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Energy-efficient design and application of geothermal energy in buildings of areas of protected cultural heritage: Case study Mani, Greece

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Cover: *Panoramic view of village of Vatheia in Oitylo Municipality*
Photo by Elias Hantzakos, 2003

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To:
Panagiotis and Stavroula Routsolias;
Theodoros and Anthoula Danas

"*They seeded the ground, so that*
We harvest the corps…"

Abstract

The objective of this study is to present a feasible sustainable solution for the touristic development of the sensitive area of Mani, in south Greece. Primary attention was given in the special architecture and cultural elements of Mani, which are protected under the Greek legislation system due to its unique nature, locality and historical importance. The case that is examined is based on the initiative of Mauroeidakos family to renovate its Tower-dwelling and transform its private usage to hotel facility service. The idea was realized under the guide of the "*Oikomorphes*" company and the author extended its scope to meet synchronous practices of sustainable development. The Tower's architectural restoration was strict and precise according to the advice of the Archaeological Service and the guidelines of Greek Law *3028/2002*. The structure was thoroughly studied in the energy simulation software *Consolis Energy* +, which is developed by Professor Gudni Johannesson and the final conclusions were made depending on the energy balance and performance. The introduction of geothermy was made by the author as a solution for heating and cooling based on case studies that are widely practiced in Sweden, Switzerland and U.S.A. and its environmental benefits. The geothermal system which is proposed for the structure is established according to the values provided by the energy design simulation and the calculations from the *RETScreen Software* for *Ground-Source Heat Pump Project Model*, free for commercial and institutional use. The study could be used as a baseline not only for touristic facilities but for private houses as well, where their owners would renovate, in accordance to their local environment of cultural heritage and the respect on Nature.

Key words: *Mani, preservation of architecture, sustainable development, energy design, geothermal energy.*

Περίληψη

Ο στόχος αυτής της μελέτης είναι να παρουσιαστεί μια εφικτή βιώσιμη λύση για την τουριστική ανάπτυξη της ευαίσθητης περιοχής της Μάνης, στη νότια Ελλάδα. Πρωταρχική προσοχή δόθηκε στη ιδιαίτερη αρχιτεκτονική και τα πολιτιστικά στοιχεία της Μάνης, που προστατεύονται από το ελληνικό σύστημα νομοθεσίας λόγω της μοναδικής φύσης, της εντοπιότητας και της ιστορικής σημασίας της. Η περίπτωση που εξετάζεται, βασίζεται στην πρωτοβουλία της οικογένειας Μαυροειδάκου να ανακαινίσει τον Πύργο-κατοικία της και να μετασχηματίσει την χρήση του από ιδιωτική σε παροχή ξενοδοχειακών υπηρεσιών. Η ιδέα πραγματοποιήθηκε με οδηγό το τεχνικό γραφείο *«Οικομορφές»* ενώ ο συγγραφέας επέκτεινε το πεδίο της ώστε να συναντήσει τις σύγχρονες πρακτικές της βιώσιμης ανάπτυξης. Η αρχιτεκτονική αποκατάσταση του πύργου ήταν αυστηρή και ακριβής, σύμφωνα με τις συμβουλές της Αρχαιολογικής Υπηρεσίας και των οδηγιών του Ελληνικού νόμου *3028/2002*. Η κατασκευή μελετήθηκε λεπτομερώς στο λογισμικό ενεργειακής προσομοίωσης *Consolis Energy* +, που αναπτύχθηκε από τον καθηγητή Gudni Johannesson και τα τελικά συμπεράσματα αποδόθηκαν βασιζόμενα στην ενεργειακή ισορροπία και απόδοση του κτιρίου. Η εισαγωγή της γεωθερμίας προτάθηκε από το συγγραφέα ως λύση για τη θέρμανση και την ψύξη βασισμένη στις εφαρμογές που ασκούνται ευρέως στη Σουηδία, την Ελβετία και τις ΗΠΑ και τα περιβαλλοντικά της πλεονεκτήματα. Το γεωθερμικό σύστημα που προτείνεται για τη κατασκευή αποδίδεται σύμφωνα με τις αριθμητικές τιμές της προσομοίωσης του ενεργειακού σχεδιασμού και από τους υπολογισμούς του λογισμικού *RETScreen Software* για αντλίες θερμότητας εδάφους-πηγής, ελεύθερο για εμπορική και ερευνητική χρήση. Η μελέτη θα μπορούσε να χρησιμοποιηθεί ως υπόβαθρο όχι μόνο για τουριστικές εγκαταστάσεις αλλά και για ιδιωτικές κατοικίες, τις οποίες οι ιδιοκτήτες τους θα ανακαίνιζαν, σύμφωνα με το τοπικό περιβάλλον της πολιτιστικής κληρονομιάς τους και με σεβασμό στη Φύση.

Βασικές λέξεις: *Μάνη, διατήρηση της αρχιτεκτονικής, βιώσιμη ανάπυξη, ενεργειακός σχεδιασμός, γεωθερμική ενέργεια.*

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The author would like to express his gratitude to his supervisor Professor Dr. Gudni Johannesson for his assistance and valuable and precious advice during the preparation of his thesis. He appreciates the fact that he was given the opportunity to participate in an interesting research project that could be a basis for further studies in the research area, by using the prototypic energy simulation software *Consolis Energy+*.

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Panagiotis Routsolias
Stockholm, May 2007

Table of Contents

CHAPTER 1

1 INTRODUCTION

Since the birth of human civilization and first society's structure organization, humans tried to find and develop their shelter with respect to their primary needs. Their shelter which in the beginning was considered only for physical phenomena protection and food storage, later on in more complicated and developed societies, became their working, family care, recreation and inspiring place. The development of human construction and building techniques were accustomed with the conditions of surrounding and relevant environment and climate conditions. Therefore, humans developed skills and methods that allowed them to build shelter-house in latter era with materials and techniques appropriate for each case.

The innovative and polymechanic mind of mankind developed the house building according to the available means, technology and topography of each area consisting it a primary episteme. All the materials that were used in building phase were from the surrounding environment and obtained by primary but sustainable techniques. The architecture was not focusing only in the functioning and external appearance sector but also in the comfortable and pleasure living conditions of the persons that were using the house. The building techniques were using simple and innovative solutions for thermal and cooling purposes in combination with the vegetation and tree plants around the house.

These house building written rules and oral tips were used for centuries effectively and sufficiently in many countries of all over the world. But the Renaissance boom in technology and economical development changed the population rate and concentrated the masses in cities. The housing sector inevitably had to change its scope and focused to the large-scale building structures capable of hosting as many as humans could. This attitude contributed to the known problems being derived by dense population of large cities in the Industrial Revolution.

Hygiene inhuman conditions and psychological problems of people living in the dense-populated areas lead scientists to propose the return of humans to practices that were used for thousand of years in the housing sector. Therefore, once more the sustainable and bioclimatic architecture was introduced for the increased needs of housing problems in developed and developing countries' societies.

1.1 Study Area

Greece throughout its long-aged and rich-cultured history had developed a lot of practices that were used for housing purposes. Many of them have been characterized by synchronous scientists and architects innovative and prototypic even for our modern world. It could be referred the paradigm of Minoan civilization in Crete or Cycladic civilization in the complex islands of Cyclades, where the houses had advanced innovations.

In Crete and the palace of Knossos, circulation of light, air, and water by means of both open drains and closed conduits (i.e. piping) was a clear priority for the builders of the complexes. Concern for such circulation of the first two, lead to a plethora of colonnades

(range of columns supporting an entablature), lightwells, clerestories, pier-and-door partitions, and windows in these structures, while concern for circulation of the last had resulted in extraordinarily complex drainage systems that reinsured water resources availability during summer.
(Source: http://projectsx.dartmouth.edu/classics/history/bronze_age/lessons/les/12.html)

In Cyclades, the houses, two- and three-storyed, were built of the material available in abundance on the island, small irregular stones and mortar of mud frequently mixed with straw. The walls were strengthened with wooden reinforcements so as to be more resistant to seismic shocks. Each house apparently ensured self-sufficiency for its occupants. Each room, according to its position in the building, had a different function. On the ground floor there were workshops and store rooms mainly for foodstuffs. This use of the ground floor also determined its architecture. The little light and air required in the food cellars was ensured through the small windows which are the rule in the ground floor apartments. In this same manner stable condition of humidity and temperature were maintained, essential for the preservation of food. The residential apartments were situated in the upper storeys where part of the furniture seems to have been the loom. The apartments of the upper storeys were flooded with light through large windows.
(Source: http://www.noteaccess.com/APPROACHES/AGW/SanArchaeologicalS.html)

Some of the developed mentioned practices of that time are used nowadays as well, such as orientation of the buildings, facade materials, heat insulation materials, cross-ventilation techniques, windows orientation and different surrounding vegetation species. The modern discovered techniques and tools could join the mentioned traditional ones and give solutions to the housing sector in Greece and relevant Mediterranean countries.

1.2 Mani (**Μάνη**)

1.2.1 History

Fig.1.1: Civil map of Mani Great Area (Source: www.mani.org.gr)

The first appearance of inhabitants in Mani is dated back in archaic days, which is proved by the finds of fossil human skeletons 300.000 years old in Dyros Cave *(source: www.mani.org.)*. According to the traveler Pausania the first inhabitants of Mani were Lelegs, while in the Homeric times it was divided into small city-kingdoms ("*πολίσματα*"). Homer was the first one to mention the cities of Mani: Messi, Vitilon (Oitylo), Kardamili (or Skardamoula), Enopi, Gerinia as well as Pefnos, Avia, Gythion, Kotronas etc.

Later on the history of Mani was associated with the history of Sparta when in 207 B.C. Navis, the tyran of Sparta, trying to save the people of Mani made them to leave for the

Tainaro peninsula where a peculiar political organization named "Society of Lacedaimons" was founded. In the Roman days, the most southern area of Mani separated from Sparta and founded a Federation under the name of "Society of Lacedaimons" which survived until the days of Byzantine Emperor Diocletian. Under the name of a "Society of Free Lacedaimons" it survived until the middle of the 3-century A.D.

Fig.1.2: National Protected village of Vatheia, as area of high cultural and architectural value (source: www.mani.org.gr)

The area acquired a special historical significance in the Franc times. After the Francs conquered Constantinople in 1204 for the better supervising of the area they built three castles in Taygetos Mountain: one - near Gythion under the name of Passava, another - the castle of Megalis Manis or Mainis on the western area of Taygetos and the third one – the castle of Lefktrou near the village of Kardamili *(source: www.mani.org.gr)*.

Under the reign of Leon of Sofu (886-912) the name of Mani was first referred either to a rather small area where the residence of a bishop was located or perhaps only just to one castle. It was called the castle of Mani or Maini (Le Mange in French) and was built by despot Villardouinos in 1248 *(source: www.mani.org.gr)*. Later on, the name Mani was applied to the area where free people lived in the period of the Ottoman Occupation.

1.2.2 Morphology

Fig.1.3: Geo-topographical map of Mani Great Area (source: members.fortunecity.com)

South Peloponnesus ends in three peninsulas which gave its characteristic formation. The middle one, occupying the northwestern section of the Laconia region and the northeastern part of the Messinia region formed with the compact shape of Mountain Taygetos in the centre, the Mani Area. The starting point in the Mani Area is 4 km northeast from the city Gythion and its last village Verga meets the borders Kalamata, capital city of Messinia region. Mani stretches along the middle finger of Peloponnesus and reaches the most southern tip of Greece's and Europe's mainland at Tainaro. On the West it is watered by the Messinia's bay and on the East – by the Laconia's one.

