installation of an energy storage system, once it becomes economically feasible and when the EAC grid is ready to support storage systems.

Since no battery storage will be installed at this stage, it is possible to install a Smart Meter, which will allow the PV system to continue operating for self-consumption in the event that the EAC disables grid export.

Στην οροφή της επέκτασης του κτιρίου





19. TECHNO-ECONOMIC ANALYSIS

19.1 Techno-Economic Analysis for Photovoltaic System

As part of the energy upgrade of the Lefkara Primary School, a techno-economic study was conducted for the installation of a 12.18 kW Net Billing photovoltaic system. The study includes estimates of annual energy production, self-consumption, cost savings, and the system's payback period.

The system consists of 21 EXIOM 580W bifacial PV panels and a 12 kW Huawei hybrid inverter. A self-consumption rate of 70% has been declared, based on the building's energy usage profile and the school's operational hours.

The estimated annual savings amount to €4,584.80, while the total investment cost is €11,500.00. The payback period is calculated at 2.51 years, making the investment highly cost-effective for the school.

The techno-economic analysis was performed using Microsoft Excel, where monthly values for PV production, building consumption, estimated self-consumption, and corresponding financial savings were entered and analyzed.

The table presents the detailed data per bimonthly period, while the accompanying graphs illustrate the comparison between electricity consumption and PV production, as well as the distribution of annual financial savings. The highest savings are observed during the summer months (April–July), due to increased solar irradiation and system performance.

This study clearly demonstrates the energy and economic viability of the proposed PV installation and supports the informed decision to proceed with implementation.

19.2 Techno-Economic Analysis for Materials

The techno-economic analysis (TEA) evaluates the financial feasibility of selected energy renovation measures for the building, combining detailed energy savings with economic investment and operational costs over the expected lifespan of each measure. The measures analyzed include double-glazing aluminium windows, roof internal insulation, wall internal insulation, and photovoltaic (PV) systems.

Methodology

The TEA incorporates:

Data				
Measure	Cost per Unit (euro)	area (m2)	Total cost (euro)	Lifetime
Double-glazing aluminium windows	300	86.3	25,890	Frame:35-50, Glass:15-25
Roof internal insulation (stone wool)	68	753.5	51,238	20-50+
Wall internal insulation (stone wool)	47	1115.2	52,414	20-40
Ceilins Fans	130	14 (number of fans)	2800	10-15+

- **Initial capital expenditure (CAPEX)** based on unit costs and renovation area. Total cost = cost per unit * area
- **Annual operational expenditures (OPEX)** including maintenance costs. Estimated
- **Annual energy savings** derived from reductions in thermal energy demand due to renovation measures. Savings were converted to monetary values using the thermal energy cost calculated from the petrol fuel price (€1.60/liter), boiler efficiency (85%), and petrol energy content (approximated as 10 kWh/liter).

$$\textbf{Annual energy savings} = \frac{((45322-43048)+17774.84)/_{0.85}}{10} \times 1.6$$

Where 45,322 kWh is the initial thermal energy demand,

43,048 kWh is the energy demand after double glazed window installation and

17,774 kWh is the electric energy demand.

The same approach is used for the rest of the examples.

- **Degradation factors** applied to energy savings to account for performance decline over time (0.2%–0.5% annually, depending on measure).
- **Discount rate** of 4% applied for present value calculations reflecting the time value of money.
- **Lifespans** of 40 years for windows and roof insulation, and 30 years for wall insulation and PV systems, aligned with typical durability data.

Key Calculations

Annual net cash flows (energy cost savings minus OPEX) were projected for the lifespan of each measure, applying degradation yearly. These cash flows were then discounted to present values using:

$$PV_t = \frac{CF_0 * (1-d)^{t-1}}{(1+r)^t}$$

where:

- CF_0 is net annual cash flow in year 1,
- d is the degradation rate,
- r is the discount rate,
- t is the year.

