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An Investigation on Climate Responsive Design Strategies of Apartment Buildings in Athens of the Period 1920-1960s

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***Abstract*—**This paper thoroughly investigates residential buildings of the period 1920-1960 in Athens and evaluates their bioclimatic response and energy performance. A methodology adapted to the specific context of the city is proposed and applied in order to assess and extract results related to the climate analysis of the city of Athens, the general/architectural design and construction characteristics of the apartment buildings constructed during the period 1920-1960, the bioclimatic strategies applied on them, and the achieved thermal comfort based on questionnaires answered by their users. The results of the current study indicate that the residential architecture of that period in the city of Athens is adapted to an extent to the local climate with various climate responsive strategies. As an outcome of the analysis, the most frequently applied strategies depending on the period of construction are presented. For this reason, the examined period is divided into 3 sub – periods: 1st period, 1920s-1930s (late neoclassicism & eclecticism), 2nd period, 1930s-1940s (modernism), 3rd period, 1940s-1960s (postwar modernism).

***Keywords*—**Athens, climatic design strategies, residential buildings, middle war and post war architecture, thermal comfort.

I. Introduction

THE climate change and global warming phenomenon have been extensively studied during the last decades and remain on the top of the environmental agenda not only in Greece but all over the advanced world. The various studies performed focus on understanding the extent of the problem [5], [14], identifying the factors that led to its occurrence, as well as seeking solutions to mitigate its effects. All studies converge on the view that definitively addressing global warming seems impossible, but at the same time point out that there is still time to mitigate its effects [6]. From an energy point of view, the building sector is among the most energy consuming in the advanced world during construction and use. To this acknowledgement, the European Union has adopted a series of directives dealing with the energy efficiency of both new buildings and existing structures, to reduce the amount of energy consumed by buildings as much as possible.

The construction sector, at European level, contributes to 18.4% of total global greenhouse gas emissions. Historic buildings amount to a significant proportion of the existing building stock. More specifically, more than 14% of them were built before 1919, 12% in the period 1919-1945 and about 40% before 1960 [1].

In terms of their uses, residential buildings constitute 22.7% of the buildings constructed before 1945, while the percentage of those dating back to the period 1945-1969 reaches 26.2% [1].

One of the main reasons that make it necessary to upgrade historic buildings is their average energy consumption, which has been proven to be significantly higher than in modern buildings. It is estimated that the renovation of the European housing stock built before 1945 could save up to 180 Mt CO_2 per year [2] and that the energy incorporated in the construction process amounts to up to 30% [3] of the total energy consumed during the life cycle of each building. During demolition, this embedded energy is lost [4]. Consequently, the preservation and upgrading of historic buildings is itself a viable solution as it preserves the energy embodied into the building shell [5]. At the same time, the upgrade of historic buildings through appropriate interventions, which respect their historic and architectural value (benign changes), is a way to ensure the preservation of the historical identity of the urban developments around the world.

The current study aims at providing a methodology to be followed in case of examining a specific building typology in terms of its energy performance, as well as discovering the basic climate responsive strategies most usually applied at residential buildings constructed in Athens between 1920 and 1960. At the same time through this study is underlined the importance of preserving the residential architecture of the middle war and post war period not just in Athens but at a global level.

II. Methodology

In recent years, various studies [5], [6] regarding the energy performance and energy upgrade of existing buildings have been performed and the various parameters that should be taken into consideration when performing such upgrades have been extensively analyzed and discussed [6].

In Greece the building stock before insulation codes were introduced varies significantly with that of different eras. Especially the residential buildings, both single and apartment buildings, retain assimilated architectural and structural characteristics of traditional Greek architecture along with the influences of foreign architectural movements of each period. The building stock of the city of Athens constitutes a group

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characterized of great variety. On the one hand are the traditional buildings made of stone, wood, mud, and lime mostly found in traditional settlements and less in the city of Athens. On the other hand, those of neoclassical, pre-industrial and interwar era made initially of stone and afterwards of concrete. Both cases offer a big opportunity for energy upgrade. For this reason, various studies have been developed aiming at analyzing the existing building stock, categorizing it in terms of its energy performance as well as examining the possibility to be reused and effectively upgraded from an energy point of view [7], [15], [16].

The present study concerns the evolution of the built environment in central Athens during the last century. Elements such as site planning, typology, construction materials and building techniques were examined. Sixty building examples including both single, double/triple residences and apartment building examples were initially analyzed in terms of their general characteristics. Afterwards, the selected case studies spread over the city of Athens were examined, analyzed, and assessed regarding the above-mentioned parameters. In the end, four out of the sixty buildings were selected and analyzed in depth to understand the specific bioclimatic strategies applied on them, evaluate their climatic response, and define their environmental footprint.

A. Analysis_Step1: Climate Analysis – Diagrams

The city of Athens is characterized by mild Mediterranean climate with an average annual temperature of 18.03 °C and sunshine during most days of the year, even in the winter period. The coldest month is January, while the hottest is July with temperatures that often reach 40 °C. In August the temperature is slightly lower compared to July due to the local airflows which effectively cool the city. Snowfall is quite rare while at the same time the mean yearly precipitation is also relatively small. The prevailing wind direction is north – south. Based on Figs. 1, 3-5, we can conclude that the cooling period is slightly more critical than the heating one. Due to the climate change consequences, variations to local climatic conditions are observed in recent years and expected in the years to come, with extreme weather conditions in both seasons.

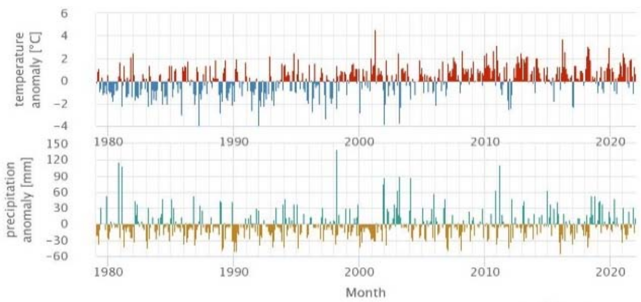

Fig. 1 Mean yearly precipitation and temperature, trend, and anomaly, 1979-2022 [8]

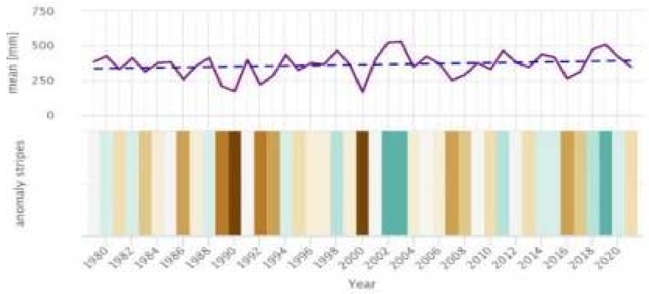

Fig. 2 Mean yearly precipitation, trend, and anomaly, 1979-2022 [8]

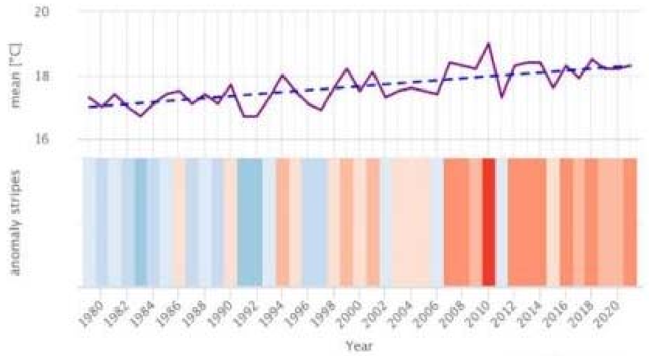

Fig. 3 Mean yearly temperature, trend, and anomaly, 1979-2022 [8]