The length of Mani is 75 km and its area equals to 1800 km^2 (*Vasilatos, 2001*). High rocks and inaccessible siliceous shores of Mani complete the picture of a wild and deserted place. Mt Taygetos which is the physical axis of the Mani Area, separates it in East Mani (in local language as "*Προσηλιακή*") and in West Mani (in local language as "*Αποσκιερή*").

Nature is the one that created one more division of Mani, between North and South. In the Limeni bay ends one deep and broad canyon (in local language as "*Κακό Λαγκάδι*"), which on the east, after many zoned earth formations, it continues until Karyoupoli dividing Mani in these two parts. The area north of this canyon until Selitsa is called *Outer Mani* whereas the area south of it until Tainaro peninsula is called *Inner Mani* (*Vasilatos, 2001*). Despite the fact that the Outer and Inner Mani are covered with the same amount of sun radiation and are watered by the same sea, they are lands with remarkable physical and morphological differences. The Outer Mani is fertile and rich in vegetation and waters coming from the dense forests of Mt Taygetos on the east, whereas Inner Mani is dry, unfertile, rocky and looking steep wild desert mountains.

Fig.1.4: Typical Mani Tower in Koita (source: www.mani.org.gr)

Due to this physical shaping, Inner Mani stayed for centuries unconquered but at the same time isolated, developing a peculiar social life. It is sure that in Mani the development of fortified architecture (Mani's unique architectural style) is dated back in Middle Age and that the tall square towers consist a typical dwelling type of the strong families (*Vasilatos, 2001*). Towers were successful defense and base structures among strong families' conflicts but also powerful resistant position points of the freedom of the Mani Area. Mani has a lot of old buildings, the high stone towers being the most characteristic among them. On the whole, there are about 800 towers and 6 castles *(source: www.mani.org.gr)* which are scattered all over Mani and could be found everywhere in villages, mountains, on seashores.

1.3 Architecture in Mani: Introduction in local architecture throughout Mani's history

1.3.1 Settlements and structures (Megalithic)

a) Antiquity-1800 A.D.

The main features of the local habitat during the middle years but in all likelihood, ancient times as well, were primarily determined by numerous settlements which still exist nowadays. Since the twentieth century, they are generally named the megalithic buildings of Mani, because as a rule, roughly worked stone blocks were used for the buildings and the subsequent construction there. This construction method is almost analogous with the works of the megalithic cultural era which flourished in the Mediterranean and elsewhere in the Neolithic period (*Moutsopoulos, 1975; Dimitrokalis, 1977*).

Usually lying far from the coast and the main lines of communication, some of these settlements were laid waste for a long time and are preserved in various stages of dilapidation in "paliochores" (*old villages such as Triantafyllia-Smoi, Agia Paraskevi of Ochia, Sketrines of Alika, Katamestika of Kotrafi etc.*) (*Saitas, 2001*). At the same time, remains of other megalithic structures have been incorporated into newer Maniat settlements of which they constituted the nucleus such as in Areopoli, Mina, Kita Loukadika etc., (*Saitas, 2001*). Adequately, there are isolated megalithic buildings (mainly houses, huts, churches, pens, cisterns) as well as works of defensive-military nature (fortifications, primitive towers) in the fields or grazing areas (*Saitas, 2001*).

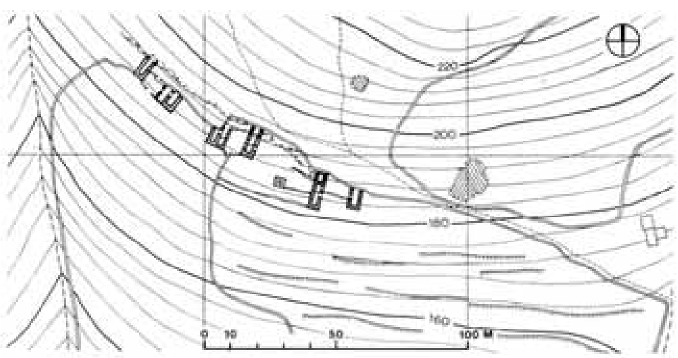


Fig.1.5: Megalithic settlement on slope with 6 houses (Pachia of Vathia) (Saitas, 2001)

The lay-out of the settlements as well as the arrangements, the orientations, the typology, the materials, the technological construction methods used in building conform to common, simple and fixed models are repeated with small variations and evolved at a very slow pace. Among the many scores of megalithic installations which have survived, only a few developed into large, extensive settlements such as on the W-SW base of Sangias region of Triantafyllia-Smoi of the community Pyrgos Dyrou (*Saitas, 2001*). As a rule the settlements constitute groups of 5-30 typical megalithic houses, enclosures, underground cisterns and one or more small churches and cemeteries (*fig. 1.5*). Small neighboring hamlets frequently form broader groups - units of agricultural, livestock raising communities which exploit a small productive hinterland (*Saitas, 2001*). Most of the settlements had no fortified elements although a few were fortified by larger, strongly made buildings at commanding positions and with fortified arrangements of thick stone fences with gates and small doors. The ruins of massive rectangular war towers, such as that of "Veletakos" at Pano Boulari, "Kavouris" at Pano Chora of Kita (*fig. 1.7, 1.6*) still exist in some settlements. They were built according to the megalithic system and reveal in the very long tradition in the region of the fortified tower (*Saitas, 2001*).

Fig.1.6: Ruins of a megalithic tower (Kavouris tower in Pano Chora, Kita) (Saitas, 2001)

The houses have an oblong, rectangular plan with the ratio of the sides fluctuating between 1:1.5 to 1:2.7 and are externally 4-7 m wide and from 7-8 m to 14-15 m long (*Saitas, 2001*). Therefore, there could be referred the variation to small (*fig. 1.7c, 1.8*), medium (*fig. 1.7b, 1.10*) and large (*fig. 1.7a, 1.9*) buildings with a mixed surface of 35-70 m^2 (small/medium are locally called *kolospita “κωλόσπιτα”* and the large *kolospitakes “κωλοσπίτακες”*) (*Saitas, 2001*). The walls are very thick (1-2 m) and get thinner as they go upward. The basic rectangular nuclei are often built on slopes, where they are arranged with the large side at right contour curves and the narrow side towards the view-gradient (*fig. 1.8, 1.5, 1.9*) (*Saitas, 2001*). When they are on level ground the large axis is constantly turned in an E-W direction, so that they can be entered from the long, southern side. Some of the structures have only one floor (one-storey) but most have an upper floor as well, so that their total height reaches 4-5 m. Usually, each level has a separate entrance (*fig. 1.9*) but it could be observed in several cases the ground floor to have two facing entrances. Often the wall of the narrow, higher façade which faced downhill was pierced on the top or on the bottom level as well, by a tiny opening ranging from 20-30 cm to 30-40 cm for observation, lighting and ventilation (*Saitas, 2001*).

The interior space on the bottom level was low (1-1.60 m) (*Saitas, 2001*) and primarily housed the animals and animal feed, while the main residential space for people was the first floor. In the buildings that are situated on the slopes, the ground floor frequently occupied only a part of the plan, because of the adaptation made to the declivity (*fig. 1.7, 1.5*). In some buildings, a transverse wall by the narrow front or the rear side of the ground floor made an enclosed storage area with a width of 0.80-1.00 m for dry or liquid products (*Saitas, 2001*). Internally it was carefully plastered and was reached from the upper floor through a small rectangular opening. In certain cases, such spaces are underground, perhaps used as an interior water cistern. In some buildings part of the ground floor is elevated wherever in others, an intermediary transverse wall-built opposite the entrance- sub-divides the space into two linked parts. A corresponding partition wall is sometimes found on the first floor as well, dividing it into two spaces and thus, this rudimentary nucleus constituted the main dwelling (*fig. 1.5*) (*Saitas, 2001*).

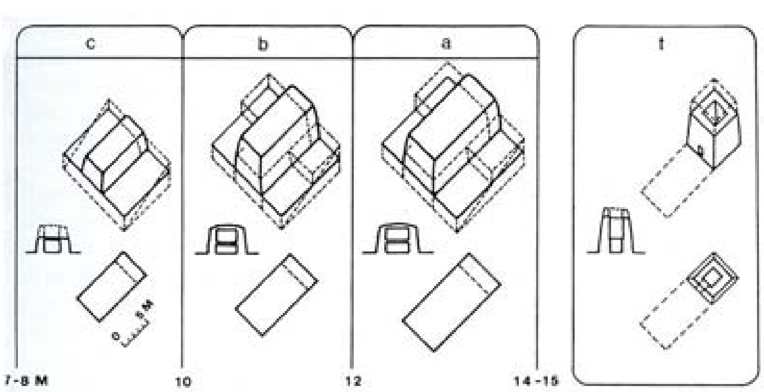


Fig.1.7: Typical sizes of megalithic nuclei of houses and a megalithic tower (Saitas, 2001)

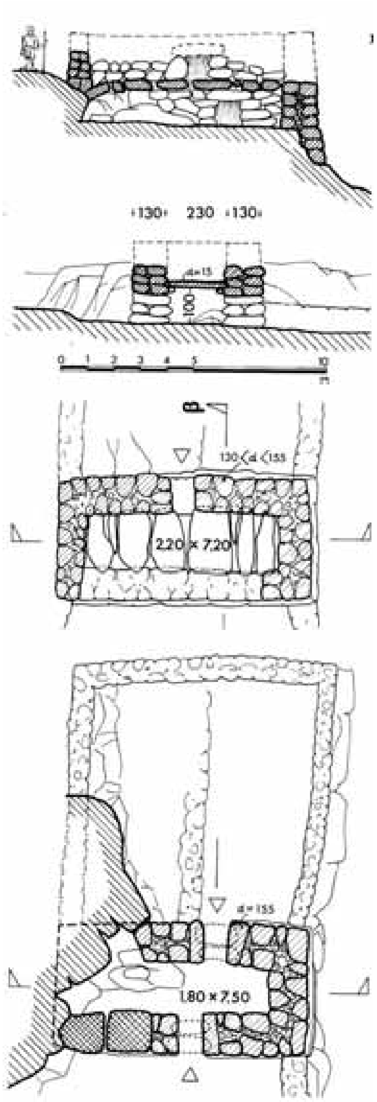


Fig.1.8: Megalithic house (kolospito, 9.80 m long) with a lower and an upper floor. From bottom to top: lower level plan, upper level plan, section by width, lengthwise section (Saitas, 2001)