The **Net Present Value (NPV)** for each renovation case was calculated as the sum of discounted cash flows minus the initial CAPEX:

$$NPV = \sum_{t=1}^{N} PV_t - CAPEX$$

The **payback period** was estimated as the time required for cumulative undiscounted net cash flows to offset the initial investment.

Internal Rate of Return (IRR) was computed as the discount rate that yields an NPV of zero, indicating the annualized return on investment.

Life Cycle Cost (LCC) aggregates all discounted costs and savings over the lifespan, providing a holistic measure of economic impact.

(*Energy Technologies and Sustainable Design, Dr. Andreas Tjirkalis, TEA Notes, 2025*)

Calculating with excel

After we calculate the annual cash flow, Annual Energy savings - OPEX

				Calcula
Scenario	CAPEX (€)	Annual OPEX (€)	Annual Energy Savings (€)	Net Annual cash flow (CFo)
Windows only	25,890	50.00	3773.903059	=E32-D32
Roof insulation only	51,238	0.00	4112.914824	4,112.91
Wall insulation	52,414	0.00	5264.538353	5,264.54
PV Systems	11,500	450	4,584.80	4,134.80
Ceiling fan	2800	0.00	10.88	10.88
SUM	**143,842**	**500**	**17,747**	17,247

We can go and extend these values to the lifespan of our case.

Windows Only						
Year	Cash Flow	Discounted CF (PVt)			IRR	LCCt
		-25,890				
1	3,723.90	3580.676018	3580.676018	-22309.32398	9%	3580.676018
2	3716.455253	=C6/((1+0.04)^B6)	6966.747812	-18923.25219		3436.071794
3	3701.604298	3290.712742	10207.46055	-15682.53945		3290.712742
4	3679.439061	3145.19993	13302.66048	-12587.33952		3145.19993
5	3650.091738	3000.109341	16252.76983	-9637.230174		3000.109341
6	3613.736532	2855.988474	19058.7583	-6831.241701		2855.988474
7	3570.587941	2713.35338	21722.11168	-4167.888321		2713.35338
8	3520.898641	2572.68615	24244.79783	-1645.202171		2572.68615
9	3464.95703	2434.432849	26629.23068	739.230678		2434.432849
10	3403.084436	2299.001908	28878.23259	2988.232586		2299.001908
11	3335.632047	2166.762972	30994.99556	5104.995559		2166.762972
12	3262.977595	2038.046179	32983.04174	7093.041738		2038.046179
13	3185.521842	1913.141869	34846.18361	8956.183607		1913.141869
14	3103.684905	1792.300698	36588.4843	10698.4843		1792.300698
15	3017.90248	1675.73412	38214.21842	12324.21842		1675.73412
16	2928.622006	1563.615232	39727.83366	13837.83366		1563.615232
17	2836.298805	1456.079924	41133.91358	15243.91358		1456.079924
18	2741.39227	1353.228315	42437.1419	16547.1419		1353.228315

Later, we calculate the discounted cash flow, with 0.04 discount rate, we can go on and find the rate at which the investment will be paid off, by the life cycle of the case.

Windows Only						
Year	Cash Flow	Discounted CF (PVt)			IRR	LCCt
		-25,890				
1	3,723.90	3580.676018	3580.676018	-22309.32398	9%	3580.676018
2	3716.455253	3436.071794	=(D6+E5-50)	-18923.25219		3436.071794
3	3701.604298	3290.712742	10207.46055	-15682.53945		3290.712742
4	3679.439061	3145.19993	13302.66048	-12587.33952		3145.19993
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8	3520.898641	2572.68615	24244.79783	-1645.202171		2572.68615
9	3464.95703	2434.432849	26629.23068	739.230678		2434.432849
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11	3335.632047	2166.762972	30994.99556	5104.995559		2166.762972
12	3262.977595	2038.046179	32983.04174	7093.041738		2038.046179
13	3185.521842	1913.141869	34846.18361	8956.183607		1913.141869
14	3103.684905	1792.300698	36588.4843	10698.4843		1792.300698
15	3017.90248	1675.73412	38214.21842	12324.21842		1675.73412
16	2928.622006	1563.615232	39727.83366	13837.83366		1563.615232
17	2836.298805	1456.079924	41133.91358	15243.91358		1456.079924
18	2741.39227	1353.228315	42437.1419	16547.1419		1353.228315

