Πανεπιστήμιο Κύπρου

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ENERGY UPGRADE OF STROVOLOS MUNICIPAL BUILDING

POL 804: ADVANCED PROJECT: INTEGRATED DESIGN AND PROJECT RESEARCH I I I

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ABSTRACT

As part of our project for the energy upgrade of the Strovolos Municipal Hall, we have completed significant steps to help us understand the current state of the building. Initially, we collected data from online sources regarding the building's location and local meteorological conditions to gain a clear understanding of the environment in which it operates.

Next, we conducted an on-site visit to the Town Hall, where we used a thermal camera for thermographic analysis of the building, identifying areas with potential thermal losses and problematic spots. At the same time, we examined the existing electromechanical equipment in collaboration with the Town Hall's engineer to assess the condition and energy efficiency of the installed equipment.

Additionally, we sent a questionnaire to the Town Hall employees to gather information about their perception of thermal comfort and working conditions inside the building. Their responses will help us better understand the needs of the building's users and propose more effective solutions.

Finally, we implemented the design of the building and specifically the 2 offices we choose to analyze into rhino in order to simulate their energy consumption, daylight analysis and thermal analysis data through ladybug/honeybee components.

These actions have provided us with a comprehensive view of the building's current condition and laid the foundation for designing the energy upgrade that will follow.

Below, all actions taken so far are detailed, which will help us propose accurate and specific solutions to reduce electrical energy consumption and increase the thermal comfort of employees, which inevitably affects their performance.

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1. PURPOSE OF STUDY

The purpose of this study is to explore and implement an integrated approach to improving the energy efficiency of building facilities through a multi-faceted process of analysis and enhancement. Initially, emphasis is placed on identifying a suitable building for the study, which will serve as the foundation for evaluating and applying the proposed measures.

The analysis of the area where the building is located includes an investigation of environmental, social, and economic factors that influence its energy needs, aiming for a deeper understanding of the local context. Simultaneously, data collection from the building's users is conducted through questionnaires, interviews, or monitoring of energy consumption. This data is crucial for capturing the usage profile and the actual needs of the building.

Subsequently, the analysis of the collected data enables the extraction of conclusions regarding energy weaknesses and potential opportunities for improvement. Through this process, it becomes possible to formulate targeted strategies for the building's energy upgrade, with a focus on sustainability, efficiency, and reducing its energy footprint.

The study aims to propose and implement practical solutions that combine technological innovation with user awareness, thus highlighting the importance of collective effort in achieving high energy and environmental goals.

2. INTRODUCTION

The Municipality of Strovolos was established in 1986, based on the Municipalities Law of 1985, and it is the second-largest municipality in Cyprus after the Municipality of Limassol, with a population of over 70,000 residents. It covers an area of 25 square kilometers, and its territory is divided into six parishes.

Since August 2001, the Municipal Service has been housed in a building on 100 Strovolos Avenue. It is a three-story building with a basement, ground floor, mezzanine, and two additional floors totaling an area of 6000 m^2. The building includes underground and outdoor parking spaces, storage areas, a reception area, a cafeteria, an event hall, a Municipal Council meeting room, committee meeting rooms, offices for housing the Municipality's departments and sectors, as well as rooms for future use.

To the north of the building, a square has been developed, surrounded by green spaces and fountains, designed for outdoor events. The square connects organically with the rest of the building and extends through a semi-open arcade towards the Linear Park and the Pedieos River.

It is immediately apparent that a building delivered to its current users in 2001—before any legislation regarding the energy efficiency of buildings or specifications for thermal facades and external insulation of the building's shell and masonry was enacted—would have significant thermal comfort issues. These issues directly affect employees and reduce their productivity.

Figure 1: Front View of the Building

Strovolos stands as the most densely populated municipality, thriving along the vibrant Strovolos Avenue – one of the island's busiest and most dynamic thoroughfares. To the north, the serene flow of the Pedieos River adds a natural touch to the urban landscape.

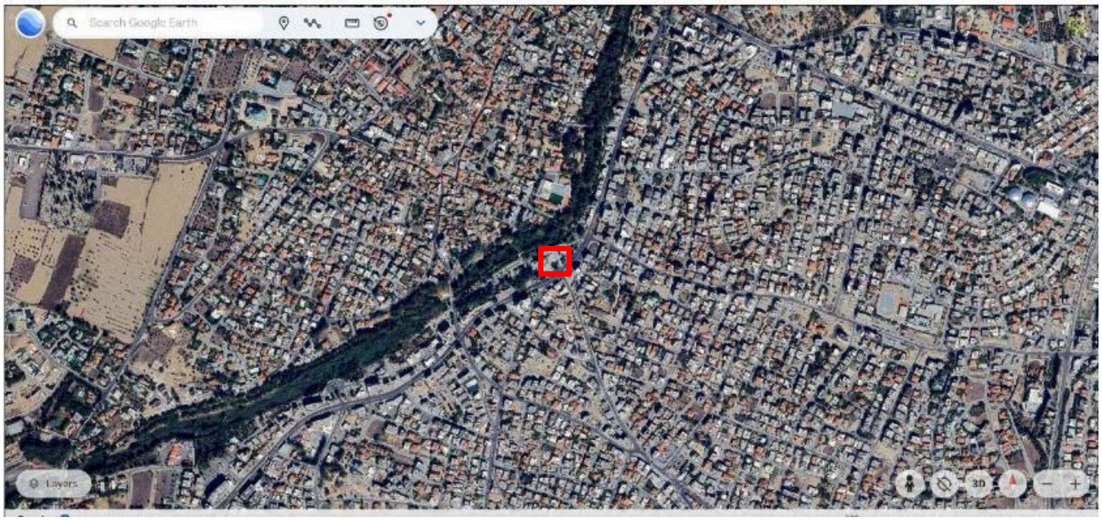

Figure 2: Satellite View with 1:15000 scale

Figure 3: Satellite View with 1:1000 scale

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The building stands at a height of 17.10 meters in an area where the tallest structure is a seven-story building, reaching a total height of 21 meters. Figure 4, illustrates the heights of all neighboring buildings, providing a clear comparison to our own. Figure 5 shows the height of the buildings of that area according to sea level.

Figure 4: Heights and types of buildings in the area.

Figure 5: Height from the sea Level

3. METEOROLOGICAL DATA

Meteorological data plays a crucial role in shaping energy efficiency strategies for our building. By understanding local weather patterns, temperature fluctuations, humidity levels, and prevailing wind directions, we can design solutions that optimize heating, cooling, and ventilation systems. This data allows us to anticipate seasonal energy demands, identify potential for natural ventilation, and implement shading or insulation strategies tailored to the building's environment. Ultimately, integrating meteorological insights ensures that our energy efficiency measures are not only effective but also sustainable, leading to reduced operational costs and enhanced comfort for occupants throughout the year.

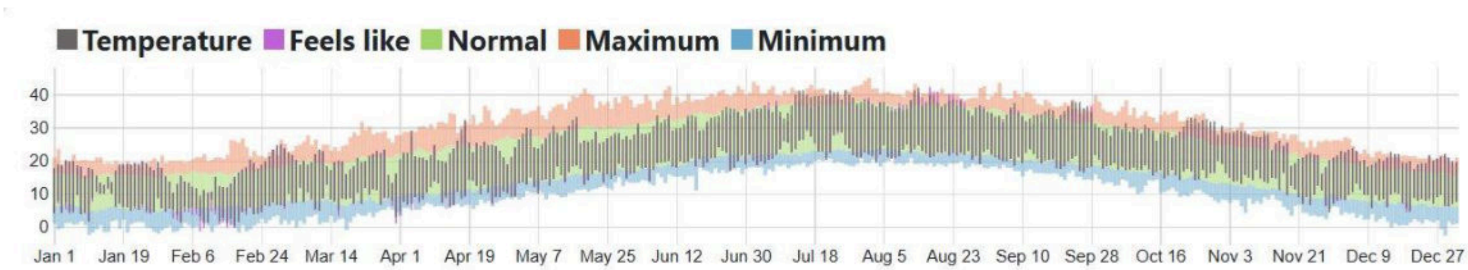

Figure 6: Meteorological data for temperature for the year 2023

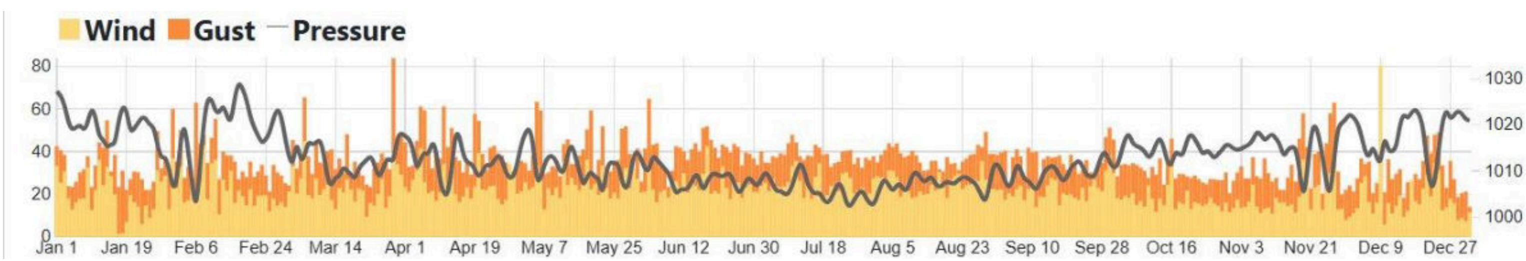

Figure 7: Meteorological data for wind speeds for the year 2023

The data presented in Figures 6 and 7 was sourced from the Visual Crossing website, utilizing information from the meteorological station at Lakatamia Airport, located just 5 kilometers from our building. This proximity ensures that the data accurately reflects the local climate conditions, providing a reliable foundation for our analysis and energy efficiency planning.

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4. ARCHITECTURAL DRAWINGS AND CONSTRUCTION MATERIALS

4.1 Floor Plans

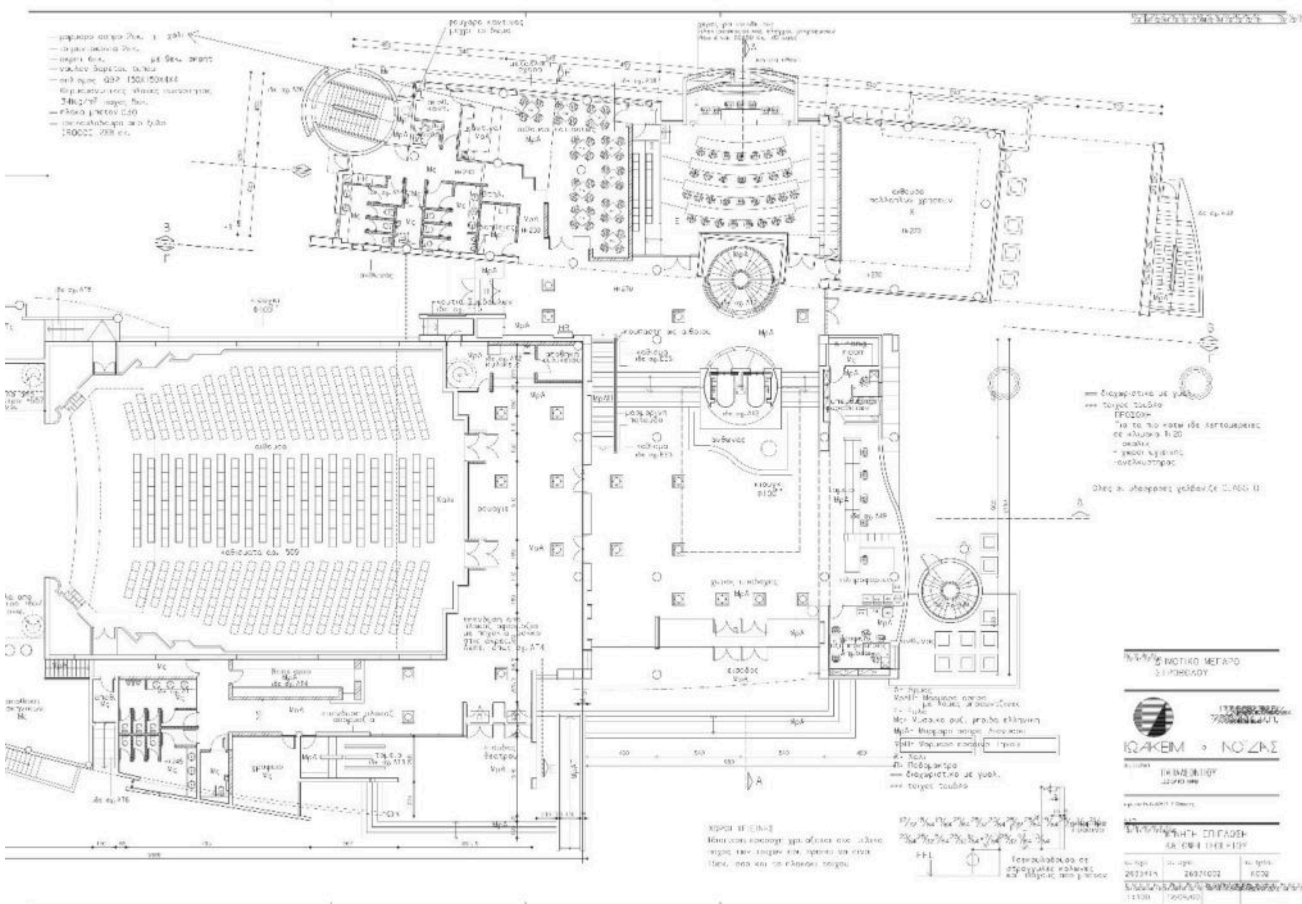

Figure 8: Ground Floor plan

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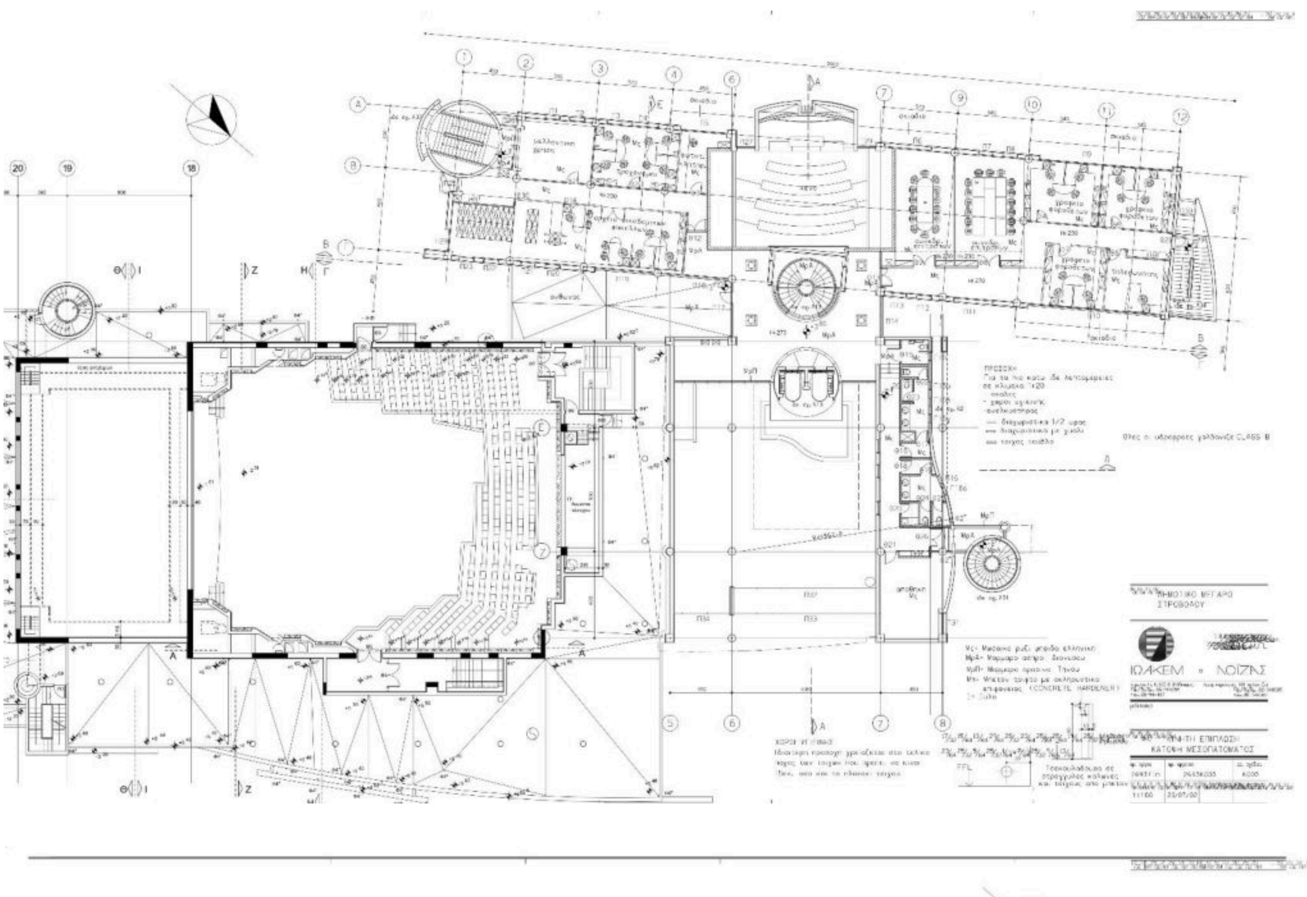


Figure 9: Mezzanine Floor plan

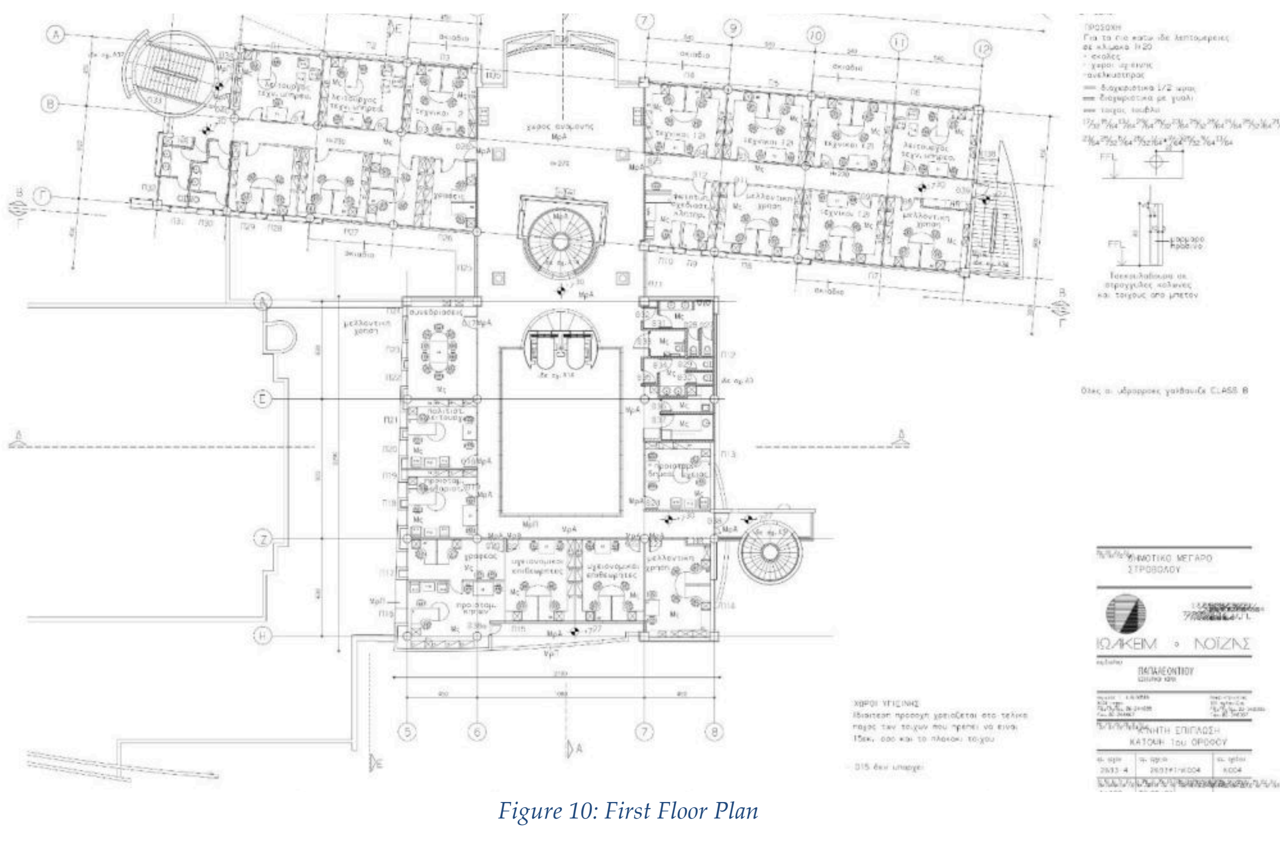


Figure 10: First Floor Plan

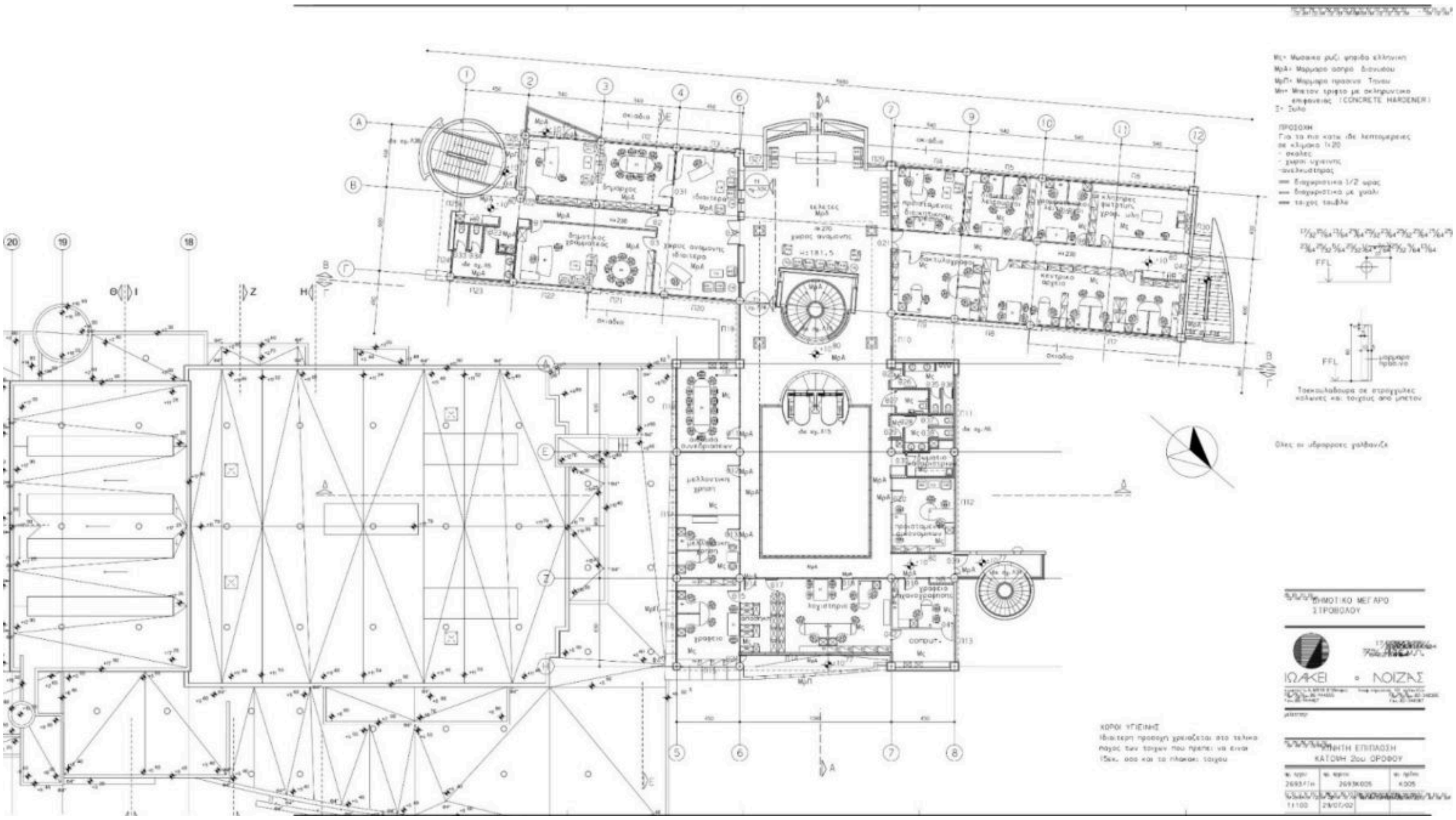
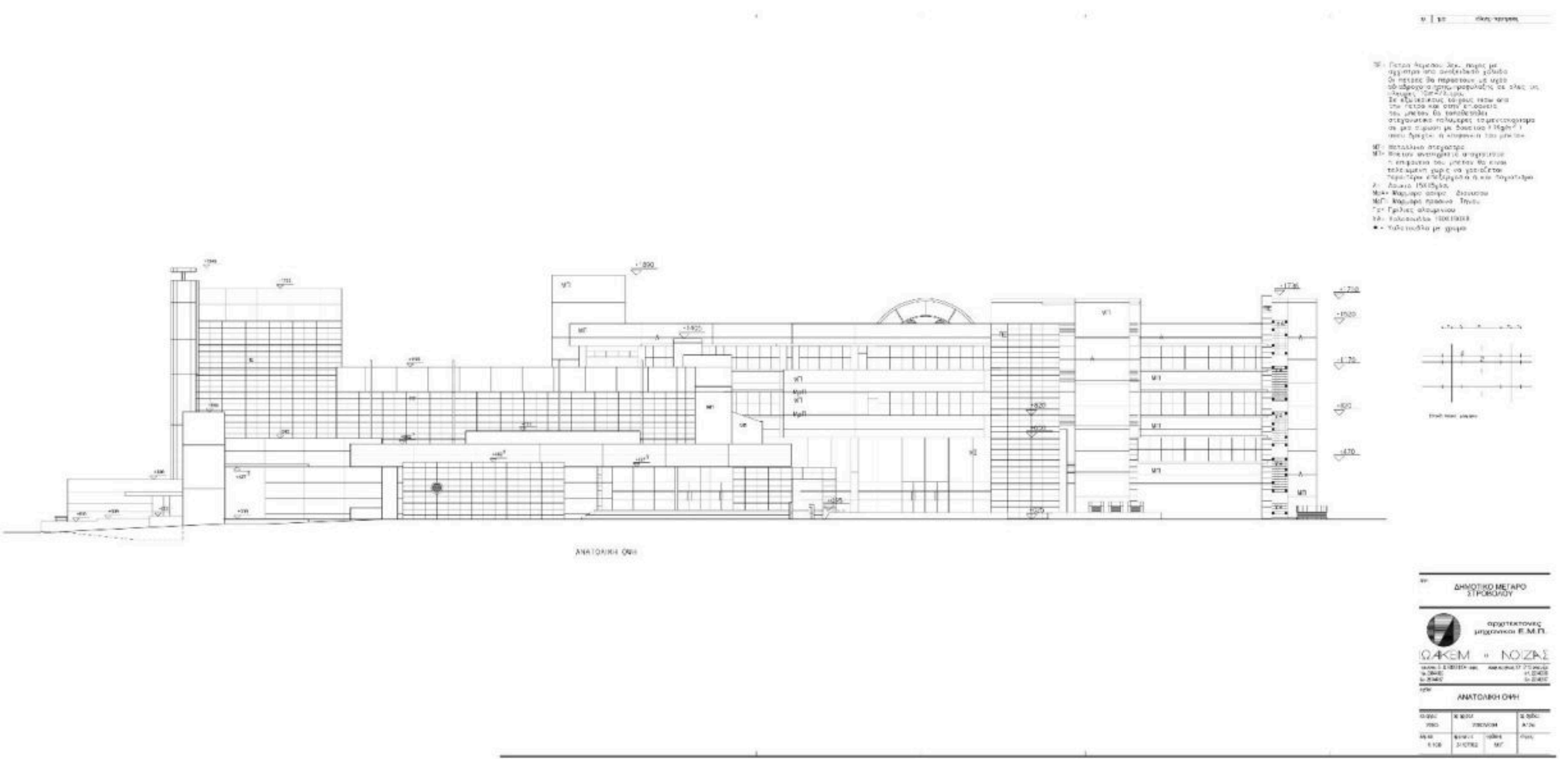
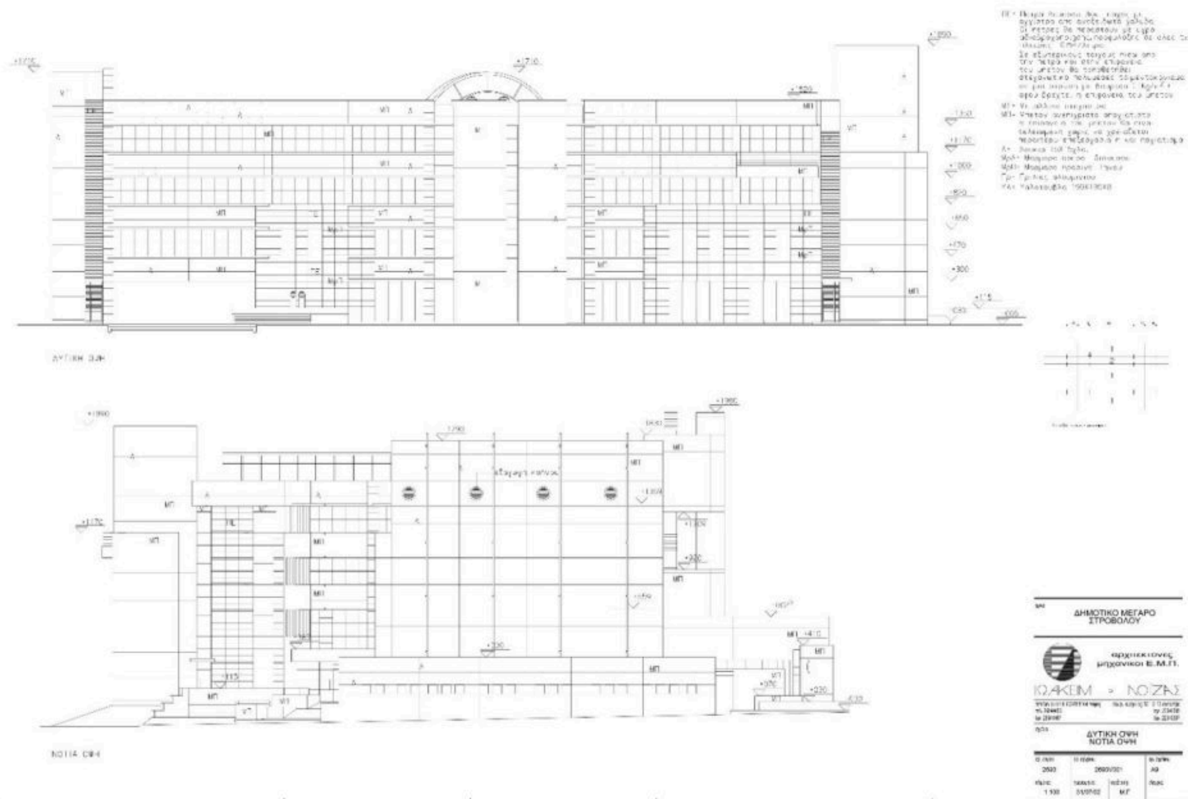