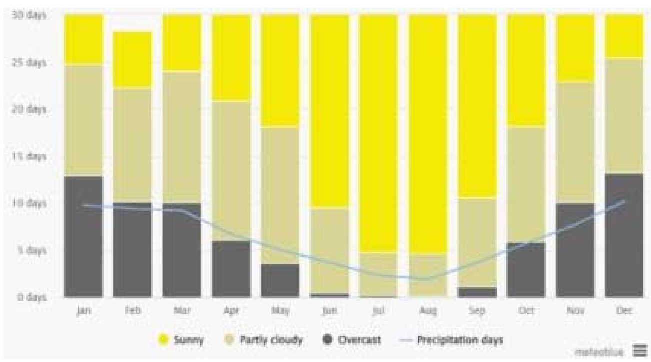

Fig. 4 Cloudy, sunny, and precipitation days during the year [8]

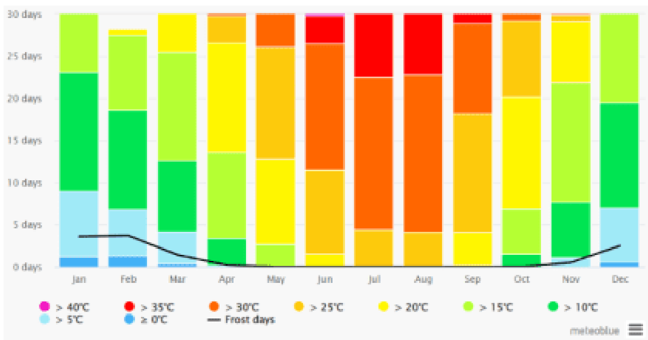

Fig. 5 Temperature minima and maxima during the year [8]

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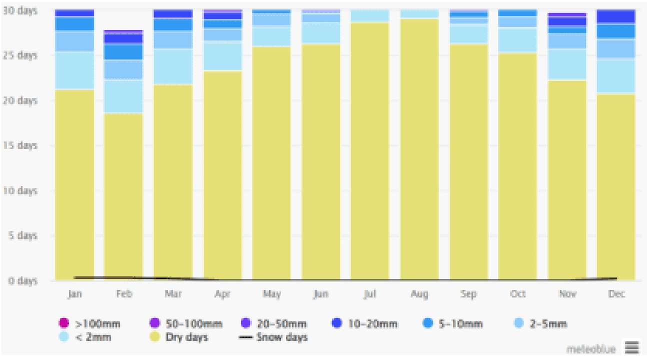

Fig. 6 Precipitation amounts during the year [8]

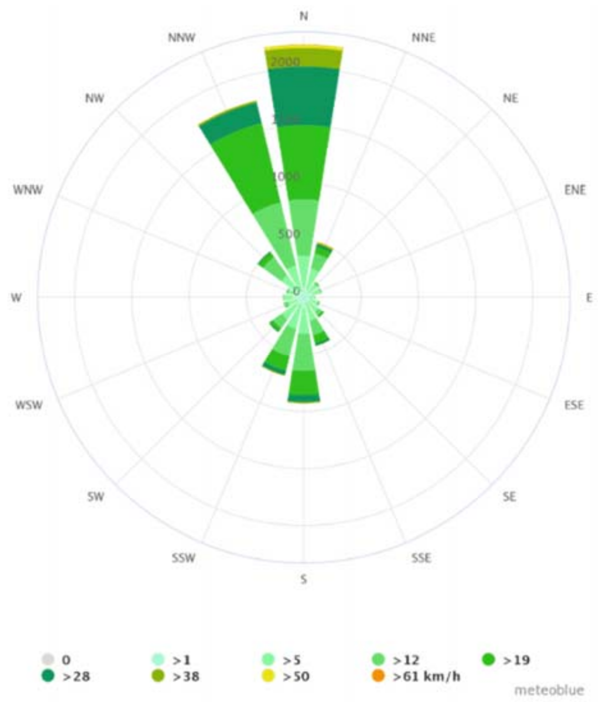

Fig. 7 Rose diagram [8]

B. Analysis_Step2: City Mapping

As defined by Marmaras [9], during the middle and early post war periods, new residential apartment buildings known with the Greek term *"polykatoikia"*, started to expand all over the city [10]. The largest amount was built in the region defined by Vasileos Konstantinou, Vasilissis Sofias and Patision Avenues, creating four main residential cores:

- The neighborhoods developed around the *Mavili*, *Koliatsou*, *Omonia*, *Kotzia* and *Syntagma Squares*,
- The *Kolonaki neighborhood,*
- The *Monastiraki neighborhood,*
- The neighborhood around the *Former Royal Palace* of Athens,

Nowadays, the biggest percentage of these buildings is still found in the *Kolonaki neighborhood*, *Plaka neighborhood* close to *Monastiraki Square* and alongside the *Patision Avenue* in neighborhoods such as *Exarxeia* and *Kypseli* [11]. This new type of residence gradually replaces the single and double residences of the late 1890s and early 1900s and will prevail after the 1930s when the modern movement appears and gradually replaces late neoclassicism and eclecticism.

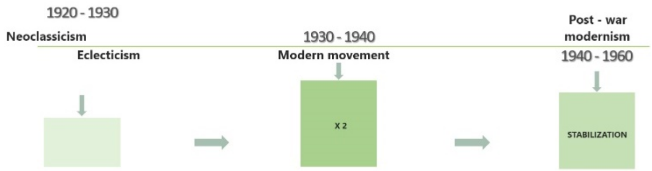

Fig. 8 Construction activity in the city of Athens for the period 1920-1960 based on Marmaras [12] research data (drawn by Angeliki Chronopoulou)

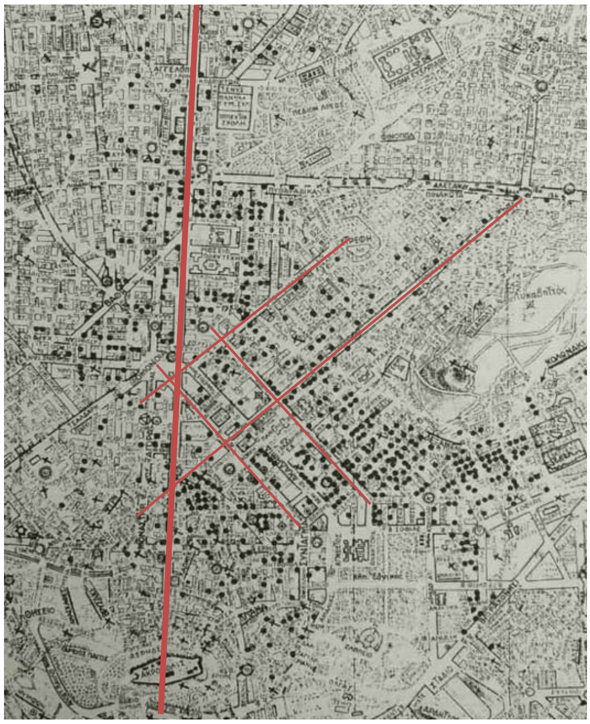

Fig. 9 Expansion of apartment buildings along the main traffic axes in the city of Athens during the Middle War period (1924-1941) [9]

C. Step3. Architectural Typology & Building Technology

After a first mapping, 60 buildings were selected, all representative examples of the Athenian Urban Residence and Apartment Buildings. For each one of them a two-page table that includes a) general information (address, year of construction, typology, building typology, plan typology) and b) construction and bioclimatic characteristics (orientation, relation to the plot, building geometry, building envelope, proportions of openings, erker (nowadays also known as bay windows), balconies, verandas, penthouse, roof, yard, skylights), was created.

The period 1920-1960 could be divided into 3 sub-periods based on the specific architectural characteristics of the buildings constructed at that time on one hand and on the construction materials and building techniques used on the other.