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Year	Cash Flow	Discounted CF (PVt)			IRR	LCCt
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1	3,723.90	3580.676018	3580.676018	-22309.32398	9%	3580.676018
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3	3701.604298	3290.712742	10207.46055	-15682.53945		3290.712742
4	3679.439061	3145.19993	13302.66048	-12587.33952		3145.19993
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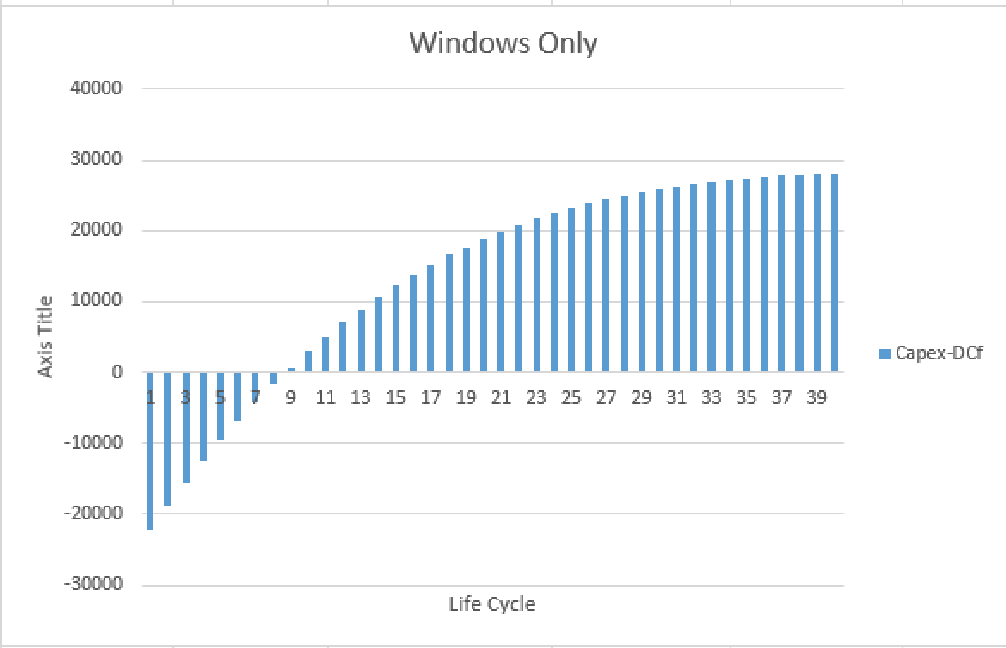
6	3613.736532	2855.988474	19058.7583	-6831.241701		2855.988474
7	3570.587941	2713.35338	21722.11168	-4167.888321		2713.35338
8	3520.898641	2572.68615	24244.79783	-1645.202171		2572.68615
9	3464.95703	2434.432849	26629.23068	739.230678		2434.432849
10	3403.084436	2299.001908	28878.23259	2988.232586		2299.001908
11	3335.632047	2166.762972	30994.99556	5104.995559		2166.762972
12	3262.977595	2038.046179	32983.04174	7093.041738		2038.046179
13	3185.521842	1913.141869	34846.18361	8956.183607		1913.141869
14	3103.684905	1792.300698	36588.4843	10698.4843		1792.300698
15	3017.90248	1675.73412	38214.21842	12324.21842		1675.73412
16	2928.622006	1563.615232	39727.83366	13837.83366		1563.615232
17	2836.298805	1456.079924	41133.91358	15243.91358		1456.079924
18	2741.39227	1353.228315	42437.1419	16547.1419		1353.228315

Side note, 50 is the annual opex for the windows.