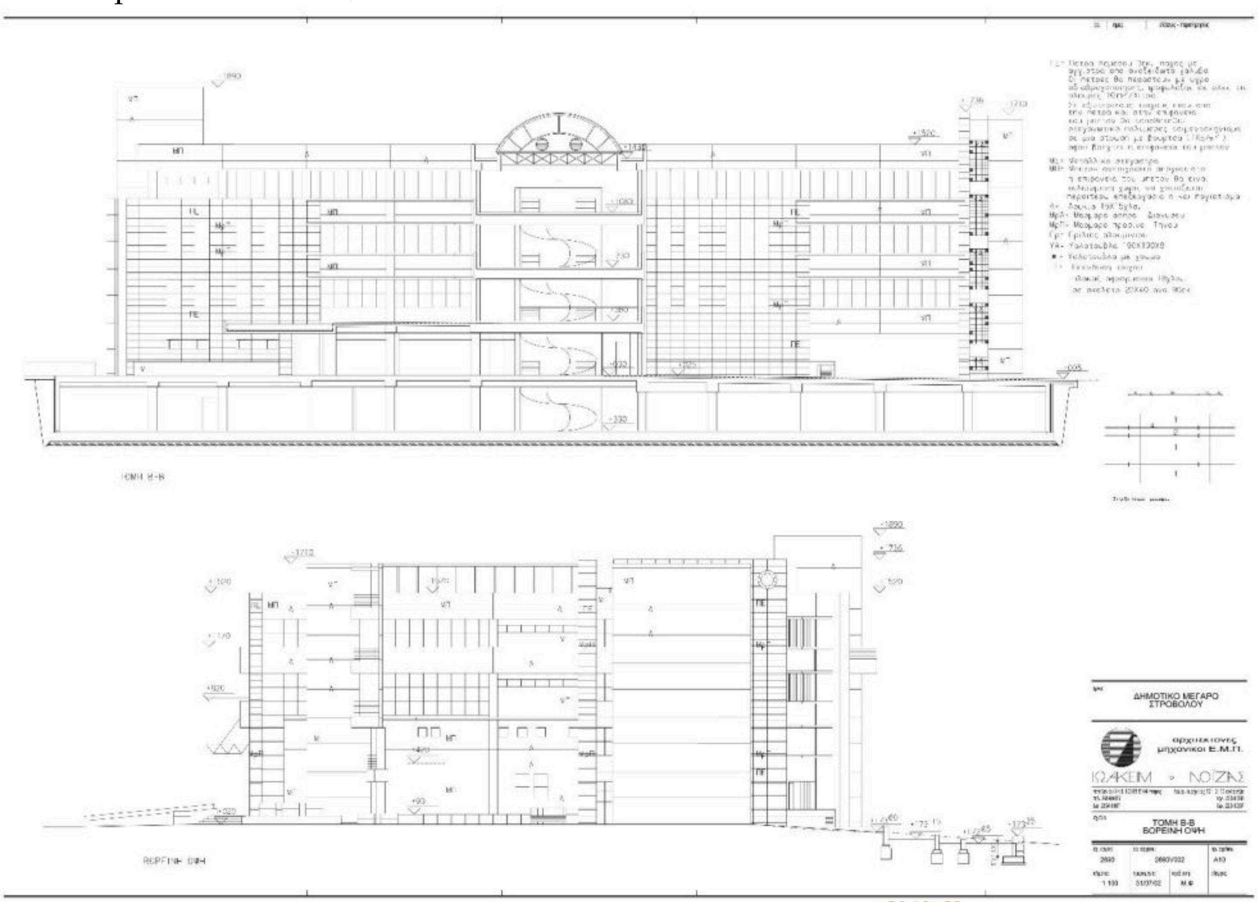
Figure 11: Second Floor Plan



4.2 Elevations and Sections



Top Plan: East Face, Bottom Plan: West and South Sides



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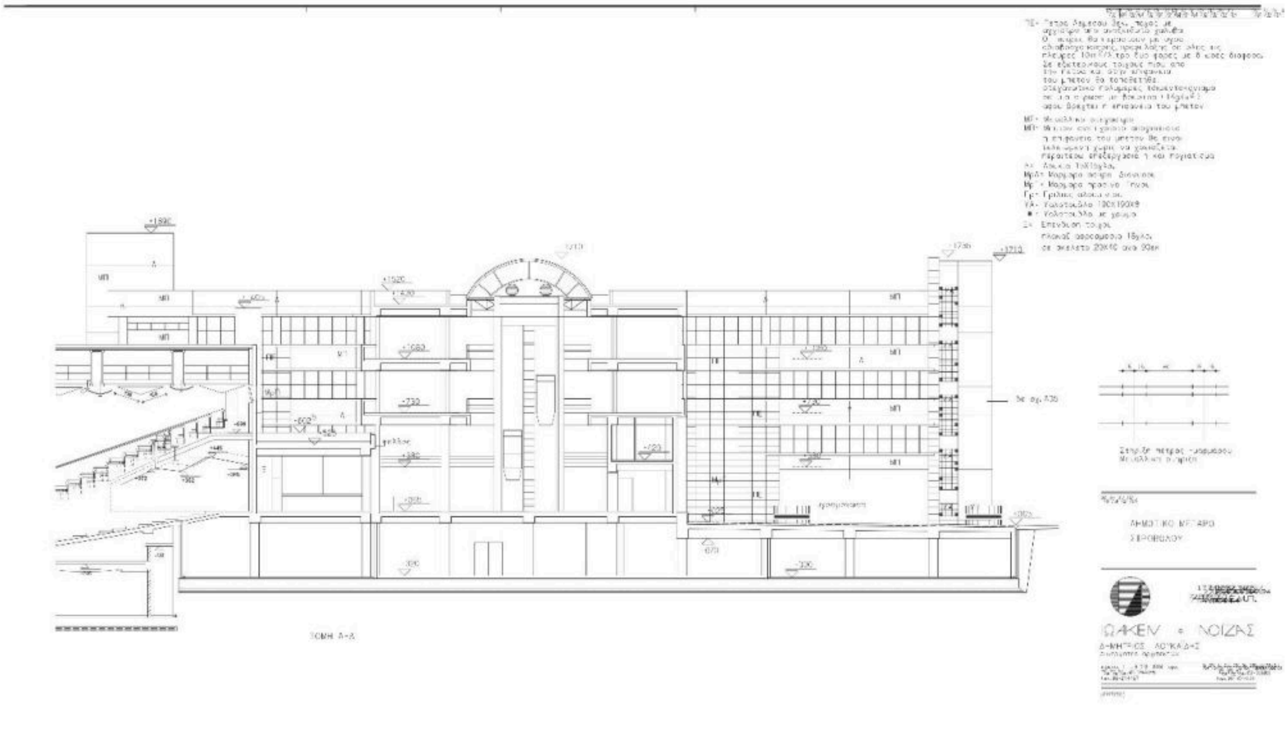
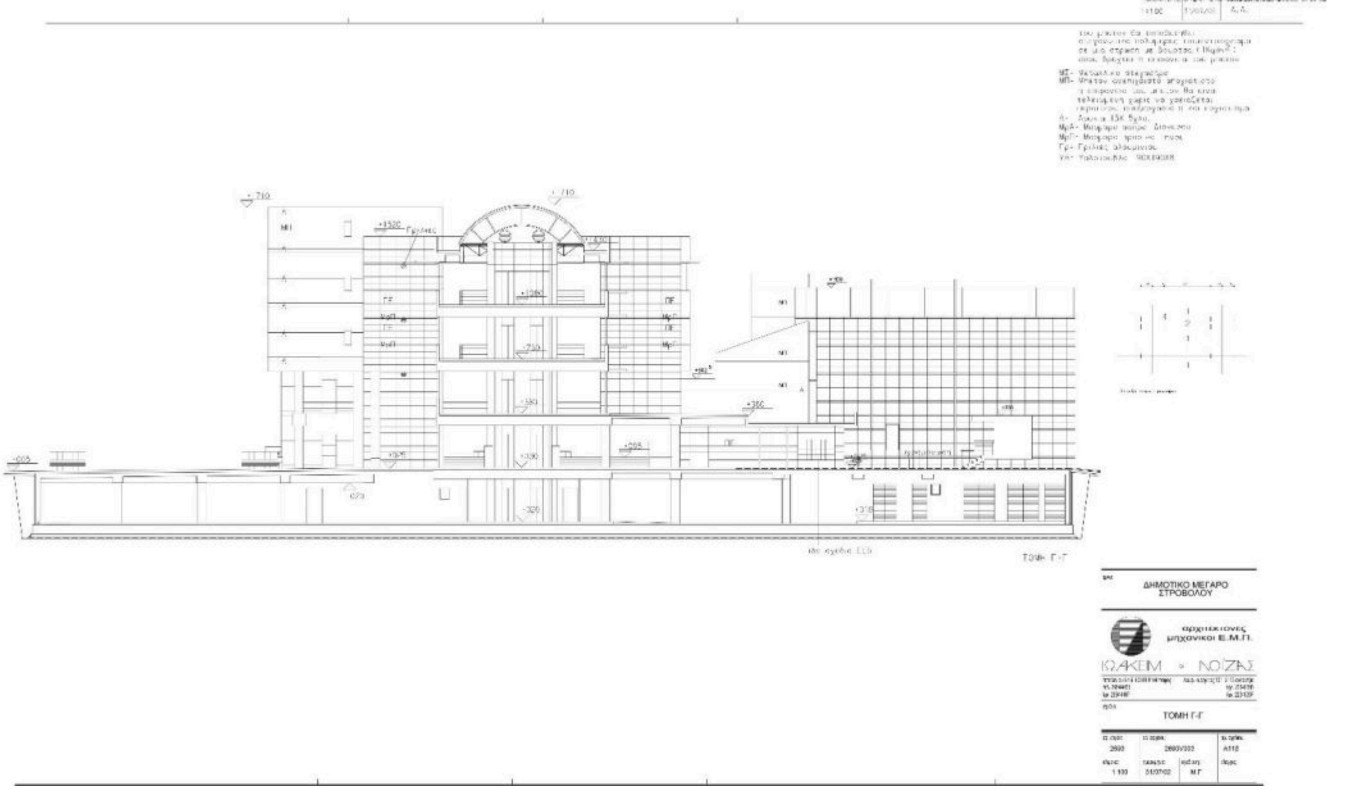
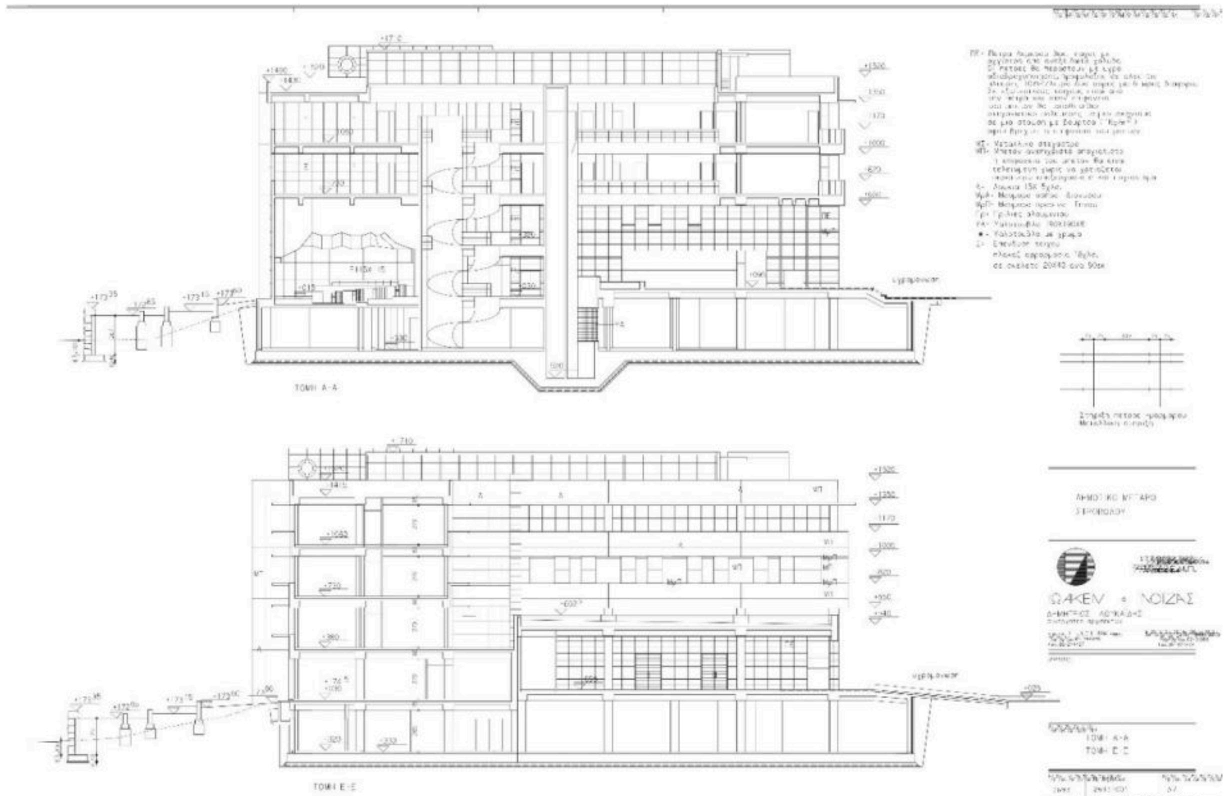
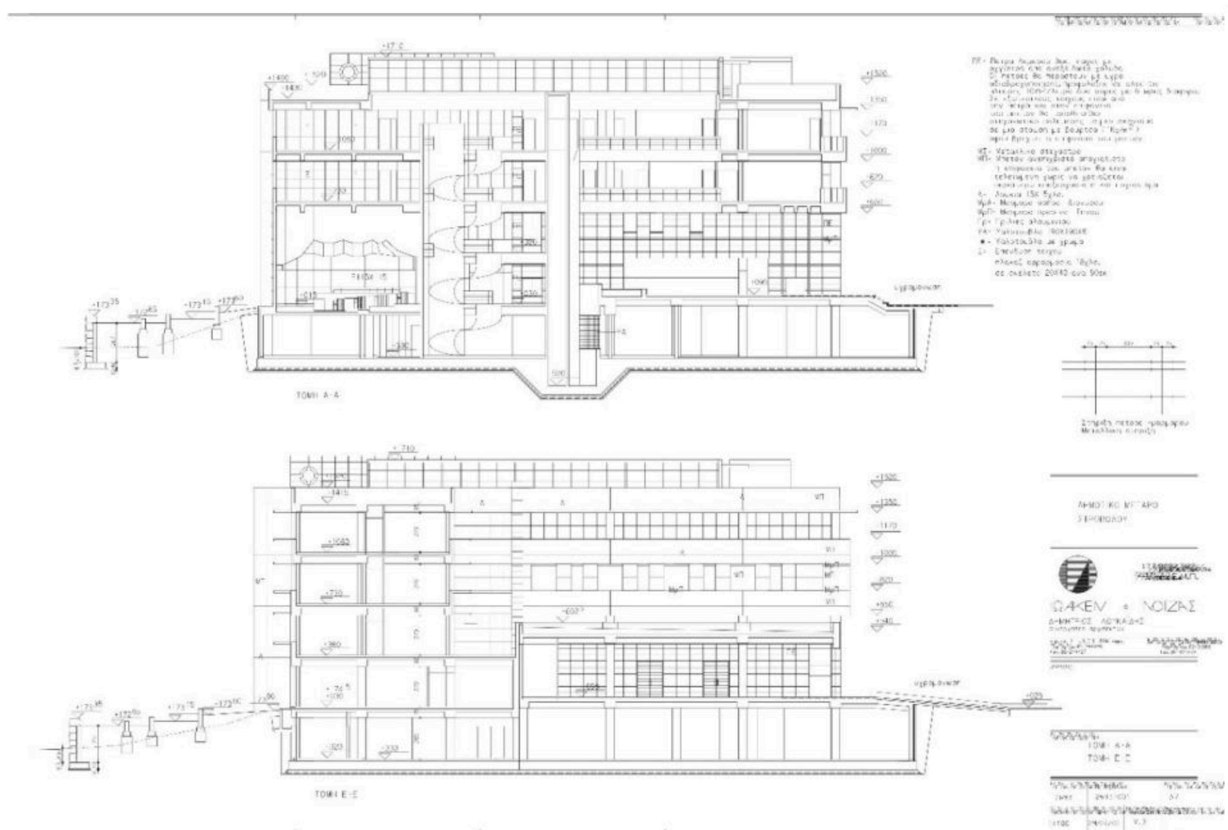


Top plan: Section DD, Bottom plan: Section GG





Top Plan: Section AA and Section EE, Lower Plan: Section BB and North Face



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4.3 Structure of the Building

The building consists of a basement, ground floor, mezzanine, and two upper floors. All areas are accessible via a central staircase, which is integrated into an internal atrium space. The ground floor mainly houses waiting areas, a cafeteria, and public service offices. The mezzanine and the two upper floors accommodate staff offices as well as meeting rooms. Finally, the rooftop and basement contain the mechanical installations and the underground parking space.

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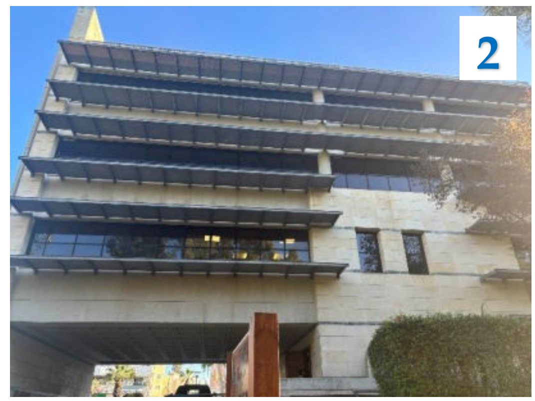
4.4 Construction Materials

- **Masonry:** Reinforced concrete with stone cladding in some places
- **Columns/Beams:** Reinforced concrete
- **Flooring:** Marble and mosaic
- **Roof:** Flat of reinforced concrete, inside there is a false ceiling
- **Frames/Windows:** Double Glazing and Aluminum
- **Doors:** Aluminum
- **Types of shading:** Metal canopies



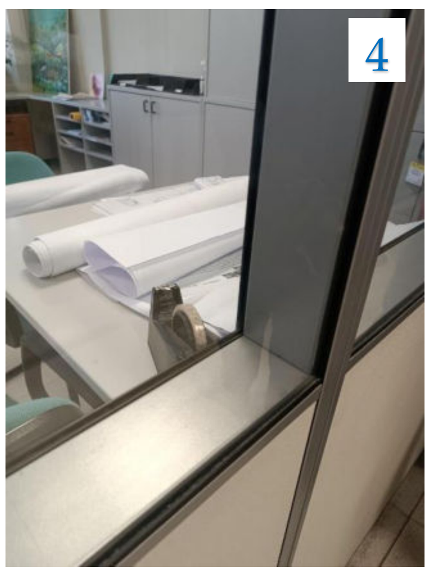
1: Reinforced concrete masonry

2: Metal canopies

3: Clear area covered by a semicircular ceiling of plexiglass material

4: Interior drywall (offices)

Source: On-site photos.



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4.5 U-value calculations for the existing building

1. Floor with marble

Material	Width (m)	Thermal Conductivity Coefficient λ (W/mK)	Thermal resistance R (m^2K/W)
Marble	0.02	2.8	0.007
Concrete	0.15	1.7	0.088
Total U-value			**1.7 W/m^2K**

2. Reinforced Concrete Columns

Material	Width (m)	Thermal Conductivity Coefficient λ (W/mK)	Thermal resistance R (m^2K/W)
Concrete	0.30	2.3	0.13
Total U-value			**2.5 W/m^2K**

3. Roof

Material	Width (m)	Thermal Conductivity Coefficient λ (W/mK)	Thermal resistance R (m^2K/W)
Concrete	0.20	2.1	0.095
Waterproof coating	0.01	0.2	0.05
Total U-value			**2.5 W/m^2K**

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4. Windows and Frames (Single Glazing)

Material	Width (m)	Thermal Conductivity Coefficient λ (W/mK)	Thermal resistance R (m^2K/W)
Single glazing	0.004	1.0	0.004
Aluminum frames		160-200	~0.001
Total U-value			**5.4 W/m^2K**

5. Ground floor

Material	Width (m)	Thermal Conductivity Coefficient λ (W/mK)	Thermal resistance R (m^2K/W)
Concrete	0.15	1.7	0.088
Surface Contact with Ground		~1.5	0.67
Total U-value			**1.0 W/m^2K**

6. External wall with brick and decorative stone (no insulation)

Material	Width (m)	Thermal Conductivity Coefficient λ (W/mK)	Thermal resistance R (m^2K/W)
Decorative Stone	0.10	2.0	0.050
Brick	0.10	0.80	0.125
Interior plaster	0.015	0.87	0.017
Total U-value			**5.21 $W/m^2 \cdot K$**

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5. INSPECTION OF BUILDING

During our visit to the building, we had the opportunity to meet its users, specifically the Architect and the Mechanical / Technical Service Officer. With their help, we managed to carry out recordings, temperature measurements, photograph the equipment and electromechanical systems of the building, as well as collect observations and problem reports from the users themselves.

Final selection and evaluation of the offices on the 2nd floor, since various measurements were taken in them as follows.

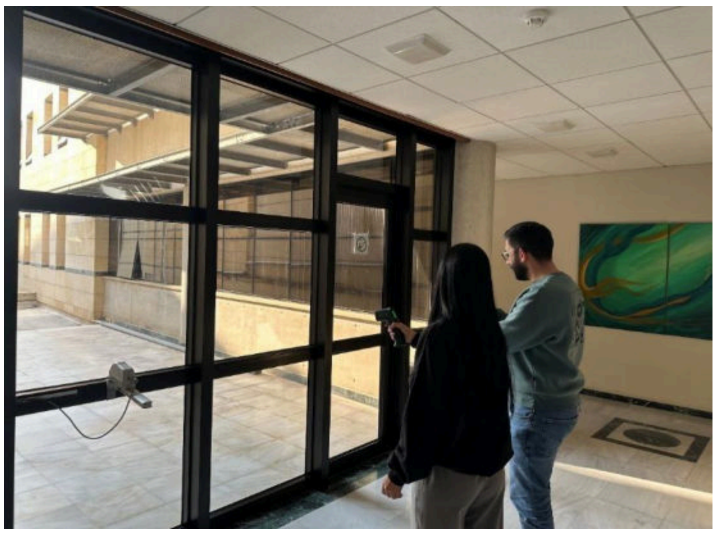
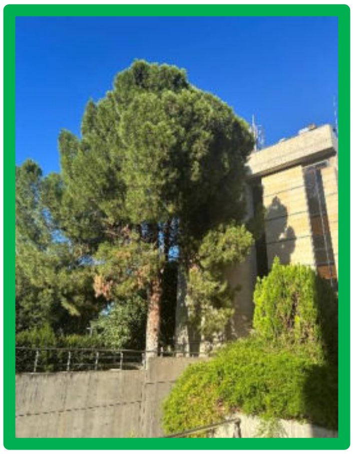


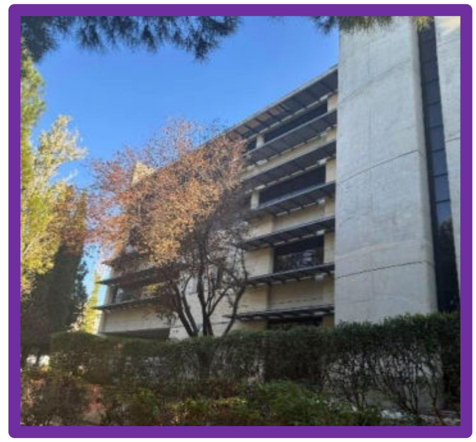
Figure 12: Window measurements

In addition, the visit helped us to better understand the function of the building, especially the offices, through the analysis of architectural plans. In particular, with the use of thermometers we detected some obvious problems in the rooms.

- Understanding the structure and spaces of the building
- Understanding how a building works
- Analysis of electromechanical equipment specifications
- Find obvious problems with premises and equipment
- Chat with engineers and building users

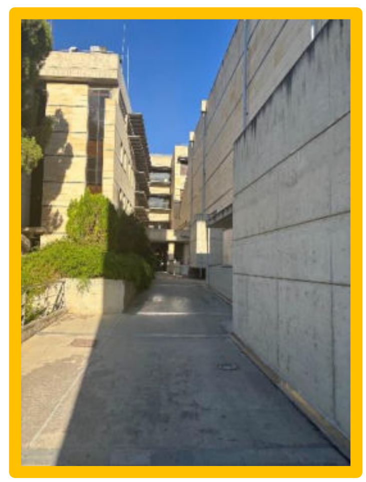


A large tree is located at the eastern side of the building, providing shade to the structure.



Special rectangular-shaped metal shades are installed on the upper sides of all the windows for shading.

A fountain is located to the northwest of the building.



Right next to the building on its eastern side is the Strovolos Municipal Theatre, which also provides shade to the building.

Points for photographing the building

6. EXISTING ELECTROMECHANICAL EQUIPMENT

The building is equipped with a variety of advanced systems to ensure functionality and comfort. It features air conditioning systems such as VRV (Variable Refrigerant Volume), Split Units, AHUs (Air Handling Units), and a Chiller. A ventilation system with duct-based air distribution provides efficient air circulation, while water supply systems, including pumps, ensure the provision of hot, cold, and potable water. The external fountain system operates with two dedicated pumps, and the sewage system includes two pumping stations for effective waste management. Additionally, the building is equipped with an elevator for vertical transportation and comprehensive lighting systems to meet all illumination needs.

6.1 Detailed explanation of each system:

VRV Air Conditioning System: VRV systems modulate the flow of refrigerant to multiple indoor units, allowing for individualized temperature control across different zones within a building. This modulation enhances energy efficiency by adjusting the refrigerant volume based on the specific cooling or heating demands of each area [1].

Split Unit Air Conditioners: Split unit air conditioners consist of an indoor unit and an outdoor unit connected by refrigerant piping. The indoor unit absorbs heat from the room air, which is then transferred to the outdoor unit where it is dissipated, effectively cooling the indoor space [2].

Air Handling Units (AHUs): AHUs are integral components of HVAC systems that manage and condition air before distributing it throughout a building. They typically incorporate elements such as filters for air purification, fans for circulation, heat exchangers for temperature regulation, and humidifiers or dehumidifiers to control humidity levels [3].