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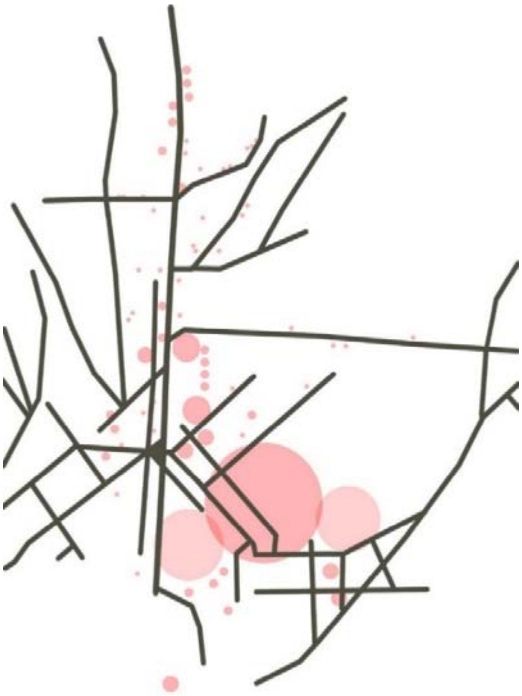

Fig. 10 City of Athens – Residential cores diagram 2022, (drawn by Angeliki Chronopoulou)

Fig. 11 (a) The double residence, Massalias and 7 Kaplanon street, year of construction: 1924, by Angeliki Chronopoulou, 2021; (b) The apartment building, Plapouta and Kallidromiou streets, year of construction: 1926, by Angeliki Chronopoulou, 2021; (c) The single residence, 28 Karaiskaki street, period of construction: early 1900s, by Aris Vedertsis

The first sub-period, composed by buildings dating back to the 1920s, is characterized by the absence of restrictive legislation, the lack of socio-economic framework and the use of outdated construction technology [5]. During this period, known as late neoclassicism and eclecticism, single or double residences that retain the main of the characteristics of the neoclassic period in most of the cases are still constructed slightly simplified and with less decorative elements. The interior layout remains the same with that of the previous century, while the materials used are still stone and solid bricks. Reinforced concrete is introduced during this period and gradually prevails after 1925.

The second sub-period, the decade 1930-1940, is a period characterized by the effects of the Greco - Turkish War and the Smyrna Catastrophe (1922) which resulted in massive waves of refugees entering the city of Athens. The upcoming housing problem combined with the establishment of appropriate building legislation (horizontal ownership) and the extensive use of the new materials (concrete and iron) led to the creation of new building typology (multistorey apartment building) [6].

Fig. 12 (a) The Small Condominium, 17 Dionysiou Areopagitou pedestrian street, year of construction: 1932; (b) The Apartment Building at Stournari and Zaimi Streets, year of construction: 1933, photos by Angeliki Chronopoulou, 2021

Fig. 13 (a) The Blue Condominium, Themistocleous and Arahovis streets, year of construction: 1933; (b) The big Residential complex at 6-7 Vasilissis Sofias Avenue, year of construction: 1934, photos by Angeliki Chronopoulou, 2021

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Fig. 14 (a) Lourou Apartment Building, 5 Semitelou street, year of construction: 1953; (b) Averof Apartment Building, Hrodou Attikou and Mourouzi Streets, year of construction: 1951; (c) The Apartment building at Kifissias Avenue 272, photos by Angeliki Chronopoulou, 2021

The third sub-period, 1940-1960, is characterized by the consolidation of the annual production of the apartment buildings and the generalization of the *"Greek Polykatoikia"* as the new prevailing type of housing, the catholic approval of which was enhanced by the better organization at the level of the production process which allowed its quick and easy construction.

As it comes out, 60% of the buildings examined were constructed between 1940 and 1960, the 23% of them between 1930 and 1940, while only 17% of them were constructed between 1920 and 1930. Regarding their typology, 2% of the buildings belong to the neoclassic period, 6% to the eclecticist period, 23% to modern movement and the biggest percentage of them, around 70% belong to post-war modernism.

As far as the building typology is concerned, most of the cases examined belong to the category of apartment buildings, reaching an amount of 81%. The smallest amount is that of single residences, around 4%, while double residences and big groups of apartment buildings both reach a percentage of 8% respectively.

Regarding the floor plan typology, six different categories exist. The small size corner apartment buildings typology, the first that was constructed and had a small number of flats per floor, constitutes the 10% of the buildings examined. At the same time big blocks of apartment buildings (residential complexes) amount to 7%, the middle size corner apartment buildings 42% and the middle size apartment buildings 27%. The last two categories are these of the buildings in contact with the edges of the plot and in contact with none of the edges of the plot and account for 12% and 3% respectively.

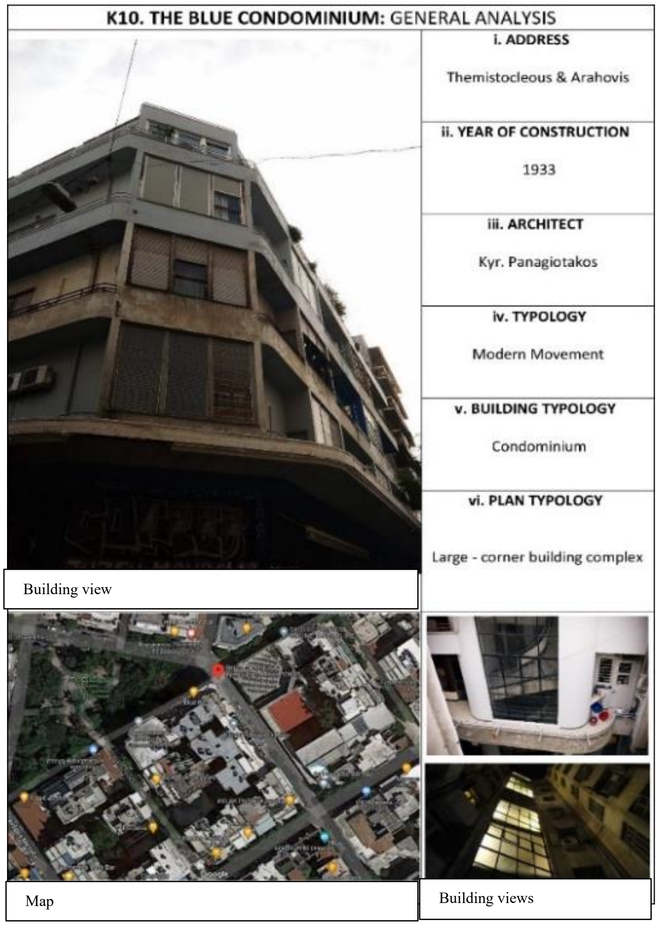

Fig. 15 Page 1 of the two – page table for the analysis of the selected buildings (drawn by Angeliki Chronopoulou)

D.Step4. Bioclimatic Strategies

After the first general analysis, the bioclimatic analysis was performed. The prevailing strategies used in the city of Athens during the period 1920-1960 were categorized and expressed in seven general architectural elements as follows:

1. Building orientation and shape
2. Cooling strategies

– Natural ventilation:

- Comfort cross ventilation,
- Stack ventilation
- Night cooling
- Light shafts and internal yards

– Shading

- Shutters
- Overhangs
- Building Geometry
- Outdoor areas and planting

3. Heating strategies

- Direct gain through S, SE, SW openings
- Thermal mass
- Internal gains

4. Natural lighting,

- Windows

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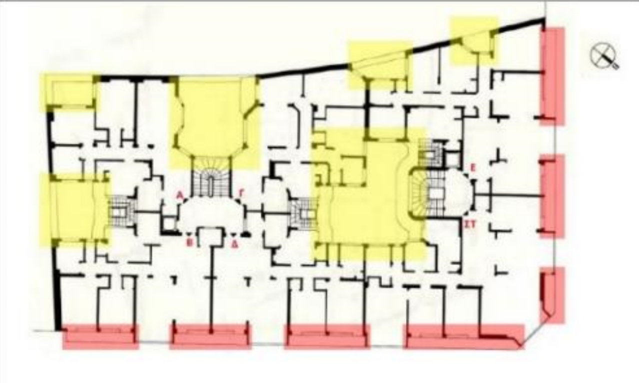
THE BLUE CONDOMINIUM
CONSTRUCTION AND BIOCLIMATIC CHARACTERISTICS