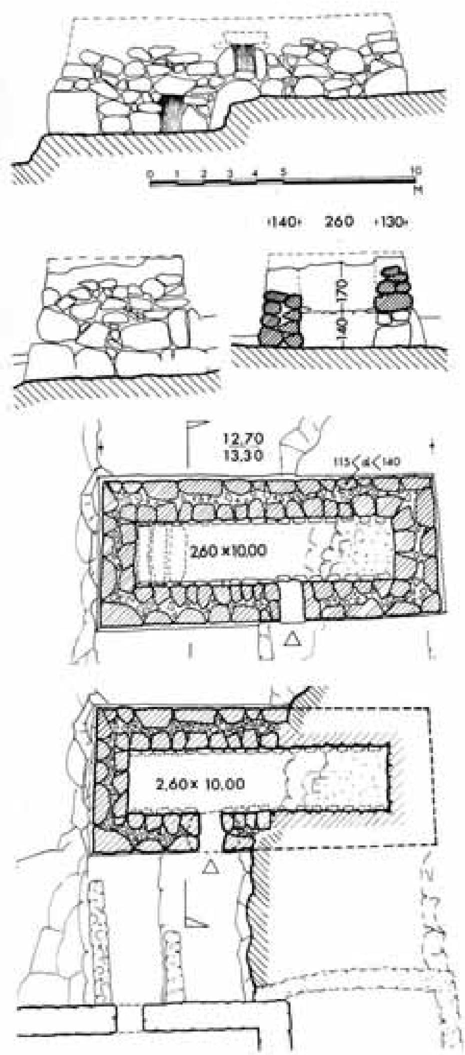


Fig.1.9: Megalithic house with a lower and an upper floor (kolospitakas, 13.0 m long) (Katamestika, Tsikalia). From bottom to top: lower level plan, upper level plan, section by width, facades (Saitas, 2001)

Fig.1.10: Ruined megalithic house (Triantafyllia, Pyrgos Dyrou) (Saitas, 2001)

The simple, conventional houses were usually arranged at short distances from each other (*fig. 1.5*). Often stone fences, walls or retaining walls made of dry stone define their courtyard where additional auxiliary outbuildings are found. Neighboring houses, usually in pairs (*fig. 1.5*) are combined and share a courtyard between them which has a common entrance. When the basic nuclei are not sufficient, they are extended through other similar ones which are frequently built in contact with each other in order that they have one of the narrow sides of the original unit in common. Thus a composite oblong building is created with two or three nuclei in a row. In other cases, two-three nuclei are added and increase the width , whenever the area is more confined, such as in the mountains, the combinations are denser and the closed and open spaces more complex (*Saitas, 2001*).

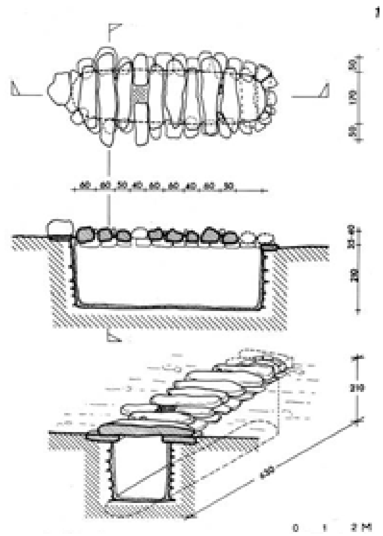


Fig.1.11: Megalithic cistern (koloyisterna) with makronia (Saitas, 2001)

The dug-out megalithic cisterns for water, the *koloysisternes* (*fig. 1.11*) are in the yards or the open public spaces of the settlements. In general, they are long and narrow with a length of 4-12 m and a width of 1.50-2.60 m and a depth of 2-2.50 m (*Saitas, 2001*). Strong *kourasani "κουραζάνη"* plasters and waterproofs the dry stone or the rocks of the walls and the bottom. Massive monolithic beams (the *makronia "μακρόνια"* or *plechtoura "πλέχτουρα"* with a length of 1.50-3.20 m and an average section of 50×50 cm) placed parallel to each other, cover the opening (*fig. 1.11*) (*Saitas, 2001*). The small empty spaces between the *makronia* are blocked by wedge-shaped stones and the entire structure is covered with additional small stones acting as filters. A small rectangular opening is left, like a well-head and is covered by a stone slab (*Moutsopoulos and Dimitrokalis, 1975*).

Megalithic construction is very distinctive. The buildings are erected directly on the limestone rock ground using the large blocks which are quarried in situ or brought from nearby sites. The walls are built on two independent facades (inside-outside), the outside ones made with an incline of 5-10% to make them more stable. The stone blocks are laid in successive rows, more or less regular without any mortar. Small stones and pieces of stone (rubble) fill the core between the two facades and supplement the joints on the surfaces. Larger blocks are used on the exterior facades and the lower parts and smaller ones on the interior and the upper parts. The dimensions of the average block ranges from 60×60×70 cm to 30×30×40 cm but other sizes are also used such as 170×60×70 cm or 140×110×110 cm (*Saitas, 2001*). Depending on the nature of the raw materials and its dressing, the surfaces of the stones are either curved-humped (*fig. 1.10, 1.12, 1.6*) or irregular or more regular like a slab. The larger, long blocks are used as cornerstones (*fig. 1.12*) and as jambs or lintels of the doors (typical dimensions 200×60×70 cm or 230×50×60 cm or 150×40×50 cm) (*Saitas, 2001*). The entrance opening has a width of 0.80-1.10 m and is low 0.90-1.50 m (*fig. 1.10*) (*Saitas, 2001*). To make the jambs of this kind of doors,

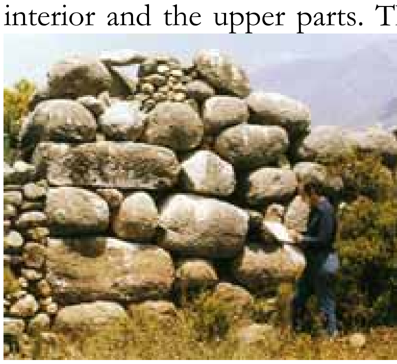


Fig.1.12: Masonry of a megalithic house (Triantafyllia) (Saitas, 2001)

they used from one to three successive rows of criss-cross blocks so that certain ones (usually of the first and third row) are cross laid longitudinally. To bridge the door and secure from earthquakes over the entire thickness of the wall, a lintel of two or three *makronia* is required. In certain circumstances, the exterior lintel has a more carefully dressed facade and is decorated with carved crosses and other symbolic-decorative motifs, which is also found on some cornerstones.

The covering of the spaces, especially on the ground floor, was done with the *makronia* or *plechtoura* e.g. large monolithic slabs which were placed in contact with each other and bridged the opening (*fig. 1.8, 1.6*). They were supported at both ends on a layer of well-embedded stones which projected from the opposite long walls. The empty spaces between the basic *makronia* were closed off with smaller slab-like stones or with small stones wedged in and this was covered with pebbles and beaten clay earth mixed with manure. They also used a layer of pebbles and a kind of *kourasani* on the flat roofs (*doma "δώμα"*). A few more advanced buildings were covered by wooden beams. These were embedded in beam-brackets, either on both ends or only on one, while the other rested on a recess of the opposite wall, which on the first floor was not as thick as on the ground floor. The more advanced varieties of houses would have a wooden roof covered with tiles or limestone slabs (*Saitas, 2001*).

b) **The Byzantine presence**

Even though the rough "megalithic" represent the basic indigenous staring point for the long, drawn-out evolution to the more traditional houses, particularly in the southern sections of the peninsula, the Byzantine tradition also supplied influential prototypes. The provincial structures that were built at certain times in Mani, at the initiative of the administration or the local aristocracy enriched or consolidated local technical solutions and included cohesive mortar, vault construction, decorative features, etc. (*Saitas, 2001*). The new techniques were more widespread in the northern sections of the peninsula particularly after the establishment and the flourishing of the Despotate of Mystras.

An interesting example of the Byzantine presence is the deserted castle of Palia Karyoupolis in NW Mani *(fig. 1.13)* built as a refuge on the peak of an important hill in the defile Gythion-Oitylo. The settlement had already been around for many centuries when, at the end of the 15th century, it was reorganized and became the seat of the bishopric and military garrison under a Byzantine commandant in the service of Constantine Palaiologos (*Etzeoglou, 1982*). The walled space at the top of the hill (alt. 425 m) had an area of approximately 1 hectare and contained buildings from various periods (*Saitas, 2001*).

Near the eastern entrance, at the highest spot on the hill and at the edge of the wall, a prominent, powerful Byzantine tower (*A in fig. 1.13*) with a rectangular plan 5.75×7.85 m and a preserved height of 7.70 m rises up in a spacious yard (*fig. 1.13-1.16*) (*Saitas, 2001*). Its thick walls (width of 1.50-1.70 m) were made with small, roughly hewn stones, numerous sites, and abundant slaked lime mortar and carved cornerstones of medium size. The traces of the wooden beams from the scaffolding used by the building crew are clearly visible. The entrance was approximately 2 m above the ground and led to a space with average dimensions of 2.50×4.50 m (*Saitas, 2001*), which on three sides had characteristic opening-embrasures (with a trapezoidal plan, a small, narrow external façade and a broad arched façade internally). It was covered by a barrel-vault and the traces of beam brackets show there was an intervening wooden floor which divided the area in two floors (*Saitas, 2001*).

Fig.1.13: The walled hamlet-castle of Palia Karyoupoli. A: Byzantine tower. K: large official building. 1: Agios Nicolaos. 2: Agios Georgios. 3-6: churches around the castle (Saitas, 2001)

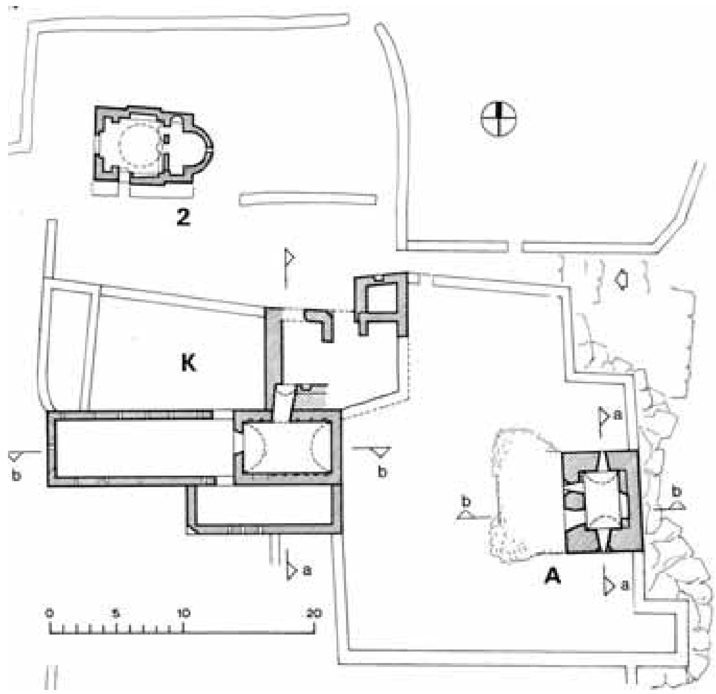


Fig.1.14: The section of the castle with a fortified entrance, the church of Agios Georgios (2), the tower (A) and the large official building (K) (Saitas, 2001)

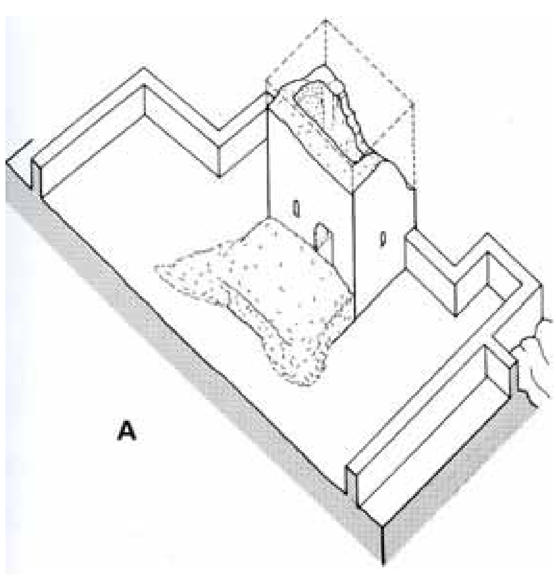


Fig.1.15: Axonometric plan of the Byzantine tower A (Saitas, 2001)