Chiller Systems: Chillers remove heat from a liquid via a vapor-compression or absorption refrigeration cycle. This cooled liquid circulates through a heat exchanger to provide air conditioning in large buildings or to cool equipment. Chillers are essential for maintaining desired temperatures in various industrial and commercial applications [4].

Ducted Ventilation Systems: Ducted ventilation systems utilize a network of ducts to distribute fresh air throughout a building, ensuring adequate indoor air quality. These systems can operate by supplying fresh air, exhausting stale air, or balancing both to maintain optimal ventilation [5].

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Water Supply Pumps in Buildings: Water supply pumps are crucial in buildings for delivering water to various systems, including heating, cooling, potable water, and fire safety. They ensure consistent water pressure and flow, adapting to the building's varying demands to maintain efficient operation [6].

Fountain Pump Systems: Fountain pumps circulate water in fountains, creating continuous movement and preventing stagnation. Submerged in the fountain's reservoir, these pumps draw water in and propel it through the fountain's nozzle, producing the desired water display [7].

Sewage Pumping Stations: Sewage pumping stations are employed when gravity alone cannot transport wastewater to the main sewer system. They collect sewage in a holding tank; once it reaches a certain level, pumps activate to move the waste to higher elevations or treatment facilities, ensuring proper waste management [8].

Elevator Systems: Elevators facilitate vertical transportation within buildings. They typically operate using electric motors that drive traction cables and counterweights or hydraulic systems that raise and lower the elevator car, providing safe and efficient movement between floors [9].

Lighting Systems in Buildings: Building lighting systems are designed to provide adequate illumination for various spaces, considering factors such as light distribution, energy efficiency, and the visual comfort of occupants. Effective lighting design enhances functionality and aesthetics while minimizing energy consumption [10].

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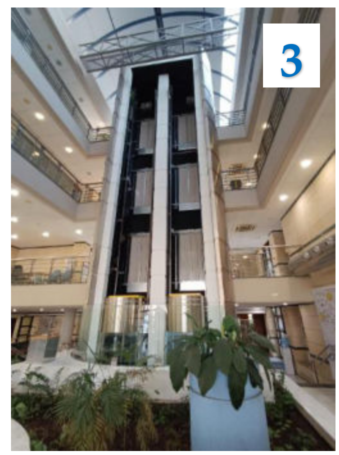
Type of System	Quantity/Power	Brand name
CHILLER	1 x 115 kW	BLUEBOX
VRV	20 x 20 kW	DAIKIN
SPLIT UNITS	5 x 3.5 kW	DAIKIN
AHUs	30 kW	CLEVER
PUMPS	20 kW	WILO
FOUNTAIN	502 W	OASE

Table 1: Existing electromechanical equipment



1: Indoor AC unit

2: AHU outdoor unit

3: Elevator

4: VRV outdoor units

5: VRV outdoor unit label

7. CURRENT ENERGY PERFORMANCE CERTIFICATE

The current Energy Performance Certificate (EPC) of the Town Hall, issued in 2022, reveals significant shortcomings in the building's energy efficiency. With an energy efficiency rating of D, the building consumes a substantial 422 kWh/m² annually, which classifies it as highly inefficient and environmentally detrimental. This inefficiency is further highlighted by its carbon dioxide emissions, which reach 123 kg CO_2/m² per year, contributing significantly to the building's carbon footprint. Moreover, there is a complete lack of integration of renewable energy sources (RES) in the building's energy system, as its annual RES contribution is recorded at 0 kWh/m². These findings underscore the urgent need for comprehensive energy-saving measures and the adoption of sustainable technologies to improve the building's overall performance and environmental impact.

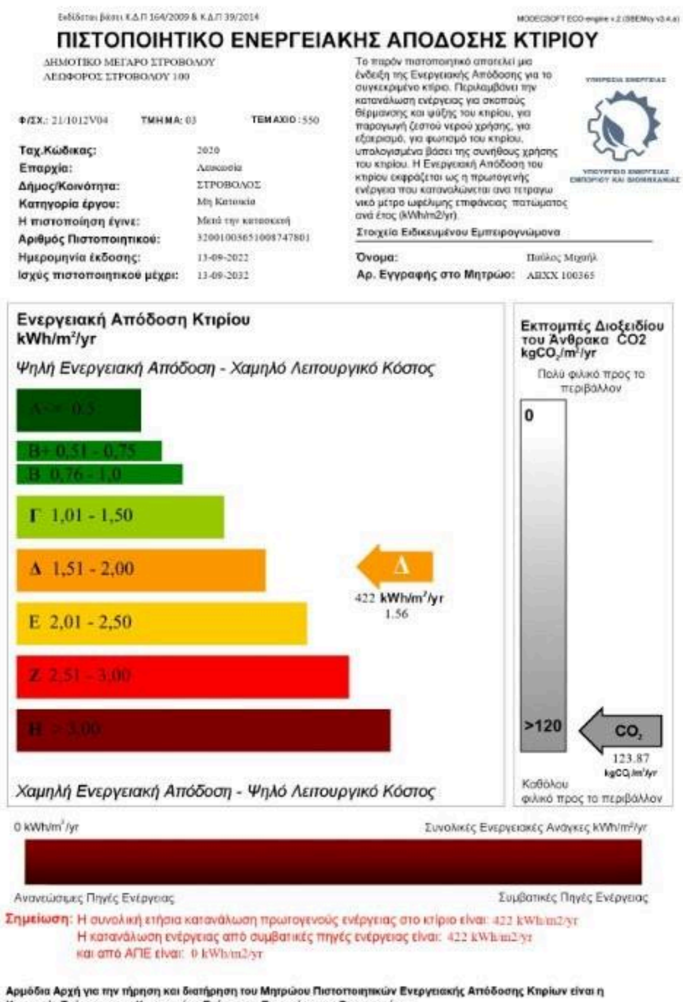


Figure 13: Current EPC of Strovolos Municipal

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8. CURRENT PROBLEMS AND OBSERVATIONS

During our visit to the offices, we identified some problems related to the openings, the built-in air conditioner and their maintenance.

In Figure 14, in the indoor air conditioning units, a leak was observed from the condensate pipe in the suspended ceiling, resulting in the accumulation of water and wear of the suspended ceiling.

In Figure 15, insufficient thermal insulation was found in the office frames, which causes instability in the temperature of the rooms. In addition, the luminaires are not LED technology, thus leading to unnecessary energy consumption.

In Figure 16, difficulty was observed in cleaning the windows due to the external shades. Although their original purpose was to offer convenience, they ultimately act as a barrier, allowing dust to accumulate on window surfaces.

Figure 14: Leakage from the condensate pipe in the suspended ceiling

Figure 15: Office frames and lighting fixtures

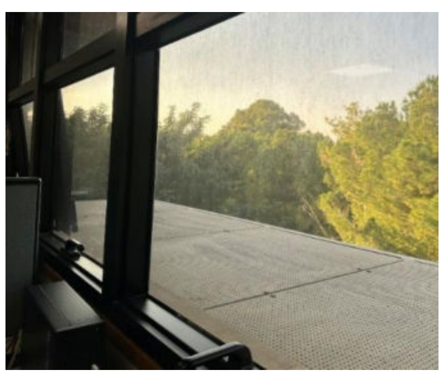

Figure 16: Windows and exterior sunshades

The insulation of the VRV and Chiller piping was found to be damaged, leading to substantial energy losses. This deterioration in insulation compromises the efficiency of the systems, as heat transfer is no longer adequately controlled. Furthermore, critical equipment was left exposed to extremely high temperatures, which not only reduces the performance of the machinery but also increases the risk of wear and tear over time. These problems underscore the urgent need for maintenance and protective measures to ensure both energy efficiency and the longevity of the equipment.

Figure 17: Piping wear and damages

Figure 18: Piping wear and damages

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Figure 19: Piping wear and damages

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9. TEMPERATURE MEASUREMENTS

9.1 Technical Characteristics of equipment

During our site visit to the building, we conducted a detailed thermographic analysis using thermal cameras. This process allowed us to identify areas of significant heat loss, thermal bridging, and insulation gaps that are not visible to the naked eye. By capturing infrared images, we were able to pinpoint problematic zones in the building envelope, such as windows, doors, and external walls, where energy inefficiencies are most pronounced. This valuable data will guide our efforts in recommending targeted insulation improvements and sealing measures, ultimately enhancing the building's overall thermal performance and reducing energy consumption.

Figure 20: FLIR Thermal Camera

Figure 21: MASTECH Thermometer

Thermal Camera

- Thermal sensitivity < 0.15° C at 25° C
- Temperature range -10° C to +100° C
- Field of view/min focus distance Fixed 25° x 25°/0.3m

Thermometer with laser

- Temperature range: -20°C ~ 500°C
- Accuracy: ± (2% + 2 ° C)
- Detection distance 50-150mm

9.2 Thermal Images and Analysis

During the building inspection, a thermal camera and a specialized thermometer were used to measure and record temperatures of various structural elements and equipment throughout the building. It's worth noting that these measurements were taken on November 8th at 2:00 PM (14:00).

Figure 22 shows the temperature measurement of the cold-water pipes' external surface located on the building's roof, registering at 22.8°C. Figures 23 and 24 display measurements taken at the northwestern and southwestern office window frames, respectively. A notable observation is the significant temperature difference between these locations - the southwestern frame measured 36.8°C, while the northwestern frame showed 25.3°C.

This substantial temperature variation can be attributed to the building's positioning. The office on one side faces the Pedieos River, which creates a cooler microclimate. In contrast, the opposite office receives constant solar radiation exposure, resulting in higher thermal loads and maintaining elevated temperature levels. This temperature differential wasn't limited to just window frames; it was consistently observed across walls, columns, beams, ceiling, and even the floor.

These measurements provided valuable insight into why employees, despite working in the same section of the building, experience varying levels of thermal comfort depending on their office orientation. The physical location and exposure to environmental factors significantly influence their perception of temperature and overall comfort in their workspace.

Concurrently with the thermal camera readings, measurements were also taken using a laser thermometer at the same locations. It's important to understand that this laser thermometer doesn't offer the same level of precision as the thermal camera, which explains why the temperature readings don't exactly match between the two devices. Nevertheless, the fundamental temperature difference between the two sides of the building remained evident, confirming the initial observations about the building's thermal behavior and its impact on occupant comfort

This comprehensive analysis helped to understand how building orientation and environmental factors can create distinct microclimates within the same structure, directly affecting the comfort levels of its occupants.

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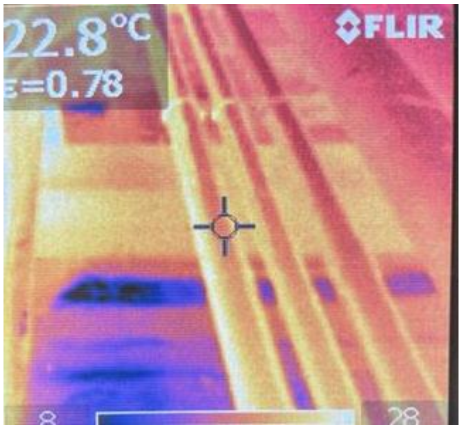

Figure22: Cold water pipes at roof (14:00)

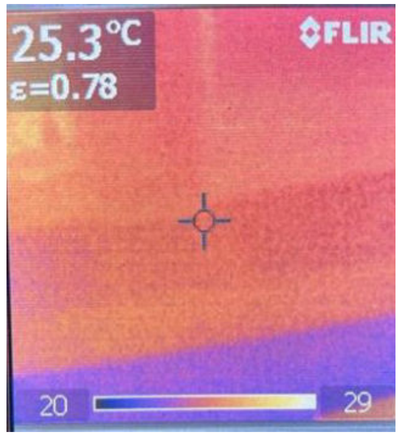

Figure 23: Northwestern office window frame (14:00)

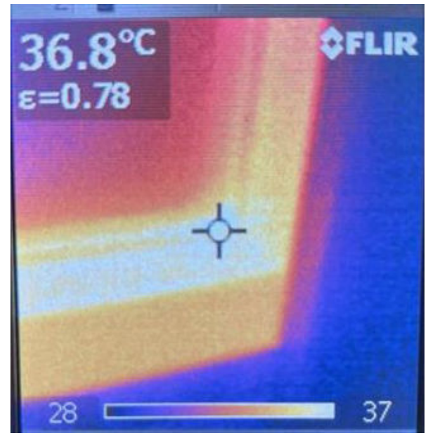

Figure 24: Southwestern office window frame (14:00)

Figure 25: Eastern office window frame (14:05)

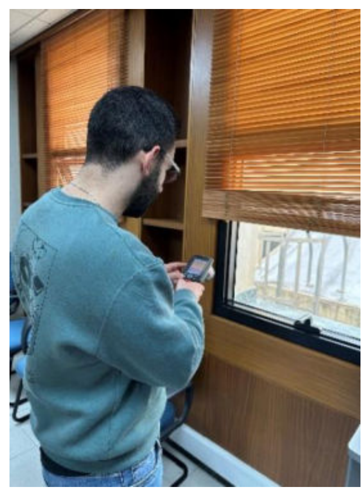

Figure 26: Eastern office window frame (14:05)

Figure 27: East-facing column (14:05)

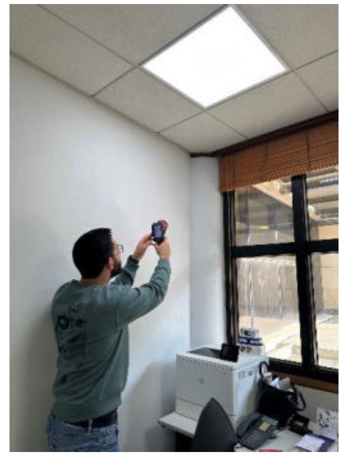

Figure 28: North-facing column (14:05)

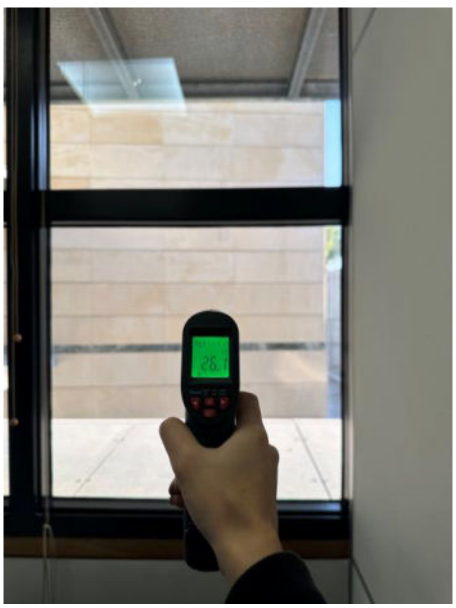

Figure 29: Northwest office window at 14:00, 26.1 °C

Figure 30: Northwest office window frame at 14:00, 27.6 °C

10. 3D BUILDING MODEL - GRASSHOPPER-LADYBUG INTERFACE

10.1 3D Building Model in Rhino program

Using the Rhinoceros program, we created the form of the building along with its openings. We found that the building has a plethora of openings on both its north and south sides. This feature can be particularly useful in the next stage, if properly utilized.

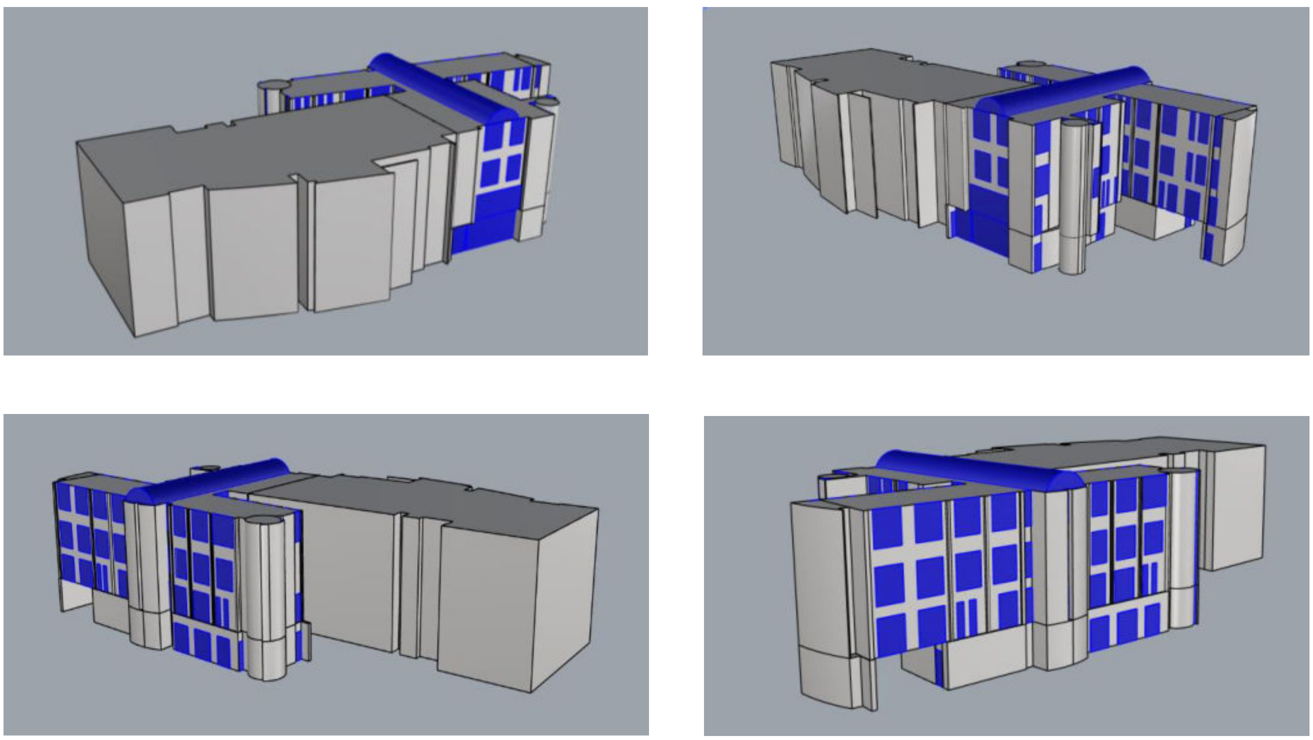

Figure 31: 3D model of the building from all orientations and openings to the north and south

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10.2 Grasshopper-Ladybug Interface

Using the Grasshopper/Ladybug plug-ins of Rhinoceros, we were able to create sunpath diagrams and sunhourpositions diagrams. This will be followed by the process of creating the command interface and explaining them.

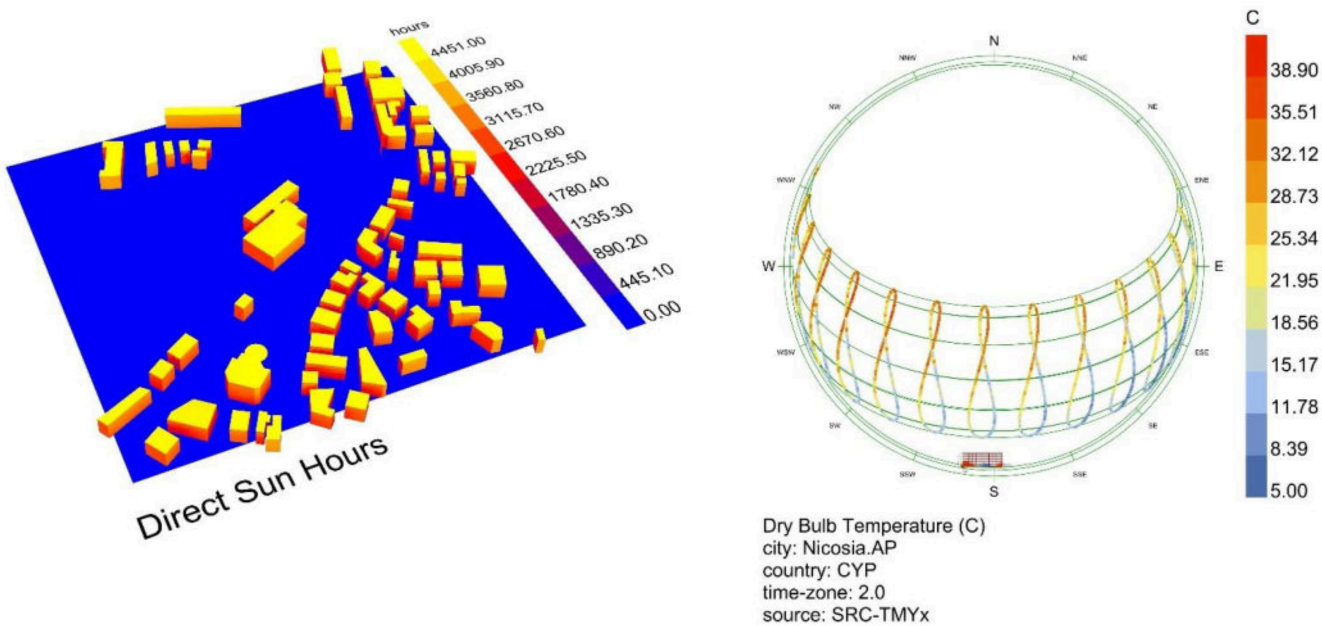
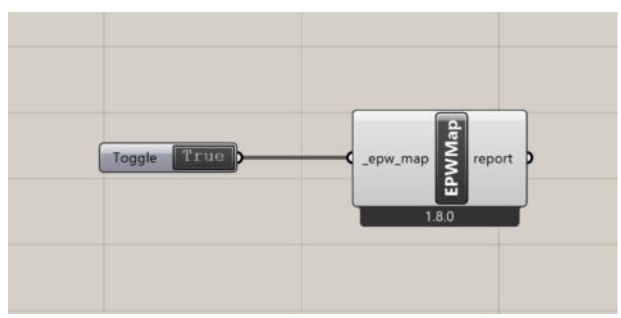


Figure 32: Left: 3D model of the building with the surrounding buildings. Right: Sunpath for the whole duration.

10.3 Collecting data from EPW maps/Meteorological data station

The first step of creating the sunpath diagram and sunhour positions was to acquire data from a Meteorological data station and with the help of EPW maps plugin toggle from ladybug we get access to the maps and choose the closest station to our building site.



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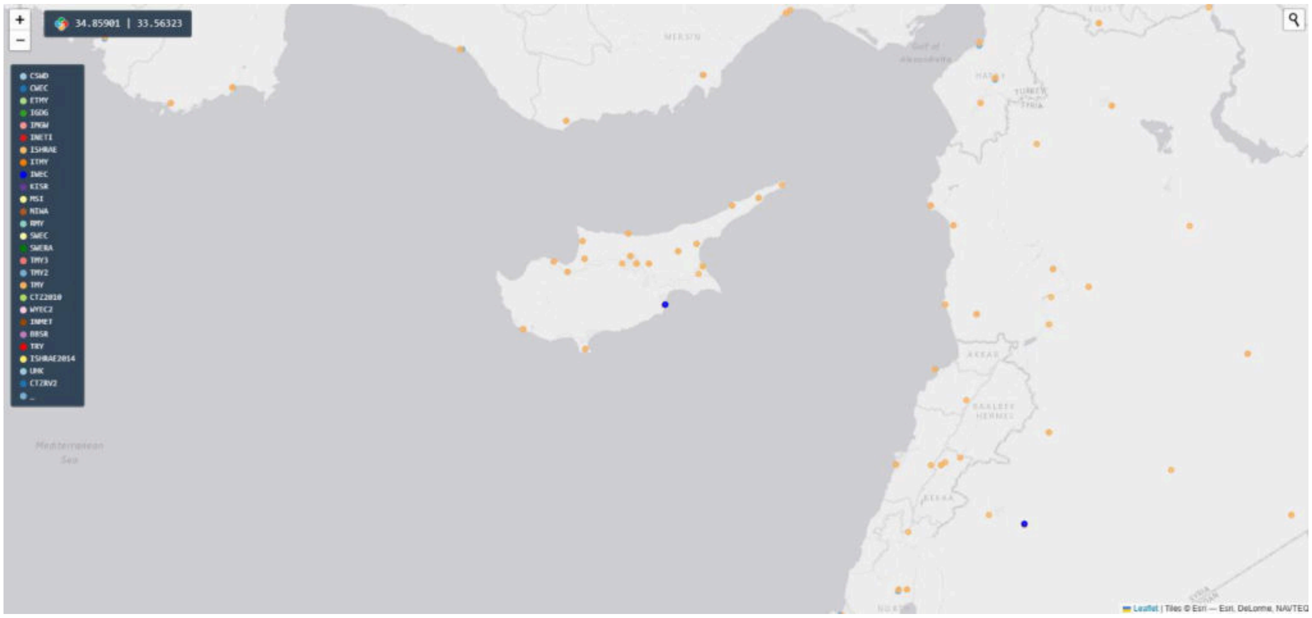
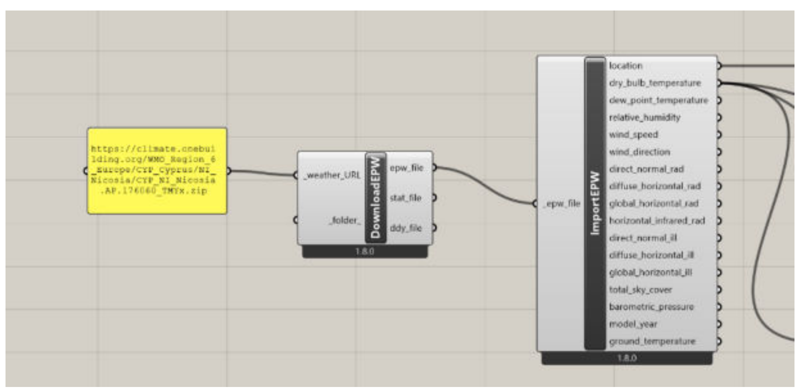
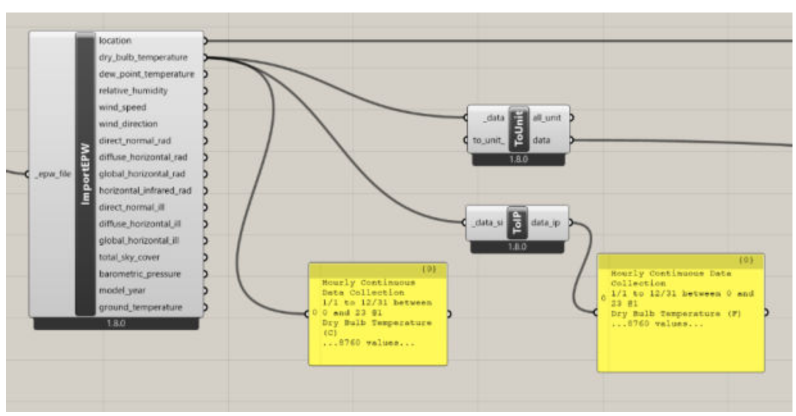


Figure 33: EPW Meteorological Station Data, Cyprus

10.4 Transforming the data into grasshopper accessible data

By using the plugin DownloadEPW and ImportedEPW we can start using the data of the location. However the data must be changed into units and IP in order to suit our yearly,monthly and hourly number system. We do that by using data converters.





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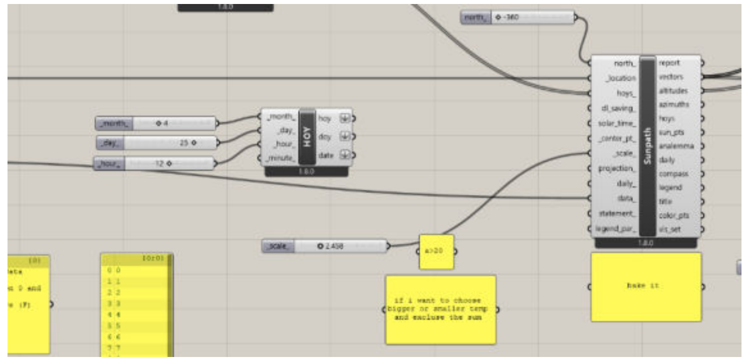
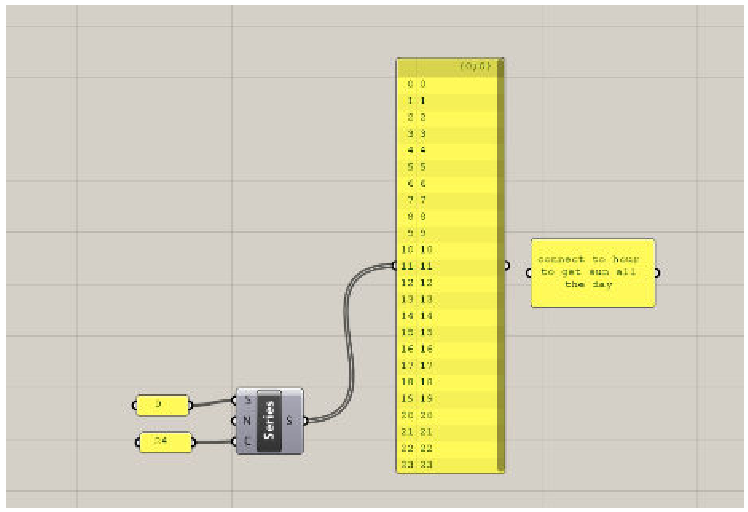
10.5 Creating our Sunpath plugin

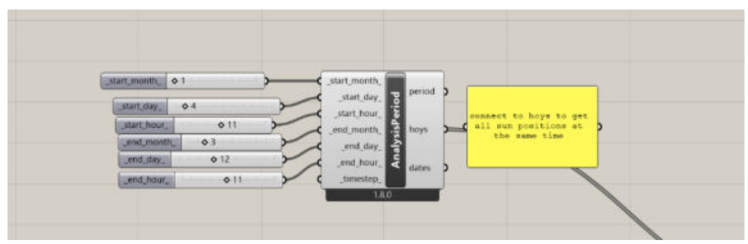
Now using the SunPath plugin we start connecting different plugins to it so we can create our sunpath diagram with different options.