Εικ5. Typical floor plan

i. SRUCTURE **B.S.** Concrete **Non B.W.** Brick	**v. VERANDA** Yes	**ix. POSITION ON SITE** Limits	**x. SKYLIGHTS** 6
ii. OPENINGS Square and rectangular	**vi. PENTHOUSE** Yes	**ORIENTATION** **Sitting room** Varies	
iii. ERKER Yes	**vii. Roof flat/pitched** Yes / No	**ORIENTATION** **Bedrooms** Varies	
iv. BALCONIES Yes	**viii. YARD** Interior / Exterior	**ORIENTATION** **Auxiliary spaces** Varies	

Fig. 16 Page 2 of the two – page table for the analysis of the selected buildings (drawn by Angeliki Chronopoulou)

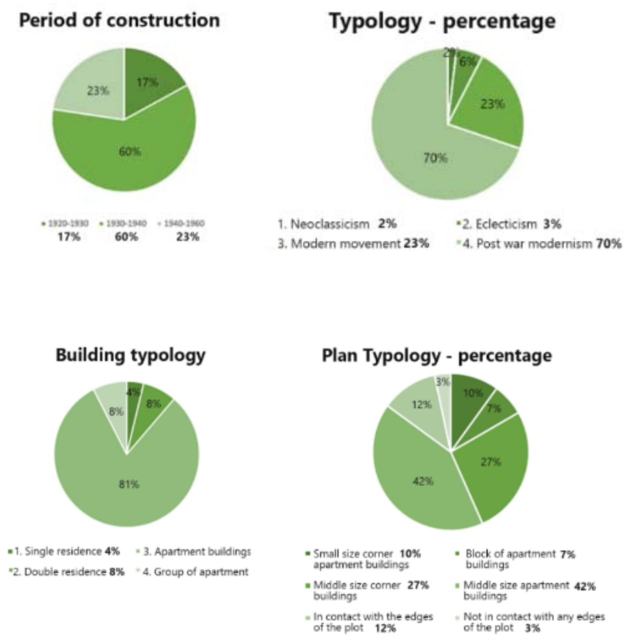


Fig. 17 Period of construction, typology, building typology and plan typology percentages for the 60 buildings analyzed (drawn by Angeliki Chronopoulou)

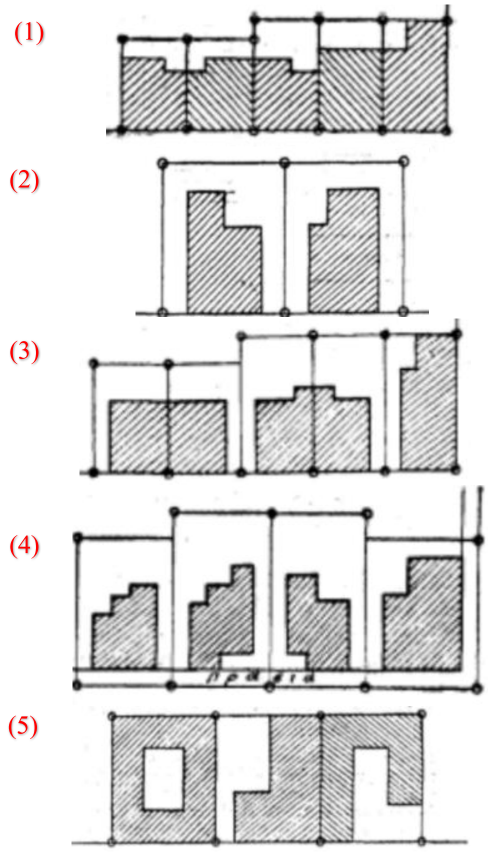


Fig. 18 Different positions of the apartment building on the plot: 1. continuous system, 2. Non-continuous system, 3. Mixed system, 4. Free system, 5. Wing system

- Erkers and bay windows
- Light shafts and internal yards

5. Materials with high thermal mass:

- Masonry (stone, brick)
- concrete

6. Type of roof:

- flat roof
- pitched roof

7. Balconies & Verandas

Heating Strategies

As it comes out and as expected, the predominant heating strategy is to utilize the direct solar gains obtained through the south, southeast and southwest openings. In cases where the south openings are limited, due to the location of the building, the building system used or due to its shading by neighboring buildings, thermal gains are obtained indirectly through the uninsulated building shell (masonry, roof). As is already known from relative studies [13], [15], a basic heating strategy is to control heating losses of the building envelope by wind protection of north facade (limited number and area of openings, planting of evergreen trees, adjacent buildings, tall adjacent wall, heavy curtains etc.).

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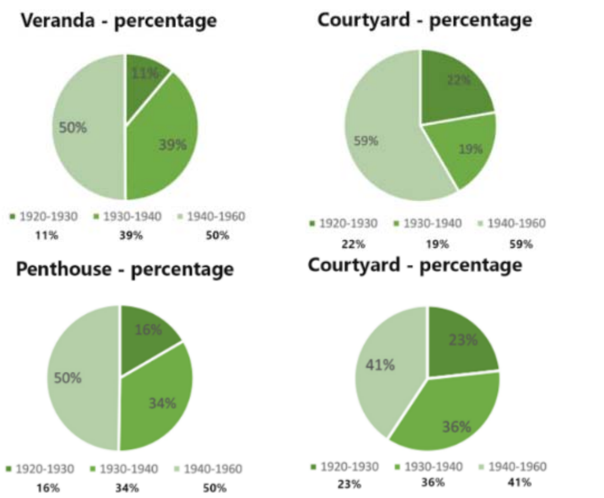

Fig. 19 Bioclimatic strategies adopted – percentages per period of construction_ part1 (drawn by Angeliki Chronopoulou)

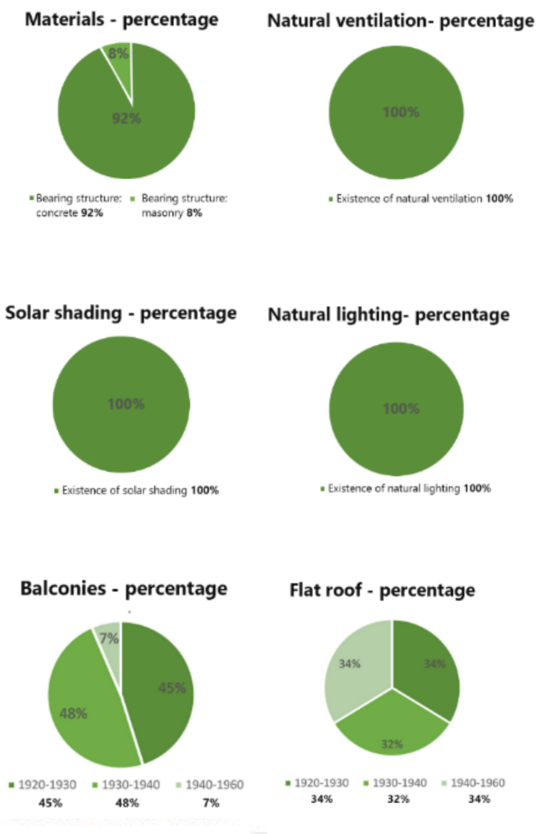

Fig. 20 Bioclimatic strategies adopted – percentages per period of construction_ part2 (drawn by Angeliki Chronopoulou)

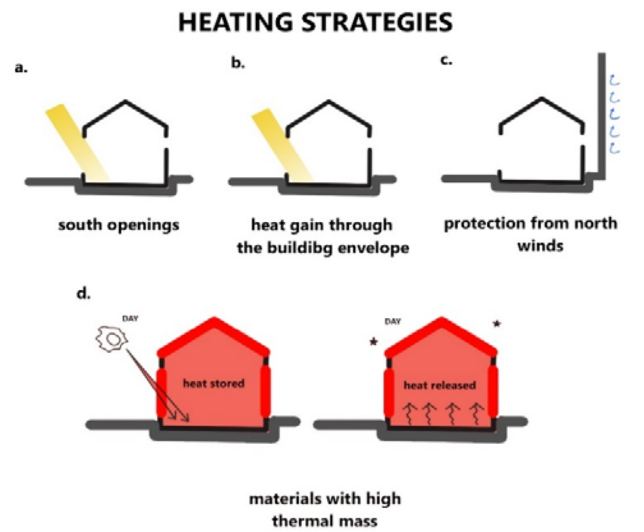

Fig. 21 Heating strategies used in Athenian residences of the period 1920-1960 (drawn by Angeliki Chronopoulou)

Cooling Strategies

The most important cooling strategy that remains to this day is the reduction of heat gains with the implementation of shading devices and green elements. The various types of shading devices featured in the period under study control solar gains in different ways. The "German type": louvered wooden operable shutter is blocking sun radiation but at the same time promotes air flow through the opening. Similar results are achieved with the rolled wooden shutters that can be manipulated in different ways and project so as to shade but ventilate at the same time.