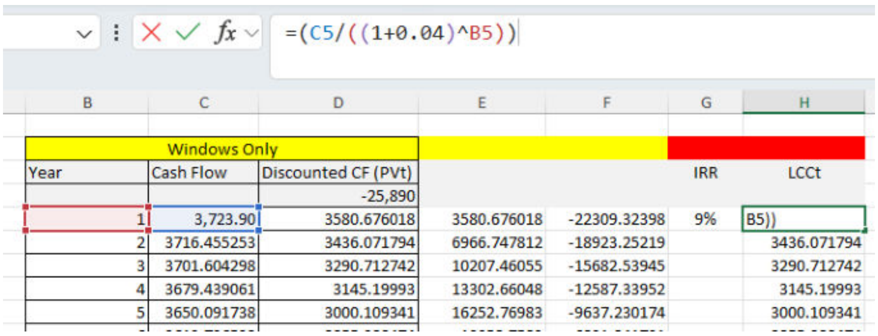
After which, we can create the following diagrams continuing the same method for the rest of the cases.



NPV, LCC and IRR calculation

We first need to find the PV which is the sum of the discounted cash flow and the NPV is the PV - CAPEX

LCC is the summation of LCCt, that is calculated by:



=(C5/((1+0.04)^B5))

B	C	D	E	F	G	H
Windows Only						
Year	Cash Flow	Discounted CF (PVt)			IRR	LCCt
		-25,890				
1	3,723.90	3580.676018	3580.676018	-22309.32398	9%	B5))
2	3716.455253	3436.071794	6966.747812	-18923.25219		3436.071794
3	3701.604298	3290.712742	10207.46055	-15682.53945		3290.712742
4	3679.439061	3145.19993	13302.66048	-12587.33952		3145.19993
5	3650.091738	3000.109341	16252.76983	-9637.230174		3000.109341

Finaly, IRR can be given by excel by selecting the Discounted CF row with the negative CAPEX

Scenario	Net Annual cash flow (CFo)	LifeCycle	PV	LCC	IRR
Windows only	3,723.90	40	56040.05808	81930.05808	9%
Roof insulation	4,112.91	40	48207.29561	99445.29561	-1%
Wall insulation	5,264.54	30	60992.4845	113406.4845	2%
PV Systems	4,134.80	30	47903.86317	59403.86317	29%
Ceiling fan	6.8	15	65	2865.199592	#NUM!

Results

Calculations											
Scenario	CAPEX (€)	Annual OPEX (€)	Annual Energy Savings (€)	Net Annual cash flow (CFo)	Degration (d)	Discount Rate (r)	Payback (years)	PV	NPV (€)	IRR (%)	LCC (€)
Windows only	25,890	50.00	3773.903059	3,723.90	0.002	0.04	6.952382914	56040.058	30,150	9%	81930.06
Roof insulation only	51,238	0.00	4112.914824	4,112.91	0.005	0.04	12.45783154	48207.296	-3,031	-1%	99445.3
Wall insulation	52,414	0.00	5264.538353	5,264.54	0.005	0.04	9.956124637	60992.484	8,578	2%	113406.5
PV Systems	11,500	450	4,584.80	4,134.80	0.005	0.04	2.781271162	47903.86	36,404	29%	59403.86
Ceiling fan	2800	0.00	10.88	10.88	0.005	0.04	257.3529412	65	-2,735	#NUM!	2865.2
SUM	**143,842**	**500**	**17,747**	17,247	0	0	**16**	213,209	69,366	#NUM!	357,051

Summary

Interpretation

- The PV systems offer the shortest payback period (~2.8-4 years) and the highest IRR (29%), driven by relatively low CAPEX and high annual savings.
- Windows present a moderately favorable payback (~9 years) and positive NPV supported by long lifespan assumptions.
- Roof and wall insulation show longer payback periods and lower IRRs, with roof insulation barely breaking even economically under current assumptions.
- Negative to low NPVs for roof insulation and ceiling fans indicate marginal financial benefits, suggesting that combining measures or leveraging subsidies could improve overall viability.
- Payback period is deferent depending on the method of calculation, in the tables we calculate it by dividing CFo/CAPEX that gives us a number that doesn't contain the discount rate. The diagrams above, include the discount rate and so give us a more realistic estimation of the payback period.
- LCC reflects the total discounted investment and operational cost balance over the lifespan, helping to compare long-term cost implications beyond simple payback.