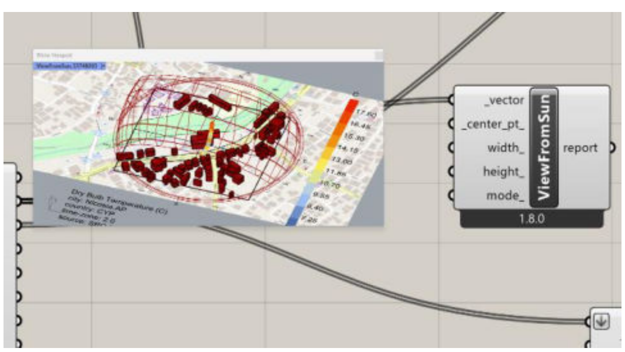
Such plugins help us have the option to:

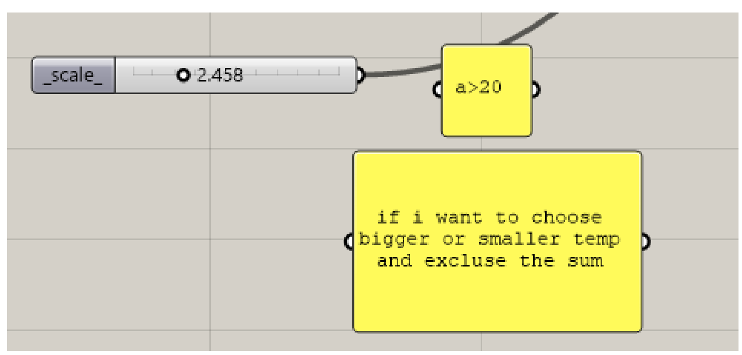
- Showcase all the sun positions all day.
- Showcase all the sun positions at the same time.
- Change the size of the sun orb and sun diagram.
- The orientation of the topography.
- The altitude of the sun.
- View from the sun's position.
- Have specific sun positions by limiting it to specific month, day and hour.











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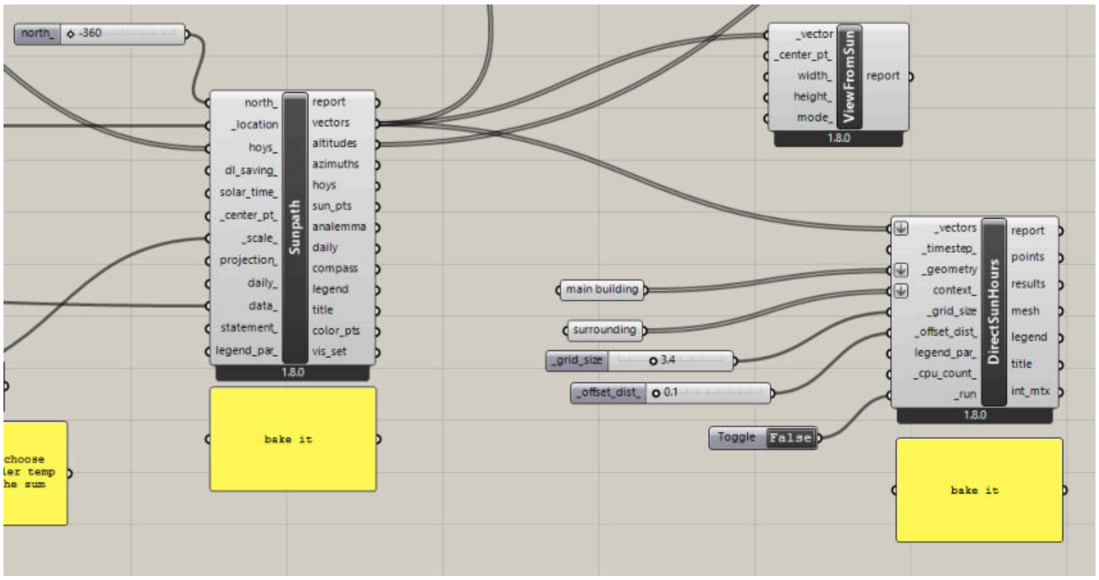
10.6 Creating the sun hour positions

After adding these helping plugins we mentioned before, we added our final plugin which is called DirectSunHours. By connecting this plugin to our previous Sunpath plugin we create a diagram which tells us about the temperature in the area at different times. Finally, we add our building and the surrounding area as mesh objects, and we bake the results.



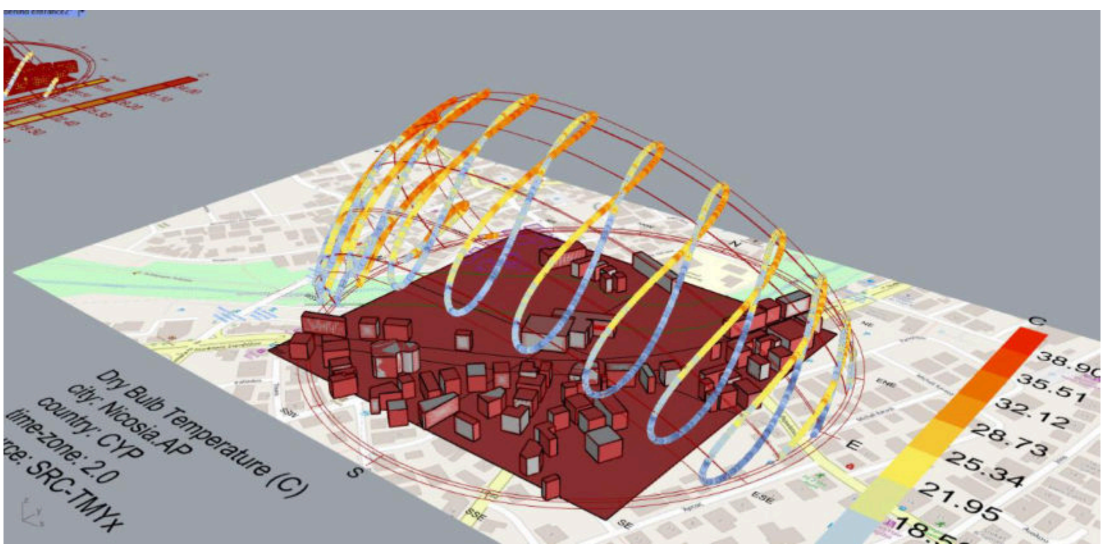
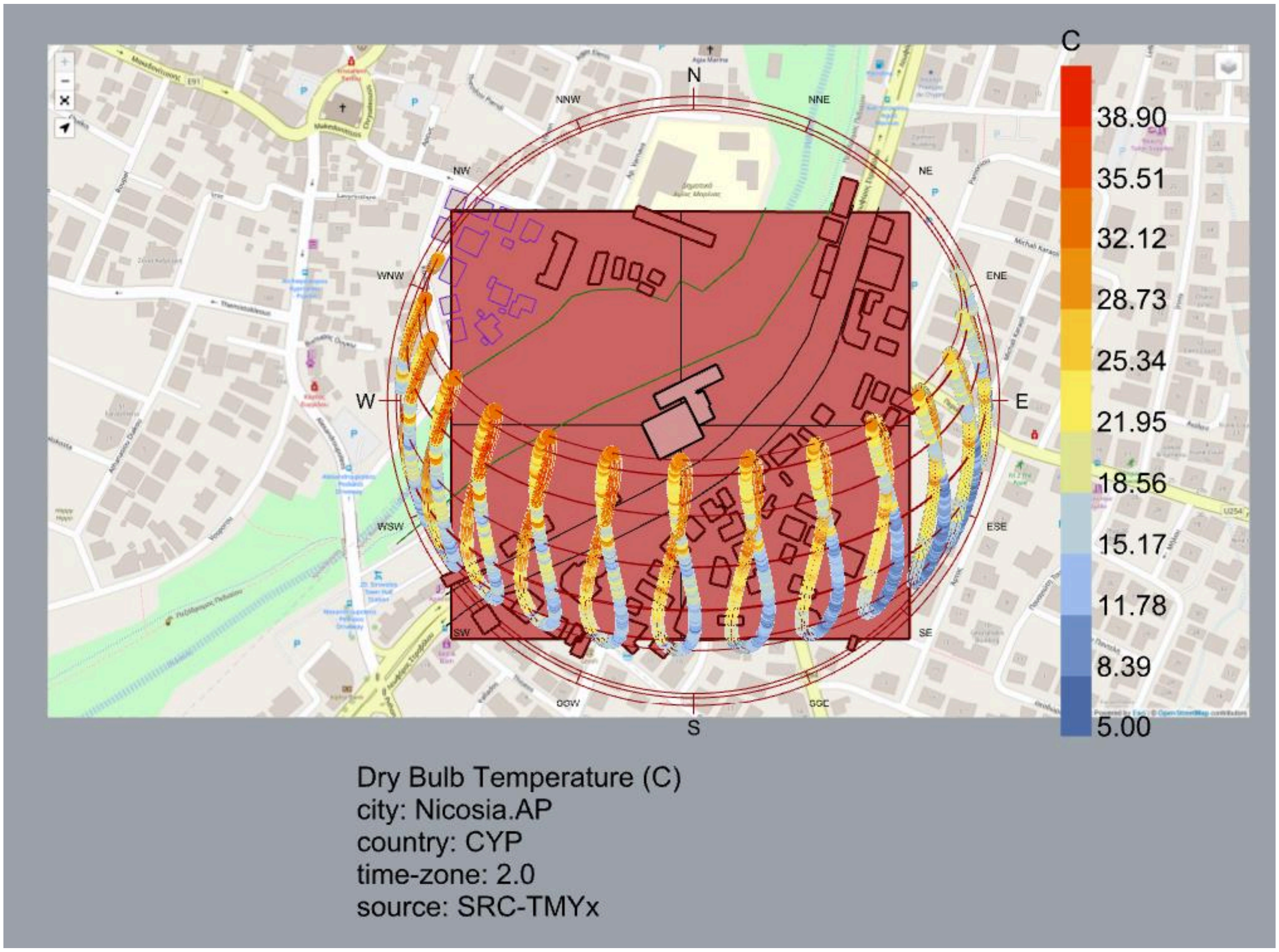
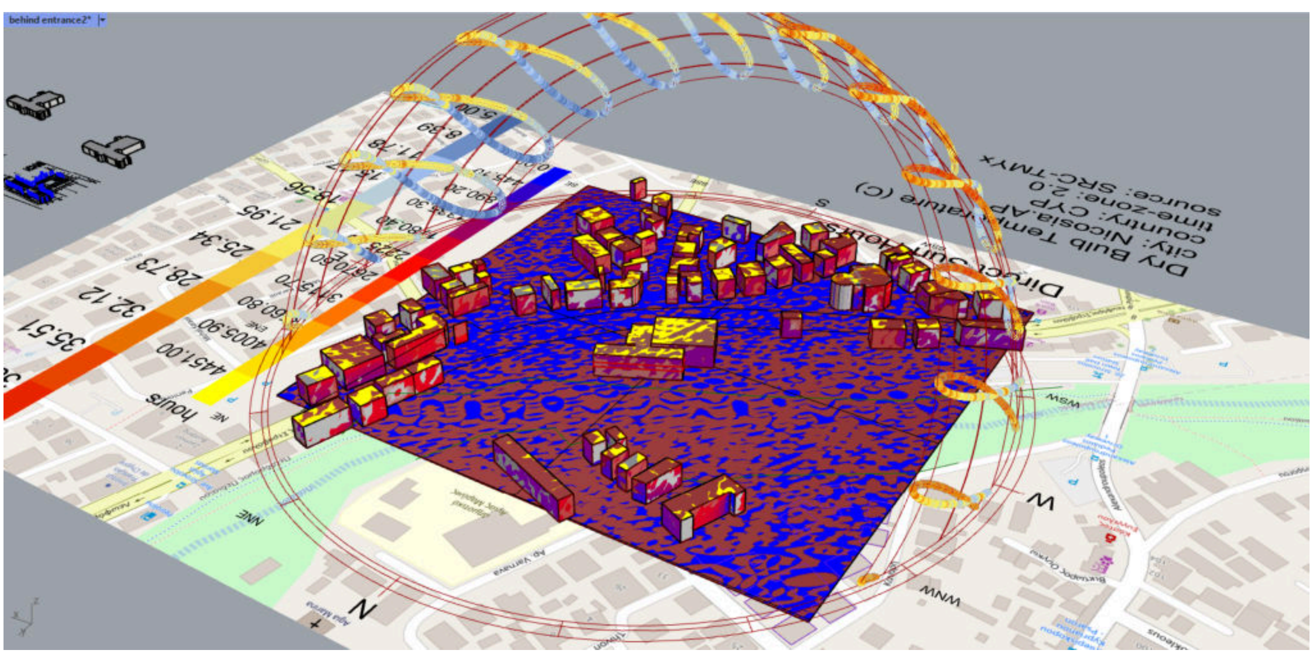


Figure 34: Azimuth sun diagram with Sun's all positions


C
38.90
35.51
32.12
28.73
25.34
21.95
18.56
15.17
11.78
8.39
5.00
N
NNW
NNE
NW
NE
WNW
ENE
W
E
WSW
ESE
SW
SE
S
Dry Bulb Temperature (C)
city: Nicosia.AP
country: CYP
time-zone: 2.0
source: SRC-TMYx



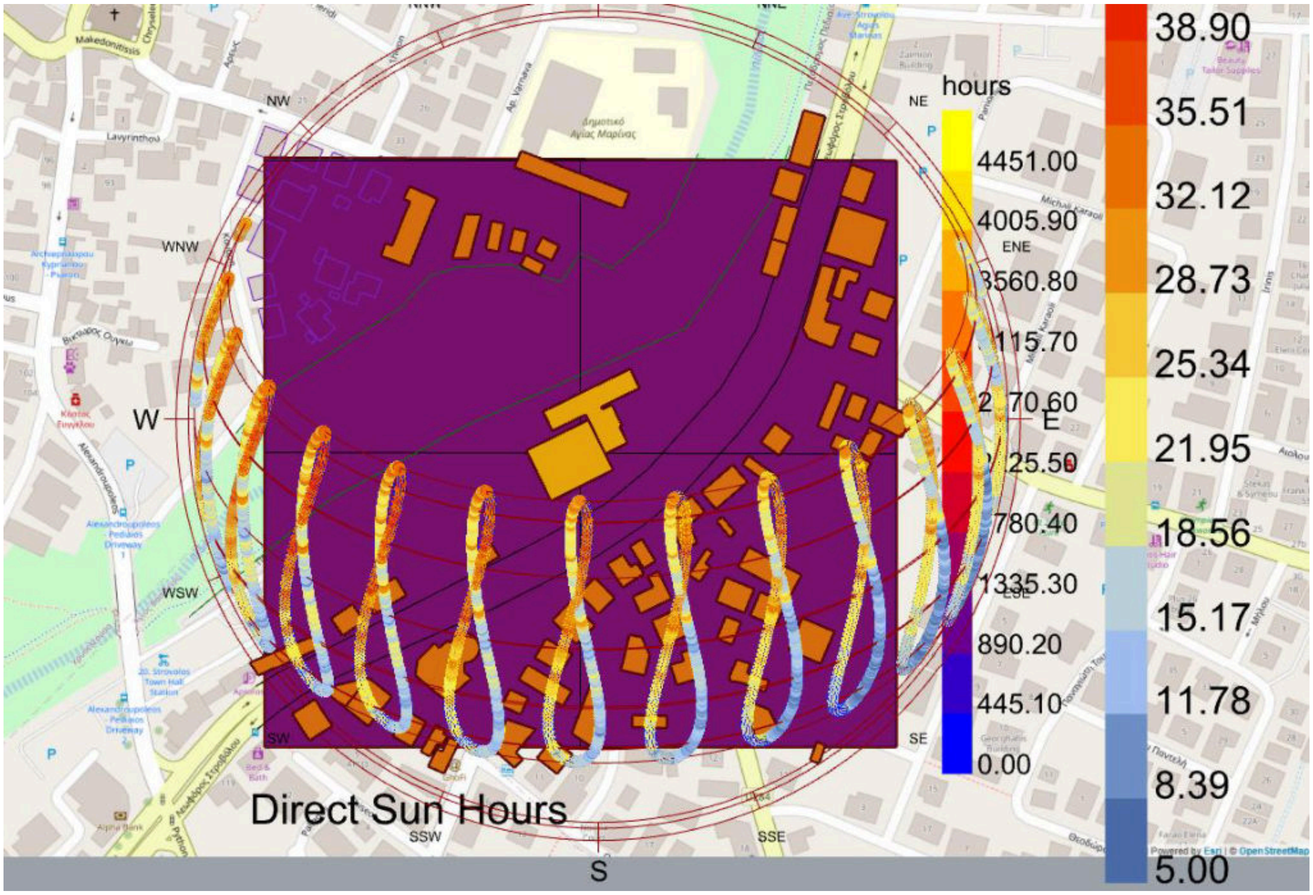


Figure 35: Top view of the Azimuth sun diagram with Sun's all positions and sun hours

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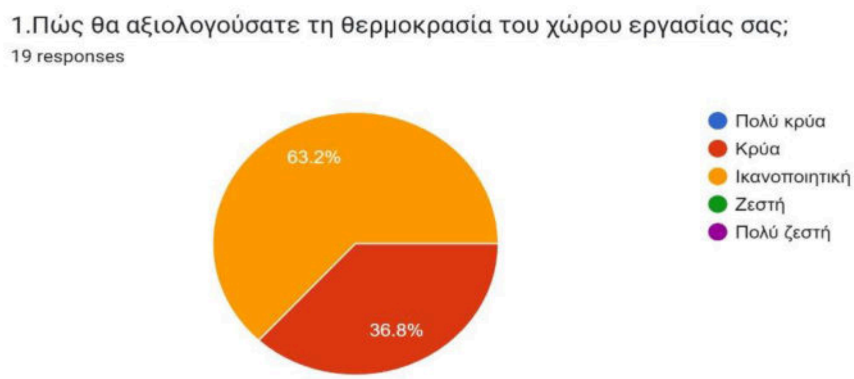
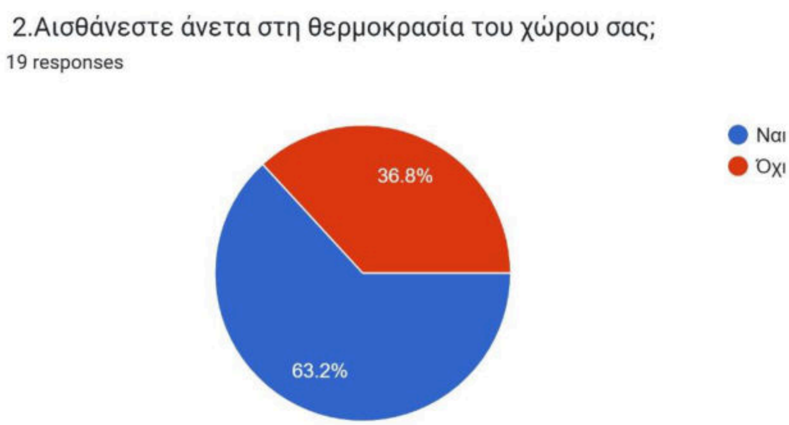
11. QUESTIONNAIRE RESULTS

After our site visit, we conducted a questionnaire and sent it to the building's users to gather insights into their experiences and perceptions of the building's thermal comfort and working conditions. This step is crucial as it provides firsthand feedback from the occupants, helping us understand the real-life impact of the building's current energy performance. By identifying areas where users feel discomfort or inefficiency, we can tailor our energy efficiency strategies to directly address these issues, ensuring that the proposed solutions will not only enhance energy performance but also improve the overall comfort and productivity of those who work within the building.

The following figures show the results of the questionnaire:





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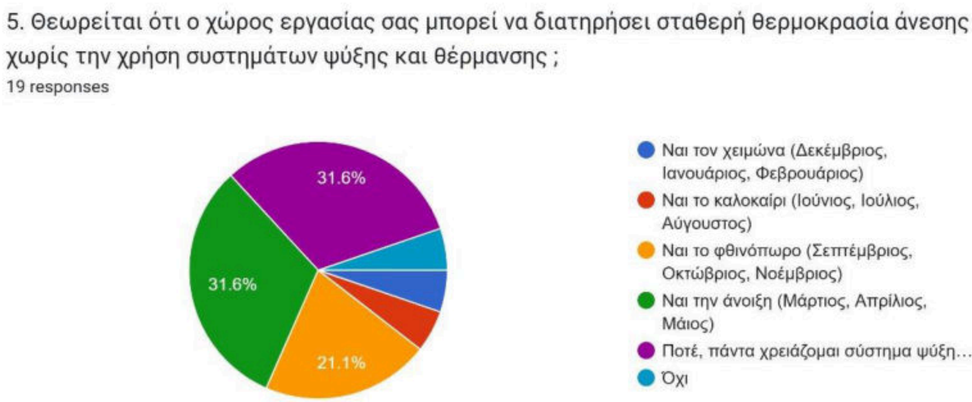
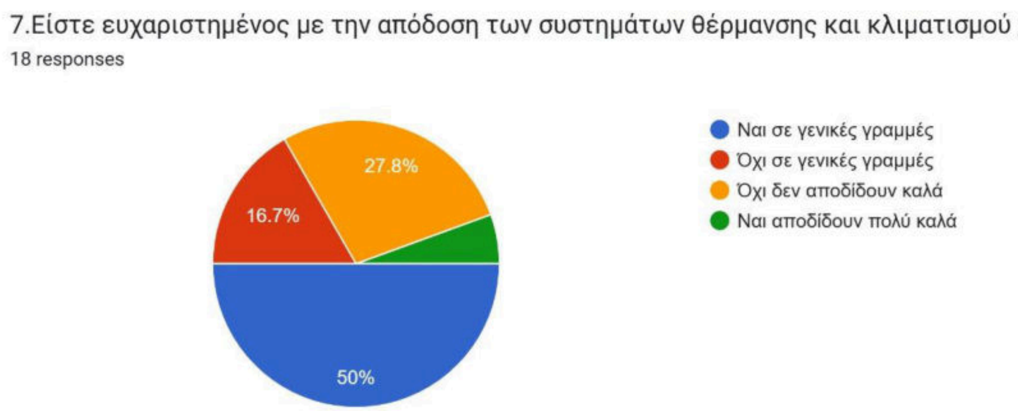
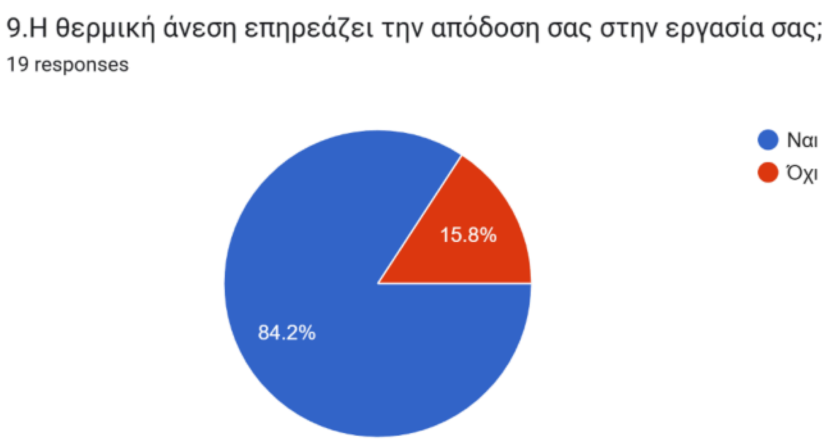

5. Θεωρείται ότι ο χώρος εργασίας σας μπορεί να διατηρήσει σταθερή θερμοκρασία άνεσης χωρίς την χρήση συστημάτων ψύξης και θέρμανσης ;
19 responses
31.6%
31.6%
21.1%
Ναι τον χειμώνα (Δεκέμβριος, Ιανουάριος, Φεβρουάριος)
Ναι το καλοκαίρι (Ιούνιος, Ιούλιος, Αύγουστος)
Ναι το φθινόπωρο (Σεπτέμβριος, Οκτώβριος, Νοέμβριος)
Ναι την άνοιξη (Μάρτιος, Απρίλιος, Μάιος)
Ποτέ, πάντα χρειάζομαι σύστημα ψύξη…
Όχι

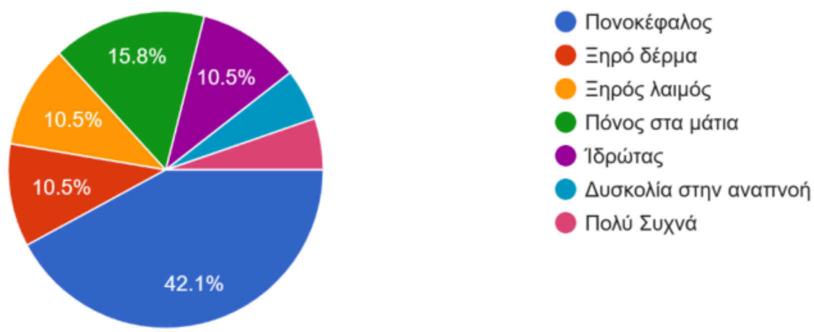

7.Είστε ευχαριστημένος με την απόδοση των συστημάτων θέρμανσης και κλιματισμού ;
18 responses
27.8%
16.7%
50%
Ναι σε γενικές γραμμές
Όχι σε γενικές γραμμές
Όχι δεν αποδίδουν καλά
Ναι αποδίδουν πολύ καλά


9.Η θερμική άνεση επηρεάζει την απόδοση σας στην εργασία σας;
19 responses
15.8%
84.2%
Ναι
Όχι

`

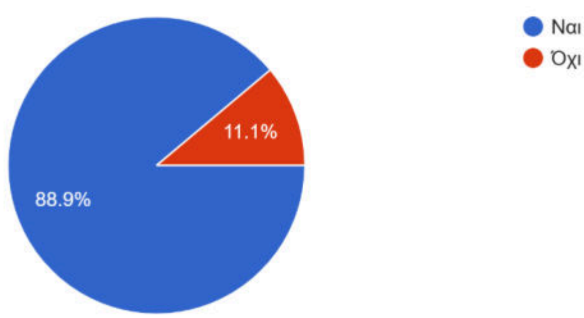
10. Αν ναι, έχετε κάποια συμπτώματα από τα παρακάτω λόγω του περιβάλλοντα χώρου εντός του κτιρίου ;

19 responses



11. Υπάρχουν σημεία στον ίδιο χώρο του κτιρίου που είναι πιο ζεστά ή πιο κρύα από αλλά στον ίδιο χώρο.