Fig. 22 Different types of louvres, photos by Angeliki Chronopoulou

The use of two layered window (French windows) provides flexible and operable control of openings during hot and cold periods. This strategy is considerably effective in the case of West openings which tend to absorb most of the incident solar radiation. At the same time, balconies and outdoor canopies shade effectively the lower floors. Of course, the level of sun protection depends on the size and the projection of the balcony.

Natural comfort cross ventilation and night cooling is also a predominant cooling strategy. Cross ventilation is really important and is achieved through proper positioning of openings on the facades of the building. In specific, hot air is removed from the building envelope and rejected to the environment through head windows. Additionally, high temperature and humidity control is also addressed with the stack effect performed due to ceiling height (3 to 4 meters in the 1920s that gradually decreases).

Additional strategies for achieving sun protection are the yards, the semi-outdoor spaces, and the light constructions with climbing plants either permanent or mobile. These elements beyond their contribution to the internal temperature adjustment, reduce humidity, improve the quality of natural light by reducing glare while at the same time protect from the rain. During the summer, trees, and all kinds of planting (hanging plants) protect the building shell from overheating. Last but not least, pitched roofs provide adequate insulation and reduce overheating through evaporative cooling. In specific, the porous materials used to construct pitched roofs tend to absorb moisture at night and release it during the day.

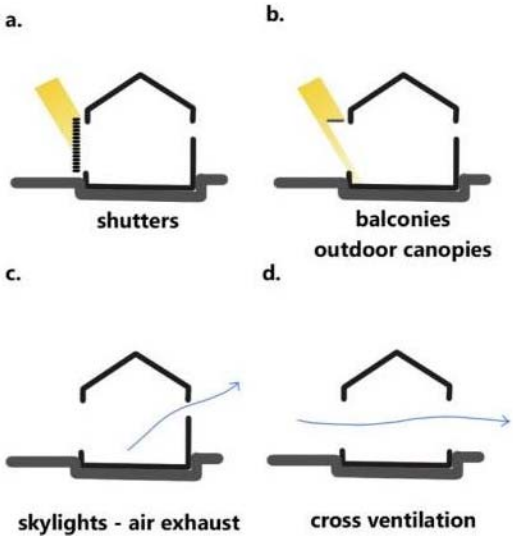

Fig. 23 Cooling strategies used in Athenian residences of the period 1920-1960 (drawn by Angeliki Chronopoulou

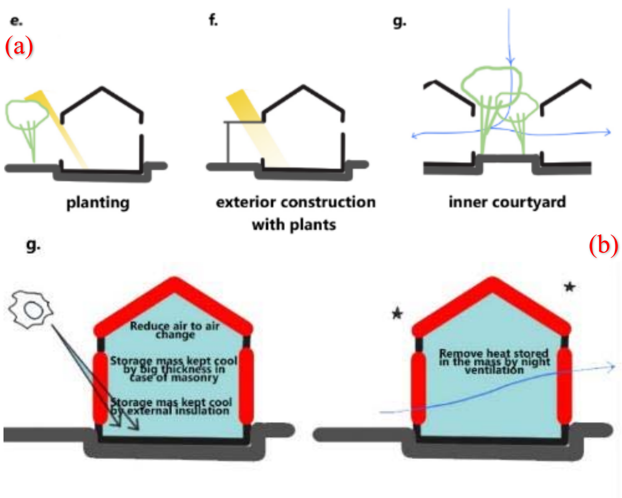

Fig. 24 (a) Outdoor comfort and microclimate diagrams; (b) Building shell temperature control (drawn by Angeliki Chronopoulou)

Lighting Strategies

Regarding the adequate natural lighting, it is mainly achieved through the number, size, and proper positioning of the window openings. Additionally, the size and the location of the skylights and the inner courtyards are key elements in providing sufficient daylight inside the buildings.

E. Step5. Building Cases Examined

Afterwards, four different buildings were analyzed in depth, all of them are characteristic examples of the period 1920-1960. The first one, the residential complex located at *28 Karaiskaki street* belongs to the first sub-period 1920-1930. The second and the third, the *Blue Condominium* and the *Apartment Building at Stournari and Zaimi Street* respectively, belong to the second sub-period 1930-1940, while the last one, the *Apartment Building at 5 Semitelou street* is a typical example of the post-war residential architecture (1940-1960).

A/A	BUILDING
1	KARAISKAKH 28 RESIDENTIAL COMPLEX
2	THE BLUE CONDOMINIUM
3	STOURNARI & ZAIMI CONDOMINIUM
4	SEMITELOU 5 CONDOMINIUM

Fig. 25 Buildings examined (drawn by Angeliki Chronopoulou)

A/A	BUILDING TYPE	BEARING STRUCTURE	NON - BEARING STRUCTURE	FLOOR STRUCTURE	FLOOR COVERING	WINDOW - FRAMES	SHADING
1	Complex of single residences	Masonry & Concrete	Masonry & Brick	Wooden structure	Timber & Concrete tiles	French windows	Wooden openable shutters
2	30's Condominium	Concrete	Brick	Concrete structure	Timber & Concrete tiles	Wooden frame	Wooden openable shutters
3	30's Condominium	Concrete	Brick	Concrete structure	Timber & Concrete tiles	Wooden frame	Wooden roller shutters
4	50's Condominium	Concrete	Brick	Concrete structure	Timber & Concrete tiles	Wooden frame	Wooden roller shutters

Fig. 26 Architectural and construction characteristics of the buildings examined (drawn by Angeliki Chronopoulou)

Case Study_1: Building Complex, 28 Karaiskaki Street

The first case to be analyzed is the building complex at 28 Karaiskaki Street. It is composed by 4 different buildings organized around a courtyard.

The two main buildings date back to early 1900's. The load bearing walls and internal partitions are stone masonry. The flooring in the first building is the initial one made of timber structural and non-structural elements, while in the second one it has been replaced by new metal structure covered with wooden flooring. Regarding the window openings in building 1, all initial window frames have been maintained, while in building 2 some of them have been replaced by double glazing aluminum windows.

Both buildings have been subjected to structural interventions such as blocked up windows and conversion of some of them into doors. Such structural interventions were necessary due to the need to link the two oldest buildings,

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building 1 & 2, with buildings 3 & 4 which were built later around 1930's. In the case of buildings 3 & 4, the bearing structure is made of reinforced concrete and the non-bearing walls from brick. Their window frames are made of aluminum and double glazing.