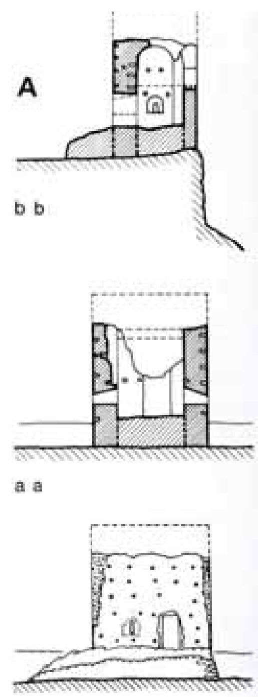


Fig.1.16: Tower A: above, section by width; lengthwise section; below, west façade (Saitas, 2001)

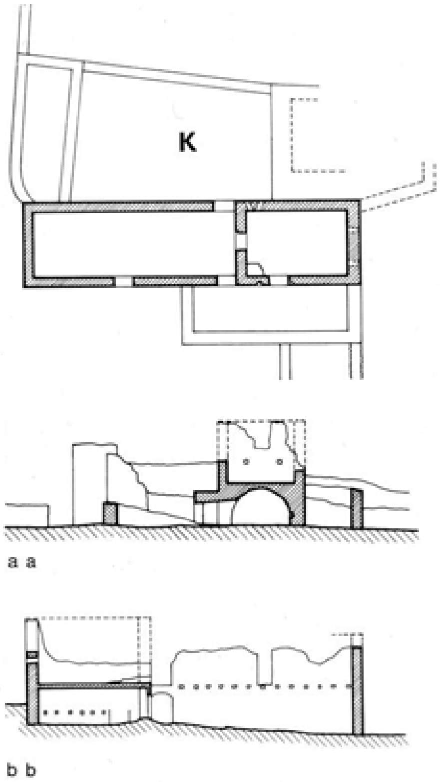


Fig.1.17: Building K: above, upper level plan; center, section by width; below, lengthwise section. (Saitas, 2001)

Between the enclosure of the tower and the courtyard of the Episcopal Church is an important ruined building (*K in fig. 1.14, 1.17*) which was perhaps a Byzantine episcopacy or post-Byzantine abbey. The unaffected two-storey rectangular main building (22.30×5.65 m) (*Saitas, 2001*) consists of two parts: the one had a vaulted ground floor space while the remaining, and larger part, had a wooden floor and wooden roof. Embrasures dot the walls which are 70-80 cm thick and are made of small stones, tiles, slaked lime mortar and carved cornerstones (*Saitas, 2001*). Of the houses inside and outside the castle, the oldest (from the early Middle Ages) belong to the category of the rough megalithic and the later ones are simple rectangular buildings of small or medium size with well-built masonry 60-70 cm thick, wooden floors and tile-covered roofs (*Saitas, 2001*). They are similar in some ways to the ordinary houses of the final Byzantine period which are found in Mystras, in Geraki and in other districts of the Despotate (*Saitas, 2001*).

c) **1460-1821** Many post-Byzantine settlements of the dense network of North and South Mani, which are referred to by written sources in the 16th and 17th century, constituted a continuation and development of medieval and Byzantine nuclei.

-The North

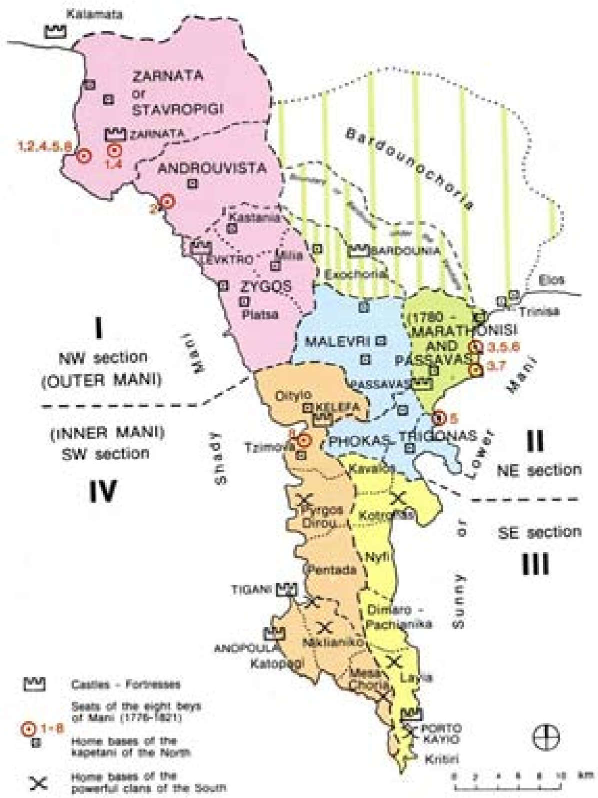


Fig.1.18: Mani in post-Byzantine time: the local entities, the castles, the seats of the powerful territorial chiefs (kapetanoi and beys) of the North and the main powerful clans of the South are noted. (Saitas, 2001)

Characteristic examples of the long life, the formation, the structure and the architecture of important centers of northwestern Mani, are Zarnata and Prastio (*Saitas, 2001*). Both centers faced Turkish and Venetian occupation for some years since their strategic position in the area made them attractive to foreigners (*fig. 1.18*). Under the Venetians, Zarnata became the metropolis of all North Mani (Alta Maina) and gathers at its peak time 600 families (*Saitas, 2001*). Prastio of Androuvitsa is one of the oldest and most important settlements of the area which lies directly south of Zarnata (*fig. 1.18*) and at its peak development 430 families inhabited in the region (*Saitas, 2001*). It could be mentioned that in both centers, the dense tissue with its squares, the network of narrow streets which are defined by the houses and the walls of the well-cared for gardens, the careful masonry of the buildings with squared stone blocks, the frequent relief of carved decorations, the use of tiles for the roofs indicate the advanced building tradition (*fig. 1.19*). Ruins of buildings show that the basic type of dwelling was the simple, rectangular oblong house with a ground floor and first floor. A typical feature was the well-made main narrow(frontal) side which was arranged facing the street, with one or two symmetrical arched windows on the first floor (*fig 1.22*).

Fig.1.19: Map of Prastio: the 30 monastic, parish and family churches, which are dated from Byzantine and post-Byzantine time, are noted in red. Most of the houses are from 18th and 19th century. (Saitas, 2001)

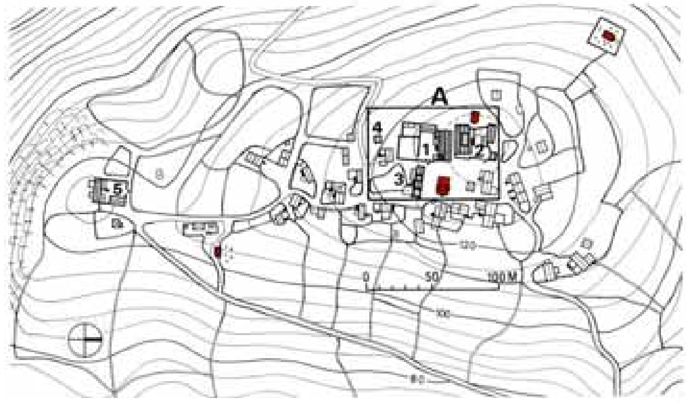


Fig.1.20: Karyoupoli (Miniakova). A: the main section at the top of the hill end and the complexes of Kavalierakis- Phokas (1, 2, 3) and the bulwark (4). The complex (5) at the south stands on an elevation. (Saitas, 2001)

Fig.1.21: The complexes 1, 2, the more recent tower of the complex 3 and bulwark 4 of Kavalierakis- Phokas at Karyoupoli (view from SW). (Saitas, 2001)

Fig.1.22: Building (cells) at Prastio. The narrow, west façade has two arched windows and between them, the engraved date 1704. (Saitas, 2001)

After the establishment of the institution of the *kapetanies "καπετανίες"* (captaincies) in the North, the presence of the chieftains became more tangible in the settlements and the countryside. These families had imposing, fortified installations at opportune sites. The most complete ones were the main residences of the owners and their guards. They were found within the settlement or occupied choice locations in the countryside. Others had specific functions, such as sentry posts-guard houses, custom houses etc., and were found on rises, in gorges, at commercial landing stages and at anchorages. While they often showed Byzantine, Latin and Ottoman influences, the circumstances of construction of most of these installations-especially the older ones-are still known as the relevant written testimony is scanty and there is a dearth of detailed studies (*Saitas, 2001; Vasilatos, 2001*).

In the settlement Karyoupoli (or Miniakova in the 18th and 19th century) in northern "sunny" Mani the interesting walled complexes of the old powerful Phokas-Kavalierakis family (*fig. 1.20, 1.21*) have been preserved. Built on top of a hill (alt. 127 m) and 8 km between Palaia Karyoupoli and the Turkish occupied fortress of Passavas (*Saitas, 2001*), these complexes controlled the main passage from Turkish occupied land to Mani as well as the small fertile valley of Dichova, which ends at the bay-harbor of Kato Vathy (*Saitas, 2001*). This important building unit (*fig. 1.20A, 1.23*) indicates the architecture elements of the era. It contains two principal walled complexes (1 and 2), a smaller adjoining complex (3) and a small tower-guardhouse (4). It is supplemented by a private chapel to the west (5) and by a large family-parish church (7) on the eastern square (6). The main gates of the two principal complexes are turned towards this square. The well-built enclosure walls (3-4 m high) of the tow main complexes are pierced by many simple or twin loop-holes, which are arranged in two or three rows. Several of the loop-holes have an especially elaborate form (*fig. 1.25*). In the south complex the gate was an imposing vaulted structure (*fig. 1.24, 1.23*). Its sandstone frame has an arched lintel with a slightly broken line supported on jambs with small capitals. Above the entrance, in a rectangular, sandstone frame with a decorative band, a relief plaque was built in with a representation of a double-headed eagle. A large decorative frame with mouldings crowns the door and the "coat-of-arms" over it (*Saitas, 2001*).

The adjoining sides of the complexes occupy two large similar buildings, which consist of two-storey oblong residences (1a, 1b and 2a, 2b) about 23m long supplemented with one-storey *liakoi* (*Saitas, 2001*). Broad arched stairs lead from the forecourt to the *liakoi "λιακοί"* which had a width of 2-3.5 m and facades with arched openings (*Saitas, 2001*). There was a row of dovecotes on the parapet breast-rail of the *liakos* of the northern complex. The ground floors were covered with barrel vaults. The first floors which were the main residential spaces were covered with gabled tiled roofs, but the commanding middle selection (2a.2) of the north complex was tower-shaped, quite high, vaulted and had a flat terrace (*doma*) with a solid stone parapet. The middle selection of complex 3, and probably the similar section 1b of complex 1, were also elevated. These higher sections with flat roofs were used as observation posts-battle stations and significantly increased the defensive capabilities of the buildings (*Saitas, 2001*).