18 responses



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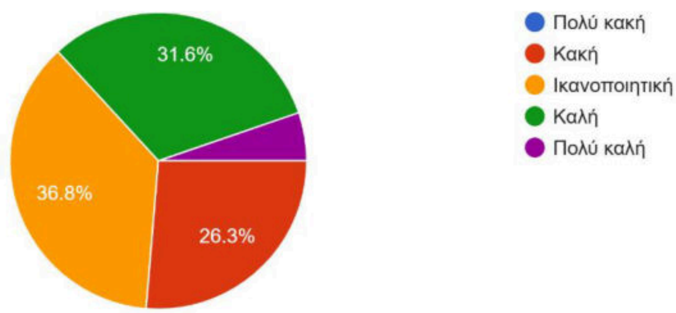
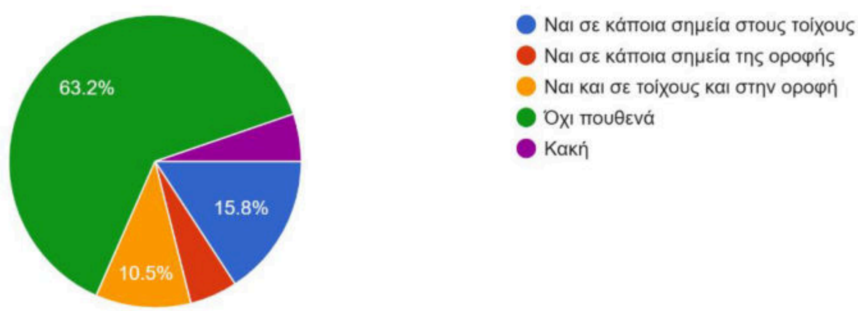
12.Πώς αξιολογείτε την ποιότητα του αέρα στον χώρο εργασίας σας;

19 responses



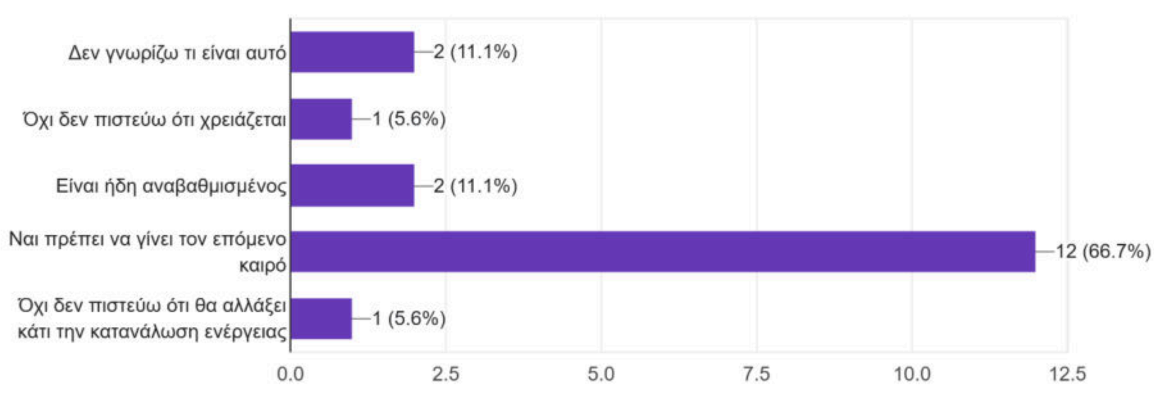
13.Υπάρχουν ορατά σημάδια υγρασίας σε οποιοδήποτε σημείο του χώρου εργασίας σας ;

19 responses



14. Θα θέλατε να αναβαθμιστεί ενεργειακά ο χώρος εργασίας σας;

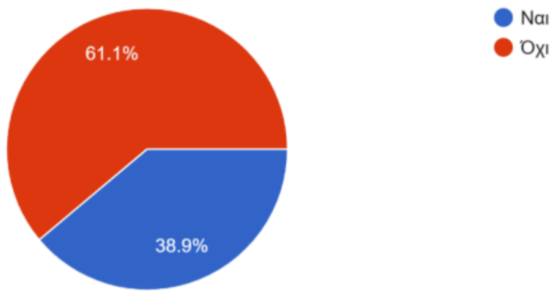
18 responses



`

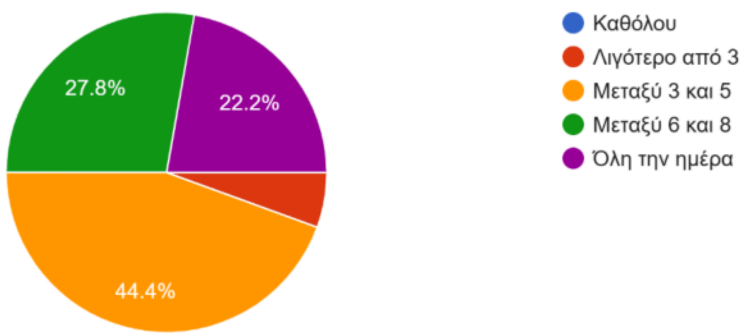
15. Θεωρείται ότι ο χώρος εργασίας σας φωτίζεται αρκετά την ημέρα χωρίς να ανάψετε τα φωτά ;

18 responses



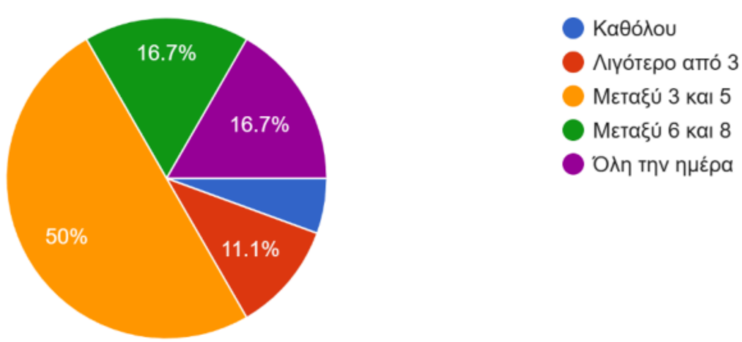
16. Πόσες ώρες λειτουργούν τα συστήματα ψύξης κατά την διάρκεια μιας ημέρας;

18 responses



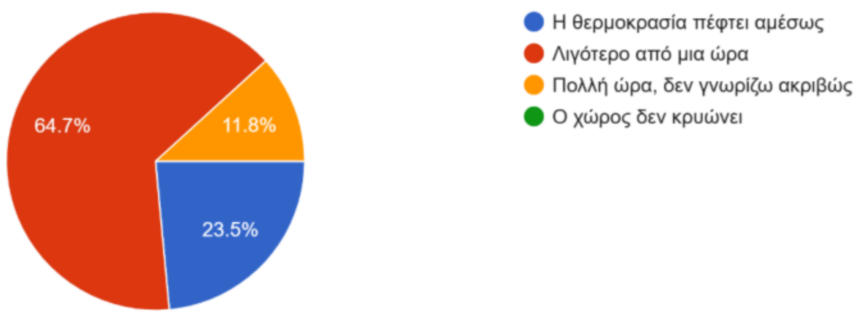
17. Πόσες ώρες λειτουργούν τα συστήματα θέρμανσης κατά την διάρκεια μιας ημέρας;

18 responses



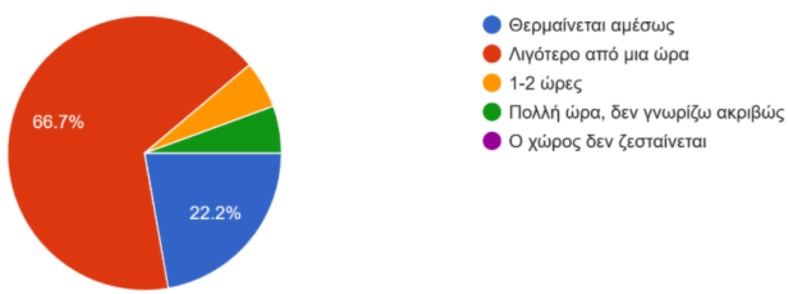
18. Όταν ανάβετε το σύστημα κλιματισμού σας πόσο χρόνο χρειάζεται ο χώρος σας για να κρυώσει και να είναι άνετος;

17 responses



19. Όταν ανάβετε το σύστημα θέρμανσης σας πόσο χρόνο χρειάζεται ο χώρος σας για να θερμανθεί και να είναι άνετος ;

18 responses



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The questionnaire provided very helpful information about the thermal comfort of the users and assisted in identifying the most problematic spaces in the building.

First, 36.8 % of the users believe that their environment is cold and that they are not feeling comfortable during their work. Also, more than 45 % are not satisfied with the performance of the electromechanical equipment or with the type of units in general.

More than 80 % of the users say that thermal comfort affects their efficiency and productivity but also something very important is that in an air conditioning space there are two places with different temperatures and that shows the inability of the AC units to do their job. More than 70% of the users want an energy upgrade at their workspace as soon as possible.

33% of the users are not satisfied with the air quality in their space and they are experiencing headaches, dizziness, sweat etc. On the question of whether they use natural openings for physical ventilation, there is a significant disparity, with 77% of respondents indicating that they do use natural ventilation, while 22% reported that they do not. This noticeable difference suggests that most occupants are taking advantage of natural airflow to regulate indoor air quality and temperature. However, the 22% who do not use natural ventilation may be experiencing barriers such as inadequate air circulation, comfort concerns, or inefficiencies in the building's design, which highlights an area that could benefit from further investigation and improvement in our energy efficiency strategy.

12. RHINO MODEL

The next phase of the project will involve a detailed study of the building's southern section, given its large surface area and potential impact on energy efficiency. A comprehensive analysis of the electromechanical systems will be carried out, focusing on identifying losses due to aging, wear, and inadequate maintenance. This will help in planning the necessary improvements to extend the equipment's lifespan and improve performance. Additionally, feedback from user questionnaires will be reviewed to better understand comfort levels and energy consumption behaviors, informing future design adjustments.

Further assessments will address the building's thermal insulation, with a focus on the materials used in structural elements such as beams, columns, floors, walls, and the roof. Window frames and glazing will also be evaluated for their energy performance. To ensure that equipment is appropriately sized, thermal load calculations will be performed. External shading solutions will be analyzed to enhance passive cooling strategies. Lastly, the development of a detailed 3D model in Rhino using the Ladybug plugin will facilitate more precise simulations, supporting efficient design and sustainability improvements.

In the 2nd semester the design of the component in Grasshopper began with the modeling of the selected building (Strovolos Town Hall and the surrounding buildings) and then focused on two specific offices on the 2nd floor. The next step was to define the building type, materials, and climate zone to carry out the necessary analyses to identify potential energy performance issues. The analyses conducted included daylight analysis, thermal analysis, and energy analysis. Finally, the results were compared for three different scenarios.

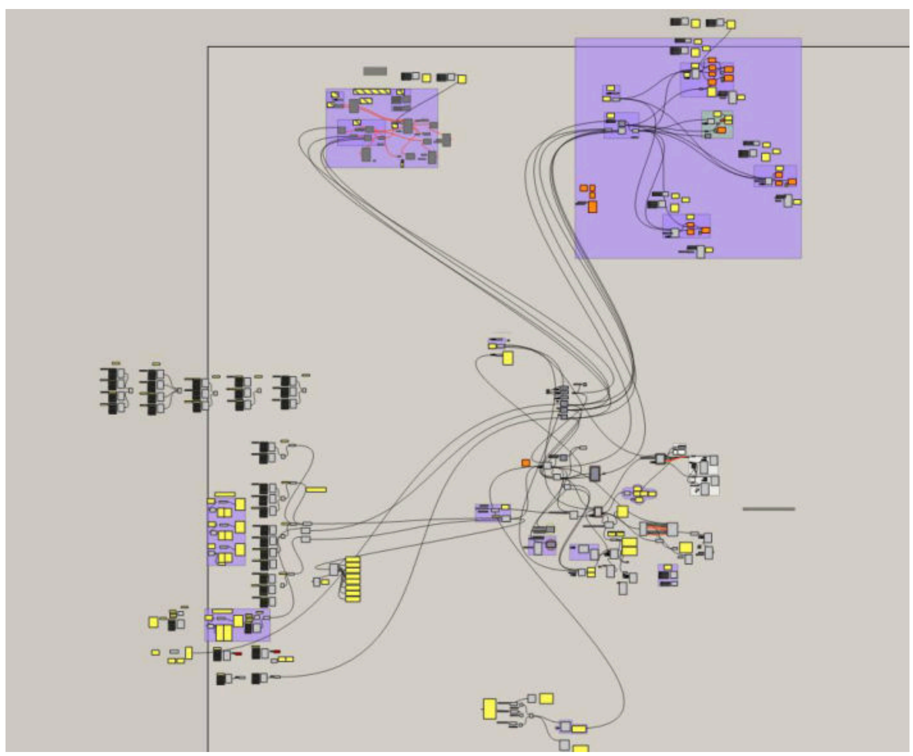


Figure 36: The rhino grasshopper model for the simulation results.

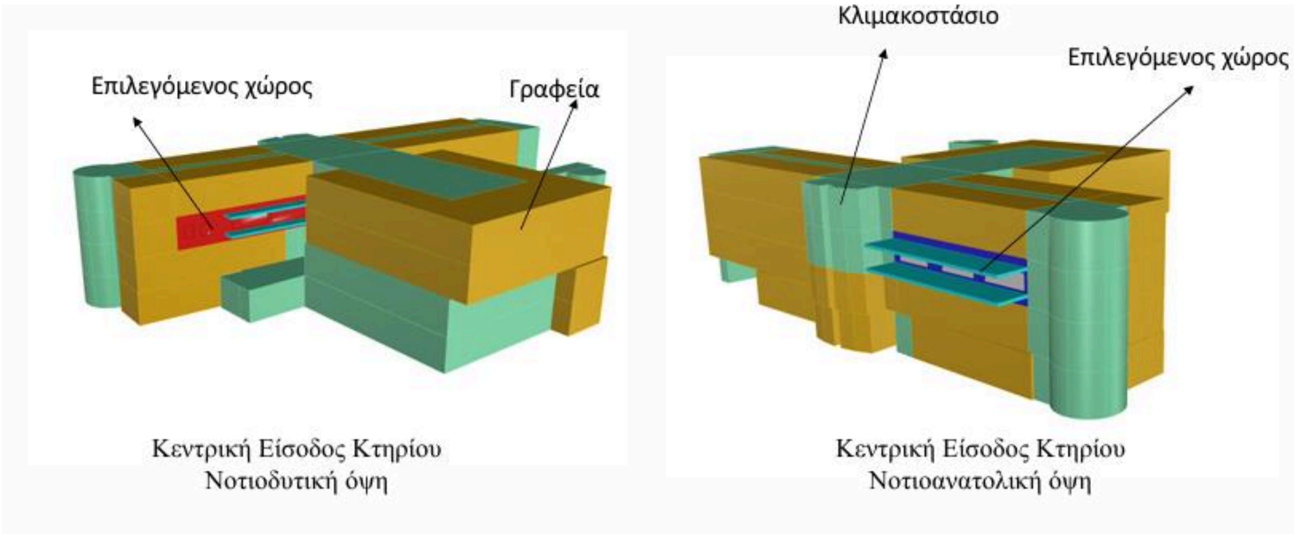


Figure 37: 3D model of whole building with indication of the spaces

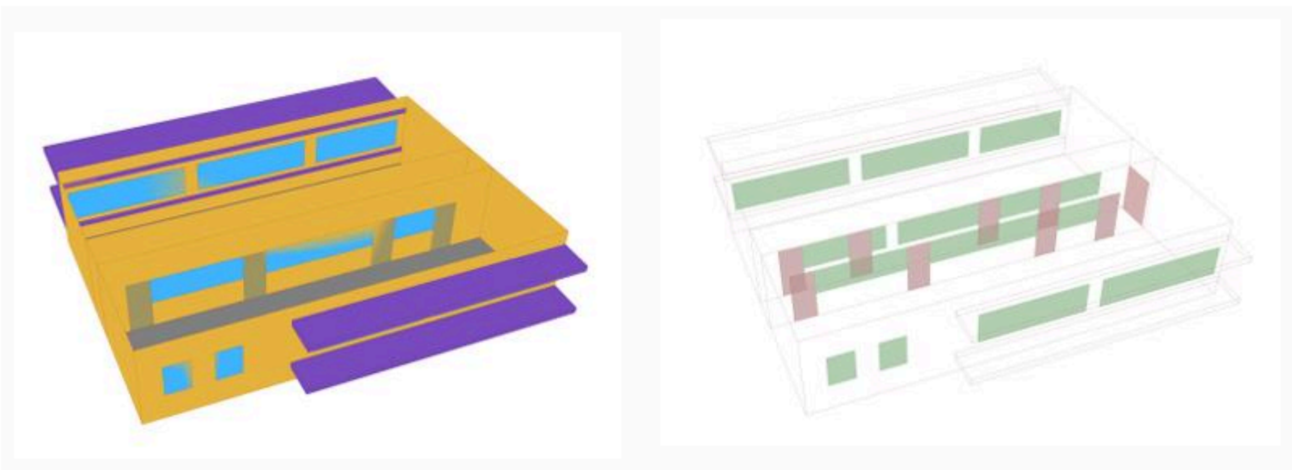


Figure 38: 3D chosen spaces of our office spaces and corridor.

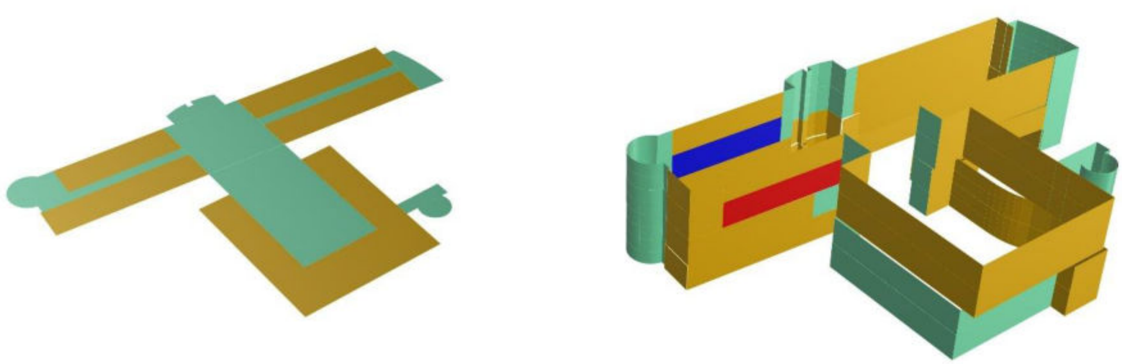
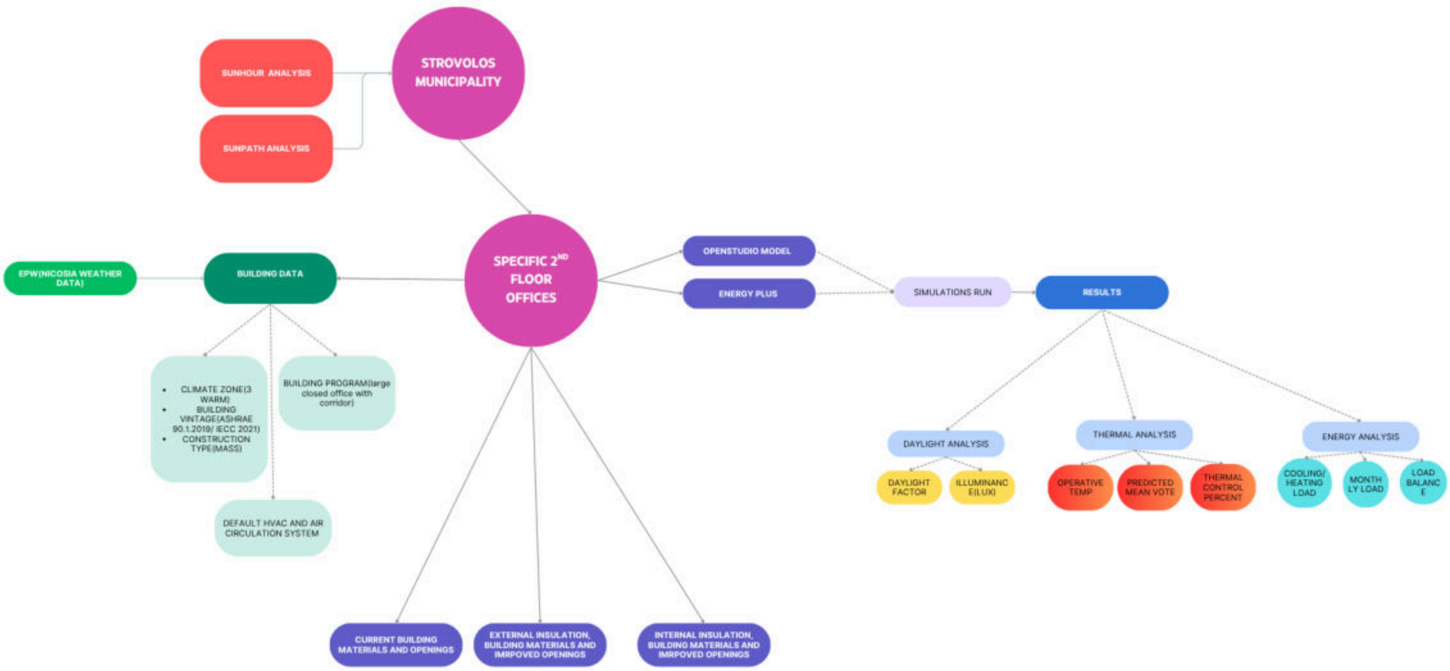


Figure 39: Roof surface: 1100 m2 & Wall and Column surface: 1920 m2



This time the designing of the rhino model continues after the last creation of the whole building and its surrounding buildings in the previous explanation which resulted in creating the sun hours and sun path diagram. By focusing on the specific offices, we create the design in rhino and then implement it into grasshopper. We add the building materials, the shadings, the windows and the doors. Like last time we used the Energy weather data to choose the same location. But this time we also add Building data which includes the building program, climate zone, vintage building and construction type. Lastly for building data we use default HVAC and Air circulation system.

After creating the building data, the next step was to choose the way the data will be analyzed and in Rhino we choose 2 ways in order to make sure the data was accurate. The name of the system is Open studio (model which is derived from Energy plus) and energy plus itself. By using these 2 systems for our 3 scenarios (current materials, external insulation and internal insulation) we ran a simulation, and the results were daylight analysis, thermal analysis and lastly energy analysis.

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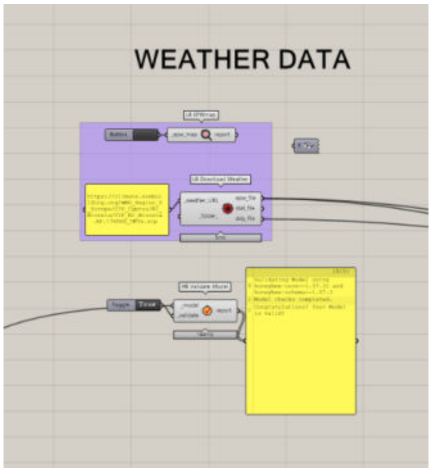
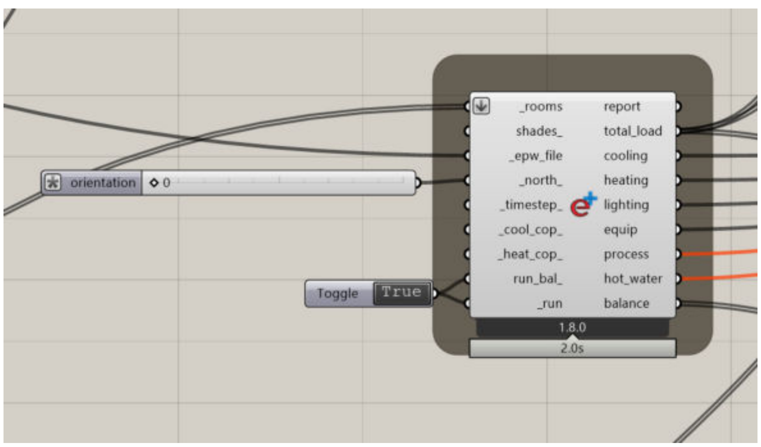
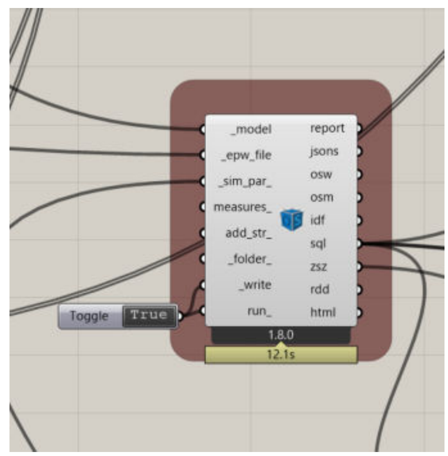
Weather Data Component

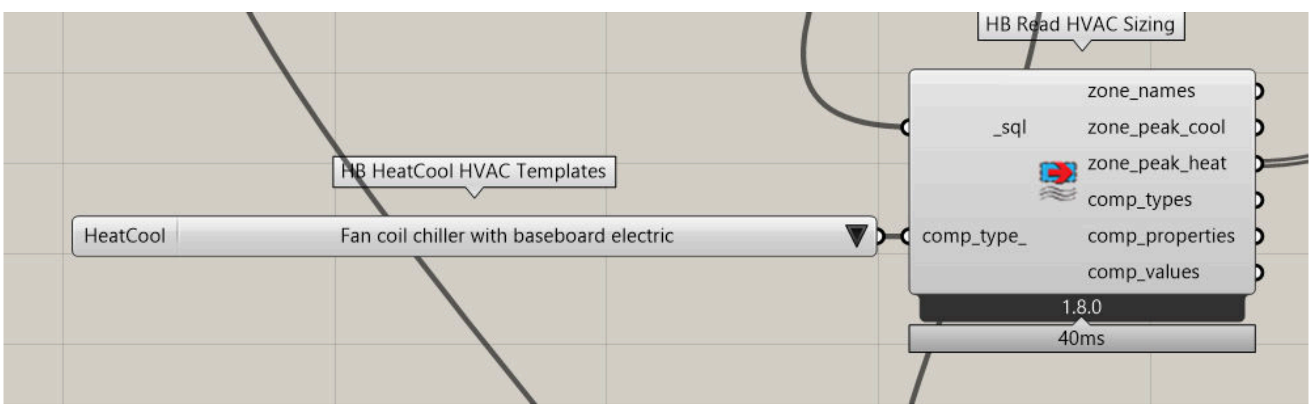


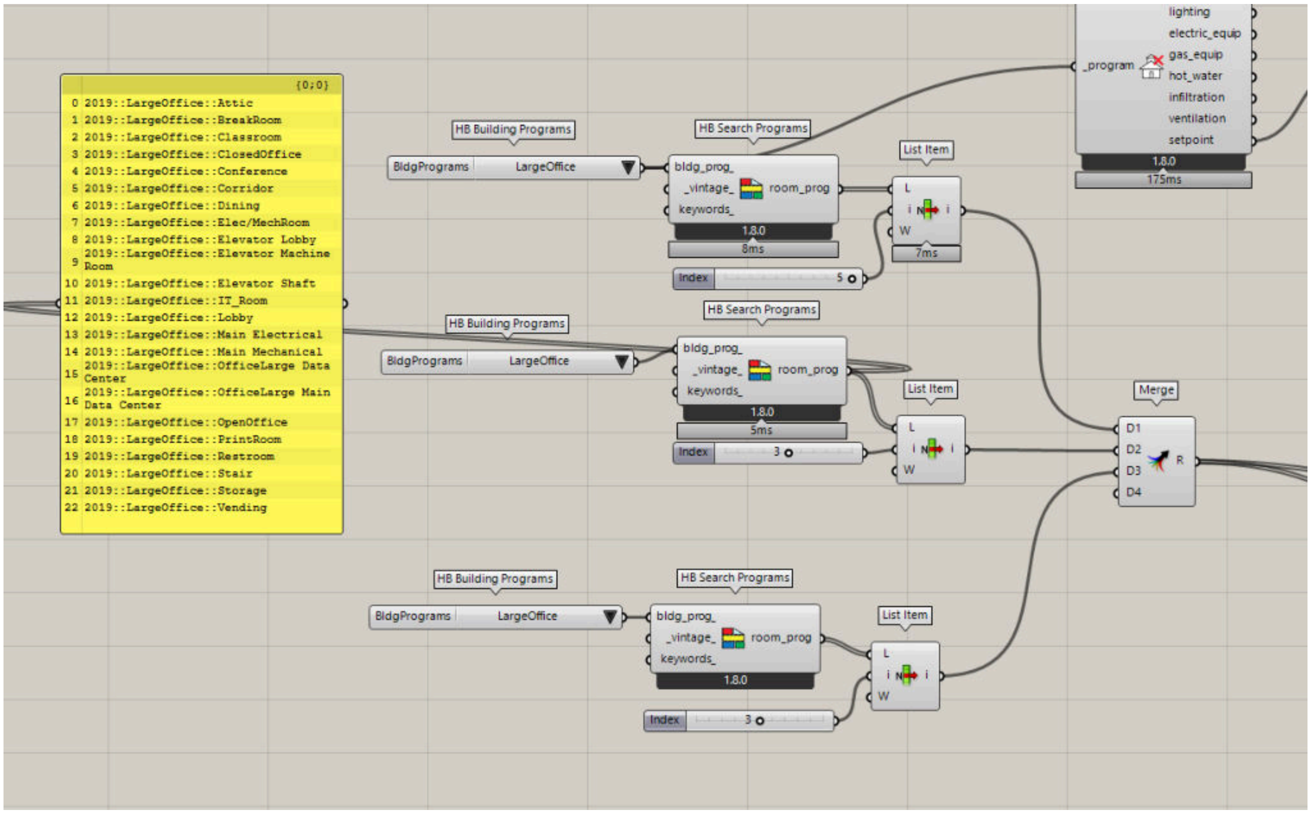
Energy plus and Open Studio Model Components