Scenarios

By eliminating the Roof insulation and ceiling fans options we can continue to three scenarios,

Σενάριο 6											
Scenario	CAPEX (€)	Annual OPEX (€)	Annual Energy Savings (€)	Net Annual cash flow (CFo)	Degration (d)	Discount Rate (r)	Payback (years)	PV	NPV (€)	IRR (%)	LCC (€)
Windows only	25,890	50.00	3773.903059	3,723.90	0.002	0.04	6.952382914	56040.058	30,150	9%	81930.06
Wall insulation	52,414	0.00	5264.538353	5,264.54	0.005	0.04	9.956124637	60992.484	8,578	2%	113406.5
PV Systems	11,500	450	4,584.80	4,134.80	0.005	0.04	2.781271162	47903.86	36,404	29%	59403.86
SUM	89,804	500	13,623	13,123	0	0	10	164,936	75,132	0	254,740

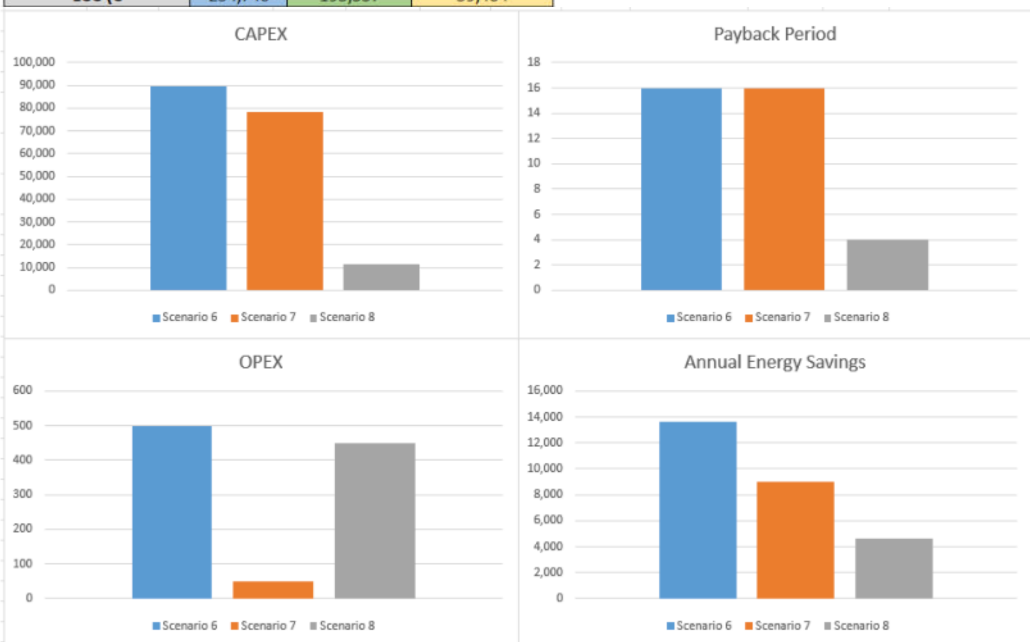
Σενάριο 7											
Scenario	CAPEX (€)	Annual OPEX (€)	Annual Energy Savings (€)	Net Annual cash flow (CFo)	Degration (d)	Discount Rate (r)	Payback (years)	PV	NPV (€)	IRR (%)	LCC (€)
Windows only	25,890	50.00	3773.903059	3,723.90	0.002	0.04	6.952382914	56040.058	30,150	9%	81930.06
Wall insulation	52,414	0.00	5264.538353	5,264.54	0.005	0.04	9.956124637	60992.484	8,578	2%	113406.5
SUM	78,304	50	9,038	8,988	0	0	10	117,033	38,728	0	195,337

Σενάριο 8											
Scenario	CAPEX (€)	Annual OPEX (€)	Annual Energy Savings (€)	Net Annual cash flow (CFo)	Degration (d)	Discount Rate (r)	Payback (years)	PV	NPV (€)	IRR (%)	LCC (€)
PV Systems	11,500	450	4,584.80	4,134.80	0.005	0.04	2.781271162	47903.86	36,404	29%	59403.86

We chose these three types of cases because of the insulation and the windows have been deemed very important renovations for the improvement of the thermal consumption of the building. We also need PV systems to reduce the energy demands.