A/A	SUB - BUILDINGS	LEVELS	BUILDING USE	FLATS PER FLOOR	NUMBER OF OCCUPANTS	AGE OF OCCUPANTS / USERS
1. KARAISKAKH 28 RESIDENTIAL COMPLEX	BUILDING 1	UNDER GROUND FLOOR	COWORKING SPACE	-	5 to 10	18 - 55
		GROUND FLOOR	COWORKING SPACE	-	15 to 20	18 - 55
		FIRST FLOOR	COWORKING SPACE	-	15 to 20	18 - 55
	BUILDING 2	GROUND FLOOR	COWORKING SPACE	-	15 to 20	18 - 55
		FIRST FLOOR	COWORKING SPACE	-	15 to 20	18 - 55
	BUILDING 3	GROUND FLOOR	COWORKING SPACE	-	5 to 7	18 - 55
		FIRST FLOOR	COWORKING SPACE	-	5 to 7	18 - 55
		SECOND FLOOR	COWORKING SPACE	-	5 to 7	18 - 55
	BUILDING 4	GROUND FLOOR	COWORKING SPACE	-	5 to 7	18 - 55
		FIRST FLOOR	COWORKING SPACE	-	5 to 7	18 - 55
		SECOND FLOOR	COWORKING SPACE	-	5 to 7	18 - 55

Fig. 27 Characteristics of heating operation, number and activity of users, thermal comfort, structural interventions, case study_1 (drawn by Angeliki Chronopoulou)

The current building complex is of great interest due to the variety of building materials and construction techniques used. It is important to mention that the use of heterogeneous materials, thus materials that have different mechanical and physical properties, affects the energy performance of the building. In most of the cases weak points are created either between more and less conductive materials or insulated and non-insulated materials. This results in the formation of thermal bridges which enhance the heat transfer and energy loss through the building fabric.

Regarding the layout of the internal spaces, building 1 is a typical example of neoclassic and eclecticist residence with the living room placed at the main façade of the building. As a result, this part of the building receives the biggest amount of solar radiation and natural light compared to the rest spaces. Bedrooms are placed along the façade facing the courtyard while auxiliary spaces are positioned on the north and back side of the building due to their limited need in natural light and fresh air.

In case of building 2, the organization of the interiors is quite simpler due to its shape. The living room and the bedrooms are positioned along the two main facades of the building. Due to the narrow shape of the building all spaces are connected in between with big openings.

HOURS OF USE	HEATING	MEASUREMENTS	UNWANTED AIR - MOVEMENT	STRUCTURAL INTERVENTIONS
09:00 - 19:00	AIR - CONDITIONING	-	NO	MAINTAIN OLD WINDOW FRAMES
09:00 - 19:00	AIR - CONDITIONING	-	YES	MAINTAIN OLD WINDOW FRAMES
09:00 - 19:00	AIR - CONDITIONING	-	YES	MAINTAIN OLD WINDOW FRAMES
09:00 - 19:00	AIR - CONDITIONING	-	YES	MAINTAIN OLD WINDOW FRAMES
09:00 - 19:00	AIR - CONDITIONING	-	YES	MAINTAIN OLD WINDOW FRAMES
09:00 - 19:00	AIR - CONDITIONING	-	NO	NEWER CONSTRUCTION - ALUMINIUM FRAMES
09:00 - 19:00	AIR - CONDITIONING	-	NO	NEWER CONSTRUCTION - ALUMINIUM FRAMES
09:00 - 19:00	AIR - CONDITIONING	-	NO	NEWER CONSTRUCTION - ALUMINIUM FRAMES
09:00 - 19:00	AIR - CONDITIONING	-	NO	NEWER CONSTRUCTION - ALUMINIUM FRAMES
09:00 - 19:00	AIR - CONDITIONING	-	NO	NEWER CONSTRUCTION - ALUMINIUM FRAMES
09:00 - 19:00	AIR - CONDITIONING	-	NO	NEWER CONSTRUCTION - ALUMINIUM FRAMES

Fig. 28 Characteristics of heating operation, number and activity of users, thermal comfort, structural interventions, case study_1 (drawn by Angeliki Chronopoulou)

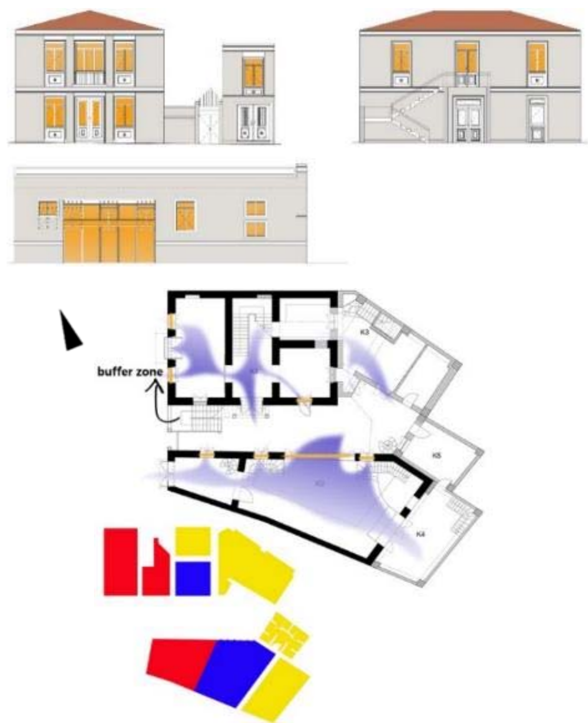

Fig. 29 Drawings, case study_1(drawn by Angeliki Chronopoulou)

The construction of buildings 3 and 4 resulted in the creation

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of a more complicated layout of the internal spaces which resulted in the reduction of natural - cross ventilation, especially in case of building 2. Bioclimatic strategies used are presented in Fig. 30.

Building orientation and shape		✓
Cross ventilation		✗
Stack ventilation		✓
Shutters		✓
Overhangs		✗
Building geometry		✗
Outdoor areas and planting		✓
Thermal mass		✓
Internal gains		✓
Windows		✓
Light shafts and yards		✓
Masonry		✓
Concrete		✓
Flat roof		✓
Pitched roof		✓

Fig. 30 Bioclimatic strategies applied in case study 1 (drawn by Angeliki Chronopoulou)

Fig. 31 (a) Exterior view, (b) interior view (photos by impact hub Athens)

Fig. 32 Interior view (photos by impact hub Athens)

Fig. 33 Interior view (photos by impact hub Athens)

Case Study_2: The Blue Condominium

The second case study analyzed is the Blue Condominium, one of the first and most accredited Apartment Buildings built in Greece in 1932. Additionally, it is one of the biggest blocks of flats constructed during the middle war period. All the flats are organized around the two main inner courtyards. Due to the big volume of the building, a flat on the 4th floor has been chosen to be further analyzed.

The flat is positioned at the corner of the apartment building. All the main uses including the living room and bedrooms are located along the two main facades of the building, while the auxiliary spaces including the kitchen and the bathrooms are positioned close to the inner courtyard. Main characteristic of the internal organization of the flat is the corridor as a continuation of the hall, along and on each side of which are distributed the different uses. All spaces, even the bathroom and the kitchen, have abundance of natural light due to the number, size, and positioning of the window openings.

The bearing structure is made of reinforced concrete and the non-bearing infill walls from brick. The apartment has been recently renovated (2019). The windows are the initial ones with wooden frame and one simple layer of glazing. Bioclimatic strategies used are presented in Figs. 38 and 39.