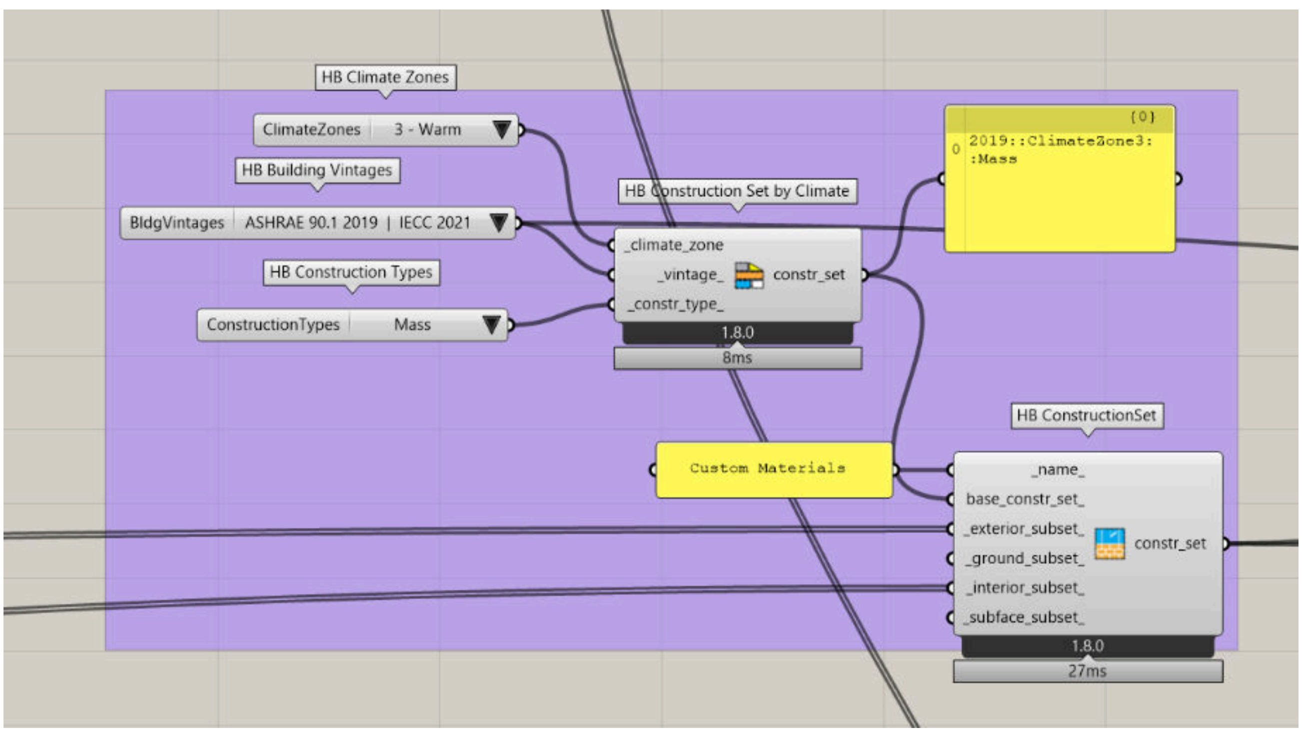




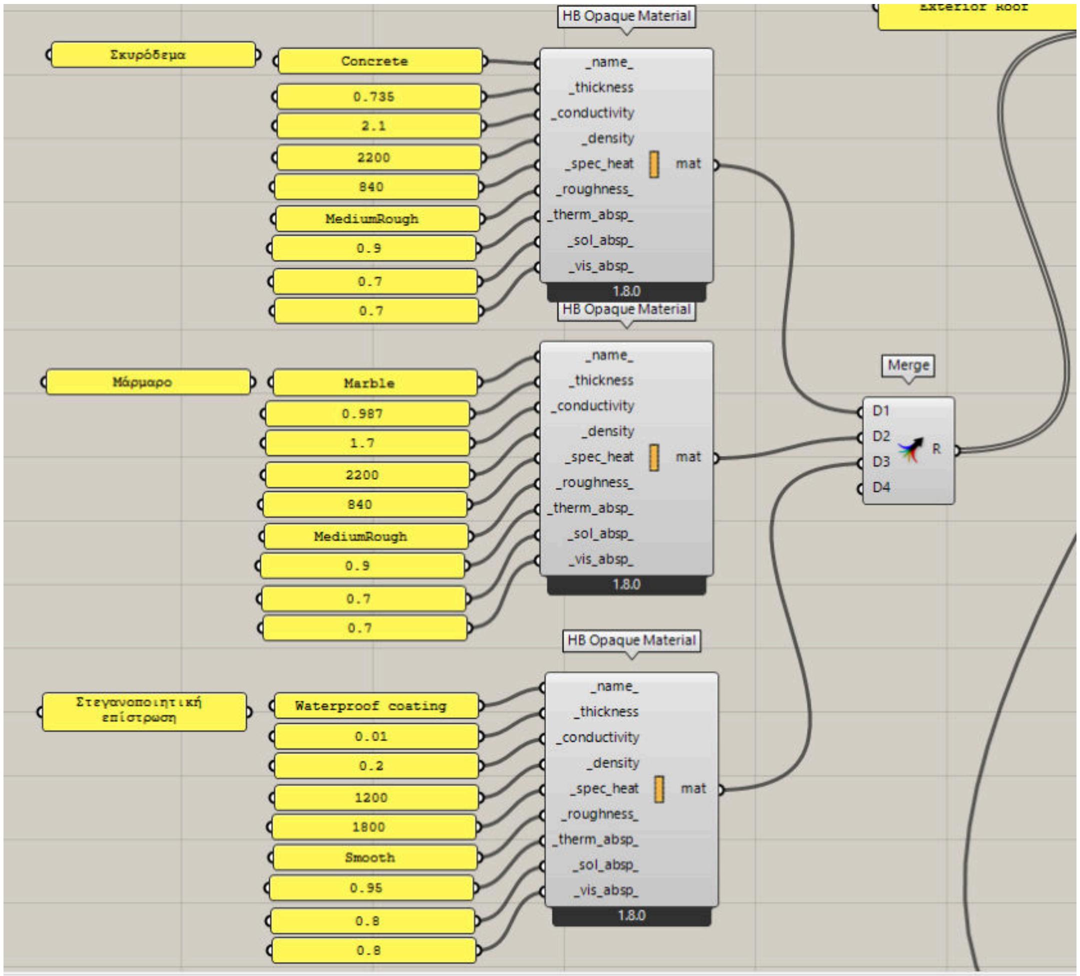
HVAC, Building Program and Climate zone components

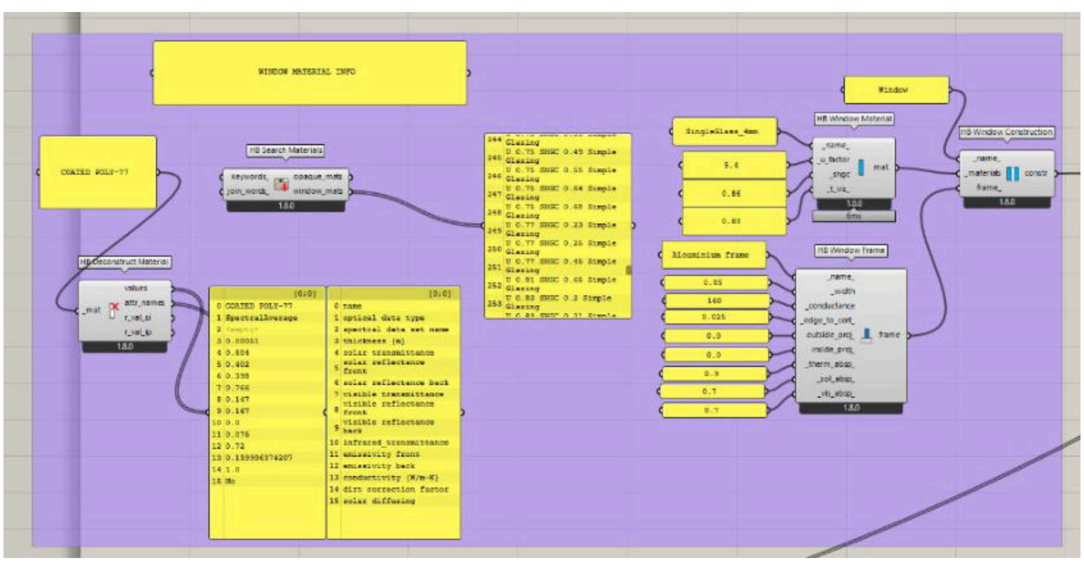



{0;0}
0 2019::LargeOffice::Attic
1 2019::LargeOffice::BreakRoom
2 2019::LargeOffice::Classroom
3 2019::LargeOffice::ClosedOffice
4 2019::LargeOffice::Conference
5 2019::LargeOffice::Corridor
6 2019::LargeOffice::Dining
7 2019::LargeOffice::Elec/MechRoom
8 2019::LargeOffice::Elevator Lobby
9 2019::LargeOffice::Elevator Machine Room
10 2019::LargeOffice::Elevator Shaft
11 2019::LargeOffice::IT_Room
12 2019::LargeOffice::Lobby
13 2019::LargeOffice::Main Electrical
14 2019::LargeOffice::Main Mechanical
15 2019::LargeOffice::OfficeLarge Data Center
16 2019::LargeOffice::OfficeLarge Main Data Center
17 2019::LargeOffice::OpenOffice
18 2019::LargeOffice::PrintRoom
19 2019::LargeOffice::Restroom
20 2019::LargeOffice::Stair
21 2019::LargeOffice::Storage
22 2019::LargeOffice::Vending
HB Building Programs
BldgPrograms
LargeOffice
HB Search Programs
bldg_prog_
vintage
room_prog
keywords_
1.8.0
8ms
List Item
L
i
W
7ms
Index
5
5ms
3
Merge
D1
D2
D3
D4
R
_program
lighting
electric_equip
gas_equip
hot_water
infiltration
ventilation
setpoint
175ms


HB Climate Zones
ClimateZones
3 - Warm
HB Building Vintages
BldgVintages
ASHRAE 90.1 2019 | IECC 2021
HB Construction Types
ConstructionTypes
Mass
HB Construction Set by Climate
_climate_zone
vintage
_constr_type_
constr_set
1.8.0
8ms
{0}
0 2019::ClimateZone3::Mass
Custom Materials
HB ConstructionSet
name
base_constr_set_
_exterior_subset_
_ground_subset_
_interior_subset_
_subface_subset_
constr_set
1.8.0
27ms

Building Material Components





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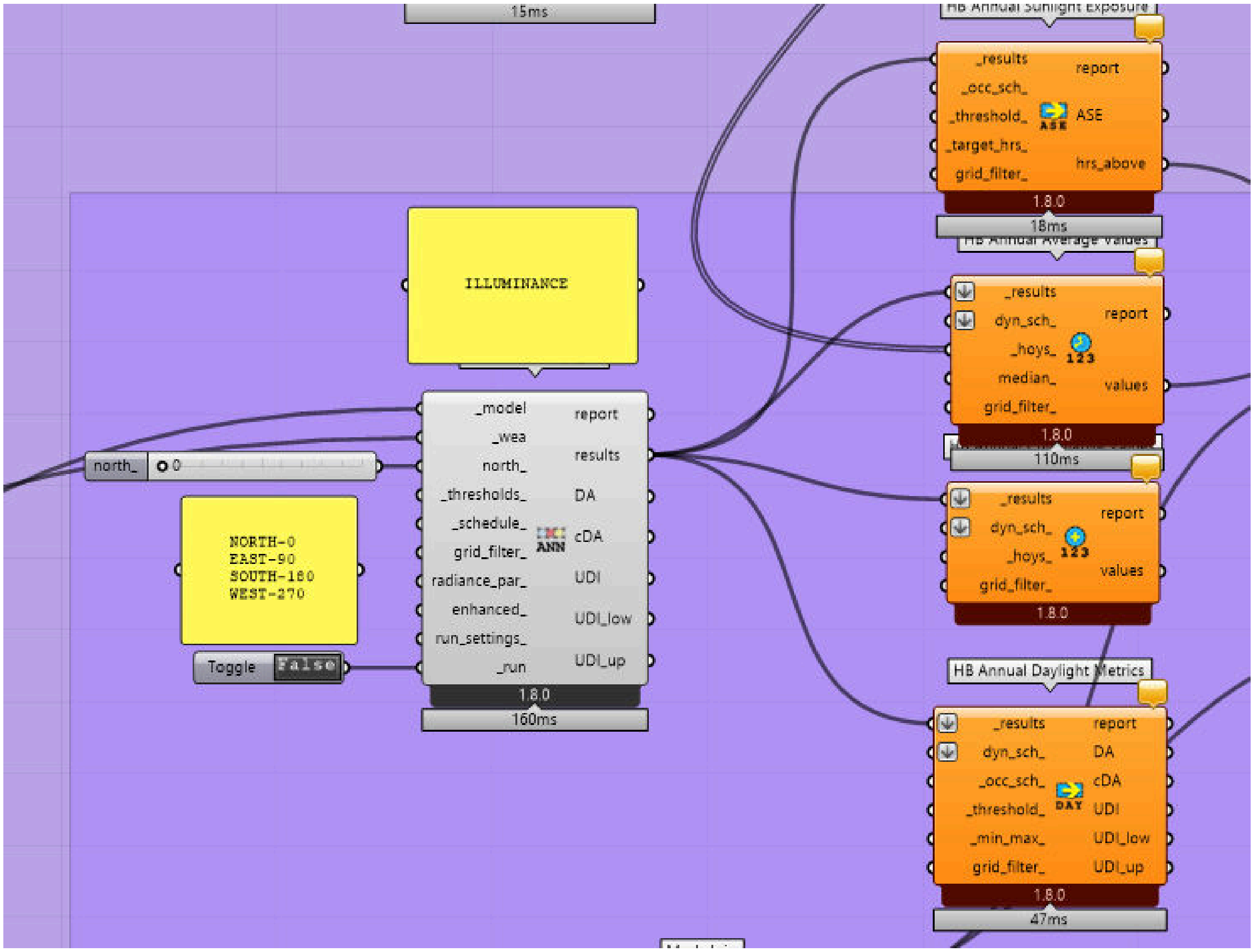
Daylight Simulation Components



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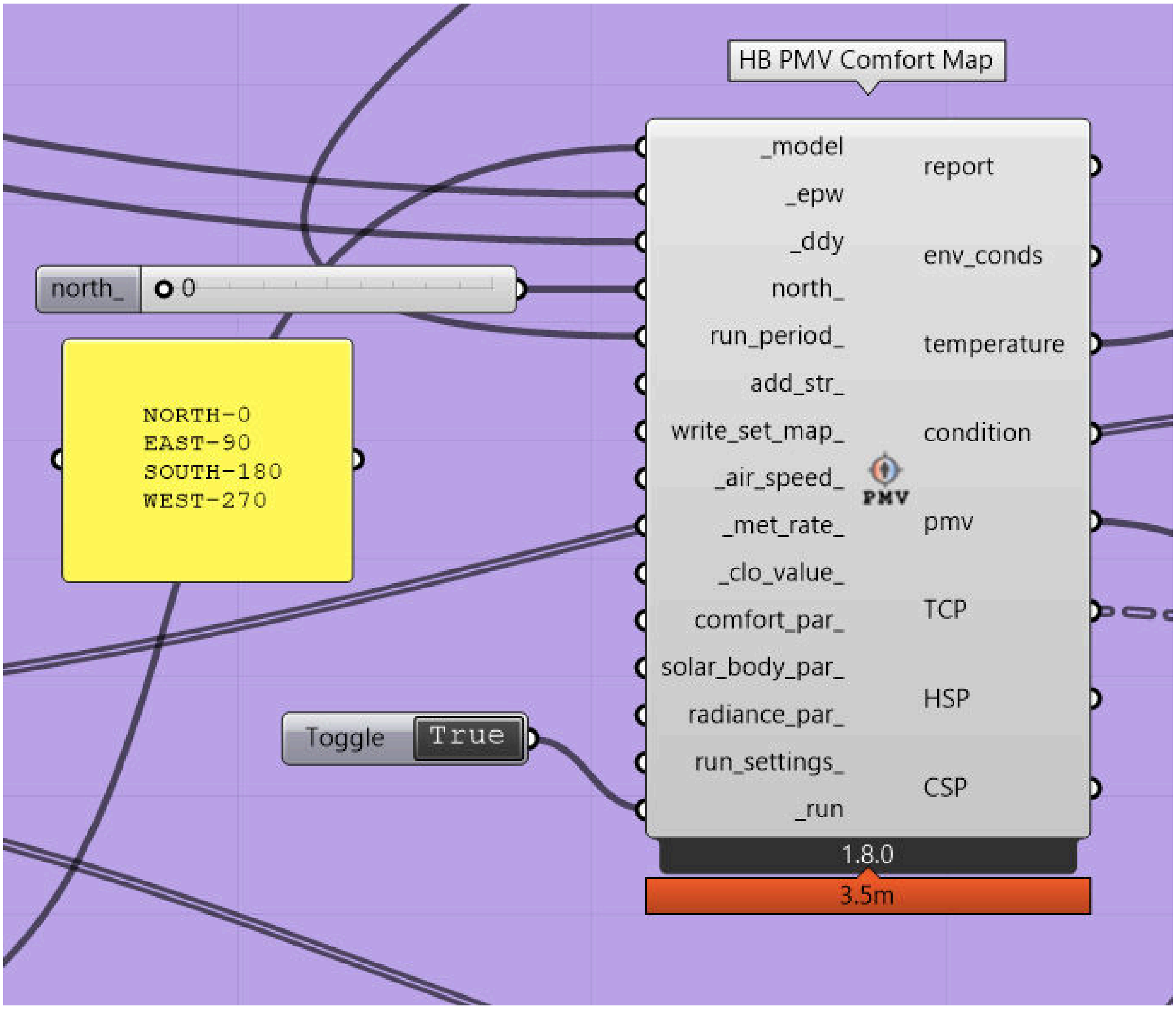
Thermal Simulation Components



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13. SIMULATION RESULTS

13.1 Energy results of the existing building

The simulation results for the existing building of Strovolos Municipality reveal distinct patterns in heating and cooling loads throughout the day for the three zones analyzed: the south-west office (in red), the corridor between the offices (in yellow), and the south-east office (in blue). During the winter design day, the total heating load begins to rise sharply around 6:00 AM, peaking at approximately 9,500 W by 8:00 AM. At this peak, the south-west office contributes about 3,800 W, the corridor around 2,500 W, and the south-east office approximately 3,200 W. These loads then gradually decrease and stabilize during working hours, maintaining a total between 8,000 and 9,000 W. A secondary peak occurs around 6:00 PM, reaching nearly 11,000 W, likely due to the drop in outdoor temperature and solar gains, before the load drops significantly after 9:00 PM.

In contrast, the summer design day cooling load shows a more consistent daytime pattern. Cooling demand begins to rise around 6:00 AM and plateaus from about 9:00 AM to 6:00 PM at a total of approximately 7,000 W. During this plateau, the south-east office contributes the most with around 3,200 W, followed by the south-west office with about 2,400 W and the corridor with approximately 1,400 W. Despite the south-west office's exposure to intense afternoon sun, its cooling demand remains lower than the south-east office, possibly due to internal shading or differences in occupancy. After 8:00 PM, the cooling load drops steadily, reaching baseline levels of around 2,000 W by 10:00 PM. Overall, it is evident that the south-east office consistently exhibits the highest energy demands, suggesting it should be a primary focus for energy efficiency improvements, particularly in insulation and solar control strategies.

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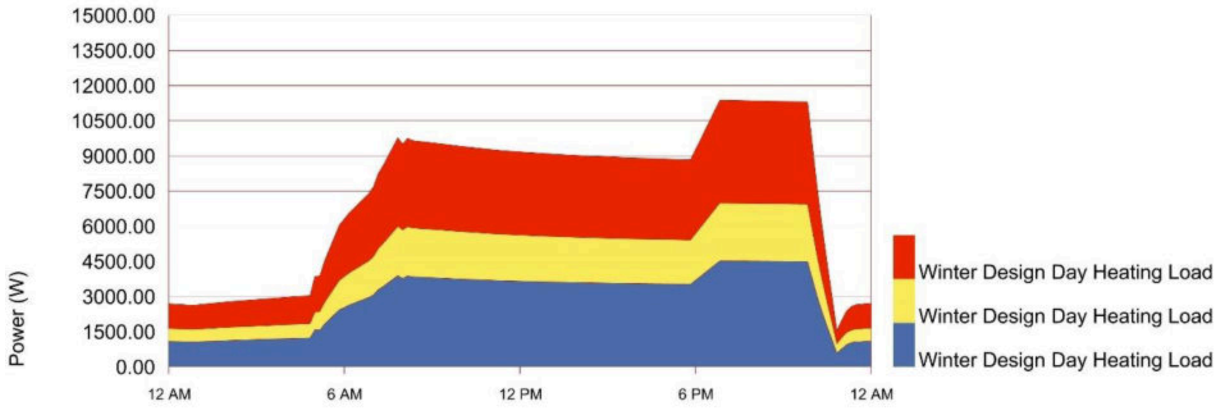

Figure 40: Thermal loads of the existing building

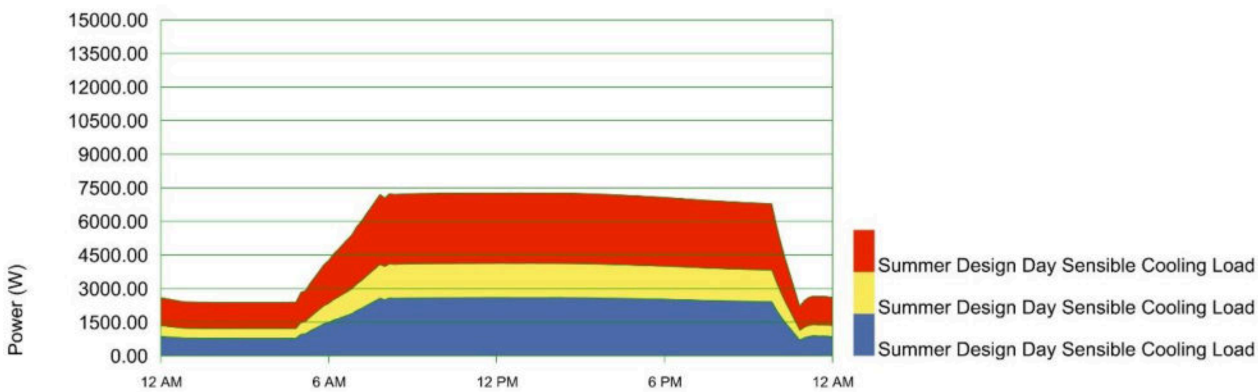

Figure 41: Cooling loads of the existing building

Based on the results of the energy analysis of the existing building without any thermal insulation presented in the chart below, we can draw important conclusions regarding the thermal performance of the building. First, the monthly loads refer to the total amount of electrical energy consumed or requested by a facility, system or area over the course of a month. In addition, Load Balance is the process of distributing demand or workload across multiple systems, resources or time periods to optimize performance, avoid overload and improve reliability.

In the graph below we can observe that the energy loads for both heating and cooling are particularly high. Heating demands peak during the winter months (January, February, March and December), while cooling loads rise significantly in the summer (June through September). The total annual energy load reaches approximately 135 KWh/m^2, making the current situation inefficient and costly in terms of energy use.

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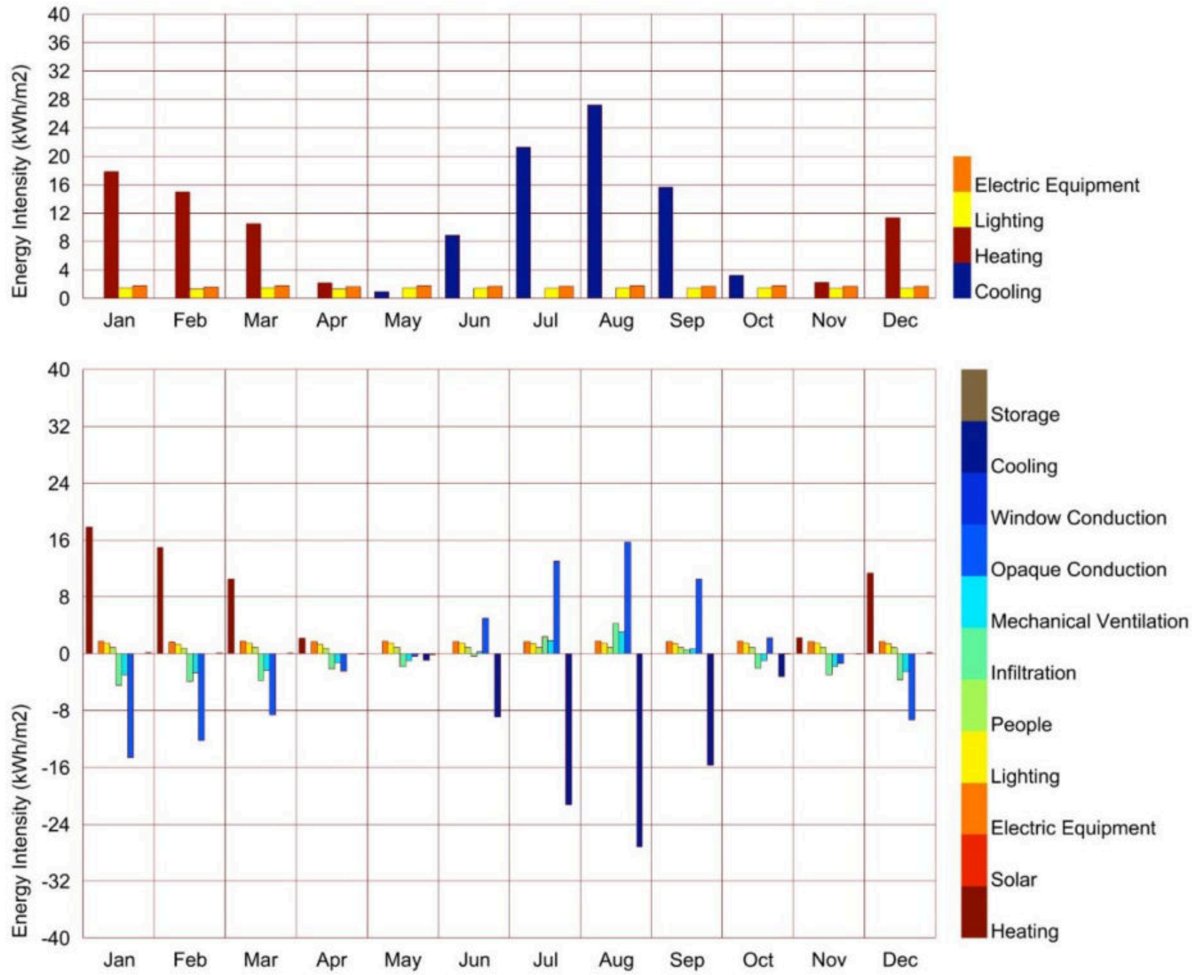

Figure 42: Monthly energy analysis of the existing building

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Scenario 1: External insulation on the external wall

For the energy upgrade of the Strovolos Town Hall, which is a significant landmark for the city, it is proposed to implement specialized thermal insulation solutions using materials available in the Cypriot market. Below are the proposals for each structural element, accompanied by the calculations of the new thermal transmittance coefficients (U-values).

Proposed Solution: Application of External Thermal Insulation System at the external walls, more specifically 8cm thick expanded polystyrene thermal insulation boards. Even though, this approach will cover the decorative stone facade of the building, we chose external insulation for the walls because it is considered the most effective method for reducing both heating and cooling loads.

External wall with external insulation

Material	Width (m)	Thermal Conductivity Coefficient λ (W/mK)	Thermal resistance R (m^2K/W)
Expanded polystyrene	0.08	0.032	2.50
Decorative stone	0.10	2.0	0.050
Brick	0.10	0.80	0.125
Internal plaster	0.015	0.87	0.017
Total thermal resistance R			2.692 $m^2·K/W$
Total U-value			**0.37 $W/m^2·K$**

`

Scenario 2: Internal insulation on the external wall

Alternatively, another solution we propose is the installation of internal insulation on the exterior walls of the building. We suggest this approach because our building is considered a type of landmark in Nicosia, which means that we cannot easily intervene in its façade or make significant changes to its exterior appearance. However, although this solution would help reduce the thermal loads, it would also result in a reduction of the usable interior floor area of the building.