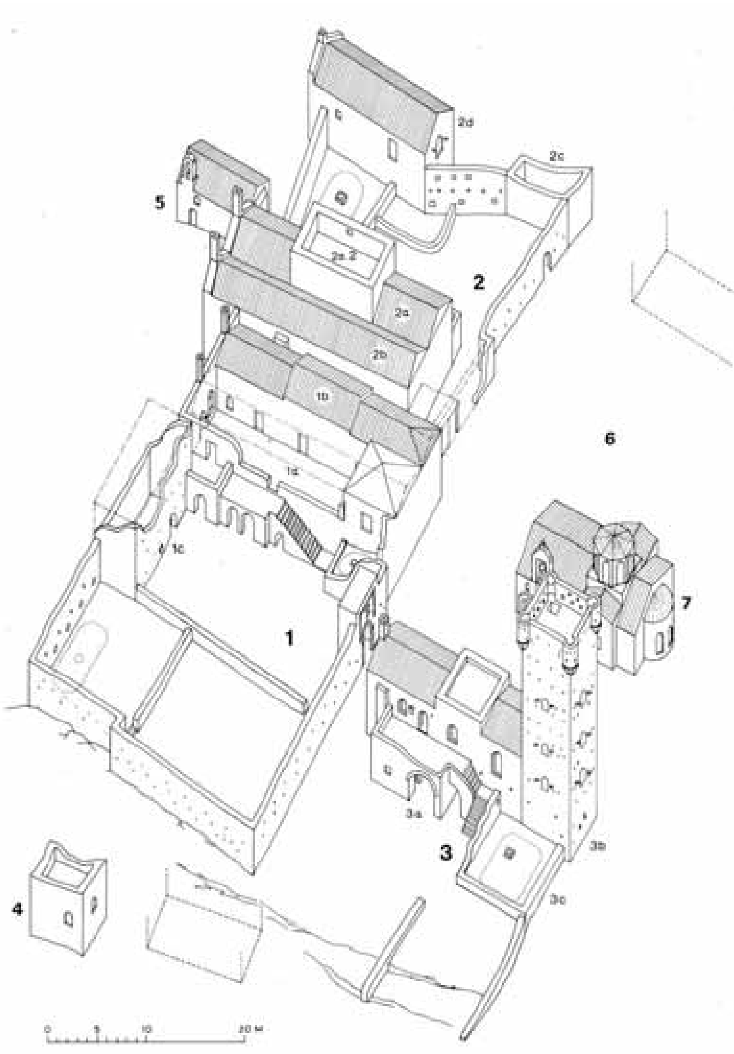


Fig.1.23: The main nucleus of the (new) Karyoupoli with the fortifications of Kavalierakis- Phokas. 1, 2: walled complexes. 3: complex with an old two-storey building and a more recent six-storey tower. 4: bulwark 5: Agios Petros 6: Square. 7: Eisodia tis Theotokou church. (Saitas, 2001)

Fig.1.24: The ornamented main gate of complex 1 in fig. 1.23. (Saitas, 2001)

Fig.1.25: Elaborate twin loop-hole on the enclosure wall of complex 1 of fig. 123. (Saitas, 2001)

Fig.1.26: The arched recesses and the axial fireplace with the tall chimney on the west wall of the building in fig. 1.23 (Saitas, 2001)

Horizontal eaves made of bands of sandstone decorated the narrow, main facades. On the west side, the apartments on the first floors had an axially placed fireplace in a recess (*archivada "αρχιβάδα"*) which was outfitted with loop-holes. This axial *archivada* was combined with two large, symmetrical, shallow, arched recesses (*fig. 1.26*). The tall, well-built chimneys (polygonal or square section) stood out from afar adding a touch of splendor. The openings were adequate in number and of suitable dimensions. Most had arched lintels, but there were also others with horizontal lintels and some with curvilinear forms in line with Venetian prototypes. Certain niches on the wall had an analogous shape. Sandstone projections were combined with certain windows. Rectangular *klouvia "κλουβιά"* with a *katachystra "καταχύστρα"* - drain projected from the walls of the main buildings (*Saitas, 2001*).

Besides the large main buildings that were described analytically, focus should be given in complex 1 contained a tower-shaped building of considerable size (plan of 4.80×11.30 m) (*Saitas, 2001*) with military features (1c). Correspondingly, complex 2 contained a small fortified corner building (2c) as well as a more recent dwelling (2d). Moreover, underground *yisternes* in the forecourts and built reservoirs on the *liakoi* guaranteed adequate amounts of water. Thus furnished, these installations were sufficient for the housing and defense of many people, as well as for the sheltering of many animals, produce and supplies. Having the buildings of the Phokas-Kavalierakis family as a nucleus and characteristic paradigm, the new Karyoupoli settlement gradually developed from the middle of the 18^{th} century on (*fig. 1.20*) and the seat of the eponymous old bishopric was transferred there in the years before the Greek War of Independence (*Saitas, 2001*).

-The South

Fig.1.27: The central section of Oitylo. On the opposite side of the ravine, the castle of Kelefa can be seen (Saitas, 2001)

In the south, the rule was smaller settlements with a simpler and more primitive structure. The exception to this rule-in the middle region of Mani-is found in the neighboring centers of Oitylo and Kelefa, which at the time had 300-400 families each and exceeded all the settlements in the peninsula in size (*Saitas, 2001*).

Oitylo built on an elevation 250 m high, on the steep north side of Kako Lagadi, occupies the site of the ancient acropolis mentioned already by Pausanias in his "Laconica" journey. In 1670, Oitylo had been already an important region center with many structures built to secure the village by the Turkish forces like towers, *ntoufekistres "ντουφεκότρυπες"*, stone houses etc. In present–day, in Oitylo (*fig. 1.27*), the central square-market, "at the Kastro", the street network that is framed by two and three-storey densely built fortified stone houses, the churches, the monasteries and fountains preserve some of the old elements (*Saitas, 2001; Vasilatos, 2001*). Lying at a distance of 1.5 km across from Oitylo, Kelefa is a settlement with linear development, simple stone houses and interesting churches and fountains (*Saitas, 2001*).

The small range of economic differentiation of the inhabitants and the other material limitations contributed to the fashioning and the continued common use, for a long period of time, of a simple, stable type of house constituted a continuation and slow development of the primitive prototype of the megalithic building (*fig 1.28*). Nevertheless gradual replacement of megalithic architecture came throughout centuries because of the special needs of the Mani Area and reached the fortified, oblong, rectangular building (*fig. 1.28-4, 1.31*) with a single space or double space first floor for people and a ground floor for animals and feed. If the house was one-storey, the animals were stabled in adjoining building. These houses, as well as the older ones, usually had a standard size, a common orientation and on the slopes were built at right angles to the contour curves. Their external dimensions

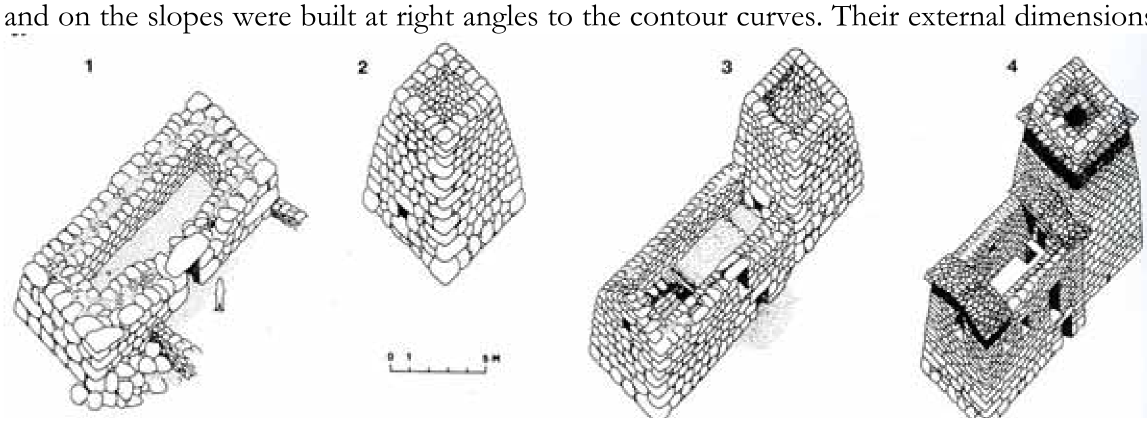


Fig.1.28: Evolution of buildings in the south: 1: megalithic house. 2: megalithic tower. 3: megalithic tower and attached later house. 4: post-Byzantine tower (Anemodouras) and attached house (Korres-Tzanaki, 1977)

were: width 4-4.5 m, length 7.5-12 m and height 4.5-6 m. The walls were quite thick (at the bottom 1-1.5 m and higher up 0.70-0.90 m) with an incline "skarpa" (*fig. 1.34*) on the outer surface (*Saitas, 2001*). Large stone blocks were now used only at the base (and primarily the lower cornerstones). The openings were tiny and limited to what was absolutely necessary. If it was not ruled out by the topography or other factors, one of the long sides was orientated to the south or southwest. This is where the courtyard with its dry stone fence was as well as the entrance to the house, to insure plentiful sunlight and protection from strong winds. If the house was two-storey, a low entrance led to the ground floor and another to the first floor. The upper entrance was reached either by a wooden stairway which was pulled up inside for security or by a rudimentary exterior stone staircase (a simple stone heap that could be easily pulled down) (*fig. 1.33-2*) or by staircase and a landing- the one-storey attached *liakos*. The *liakos* was the same length as the house or smaller (*fig. 1.33, center*). It added one or more (closed or open) covered spaces to the ground floor (for the animals) and at the same time formed a landing and a terrace for the first floor. The *liakos* was built as an addition to the basic house, but gradually it became an organic part of the dwelling nucleus (*Saitas, 2001*).

The ground floor of the house was low (usually 1.5-2 m) with a width of 2-2.5 m (*Saitas, 2001*). Its walls were either blind or had loop-holes (*polemotrypes "πολεμότρυπες"*) for defense; but more frequently they had only one small opening, a "light embrasure" in one of the narrow sides. Often there were recesses-angers for the animals on the walls. Sometimes, a part of the ground floor was fashioned into a *yisterna* into which the rainwater was channeled. Other times the cistern was completely underground, dug under the house or the *liakos* or the courtyard. The ground floor was covered either by stone beams-*makronia* or by a nearly semi-cylindrical *kamara "καμάρα"* (*fig. 1.29, 1.33*) or even by a combination of the two. The *kamara* was often not set in the ground but on stones embedded into the side walls at a height of 1 m, in a way that made them project approximately 20 cm (*Saitas, 2001*). When they re-built and re-used the megalithic buildings the point of curvature of the *kamara* was set on the projecting layer where the *makronia* were formerly put down (*fig. 1.29*). When constructing the *kamara* they used wedge-shaped stones and plain earth or dilute slaked lime mortar. The interior communication of the ground opening was the *katarrachtis "καταρράχτης"* (*fig. 1.28-4, 1.29, 1.33*). The roofing of the *liakos* which had a smaller width 1.5/2 m wide was done with *makronia* or wooden beams which bore stone slabs and clay soil (later on they were flagged or made with *kourasani*). Still later they used a combination of techniques for roofing the *liakos* (beams and *kamara*) or a plain *kamara* (*Saitas, 2001*).