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A/A	SUB - BUILDINGS	LEVELS	BUILDING USE	FLATS PER FLOOR	NUMBER OF OCCUPANTS	AGE OF OCCUPANTS / USERS
2. THE BLUE CONDOMINIUM	BUILDING	GROUND FLOOR	RESIDENCES & CAFÉ	4	-	-
		TYPICAL FLOORS (x5)	RESIDENCES	6	-	-
		PENTHOUSE	RESIDENCES	3	-	-

Fig. 34 Characteristics of heating operation, number and activity of users, thermal comfort, structural interventions, case study_2 (drawn by Angeliki Chronopoulou)

HOURS OF USE	HEATING	MEASUREMENTS	UNWANTED AIR - MOVEMENT	STRUCTURAL INTERVENTIONS
-	BOILER HEATING SYSTEM RADIATORS	-	YES	MAINTAIN OLD WINDOW FRAMES
-	BOILER HEATING SYSTEM RADIATORS	-	YES	MAINTAIN OLD WINDOW FRAMES
-	BOILER HEATING SYSTEM RADIATORS	-	YES	MAINTAIN OLD WINDOW FRAMES

Fig. 35 Characteristics of heating operation, number and activity of users, thermal comfort, structural interventions, case study_2 (drawn by Angeliki Chronopoulou)

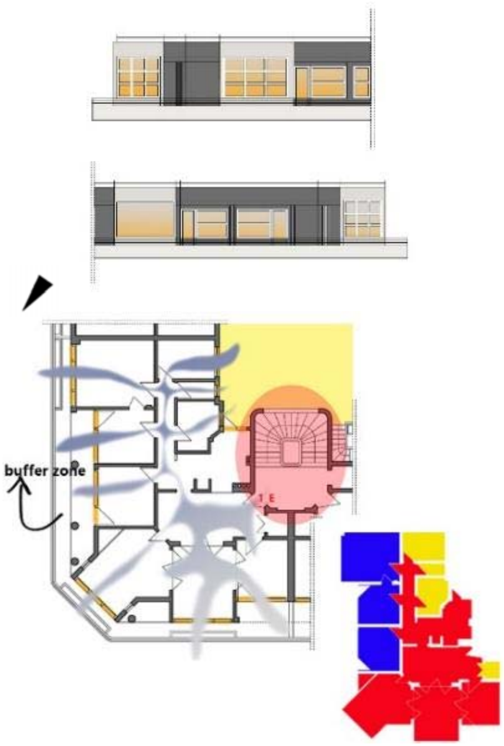

Fig. 36 Drawings case study 2 (drawn by Angeliki Chronopoulou)

Fig. 37 (a) Part of the main façade of the building (photo by Angeliki Chronopoulou), (b) Internal view of the wooden frame windows (photo by CADU Architects), (c) Internal view of the frame windows (photo by CADU Architects)

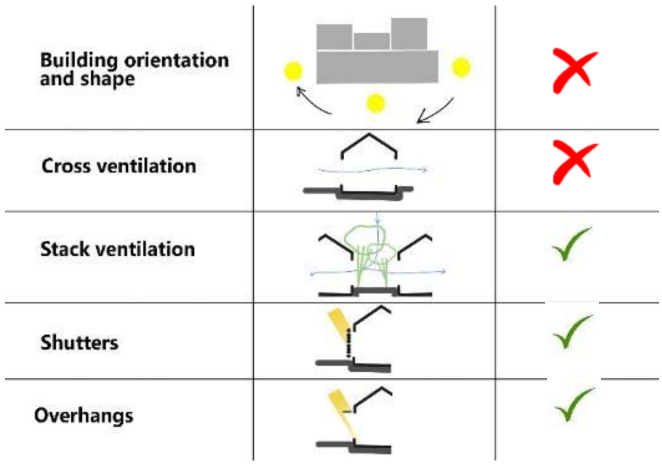

Fig. 38 Bioclimatic strategies applied in case study 2_part1 (drawn by Angeliki Chronopoulou)

Case Study_3: Apartment Building at Stournari & Zaimi

The 3rd building analyzed was the Apartment Building at Stournari & Zaimi streets. It is a typical example of middle size corner apartment building of the middle war and early post war period and one of the most well-known examples of modern architecture in Greece. Each floor has two flats. Similar with the case of the Blue Condominium, the main uses are positioned

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along the two main facades of the building, while the rest close to the skylight so that enough natural light and ventilation is achieved.

Building geometry		✗
Outdoor areas and planting		✗
Thermal mass		✓
Internal gains		✓
Windows		✗
Light shafts and yards		✓
Masonry		✗
Concrete		✓
Flat roof		✓
Pitched roof		✗

Fig. 39 Bioclimatic strategies applied in case study 2_part 2 (dawn by Angeliki Chronopoulou)

A/A	SUB - BUILDINGS	LEVELS	BUILDING USE	FLATS PER FLOOR	NUMBER OF OCCUPANTS	AGE OF OCCUPANTS / USERS
3. STOURNARH & ZAIMH CONDOMINIUM	BUILDING	GROUND FLOOR	STORES	-	-	-
		TYPICAL FLOORS (x6)	RESIDENCES	2	-	-
		PENTHOUSE	RESIDENCES	-	-	-

Fig. 40 Characteristics of heating operation, number and activity of users, thermal comfort, structural interventions, case study_3 (photos by Angeliki Chronopoulou)

HOURS OF USE	HEATING	MEASUREMENTS	UNWANTED AIR - MOVEMENT	STRUCTURAL INTERVENTIONS
-	BOILER HEATING SYSTEM RADIATORS	-	YES	MAINTAIN OLD WINDOW FRAMES
-	BOILER HEATING SYSTEM RADIATORS	-	YES	MAINTAIN OLD WINDOW FRAMES
-	BOILER HEATING SYSTEM RADIATORS	-	YES	MAINTAIN OLD WINDOW FRAMES

Fig. 41 Characteristics of heating operation, number and activity of users, thermal comfort, structural interventions, case study_3 (photos by Angeliki Chronopoulou)

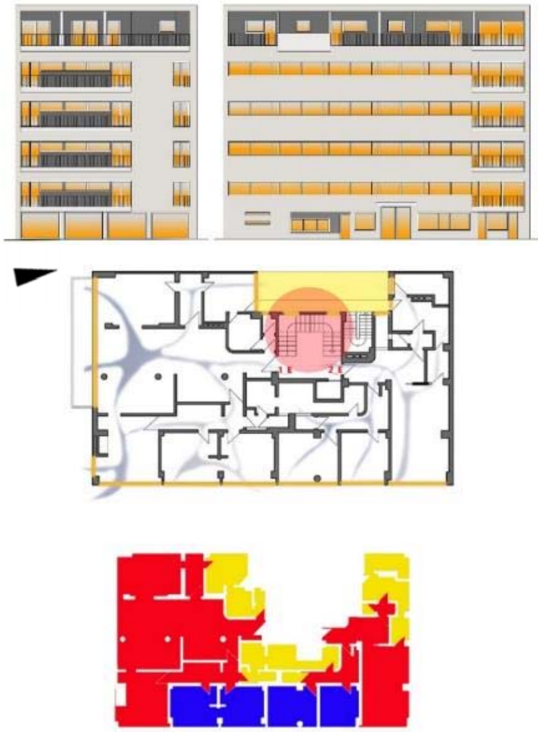

Fig. 42 Drawings, case study_3 (drawn by Angeliki Chronopoulou)

Fig. 43 (a) Exterior view of the building, (b) Interior view (photos by Angeliki Chronopoulou)

Fig. 44 (a) Exterior view from the building, (b) Interior view of the building (photos by Angeliki Chronopoulou)

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Regarding the bearing structure, similar with the rest of the apartment buildings constructed at the same period, is made of concrete. On the contrary, the non-bearing walls are made of brick. One of the main characteristics of that building that differentiates it from the rest of that period is the use of longitudinal windows extended at whole façade, following in this way one of the main principles of the modern movement. Bioclimatic strategies used are presented in Fig. 45.