External wall with internal insulation

Material	Width (m)	Thermal Conductivity Coefficient λ (W/mK)	Thermal resistance R (m^2K/W)
Decorative stone	0.10	2.00	0.050
Brick	0.10	0.80	0.125
Rockwool	0.10	0.037	2.70
Drywall	0.012	0.25	0.048
Total thermal resistance R			2.923 $m^2 \cdot K/W$
Total U-value			**0.34 $W/m^2 \cdot K$**

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Comparison of the existing building with external and internal insulation results

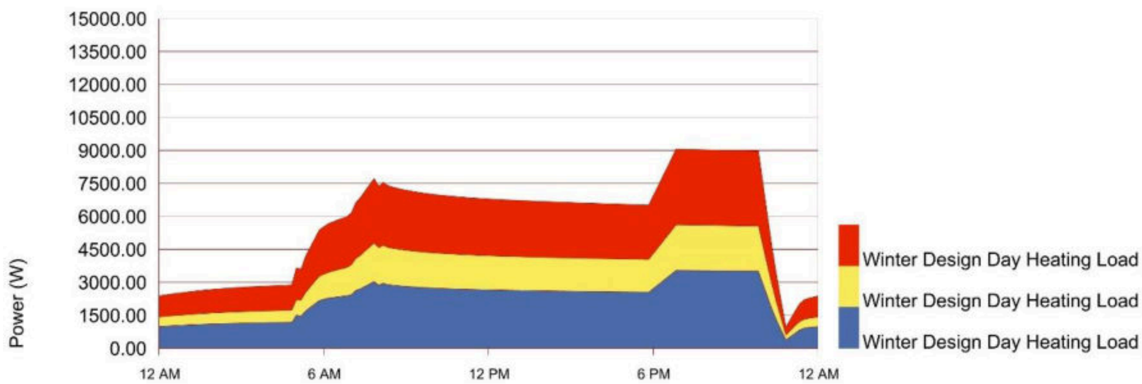

Figure 43: Thermal Loads with external insulation

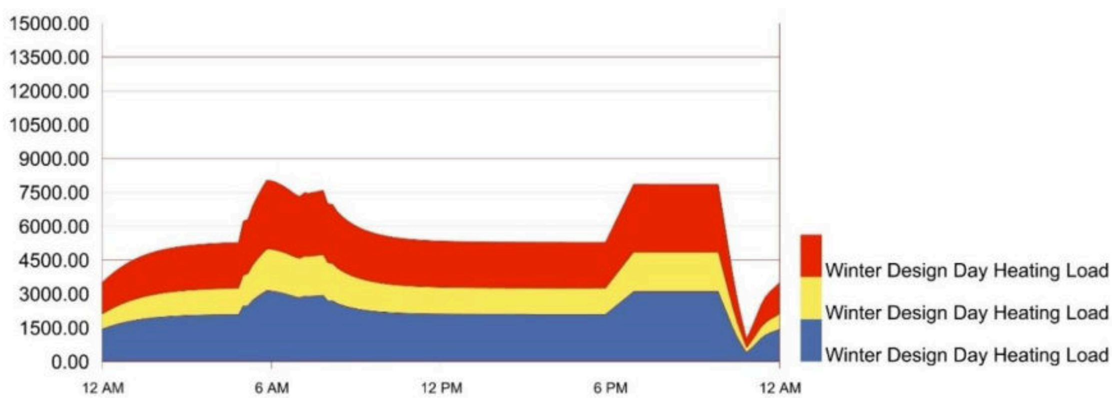

Figure 44: Thermal Loads with internal insulation

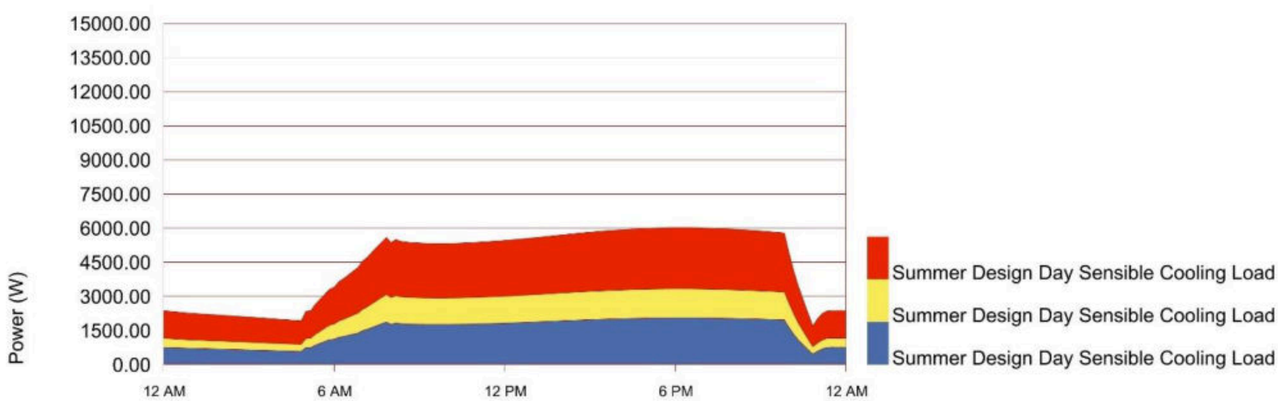

Figure 45: Cooling Loads with external insulation

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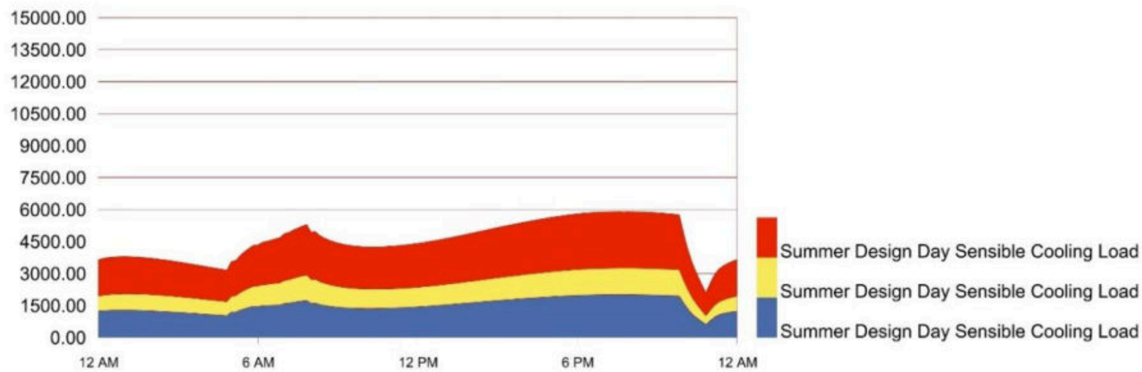

Figure 46: Cooling Loads with internal insulation

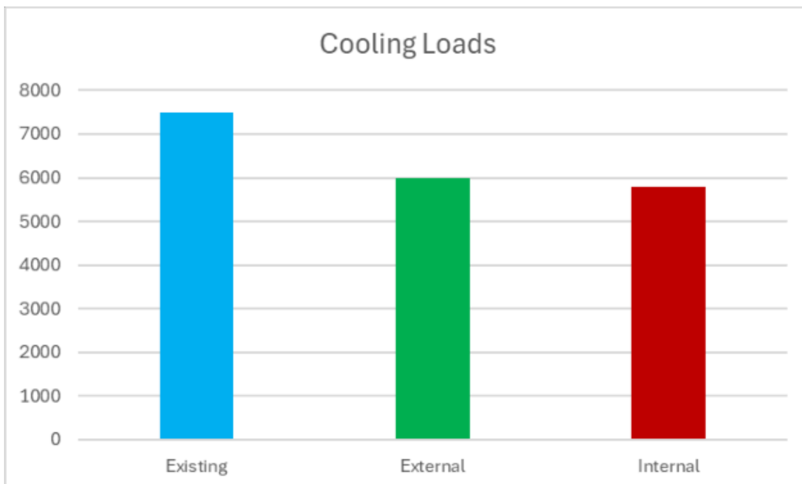

Figure 47: Cooling Load for Existing, Internal and External Insulation

Figure 47 presents the cooling demand for three scenarios: the existing insulation condition, improvements to external insulation, and improvements to internal insulation. The values are expressed in watts (W). The existing configuration shows the highest cooling load at approximately 7,300 W. With enhancements to external insulation, the cooling load is reduced to around 6,000 W. Further reduction is observed with improvements to internal insulation, bringing the load down to approximately 5,800 W. These results highlight the potential energy savings achievable through insulation upgrades, particularly emphasizing that both external and internal insulation improvements can significantly reduce the overall cooling demand.

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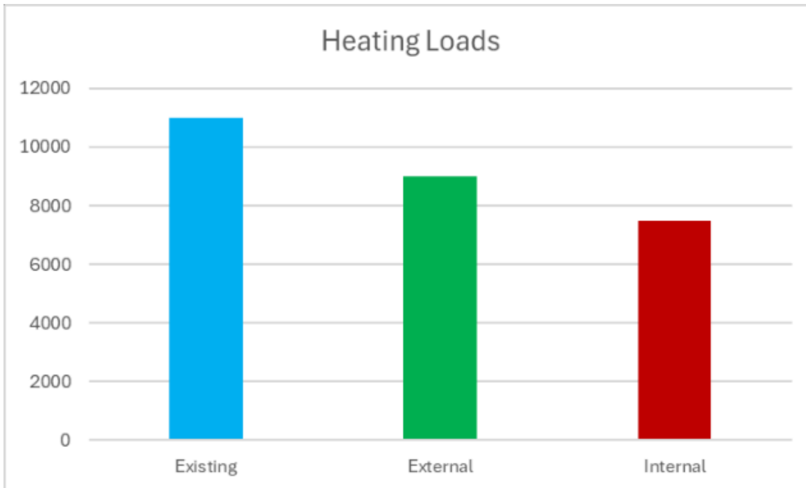

Figure 48: Heating Loads for Existing, Internal and External Insulation

Figure 48 presents the heating demand for three scenarios: the existing insulation condition, improvements to external insulation, and improvements to internal insulation. The values are expressed in watts (W). The existing configuration shows the highest cooling load at approximately 11,000 W. With enhancements to external insulation, the cooling load is reduced to around 9,000 W. Further reduction is observed with improvements to internal insulation, bringing the load down to approximately 7,800 W. These results highlight the potential energy savings achievable through insulation upgrades, particularly emphasizing that both external and internal insulation improvements can significantly reduce the overall cooling demand.

Overall reduction of energy consumption

Case	Annual Heating (kWh/m^2)	Annual Cooling (kWh/m^2)	Total (kWh/m^2)	Saving
Existing	~70	~65	**~135**	—
External Insulation	~40	~30	**~70**	~50–55%
Internal Insulation	~45	~35	**~80**	~40–45%

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13.2 Daylight analysis results of the 3 scenarios

The Daylight Factor is a percentage that indicates how much natural light reaches an interior space compared to the available light outdoors under a uniformly overcast sky (CIE overcast sky). Illuminance is the measure of light that falls on a surface and is measured in lux.

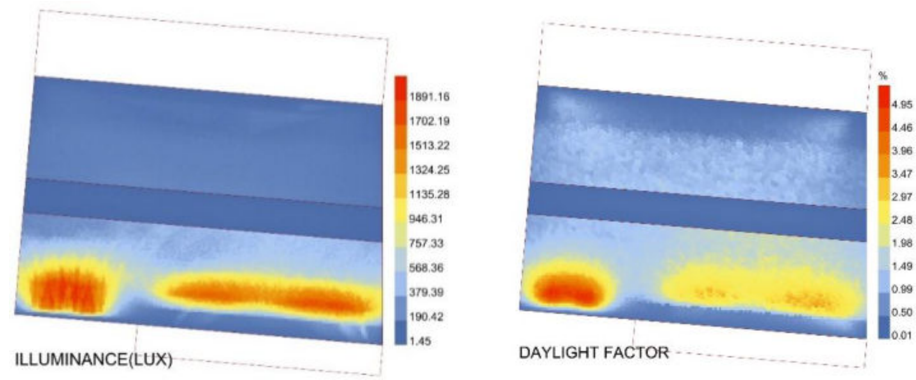


Figure 49: LUX and DF diagrams of the current building.

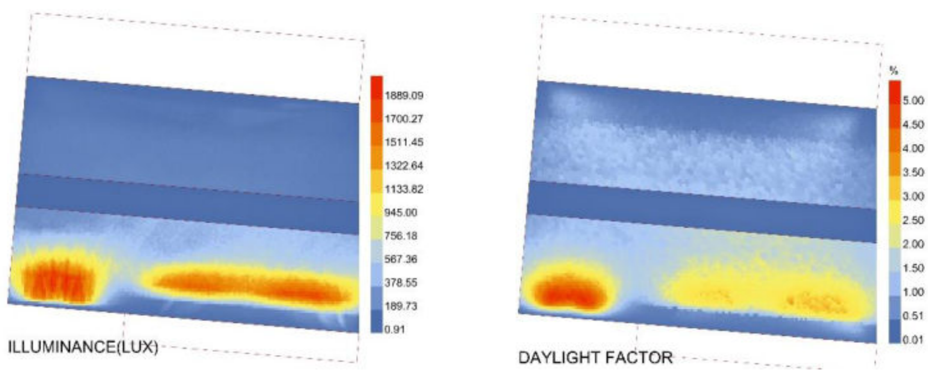


Figure 50: LUX and DF diagrams of the external insulation scenario.

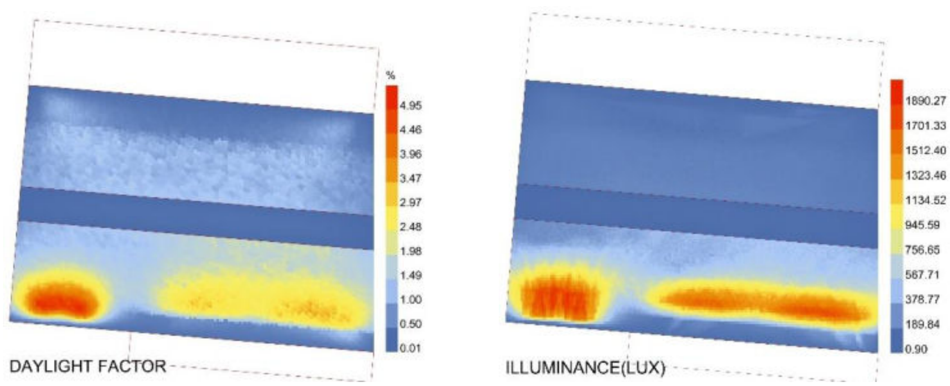


Figure 51: LUX and DF diagrams of the internal insulation scenario.

13.3 Thermal analysis results of the 3 scenarios

The Thermal Comfort Percentage (TCP) expresses the percentage of time during which the indoor temperature conditions are considered comfortable for the occupants, according to standardized models.

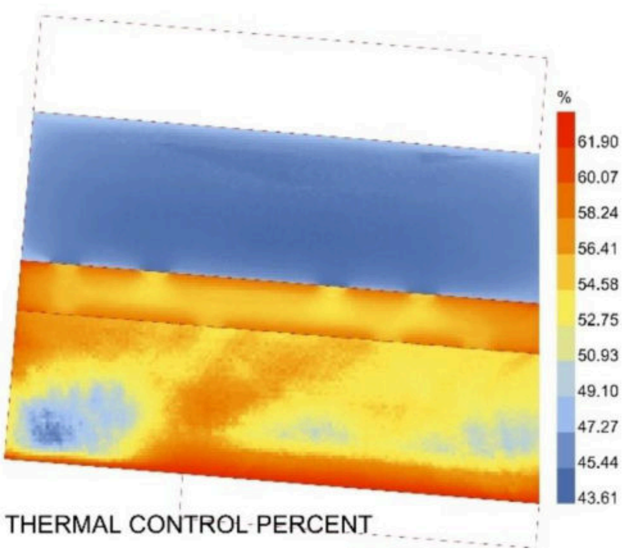


Figure 52: TCP of current building.

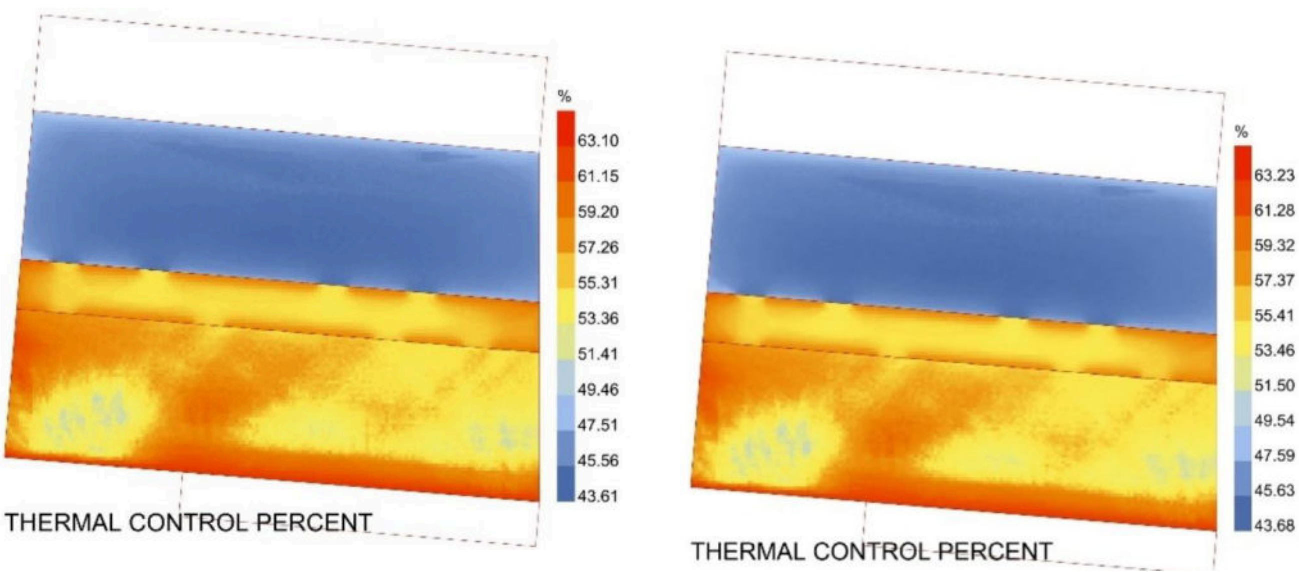


Figure 53: TCP of external and internal insulation.

The PMV (Predicted Mean Vote) indicates how a person feels thermally in a space, based on temperature, humidity, clothing, and activity level. Its value ranges from -3 (very cold) to +3 (very hot).

Ideal comfort. range: -0.5 to +0.5.

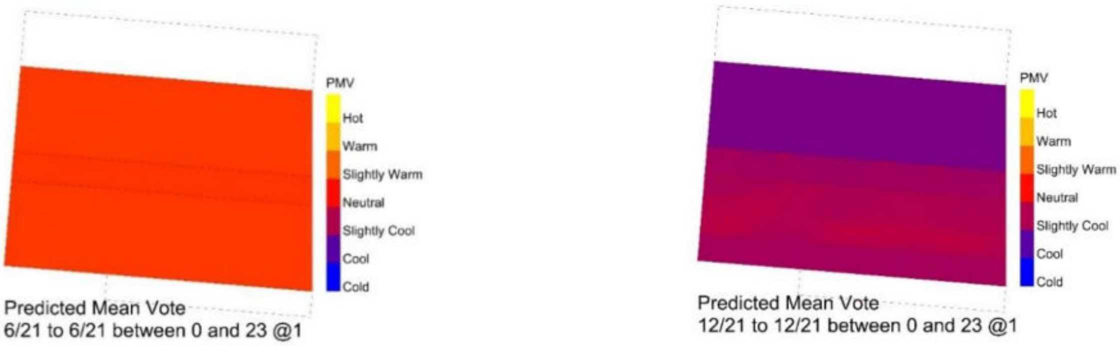


Figure 54: PMV for summer and winter solstice for current building.

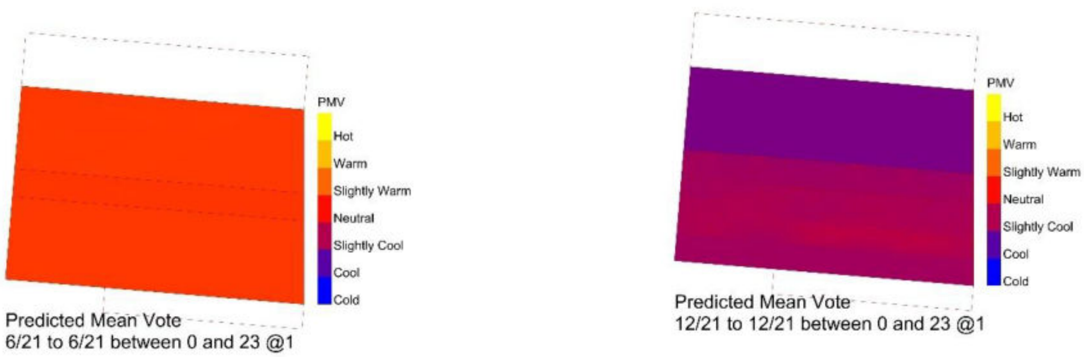


Figure 55: PMV for summer and winter solstice for external insulation.

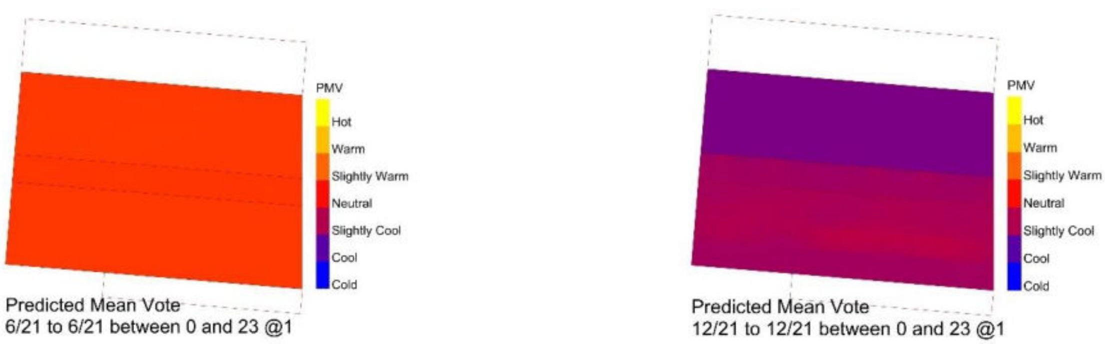
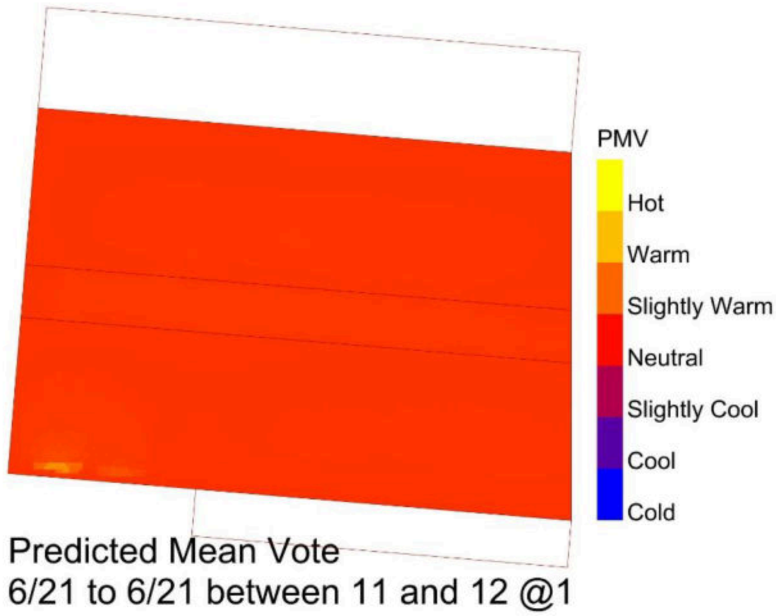


Figure 56: PMV for summer and winter solstice for internal insulation.



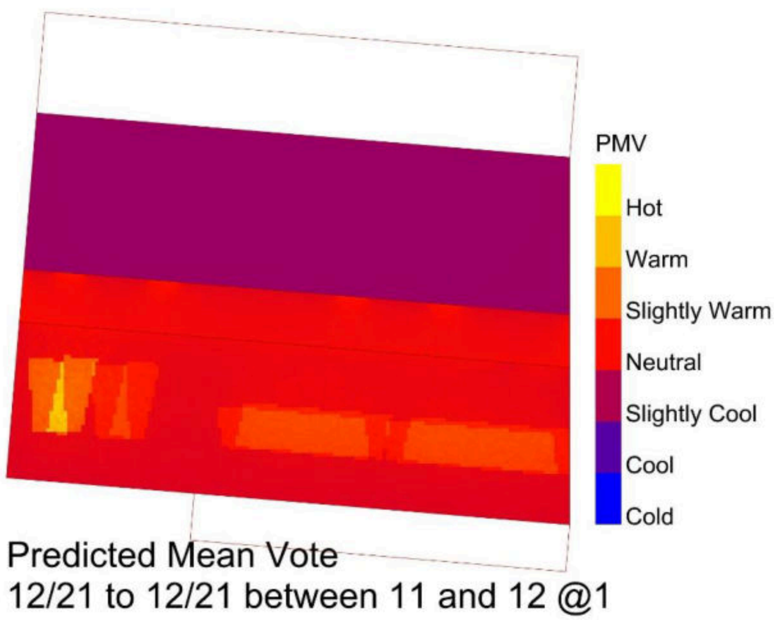


Figure 57: PMV for 1 hours in summer and winter solstice

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Scenario 3: Insulation on the roof

Proposed Solution: Installation of thermal insulating tiles, composed of extruded polystyrene and cement mortar, offering effective thermal insulation and durability.

Installing insulation on the roof is essential for improving the building's overall energy efficiency, as a significant amount of heat is typically lost through the roof during winter and gained during summer. By adding thermal insulation, we can reduce unwanted heat transfer, thereby decreasing the heating and cooling loads required to maintain comfortable indoor temperatures. This not only leads to lower energy consumption and utility costs but also enhances occupant comfort and contributes to the long-term sustainability of the building. Moreover, roof insulation helps in stabilizing indoor temperatures, reducing temperature fluctuations and improving the performance of HVAC systems.

Material	**Width (m)**	**Thermal Conductivity Coefficient λ (W/mK)**	**Thermal resistance R (m²K/W)**
Waterproof material	0.01	0.2	0.050
Concrete	0.20	2.1	0.095
Expanded polystyrene	0.10	0.035	2.86
Total thermal resistance R			**3.005**
Total U-value			**0.33 W/m²·K**

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Scenario 4: Replacement of windows and frames

The replacement of the existing windows and frames is proposed to improve the building's thermal and acoustic performance. The current frames will be removed and replaced with new thermally insulating aluminium frames that incorporate thermal break technology, along with double or triple Low-E glazed panes. These new window systems have a low thermal transmittance coefficient ($U \leq 2.25$ W/m²K), which significantly reduces heat loss during winter and heat gain during summer. Additionally, the proposed glazing offers a Solar Heat Gain Coefficient (SHGC) between 0.2 and 0.4 and a Visible Light Transmittance (VLT) of 50–70%, providing a balanced level of natural lighting while minimizing overheating. For enhanced energy efficiency and comfort, internal blinds will also be installed in combination with an external shading system. Furthermore, the new windows will offer improved sound insulation, achieving noise levels of at least 40 dB, which is particularly beneficial for office spaces.

Component	**U-value (W/m²·K)**
Thermal Insulating Aluminum Frame	2.2
Double Glazed Low-E Glass	1.1
Total Window U-value	**1.6**

By implementing the above solutions, the Strovolos Town Hall will achieve a significant reduction in thermal losses, improving its energy performance and contributing to energy savings. Furthermore, this upgrade will enhance the aesthetic and functional value of the building, while preserving its character as a landmark of the city.

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Scenario 5: Replacement of electro-mechanical equipment

As part of the energy upgrade of the Strovolos Town Hall building, it is proposed to replace a significant portion of the existing electromechanical equipment located on the roof. Currently, there are 18 Variable Refrigerant Volume (VRV) units in operation, which are of outdated technology and exhibit a low coefficient of performance (COP ≈ 3). Over time, the performance of these units has further deteriorated, resulting in increased energy consumption and reduced system efficiency.

The new VRV units, with a COP of 4.2 compared to the older units' COP of 3.0, are approximately 40% more efficient. This corresponds to an estimated energy consumption reduction of around 29%, based solely on system efficiency improvement.

$$EnergySavings = 1 - \frac{COPold}{COPnew} = 1 - 0.716$$

As part of the HVAC system upgrade, it is proposed to repair and replace the thermal insulation on the refrigerant piping of the VRV systems, both on the rooftop and within the false ceilings. Over time, the insulation on these pipes has deteriorated due to weather exposure, UV radiation, and mechanical wear, resulting in increased thermal losses and reduced system efficiency.

Poor or damaged insulation on refrigerant pipes can lead to significant energy losses. Based on typical industry data and case studies, heat loss from uninsulated or poorly insulated refrigerant lines can result in a 5% to 15% increase in energy consumption for air conditioning systems, depending on pipe length, temperature difference with the environment, and exposure conditions.

For the Strovolos Town Hall building, we can assume:

A conservative estimate of 8–10% additional energy loss is occurring due to degraded insulation.

By restoring insulation to proper standards (using UV-resistant, closed-cell insulation with adequate thickness), these losses can be virtually eliminated.