The first floor was more spacious and had height of 2-3 m. Besides the door, there was also usually a very small window (often arched) in the middle of the narrow façade with a convenient orientation (*fig. 1.30, 1.32*). More rarely, there were also a few small openings in the other walls (*fig. 1.33-2*), particularly in more recent years. There were, however, *polemotrypes*, single or twin, which were frequently combined with various sized recesses and cupboards, the *thyrides "θυρίδες"* (*fig. 1.35*). A typical arrangement (known from Byzantine prototypes) was that of two symmetrical *thyrides* right and left of the axial window on the narrow façade. Perhaps the corner recesses-sentry posts (*klouvia*) with *zematristes "ζεματίστρες"* or *katachystres* and *petromachoi "πετρομάχοι"* were already in use. The *klouvia* (*fig. 1.30, 1.33-2*) bunches together in spacious interior recesses a number of *polemotrypes* which helped to better control the perimeter of the house. On the exterior facades of the building these sentry posts either were not visible at all (*fig. 1.33-2*) or projected outward like stone canopies-turrets with a prismatic or rounded form (*fig. 1.30*). The roofing of the main house was done with wooden (or stone) beams which bore the flat roof or a simple wooden frame which supported a gabled roof with *marmares "μαρμάρες"* (*fig. 1.33*) or with an intermediary coping structure; sometimes there was a combination of one of the last two methods and a limited *doma* (on a vault) which was used as an observation post-battle section. A small opening in the roof, the *klivani "κλιβάνι"*, allowed the smoke from cooking done in the *fotogonia "φωτογωνιά"* (or *fotogania "φωτογανιά"*) or the *foko "φώκο"*, to drift out (Saitas, 2001).

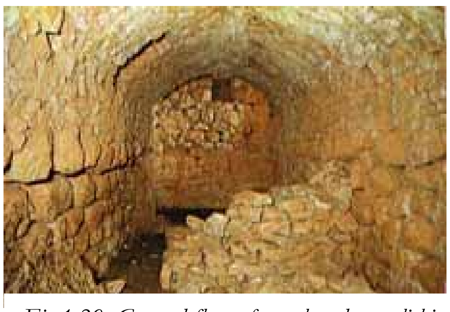


Fig.1.29: Ground floor of an altered megalithic house. The new kamara is set on the ridge with the projecting stones. (Saitas, 2001)

Fig.1.30: Fortified house with a megalithic base at Alika. The first floor has an axial, arched window and projecting corner turrets (klouvia) with loop-holes (polemotrypes). (Saitas, 2001)

Fig.1.31: Anogokatogo defensive house at Kechrianika, Niklianiko. The inclined walls are built of dry stone. (Saitas, 2001)

Fig.1.32: Anogokatogo houses at Alika. The older one, on the left, has roughly dressed masonry and an axial arched window. The adjacent later house, with a rebuilt upper part, has a better dressed stone structure and a newer rectangular window. Along the east side, a two-storey liakos was built later. (Saitas, 2001)

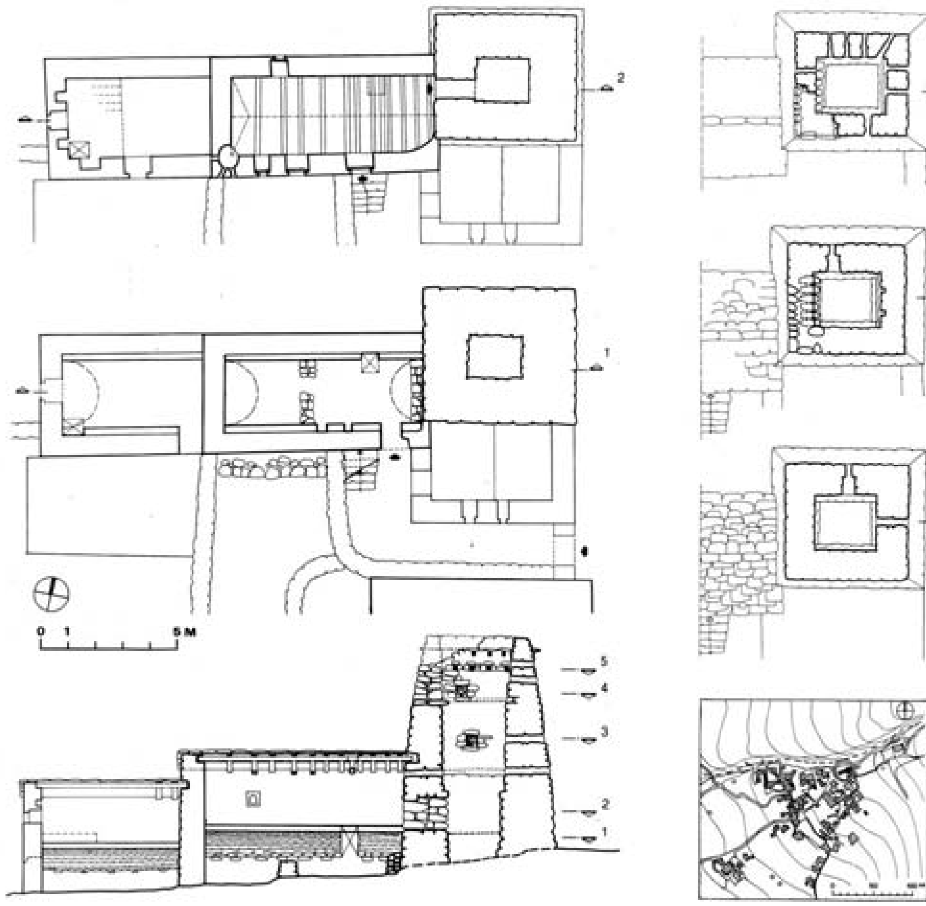


Fig.1.33: The Anemodouras tower and the later adjoining houses; Lengthwise section and plans of levels 1-5. The circle on the topographical map of Pano Boulari shows the section of the tower. (Saitas, 2001)

Fig.1.34: The Koteas war tower at Kechrianika with the old "skarpoto" section of dry stone and more recent prismatic body, built with mortar. (Saitas, 2001)

Fig.1.35: Old house with an axial arched window, a corner klouvi and thyrides. A bent trunk was used as a transverse beam of the roof. (Saitas, 2001)

Between or near the houses of the locally powerful clans, rough war towers which usually took the form of a truncated pyramid were raised at deliberately chosen, opportune sites. In certain cases their lower sections were used as bases for the more recent prismatic towers built with mortar, such as the Koteas tower in Kechrianika (*fig. 1.34*) (*Saitas, 2001*).

Fig.1.36: The Anemodouras tower at Pano Boulari. Two later houses in a row (see fig. 1.33) are attached to its west side. (Saitas, 2001)

A typical tower of this type, having still nearly its entire height, is the Anemodouras tower in Pano Boulari of Niklianiko (*fig. 1.28-4, 1.36, 1.33*) (*Saitas, 2001*). It was built without mortar (*xeropetri "ξερο-πέτρι"*) with masonry that was generally in use till 1750's. It has a height of approximately 8.5 m and exterior dimensions at the base of 5.70×5.10 m and at the top, of 4.30×3.80 m (*Saitas, 2001*). It had three floors and thick walls whose thickness was steadily reduced from 2 m at the base to 80 cm at the peak (*Saitas, 2001*). Wooden beams (which were supported either exclusively in beam brackets *–patotrypes "πατότρυπες"-* or on a layer of stones embedded in the opposite wall, projecting out 15 cm.) bore the floors. The entrance was small and rose above the ground about one meter. The lintels were massive *makronia*. The walls of the second and third floors were pierced by small openings- loop-holes. The roof consisted of a wooden frame which bore *marmares*. The circumferential *marmares* of the roof projected slightly outside the walls forming the characteristic eaves (*Saitas, 2001*). On the west side of the tower "leaned" a house (8.10×4.50 m) with a ground floor and a first floor (*fig. 1.36, 1.33*) (*Saitas, 2001*). The entrance to the tower was now via the first floor. On the first floor of this house the corner recess with the three loop-holes is characteristic; they were made useless in part when later house was built against the narrow, west side. The structure of the gabled roof of the house is representative: a tree truck is the main beam (*korfeas "κορφιάς"*) which is reinforced every 1.5-2 m by transverse bearing elements (*Saitas, 2001*). This main bearing structure is supplemented by other thinner, slanted rafters or branches, fixed at 50-70 cm between the walls and the *korfeas* (*Saitas, 2001*). The frame was given a layer of cane and a covering of *marmares*.

1.3.2 Towers – Tower-dwellings

Fig.1.37: The five-storey tower-dwelling of kapetanios K. Dourakis in Kastania. Theodoros Kolokotronis took refuge here during the persecution of the klepths in 1803. The top floor with the four circular, corner turrets is a pre-revolutionary addition. (Saitas, 2001)

Up to the past century, insecurity and defensive reasons determined, to a large degree, the organization and the structure of the buildings. This could be understood by taking into consideration that all men wore guns while the rest of the members of the family were inured to war and that relatives lived in the neighboring houses were ready to help out in case of threat. Throughout the 18th century, in particular, the increase of the influence, the wealth and prospects of the powerful families in the Mani Area as well as the settling of armed Turkish Albanians furnished additional reasons for the construction of fortified buildings (*Saitas, 2001; Vasilatos, 2001*). Thus, the *kapetani* (chief-captains) and the heads of the powerful families built tower-dwellings with three to five floors which during times of peace were used as permanent or secondary residences while during times of war, they were used as refuge and a military fortress.

Fig.1.38: The SW façade of the Oikonomeas tower-dwelling. The four main old arched and symmetrical windows have been rebuilt. (Saitas, 2001)

The tower-dwellings were built in the settlement regions (*fig. 1.37, 1.38, 1.39*) or on their outskirts (*fig. 1.41, 1.42*) but also at convenient, opportune and commanding points of the land that the *kapetani* occupied or ruled. Often they were combined with a church dedicated to the family's patron saint (*Saitas, 2001*). If the site was suitable, isolated tower-dwellings or war towers became nuclei which formed new wards or even new, independent settlements but on the other hand, regions which were of great importance hosted, and still do, isolated towers.