Final scenario's results and observations

	Scenario 6	Scenario 7	Scenario 8
CAPEX (€)	89,804	78,304	11,500
Annual OPEX (€)	500	50	450
Annual Energy Savings (€)	13,623	9,038	4,584.80
Payback (years)	16	16	4
LCC (€	254,740	195,337	59,404



TEA Conclusions

The techno-economic analysis highlights that each of the proposed energy renovation measures presents varying degrees of financial viability based on their associated costs and energy savings potential. Double-glazing aluminium windows, roof internal insulation, and wall internal insulation show significant energy savings that translate into positive cash flows over their lifespans, with their NPVs and IRRs suggesting favorable investment opportunities under the applied discount rate of 4%. The photovoltaic system, while typically involving higher upfront costs, offers additional benefits by generating renewable electricity onsite, reducing dependency on grid energy and potentially enhancing long-term financial returns.

The use of discounted cash flow analysis allows for a realistic evaluation of these measures by incorporating the time value of money, enabling informed decision-making. From an economic standpoint, these renovations not only reduce the building's energy demand but also contribute to lower operational costs and greenhouse gas emissions, aligning with sustainability goals.

Ultimately, the choice of renovation measures should consider both financial metrics and non-monetary benefits such as increased occupant comfort and environmental impact. Combining several measures could optimize overall performance and financial returns, reinforcing the importance of a holistic approach to building energy renovation.

20. CONCLUSIONS

The comprehensive energy audit of the Lefkara Primary School revealed critical areas requiring intervention and highlighted the delicate balance between energy efficiency and the preservation of cultural heritage. Using advanced tools such as DesignBuilder and thermographic imaging, combined with meteorological data, on-site observation, and user evaluation, a thorough analysis of the building's current condition was conducted.

Although the local Lefkara stone adds distinct architectural and historical value, its thermal performance is inadequate by modern standards. Additionally, the single-glazed windows and metal construction prove to be thermally inefficient, while the existing heating, ventilation, and lighting systems are outdated and energy-intensive. The thermal transmittance coefficients of the masonry and openings do not comply with regulations, making it necessary to implement discreet thermal insulation and renewable energy technologies.

By analyzing the proposed upgrade scenarios, it was found that the installation of a photovoltaic system is the most cost-effective technical solution, offering immediate energy benefits, a low life cycle cost (LCC = €59,404), and a short payback period (2.7–4 years). Replacing the window frames further enhances performance, reducing thermal losses by 59.3% and showing a positive Net Present Value (NPV), although with a longer payback period (7–9 years). Wall insulation also contributes to energy efficiency (reducing demand by 18.4%) but is accompanied by an extended payback period (10–16 years). Despite its high thermal efficiency (loss reduction of 59.2%), roof insulation is not deemed cost-effective due to its negative NPV.

Therefore, the final recommendation focuses on the immediate installation of a photovoltaic system, while a second phase—depending on the available budget and energy or economic goals—proposes upgrading the windows and/or wall insulation.

Overall, the energy upgrade strategy for the Lefkara Primary School is not merely a technical improvement plan but a targeted intervention with a deeper mission: to demonstrate that sustainability and cultural heritage can coexist harmoniously. The proposed solutions combine technological innovation with respect for the architectural identity of the place, setting a model for the future of preserved buildings in similar historical environments. With a focus on performance, aesthetic balance, and long-term sustainability, this project becomes not only technically robust but also socially and environmentally meaningful. The school's energy upgrade serves as a starting point for broader reflection on the role of education, architecture, and green technology in building a more resilient and responsible future.

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