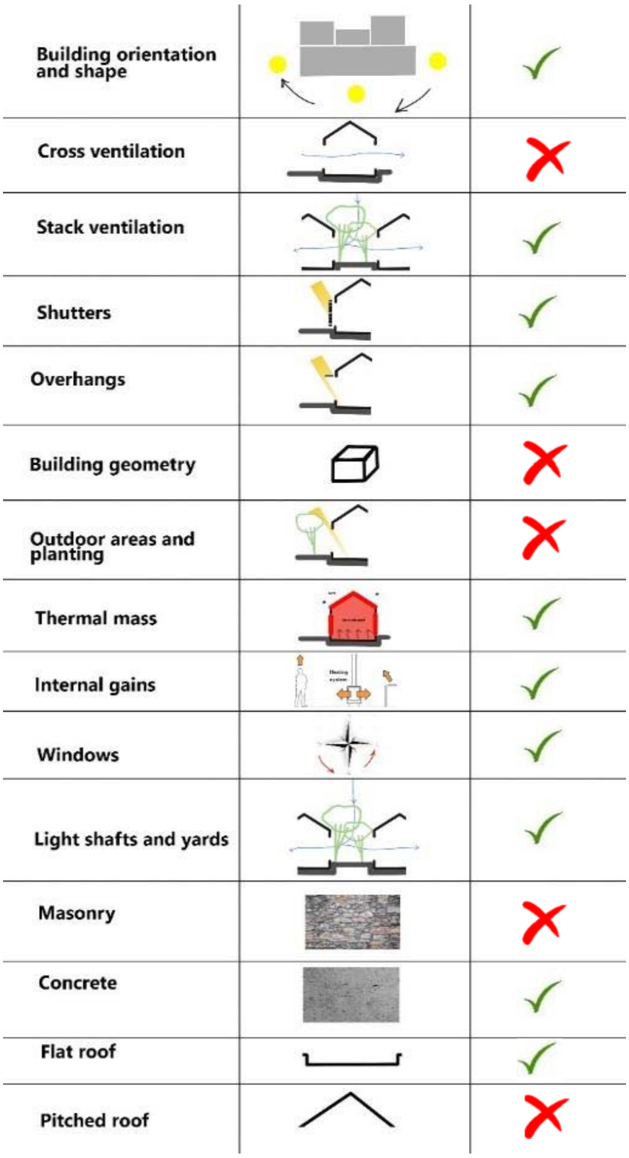

Fig. 45 Bioclimatic strategies applied in case study 3 (by Angeliki Chronopoulou)

Case Study_4: Apartment Building at 5 Semitelou Street

The last building analyzed is the apartment building located at 5 Semitelou street. It is a typical example of the post war architecture of the city of Athens; a medium size apartment building with two flats per floor. Its main characteristics are the free plan design and the detachment from the bearing structure (reinforced concrete). Additionally, the longitudinal shape of the building and the positioning of big openings on the two main facades guarantee cross ventilation, something rarely achieved in the buildings constructed during that period. Bioclimatic strategies used are presented in Figs. 50 and 51.

A/A	SUB - BUILDINGS	LEVELS	BUILDING USE	FLATS PER FLOOR	NUMBER OF OCCUPANTS	AGE OF OCCUPANTS / USERS
4. SEMITELOY 5 CONDOMINIUM	BUILDING	GROUND FLOOR	RESIDENCES	2	-	-
		TYPICAL FLOORS	RESIDENCES & STORES (x4)	2	-	-
		PENTHOUSE	RESIDENCES	2	-	-

Fig. 46 Characteristics of heating operation, number and activity of users, thermal comfort structural interventions, case study 4 (by Angeliki Chronopoulou)

HOURS OF USE	HEATING	MEASUREMENTS	UNWANTED AIR - MOVEMENT	STRUCTURAL INTERVENTIONS
-	BOILER HEATING SYSTEM RADIATORS	-	NO	MAINTAIN OLD WINDOW FRAMES
-	BOILER HEATING SYSTEM RADIATORS & AIR - CONDITIONING	-	NO	MAINTAIN OLD WINDOW FRAMES
-	BOILER HEATING SYSTEM RADIATORS & AIR - CONDITIONING	-	NO	MAINTAIN OLD WINDOW FRAMES

Fig. 47 Characteristics of heating operation, number and activity of users, thermal comfort structural interventions, case study_ 4 (by Angeliki Chronopoulou)

Fig. 48 (a) The courtyard photo by Angeliki Chronopoulou), (b) View from the balconies (photo by Valsamakis archive)

Apart from the bioclimatic strategies used in the case of existing buildings and especially the historic ones, there are also some disadvantages, regarding the design choices and materials used during the examined period, that should be mentioned. The most important is the use of single glazed windows. Typical window glass used ranges from 3 mm to 10 mm, which does not provide adequate insulation. It is estimated that single

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glazed windows are approximately 20 times less efficient than insulated walls from energy loss and storage point of view [12]. This is especially restrictive when dealing with protected/listed buildings since in most of the cases the replacement of the initial windows may be forbidden due to the strict legislation existing. Additionally, the lack of insulation does not help in controlling the interior temperature. For example, in case of buildings made of stone and brick during the winter period more energy is needed for heating, while in the case of buildings made of concrete and brick both during winter and summer the energy required to heat and cool is higher compared to the amount of energy that would be needed if the building was insulated [13].

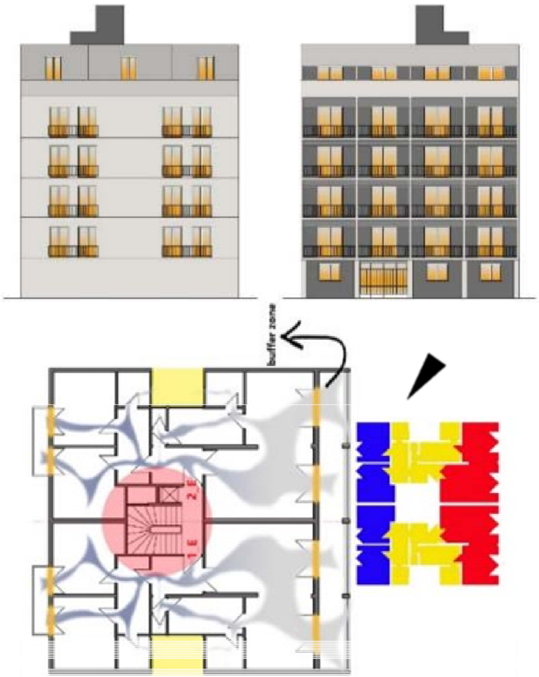

Fig. 49 Drawings, case study_4 (drawn by Angeliki Chronopoulou)

III. Conclusion

The energy upgrade, revitalization and continuous use of the existing building stock seems to be one of the most efficient ways to mitigate the climate change and its effects. The first step so as to achieve this is to analyze in depth the existing buildings and evaluate their functional structural and thermal performance. The current study tries to create a guideline for analyzing the climate responsive design strategies applied on existing residential buildings, having as a starting point the city of Athens and its existing building stock.

Initially was performed a general/architectural design and construction analysis for *60* buildings and afterwards a more detailed analysis on the applied bioclimatic strategies for 4 selected case studies.

Building orientation and shape		✓
Cross ventilation		✓
Stack ventilation		✗
Shutters		✓
Overhangs		✓
Building geometry		✗
Outdoor areas and planting		✓
Thermal mass		✓
Internal gains		✓
Windows		✓

Fig. 50 Bioclimatic strategies applied in case study 4_part 1 (drawn by Angeliki Chronopoulou)

Light shafts and yards		✓
Masonry		✗
Concrete		✓
Flat roof		✓
Pitched roof		✗

Fig. 51 Bioclimatic strategies applied in case study 4_part 2 (drawn by Angeliki Chronopoulou)

As a basic outcome, the apartment buildings in Athens constructed between 1920 and 1960 adapt well to climatic conditions by using low-energy design principles which ensure human comfort and health. Natural ventilation, building orientation - building shape, and solar shading are among the strategies most employed. Application of thermal insulation should be examined accordingly at each case since in some buildings the use of opaque elements is much smaller than that of windows, for example. Moreover, in some buildings thermal insulation layers may distort its architectural and historic importance. However, the use of insulation panels would improve indoor thermal comfort during winter and summer

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period. Moreover, building courtyards and skylights played a significant role on ventilation flow rate of the interiors as well as on temperature and humidity control. Last but not least, it is really important each building to be examined and analyzed separately because different strategies may be used depending on the specific characteristics and architectural value of each case examined.

The present study has limitations as quantitative assessment was not carried out. Further investigation is therefore needed. Energy simulations will provide more accurate results regarding the effectiveness of each strategy applied.

Acknowledgment

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