Fig.1.39: Tower-dwelling with a cylindrical corner turret and an adjoining house in Kambos, Zarnata. (Saitas, 2001)

Fig.1.41: Koumoundouros tower-dwelling at Garbelia, Zarnata. A more recent building has been connected to the older cylindrical windmill forming a protected corner. (Saitas, 2001)

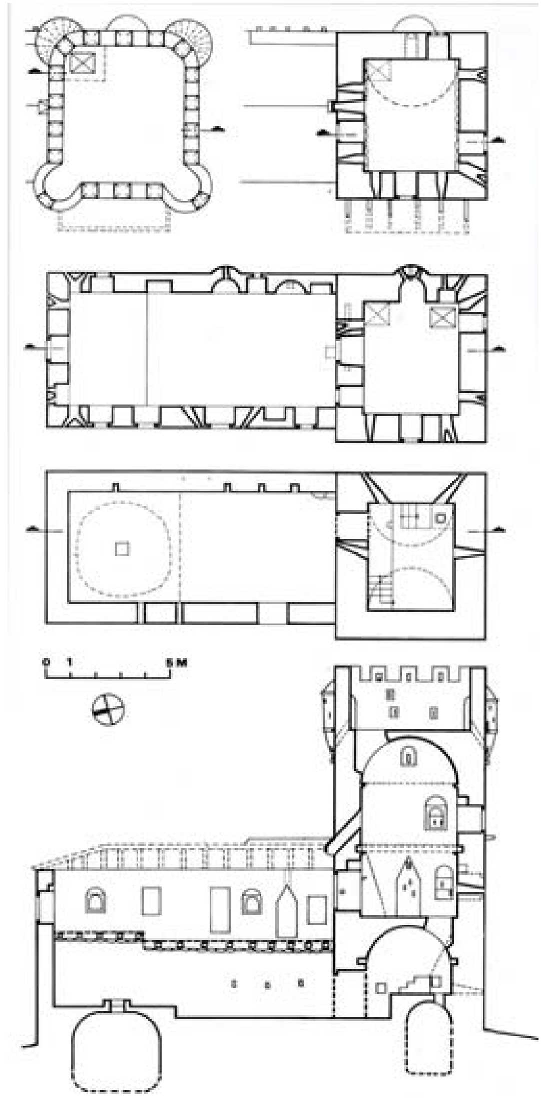


Fig.1.40: Well-outfitted war tower and contiguous official residence of the Kapetanakides in Myli, Almyros. From bottom to top: section, plans of first, second and third levels and the flat roof (korfari). (Saitas, 2001)

Fig.1.42: The south façade of the Mavrikos tower (1814) at Malta. (Saitas, 2001)

Some tower-dwellings have a form strictly prismatic and conservative (*fig. 1.38, 1.43, 1.44*), others have a more formal and well-crafted look with Latin or Ottoman influences (*fig. 1.39, 1.40, 1.42*). In general, they have a rectangular or nearly square plan, with side ratios ranging from 2:3 to 1:1 (*Saitas, 2001*). The exterior dimensions are: width from 4.5-6 m, length from 6-9 m, and total height from 9-18 m (*Saitas, 2001*). The walls are 150-90 cm thick at the base, 100-70 cm in the middle and the upper floors and 40-50 cm on the parapet of the flat roof (*Saitas, 2001).* Sometimes, regular or incomplete wooden bands, made with raw or carved wood, ring the building at various heights. In some towers the junctions of the walls are reinforced internally with oblong stones which are placed at the interior corners each 1-1.5 m (*fig. 1.47*) (*Saitas, 2001*).

The one-storey or two-storey ground floor had a vaulted roof (*fig. 1.40, 1.44, 1.46*); in many cases though the main upper floor was also vaulted forming a solid, durable terrace (*fig. 1.40*). The floor in the mezzanine of the ground floor (when it existed) was of wood as it was between the main storeys and even at times on the upper storey where the flat roof needed suitable covering (*fig. 1.46*). Quite a few of the towers had a wooden roof-tiled or with *tikles "τίκλες"* (*fig. 1.39, 1.43, 1.52, 1.55*) - which was often protected by a low, stone parapet. The towers with a *korfari "κορφάρι"* (flat roof) – observation post and battle station- had a high circumferential parapet (1.50-2 m high) (*Saitas, 2001*) often topped by serrated battlements with *ntoufekistres* (*fig. 1.40, 1.46*)

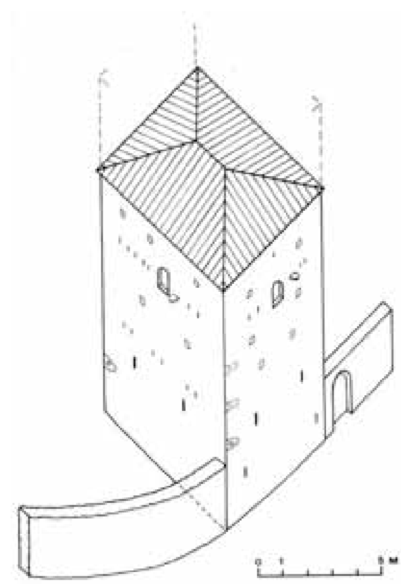


Fig.1.43: Tower (1786) of kapetanios Kitriniaris in Nikovo of Exochori, Androuvitsa. It was formerly one-storey higher. (Saitas, 2001)

In a group of important and characteristic towers, round turrets (*klouvia* or *vigles "βίγλες"*) projected from the corners of the building or from the last roofed floor where they were supported on reversed conical bases (*fig. 1.39, 1.40, 1.48, 1.49*). In many cases, rectangular or rounded *klouvia* or *petromachi-polemistres* projected slightly out from the walls of the intermediate floors. Internally, they corresponded to recesses which were often used as hearths-fireplaces or as lavatories (*fig. 1.40, 1.46*).

The ground floor (*katoi "κατώι"*) was usually a storage area, the shelter of the garrison or a stable for the large animals and a hay loft. Sometimes, a wooden mezzanine floor or loft was built because the space was quite high and developed on two levels (*fig. 1.45*). Usually, it contained an underground cistern (*gouva "γούβα"*) for storage of the agricultural production (*fig. 1.40*). In many cases, an entrance was opened on the ground floor in subsequent, less turbulent periods (*fig. 1.40, 1.46*) while formerly the thick walls were completely blind or had *ntoufekotrypes* as well as a small window, high up, for ventilation and lighting (*Saitas, 2001*).

The main floors were, as a rule, single space (*fig. 1.45, 1.46, 1.51, 1.52*). The floors were communicated with each other by a fixed or movable wooden staircase (*fig. 1.40, 1.45, 1.51, 1.53*) which took up a minimal amount of space. The main exterior entrance to the building was on the main floor, elevated 3 to 5 m above the ground. This was reached in several means (*Saitas, 2001*):
-by movable wooden stairs (*fig. 1.42, 1.46*),
-by a stone staircase built at a distance of 1.5-2 m from the main structure mass (the space was bridged by wooden boards which were pulled inside in the evening and in threats) (*fig. 1.50-3, 1.65*),
-by stone staircase built flush with the wall (*fig. 1.50-1*),
-by an added *liakos* (*fig. 1.44, 1.45*),
-through the first floor of another house which was in contact with the tower (*fig. 1.40*). The entrance door was arched, usually tiny, strongly made and secured with a thick wood from inside (*ambara "αμπάρα"*). Very often loop-holes (*ntoufekotrypes)* which set an angle to it or *zematistra-katachystra* above it defended the building by external attacks.

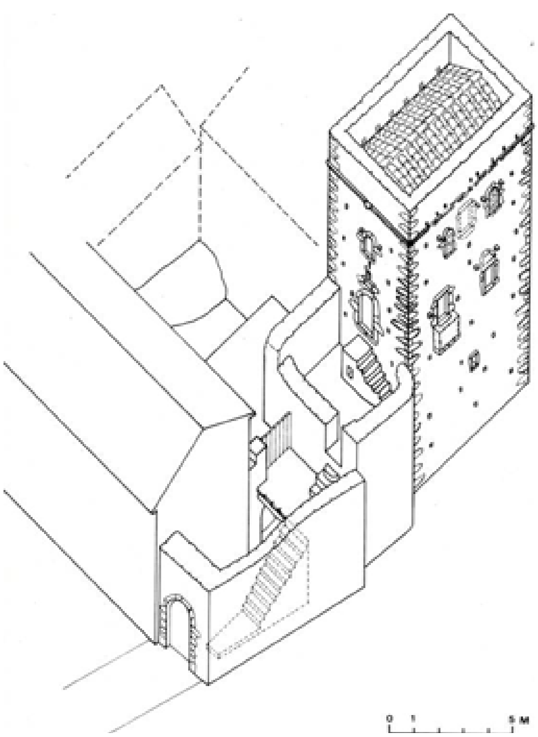


Fig.1.44: Axonometric plan of the Oikonomeas tower-dwelling at Lagada (1757). (Saitas, 2001)

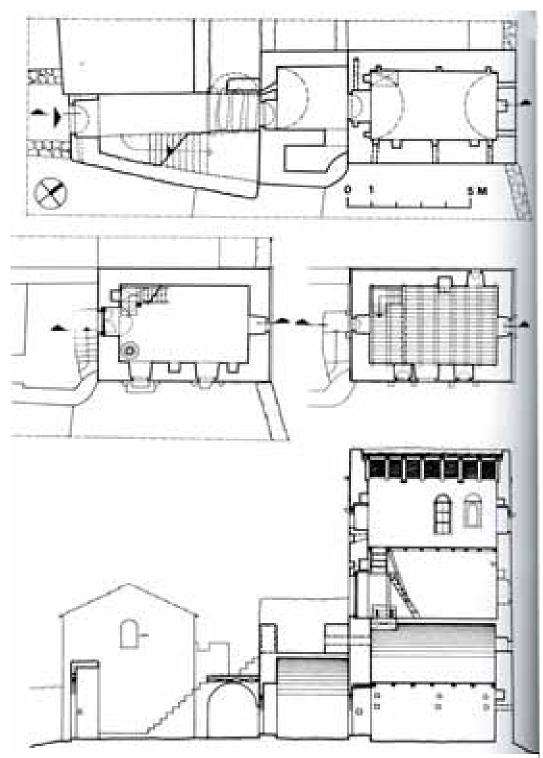


Fig.1.45: The Oikonomeas tower-dwelling. Above: ground floor plan. Center: left, third level plan; right fourth level plan. Below: lengthwise section. (Saitas, 2001)

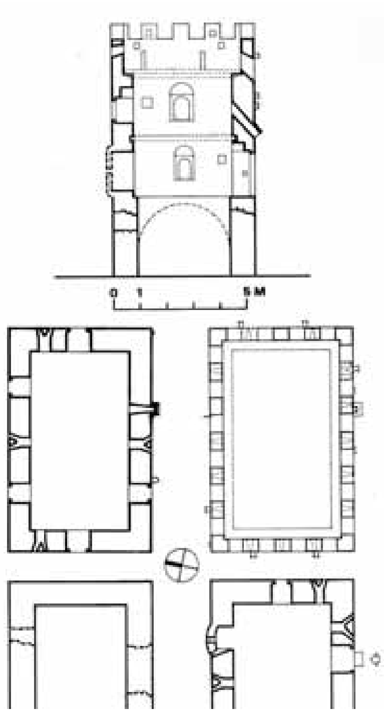


Fig.1.46: The tower of Mavrikos (1814), a notable of Malta. Below: plam of first and second level; center: plan of third level and flat roof; above: section. (Saitas, 2001)

Fig.1.47: The interior of the Mourtzinos war tower in Pano Kardamyli. The projecting stones for the support of the floors and the diagonal stones to firm up the corners of the walls could be seen. (Saitas, 2001)

Fig.1.48: Turret-vigla on the Aloupis tower-dwelling (fig. 1.39). At the bottom of the conical base with the large polemistres-zematistres, the mouth of a canon juts out. (Saitas, 2001)

Fig.1.49: Turret-vigla with marble head on the Dourakis tower (fig 1.37). (Saitas, 2001)