The replacement of the existing chiller unit, which was installed in the year 2000 and operates with a relatively low Coefficient of Performance (COP) of approximately 2.5. The proposed new unit is the DAIKIN EWWQ-KC, with a cooling capacity of 115 kW and a significantly higher COP of 4.5, representing an improvement of approximately 60% in efficiency

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compared to the current system. This chiller also offers the capability to connect to six separate hydraulic circuits, as opposed to the two supported by the existing unit, allowing for greater flexibility and improved load distribution across multiple zones. The energy savings from the chiller replacement is calculated

$$EnergySavings = 1 - \frac{COPold}{COPnew} = 1 - 0.556$$

In recent decades, there have been substantial technological advancements in chiller systems, particularly in terms of energy efficiency, control systems, and performance under varying temperature conditions. The new unit is designed to maintain high efficiency even at elevated ambient temperatures, further enhancing its suitability for the local climate.

Overall, this upgrade is expected to significantly reduce the energy consumption associated with central cooling in the building, contribute to lower operational costs, and improve system reliability and controllability.

Scenario 6: Lighting technology

The existing lighting system in each office consists of four halogen-based ceiling panels, each rated at 65 W and providing approximately 1,350 lumens. This setup results in a total power consumption of 260 W per office and an estimated lighting level of 600 lux, which just meets but does not significantly exceed the minimum recommended illuminance level of 500 lux for office environments.

The proposed upgrade involves replacing these four halogen panels with two high-efficiency LED luminaires, each consuming 36 W and producing 3,860 lumens, for a total power draw of just 72 W per office. Despite using significantly less energy, the new system provides a combined light output of 7,720 lumens, which translates to an estimated illuminance of 857 lux—a 25% increase in light levels compared to the existing setup.

This results in impressive energy savings of approximately 72% when comparing total wattage (**260 W → 72 W**). Additionally, when factoring in the higher light output, the system achieves a **361%** increase in luminous efficacy (lumens per watt), meaning vastly improved lighting quality at a fraction of the energy cost.

The new LED lighting configuration not only surpasses the minimum lighting standards for office spaces but also contributes meaningfully to the overall energy efficiency goals of the building retrofit.

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Figure 58: Lighting specifications

Scenario 7: Photovoltaic System Integration

As part of the broader energy efficiency and sustainability strategy for the Strovolos Town Hall building, a photovoltaic (PV) system is proposed with a total installed capacity of 102.52 kWp. The system comprises 233 solar panels of the model Tiger Neo N-type 54HL4R-(V), each with a nominal output of 440 W. The system will be supported by two HUAWEI SUN2000-50KTL-M3 inverters, which offer high conversion efficiency and advanced monitoring capabilities.

Based on the current energy consumption profile of the building and local solar potential, the PV installation is expected to cover approximately 6% of the building’s total annual energy demand. While this percentage may seem modest, it contributes to the diversification of the building’s energy mix, reduces reliance on grid electricity, and aligns with national goals for increased integration of renewable energy sources.

Beyond its primary function of generating renewable energy, the PV system serves two key roles in the building's energy and environmental strategy:

1. Shading of Rooftop Equipment: By covering a large portion of the rooftop, the PV panels provide passive shading for the electromechanical equipment installed on the roof (such as VRV units), reducing their exposure to direct sunlight and lowering their thermal stress and cooling loads.
2. Reduction of Thermal Gains: The presence of PV panels significantly decreases the thermal radiation absorbed by the building's roof, thereby reducing heat transfer into interior spaces. This helps to improve the overall thermal performance of the building envelope, particularly during the hot summer months.

Together, these functions make the PV installation a multifunctional energy intervention—supporting both active and passive energy-saving strategies, enhancing occupant comfort, and reinforcing the municipality's commitment to environmental sustainability.

Figure 59: PV Installation on the roof

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14. VALIDATION OF RESULTS

To validate the simulation results of the Strovolos Municipality building, we compared them with a published case study titled *"Energy renovation of an existing building in Nicosia, Cyprus and investigation of the passive contribution of a BIPV/T double façade system: A case study"*[11]. The reference building analyzed in the article has a total floor area of approximately 1117.85 m², whereas the Strovolos Municipality building has a total area of 6000 m². However, for the purpose of our simulation, we modeled a representative and repetitive section of the building in Rhino, with a floor area of 735 m², which accurately reflects the overall energy behavior of the entire structure. Our energy performance simulations yielded annual primary energy consumption values of 137 kWh/m² for the scenario with external wall insulation and 141 kWh/m² for the internal insulation scenario. These values are close to the 123 kWh/m²/year reported in the case study, which was achieved after the implementation of significant energy efficiency measures. Despite the difference in total building size, both cases concern large public-use buildings located in Nicosia, with similar climatic conditions and construction typologies. The consistency between our results and those of the validated article supports the reliability of our simulation and indicates that the proposed insulation interventions would bring the building's energy performance within the expected regional and typological standards.

Another way to validate our results, we compared the EPC findings with those generated by our software. The EPC report indicates an annual energy consumption of **422 kWh/m²/year** for the entire **6,000 m²** building, while our simulation yielded **175 kWh/m²/year** for a **750 m²** partition. This discrepancy is both logical and expected, given that our analysis focuses on a specific area with significantly lower energy demands.

The partition we modeled utilizes only two VRV units for cooling and is equipped with minimal halogen lighting. In contrast, the most energy-intensive areas of the building are excluded from our scope. These include the entrance, which relies on a 25-year-old chiller and a 25-year-old 100% fresh air handling unit, both of which are inefficient by modern standards.

Additionally, the building's central rooftop features a convex dome constructed from different materials and with lower insulation compared to the rest of the roof. This dome is a major contributor to the building's overall heat gains, further explaining the higher energy use reflected in the EPC results.

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15.TECHNOECONOMIC ANALYSIS

15.1. 102.65 kWp Photovoltaic System

One of the major problems with building is that 0% of its total energy consumption is currently produced from renewable energy sources. This is particularly concerning given that it is a public building, and according to EU policies, all public sector buildings are required to be nearly zero-energy buildings (nZEB) by 2030.

Additionally, the cost of electricity has risen dramatically in recent years due to several global crises, including the COVID-19 pandemic, the Russia-Ukraine war, and ongoing conflicts in the Middle East. In contrast, the cost of photovoltaic (PV) systems has decreased significantly, thanks to advancements in technology and increased research and development in the sector.

As a result, a techno-economic analysis was conducted for the installation of a 102.65 kWp PV system on the roof of the Strovolos Municipality building. The details of this analysis are presented below.

- **System size:** 102.65 kWp
- **Cost per kWp:** €1,000 → **Initial investment:** €102,650
- **Annual production:** 128,312.5 kWh
- **Degradation:** 0.5%/year
- **Curtailment: 15%/year**
- **Maintenance cost:** 0.5%/year of initial cost → €513.25/year
- **Electricity value:** €0.30/kWh
- **Discount rate:** 6%
- **Project duration:** 25 years

$$NPV = -InitialInvestment + \sum_{t=1}^{25} \frac{NetCashFlowt}{(1+r)^t}$$

Present Value → PV= € 336,032.60

Initial investment = €102,650

IRR: 22%

NPV = €223.382,6

Payback Period: 3.5 Years

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YEAR	CASH FLOW	PV FACTOR (6%)	PRESENT VALUE
1	32206.43	0.94	30383.42453
2	31532.14785	0.88999644	28063.49933
3	30861.23711	0.839619283	25911.68978
4	30193.68093	0.792093663	23916.22333
5	29529.46252	0.747258173	22066.13221
6	28868.56521	0.70496054	20351.19933
7	28210.97238	0.665057114	18761.90786
8	27556.66752	0.627412371	17289.39412
9	26905.63418	0.591898464	15925.40353
10	26257.85601	0.558394777	14662.24965
11	25613.31673	0.526787525	13492.77574
12	24972.00015	0.496969364	12410.31902
13	24333.89015	0.468839022	11408.67726
14	23698.9707	0.442300964	10482.07759
15	23067.22584	0.417265061	9625.147392
16	22438.63971	0.393646284	8832.887135
17	21813.19652	0.371364419	8100.645042
18	21190.88053	0.350343791	7424.093423
19	20571.67613	0.33051301	6799.206609
20	19955.56775	0.311804727	6222.240352
21	19342.53991	0.294155403	5689.712617
22	18732.57721	0.277505097	5198.385654
23	18125.66432	0.261797261	4745.249278
24	17521.786	0.246978548	4327.505271
25	16920.92707	0.232998631	3942.552835

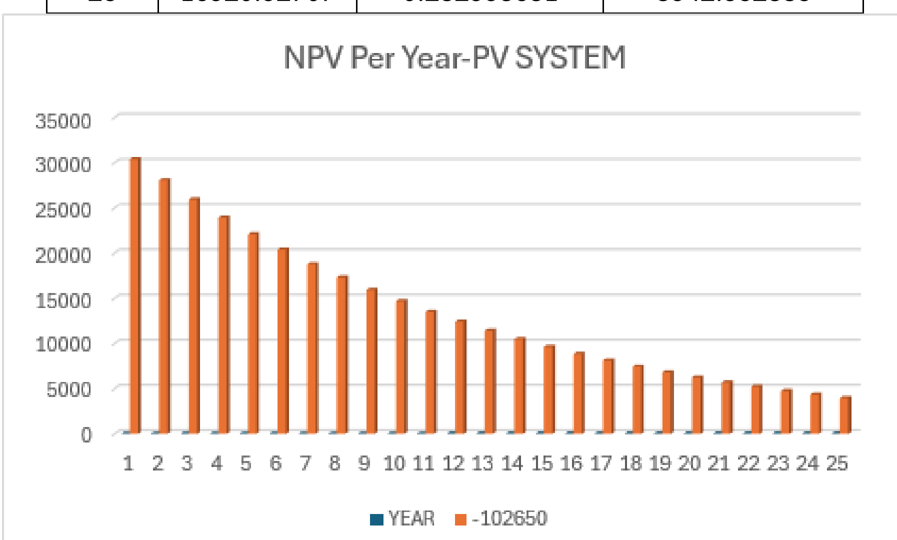

Figure 60: NPV per year for PV System

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15.2. Lighting Replacement

Another significant improvement proposed for the building is the replacement of outdated halogen lighting with modern LED technology. Halogen bulbs are highly inefficient, consuming much more energy compared to LEDs, and have a considerably shorter lifespan. By switching to LED lighting, the building can substantially reduce electricity consumption, contributing to both energy efficiency goals and operational cost savings.

In addition to energy savings, LED lighting systems provide better control over light distribution and intensity, helping ensure that illumination levels (lux) meet the required standards for office environments. According to EN 12464-1:2021, the recommended average illumination for general office tasks such as reading, writing, and computer work is 500 lux. LEDs can be precisely calibrated to meet or exceed this standard, improving visual comfort, employee productivity, and overall indoor environmental quality.

This upgrade not only aligns with the building's path toward nearly zero-energy performance but also enhances lighting quality, maintenance efficiency, and compliance with EU regulations for public sector buildings.

Total lighting points replaced: 800

Cost per lighting point: 200€

Total Energy consumption: 422 kWh/m^2 /year

Lighting energy consumption: 20% of total energy consumption → 84.4 kWh/m^2 /year

Cost of kWh: 0.30€

Total money spent on lighting each year: 113.940€

With LED we have 1.8 times lower consumption

IRR:24%

NPV= € 399,329.07

Payback Period: 4.5 Years

YEAR	CASH FLOW	FACTOR (6%)	PV
1	50640	0.94	47773.58491
2	49873.55	0.88999644	44387.28195
3	49110.93225	0.839619283	41234.48572
4	48352.12759	0.792093663	38299.41387
5	47597.11695	0.747258173	35567.33465
6	46845.88137	0.70496054	33024.49785
7	46098.40196	0.665057114	30658.07015
8	45354.65995	0.627412371	28456.07475
9	44614.63665	0.591898464	26407.33488
10	43878.31347	0.558394777	24501.42106
11	43145.6719	0.526787525	22728.60173
12	42416.69354	0.496969364	21079.79719
13	41691.36007	0.468839022	19546.53649
14	40969.65327	0.442300964	18120.91715
15	40251.55501	0.417265061	16795.56754
16	39537.04723	0.393646284	15563.61171
17	38826.11199	0.371364419	14418.63651
18	38118.73143	0.350343791	13354.66088
19	37414.88778	0.33051301	12366.1072
20	36714.56334	0.311804727	11447.77439
		TOTAL	**€ 515,731.71**

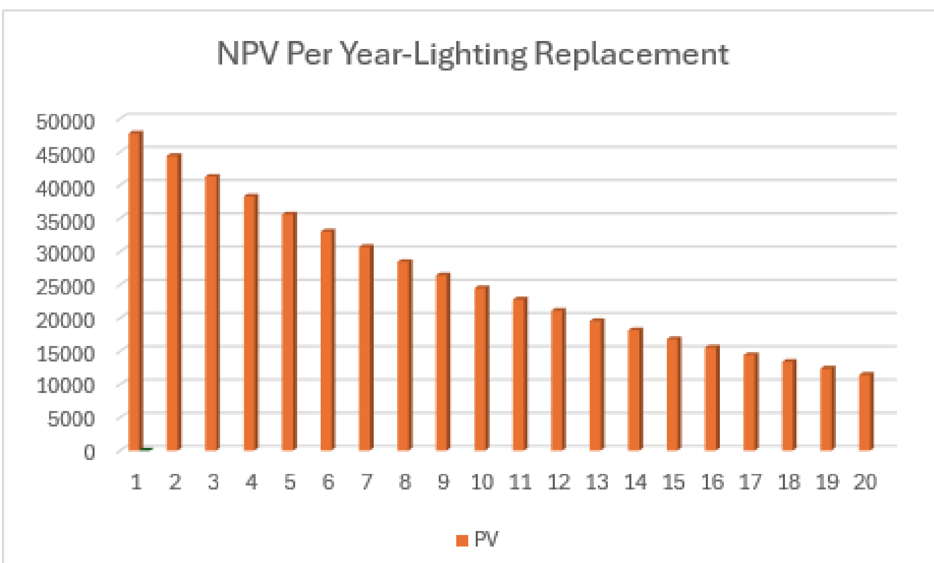

Figure 61: NPV per year for Lighting Replacement

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15.3. Addition of Internal Insulation

Because of the High U-Value of the external walls of the building we have huge energy losses and worst thermal comfort because of it. This is why the third technoeconomic analysis regards internal insulation, which is a passive solution that will decrease energy needs and also will increase thermal comfort.

SQUARE METERS	1920
COST /M^2	104€
INITIAL INVESTMENT	€ 200,000.00
REDUCTION IN ENERGY CONSUMPTION	21kWh/m^2
TOTAL INTERNAL AREA	4500
REDUCTION IN kWh	99900
REDUCTION IN EURO	**€ 30,000.00**

YEAR	CASH FLOW	FACTOR (6%)	PV
1	30000	0.94	28301.88679
2	30000	0.88999644	26699.8932
3	30000	0.839619283	25188.57849
4	30000	0.792093663	23762.8099
5	30000	0.747258173	22417.74519
6	30000	0.70496054	21148.81621
7	30000	0.665057114	19951.71341
8	30000	0.627412371	18822.37114
9	30000	0.591898464	17756.95391
10	30000	0.558394777	16751.84331
11	30000	0.526787525	15803.62576
12	30000	0.496969364	14909.08091
13	30000	0.468839022	14065.17067
14	30000	0.442300964	13269.02893
15	30000	0.417265061	12517.95182
16	30000	0.393646284	11809.38851
17	30000	0.371364419	11140.93256
18	30000	0.350343791	10510.31373
19	30000	0.33051301	9915.390315
20	30000	0.311804727	9354.141807
21	30000	0.294155403	8824.662082

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22	30000	0.277505097	8325.152907
23	30000	0.261797261	7853.917837
24	30000	0.246978548	7409.35645
25	30000	0.232998631	6989.958915
26	30000	0.219810029	6594.300863
27	30000	0.207367952	6221.03855
28	30000	0.195630143	5868.904293
29	30000	0.184556739	5536.702163
30	30000	0.174110131	5223.303927
31	30000	0.16425484	4927.645214
32	30000	0.154957397	4648.7219
33	30000	0.146186223	4385.586699
34	30000	0.137911531	4137.345942
35	30000	0.130105218	3903.156549
36	30000	0.122740772	3682.223159
37	30000	0.115793181	3473.795433
38	30000	0.10923885	3277.165503
39	30000	0.103055519	3091.665569
40	30000	0.097222188	2916.665631
41	30000	0.091719045	2751.57135
42	30000	0.086527401	2595.822029
43	30000	0.081629624	2448.888706
44	30000	0.077009079	2310.272364
45	30000	0.072650074	2179.50223
46	30000	0.068537806	2056.13418
47	30000	0.064658308	1939.749226
48	30000	0.060998403	1829.9521
49	30000	0.057545664	1726.369906
50	30000	0.054288362	1628.650855
		TOTAL	**€ 472,855.82**
		INITIAL INVESTMENT	**€ 200,000.00**
		NPV	**€ 272,855.82**
		IRR	**8%**
		PAYBACK PERIOD	**8 years**

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15.4. Replace of Mechanical equipment

The HVAC systems of the Strovolos Municipality building account for approximately 50% of the total annual energy consumption, making them a critical focus area for improving overall energy efficiency. As part of the proposed upgrade, we suggest the full replacement of the existing 18 VRV systems, each with a capacity of 20 kW and a high-efficiency COP of 4.2, with reliable brands. The estimated cost for each unit, including supply, installation, transport, and commissioning, amounts to €15,000, resulting in a total VRV system upgrade cost of €405,000. Additionally, the outdated central chiller system, currently rated at 115 kW with a COP of 2.5 and manufactured in 2000, will be replaced with a modern high-efficiency unit (COP = 4.2). The chiller's total replacement cost, including transport and testing, is calculated at €45,000. Therefore, the overall investment required for the HVAC equipment replacement amounts to €450,000.

The technoeconomic analysis of the following are presented below:

TOTAL INVESTMENT	€ 450,000.00
ENERGY CONSUPTION FOR HVAC	40%
CONSUPTION IN KWh BEFORE INVESTMENT	950,000
CONSUPTION IN kWh AFTER INVESTMENT	570,000
REDUCTION IN kWh	380,000
REDUCTION IN EUROS	€ 114,000.00
DELAGATION	0.5% ANNUALY
O&M	€ 513.25

YEAR	CASH FLOW	FACTOR (6%)	PV
1	114000	0.94	107547.1698
2	112916.75	0.88999644	100495.5055
3	111838.9163	0.839619283	93902.11068
4	110766.4717	0.792093663	87737.42031
5	109699.3893	0.747258173	81973.76522
6	108637.6424	0.70496054	76585.25107
7	107581.2042	0.665057114	71547.64511
8	106530.0481	0.627412371	66838.27012
9	105484.1479	0.591898464	62435.90506
10	104443.4772	0.558394777	58320.69212

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11	103408.0098	0.526787525	54474.04957
12	102377.7197	0.496969364	50878.59021
13	101352.5811	0.468839022	47518.04503
14	100332.5682	0.442300964	44377.19168
15	99317.65537	0.417265061	41441.7875
16	98307.81709	0.393646284	38698.50686
17	97303.02801	0.371364419	36134.88242
18	96303.26287	0.350343791	33739.25021
19	95308.49655	0.33051301	31500.69812
20	94318.70407	0.311804727	29409.01776
		Total	**€ 1,215,555.75**
		Total Investment	**€ 450,000.00**
		NPV	**€ 765,555.75**
		IRR	**17%**
		PAYBACK PERIOD	**5 years**

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15.5. Addition of Roof insulation

Roof insulation is another passive solution that will also decrease energy needs and also increase the thermal comfort of the building.

AREA	1100
COST /M^2	50 €
INITIAL INVESTMENT	55,000
REDUCTION OF ENERGY CONSUMPTION	10.5kWh/m^2
TOTAL INTERNAL AREA	4500
REDUCTION IN kWh	47250
REDUCTION IN EURO	**€ 14,175.00**

YEAR	CASH FLOW	FACTOR (6%)	PV
1	14750	0.94	13915.09434
2	14750	0.88999644	13127.44749
3	14750	0.839619283	12384.38442
4	14750	0.792093663	11683.38153
5	14750	0.747258173	11022.05805
6	14750	0.70496054	10398.16797
7	14750	0.665057114	9809.592426
8	14750	0.627412371	9254.332477
9	14750	0.591898464	8730.502337
10	14750	0.558394777	8236.322959
11	14750	0.526787525	7770.116
12	14750	0.496969364	7330.298113
13	14750	0.468839022	6915.375578
14	14750	0.442300964	6523.939225
15	14750	0.417265061	6154.659646
16	14750	0.393646284	5806.282685
17	14750	0.371364419	5477.625174
18	14750	0.350343791	5167.570919
19	14750	0.33051301	4875.066905
20	14750	0.311804727	4599.119722
21	14750	0.294155403	4338.79219
22	14750	0.277505097	4093.200179
23	14750	0.261797261	3861.509603
24	14750	0.246978548	3642.933588

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25	14750	0.232998631	3436.7298
26	14750	0.219810029	3242.197924
27	14750	0.207367952	3058.677287
28	14750	0.195630143	2885.544611
29	14750	0.184556739	2722.211897
30	14750	0.174110131	2568.124431
31	14750	0.16425484	2422.758897
32	14750	0.154957397	2285.621601
33	14750	0.146186223	2156.246793
34	14750	0.137911531	2034.195088
35	14750	0.130105218	1919.05197
36	14750	0.122740772	1810.426387
37	14750	0.115793181	1707.949421
38	14750	0.10923885	1611.273039
39	14750	0.103055519	1520.068905
40	14750	0.097222188	1434.027269
41	14750	0.091719045	1352.855914
42	14750	0.086527401	1276.279164
43	14750	0.081629624	1204.036947
44	14750	0.077009079	1135.883912
45	14750	0.072650074	1071.588597
46	14750	0.068537806	1010.932638
47	14750	0.064658308	953.7100362
48	14750	0.060998403	899.7264492
49	14750	0.057545664	848.798537
50	14750	0.054288362	800.7533368
		TOTAL	**€ 232,487.44**
		INITIAL INVESTMENT	**€ 55,000.00**
		NPV	**€ 177,487.44**
		IRR	**20%**
		PAYBACK PERIOD	**4 years**

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15.6 Combined Scenarios

In order to be able to provide a completed solution for the client we combined some scenarios to see the viability of that investment with much higher initial cost. The combined scenario is the active scenario where the **mechanical equipment is replaced alongside with the PV System.**

The results of this analysis are presented below:

YEAR	CASH FLOW	FACTOR (6%)	PV
1	135500	0.94	127830.1887
2	133809.25	0.88999644	119089.7561
3	132626.9538	0.839619283	111356.1478
4	131450.569	0.792093663	104121.1627
5	130280.0661	0.747258173	97352.84418
6	129115.4158	0.70496054	91021.27331
7	127956.5887	0.665057114	85098.43957
8	126803.5558	0.627412371	79558.11963
9	125656.288	0.591898464	74375.7638
10	124514.7566	0.558394777	69528.38971
11	123378.9328	0.526787525	64994.48269
12	122248.7881	0.496969364	60753.90243
13	121124.2942	0.468839022	56787.79565
14	120005.4227	0.442300964	53078.51419
15	118892.1456	0.417265061	49609.53835
16	117784.4349	0.393646284	46365.40506
17	116682.2627	0.371364419	43331.64064
18	115585.6014	0.350343791	40494.69779
19	114494.4234	0.33051301	37841.89655
20	113408.7013	0.311804727	35361.36912
21	112328.4077	0.294155403	33042.00802
22	111253.5157	0.277505097	30873.41766
23	110183.9981	0.261797261	28845.86894
24	109119.8281	0.246978548	26950.25675
25	108060.979	0.232998631	25178.06012
		TOTAL	**€ 1,592,840.94**
		INITIAL INVESTMENT	**€ 552,650.00**
		NPV	**€ 1,040,190.94**
		IRR	**16%**
		PAYBACK PERIOD	**5.2 years**

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The second combined scenario is the passive scenario where we **install internal insulation and roof insulation** to reduce the energy needs but also to improve the energy efficiency and thermal comfort of the users. This solution will also increase productivity and the efficiency of the users.

The results of this analysis are presented below:

YEAR	CASH FLOW	FACTOR (6%)	PV
1	44750	0.94	42216.98113
2	44750	0.88999644	39827.34069
3	44750	0.839619283	37572.96292
4	44750	0.792093663	35446.19143
5	44750	0.747258173	33439.80324
6	44750	0.70496054	31546.98418
7	44750	0.665057114	29761.30583
8	44750	0.627412371	28076.70362
9	44750	0.591898464	26487.45624
10	44750	0.558394777	24988.16627
11	44750	0.526787525	23573.74176
12	44750	0.496969364	22239.37902
13	44750	0.468839022	20980.54625
14	44750	0.442300964	19792.96816
15	44750	0.417265061	18672.61147
16	44750	0.393646284	17615.6712
17	44750	0.371364419	16618.55773
18	44750	0.350343791	15677.88465
19	44750	0.33051301	14790.45722
20	44750	0.311804727	13953.26153
21	44750	0.294155403	13163.45427
22	44750	0.277505097	12418.35309
23	44750	0.261797261	11715.42744
24	44750	0.246978548	11052.29004
25	44750	0.232998631	10426.68872
26	44750	0.219810029	9836.498788
27	44750	0.207367952	9279.715838
28	44750	0.195630143	8754.448903

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29	44750	0.184556739	8258.91406
30	44750	0.174110131	7791.428358
31	44750	0.16425484	7350.404112
32	44750	0.154957397	6934.343501
33	44750	0.146186223	6541.833492
34	44750	0.137911531	6171.54103
35	44750	0.130105218	5822.208519
36	44750	0.122740772	5492.649546
37	44750	0.115793181	5181.744855
38	44750	0.10923885	4888.438542
39	44750	0.103055519	4611.734474
40	44750	0.097222188	4350.6929
41	44750	0.091719045	4104.427264
42	44750	0.086527401	3872.101193
43	44750	0.081629624	3652.925653
44	44750	0.077009079	3446.156277
45	44750	0.072650074	3251.090827
46	44750	0.068537806	3067.066818
47	44750	0.064658308	2893.459262
48	44750	0.060998403	2729.678549
49	44750	0.057545664	2575.168443
50	44750	0.054288362	2429.404191
		TOTAL	**€ 513,278.97**
		INITIAL INVESTMENT	**€ 255,000.00**
		NPV	**€ 258,278.97**
		IRR	**11%**
		PAYBACK PERIOD	**8.5 years**

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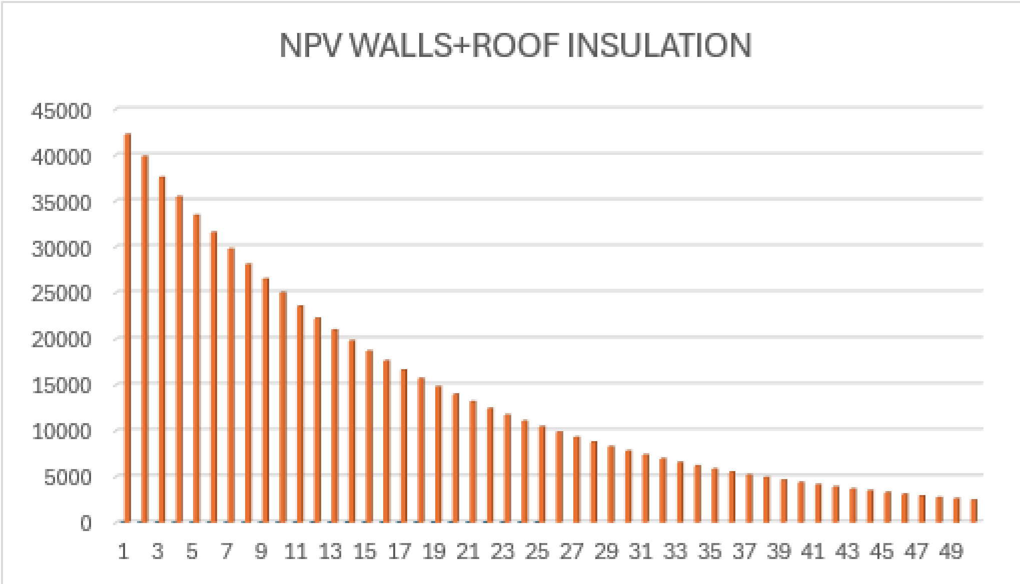

Figure 62: NPV per year for Internal & Roof Insulation

16. CONCLUSIONS

Due to the size of the building, the existing outdated equipment, and the complete lack of thermal insulation, it is imperative to invest in its energy upgrade.

An assessment of the current condition clearly revealed that the building suffers from significant deficiencies in terms of thermal comfort.

The addition of thermal insulation to the roof and the building envelope results in a substantial reduction in heating and cooling needs, thereby contributing to overall energy efficiency.

All techno-economic studies demonstrate the viability of the investment, as the rising cost of electricity, combined with the low efficiency of the obsolete electromechanical equipment, make such interventions necessary.

At the same time, investing in Renewable Energy Sources (RES) is essential for the building to become more environmentally friendly, comply with European directives, and meet part or all its energy needs through self-consumption.

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