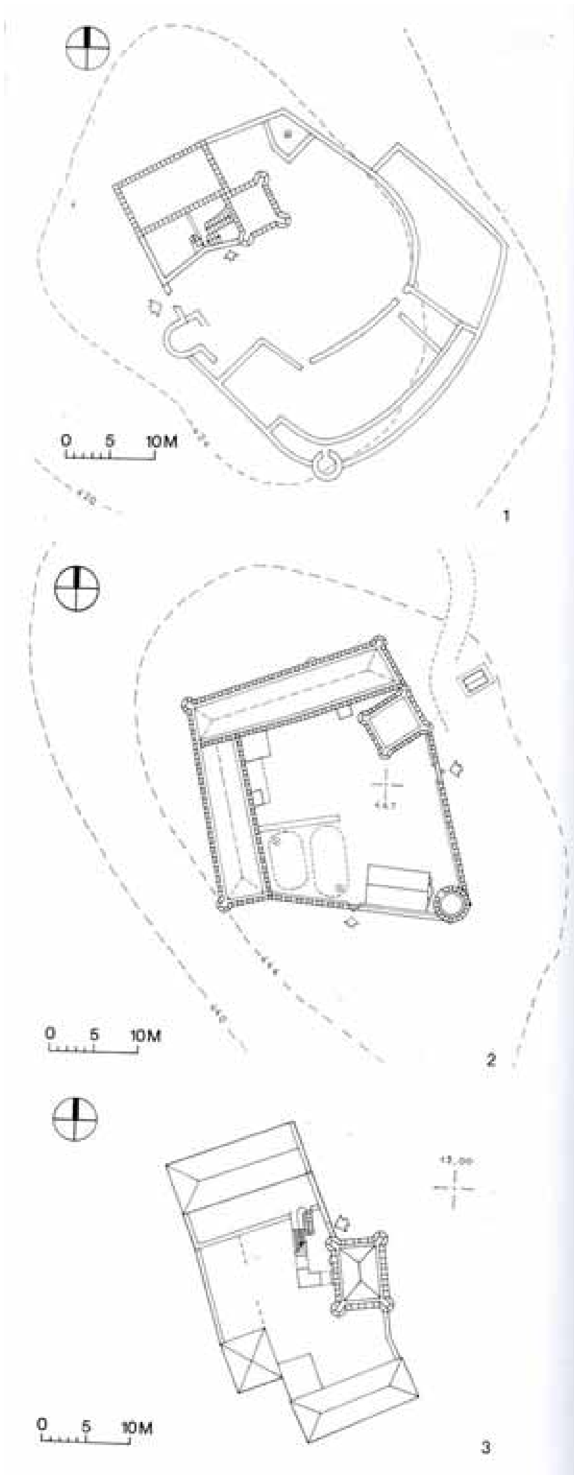


Fig.1.50: Plans of three walled complexes of the kapetanoi. 1: Complex at the castle of Zarnata, with a war tower, atwo-storey dwelling, walled courtyard and a fortified enclosure. 2: complex of Kapetanakides at Tsikova with war tower, two oblong dwellings on a corner and a chapel. 3: Christeas complex at Agios Dimitrios, Selinitsa, with a war tower, an oblong official building, etc. (Saitas, 2001)

Fig.1.51: Interior of the third level of the Oikonomeas dwelling. (Saitas, 2001)

Fig.1.52: Interior of the fourth level of the Oikonomeas dwelling. (Saitas, 2001)

Fig.1.53: Interior of the third level of the Dourakis tower in Kastania. (Saitas, 2001)

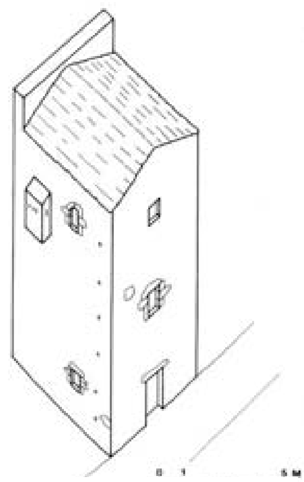


Fig.1.54: The Prokopeas war tower in Androuvitsa. (Saitas, 2001)

In many cases, each main floor had one to four arched windows. It also had one or more recesses, either in the form of wall vacuums (*thyrides*) with small shelves (*fig. 1.39, 1.40, 1.52*). Numerous loop-holes (*ntoufekistres*) single, double or triple, were on all the floors but especially on the upper flat roof (*doma*). They were made at various heights in order to ease attacked people to fire either standing, or kneeling or lying down (*fig. 1.40*). Moreover, the corner turrets (*klouvia*) which projected from the *doma* had a large pair of *polemistres-zematistres* at their base (*fig. 1.48, 1.49*) (*Saitas, 2001*)

In the simple towers (*fig. 1.43, 1.54*) there was either a complete lack of exterior decoration or it was limited to rudimentary talismanic, eugenic decorative incisions or relieves and the carved date of construction. The well-made buildings are distinguished for the better details in the doors and windows, the well-crafted *zematistres* and the semi-cylindrical bands-*kordonia "κορδόνια"*. The *kordonia* girded the main body as well as the turrets at the base of the parapet of the *doma* (*fig. 1.57, 1.60*). At the bottom of each corner turret there was usually a marble or sandstone human head-mask in high relief or full relief or the mouth of a cannon (*fig. 1.38, 1.39, 1.48, 1.49, 1.57*). A full relief human head (of the owner-warrior) might also be found at other points, such as the *zonari "ζωνάρι"* of the *doma* (*fig. 1.44, 1.45*) or axially above the entrance door and the *zematistra* (*fig. 1.42, 1.46, 1.60*). Built-in stone relieves or engraved representations are also frequently found on the walls (*fig. 1.42*). During the first decade after the Greek War of Independence in 1821, certain tower-dwellings or tower-houses were built or remodeled where there was less emphasis on military features and more on comfort (*fig. 1.55, 1.56*) (*Saitas, 2001*).

Besides the towers where the powerful locals lived, small two and three-storey towers were built (*fig. 1.54, 1.59*). Others were erected as sentry posts-observation towers along the coasts, the anchorages, the commercial harbors or as guardhouses at the passes (*dervenia "δερβένια"*) in the hinterland or along the borders. Others were erected as guardhouses in the fields or next to important production installations like the watermills when others protected fortified works (*tambouria "ταμπούρια"* and *mandres "μάνδρες"*) or even monasteries (*Saitas, 2001*)

The smaller and lower towers had two or three floors, with a height of 8-11 m (*fig. 1.54*) (*Saitas, 2001*). As in tower-dwellings, the floors were set apart either by stone vaults or wooden floors while the roofs were wooden gabled ones or a *doma* formation (*fig. 1.59*). Most of these towers had a strictly prismatic form, with a square or nearly square plan and a length on each side, externally, of 4-4.5 m and internally, 2.5-4 m (*Saitas, 2001*). The external decoration of these towers was very poor and without any morphological features as previously mentioned. But, they were strongly built and furnished with all the military means found in the tower-dwellings.

Fig.1.55: The comfortable top floor of the Troupakis tower-dwelling at Kato Kardamyli. (Saitas, 2001)

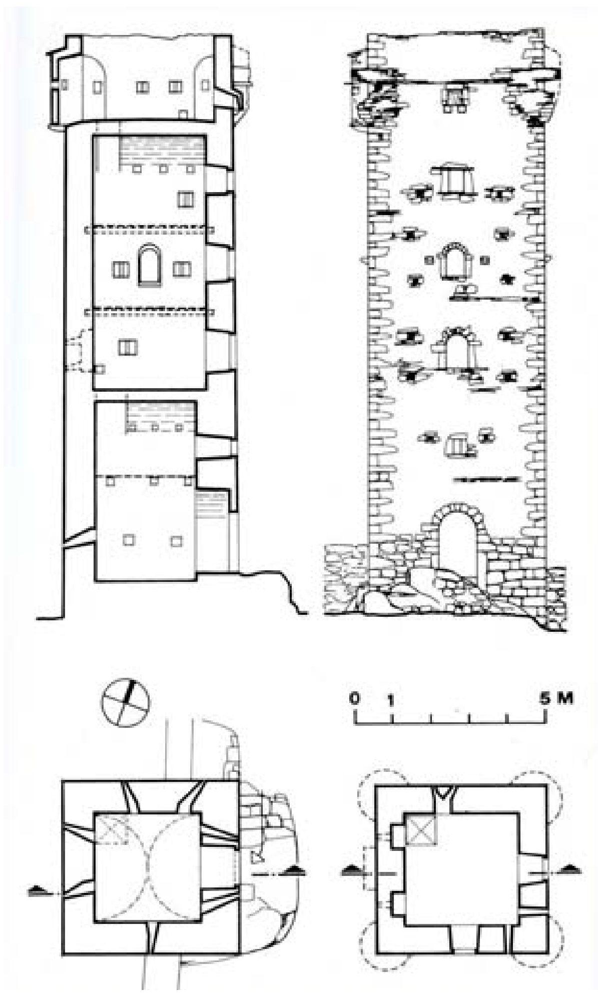


Fig.1.57: The Kapitsinos war tower in Lagada. Below: left, ground floor plan; right first floor plan. Above: left, section; right, south façade. (Saitas, 2001)

Fig.1.56: The renovated, imposing Patriarcheas tower-dwelling in Kato Kardamyli. (Saitas, 2001)

Fig.1.58: Mouth of a cannon, high relief of the head of the owner-warrior and decorated zematistra with the date 1814 on the Mavrikos tower. (fig. 1.42, 1. 46) (Saitas, 2001)

Fig.1.59: The Kapetanakides tower in Trikotsova, as seen from the courtyard of the fortification. (Saitas, 2001)

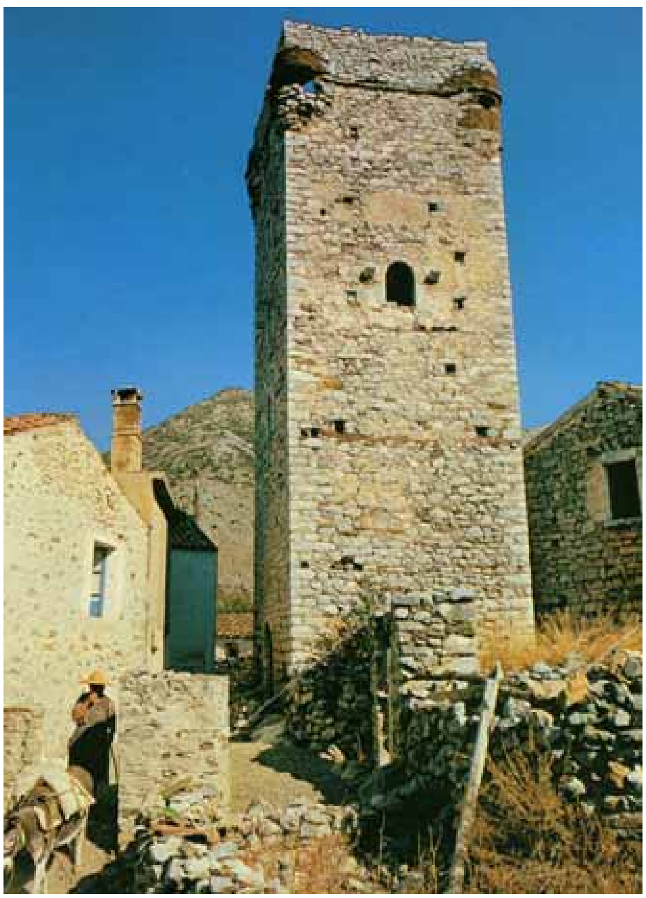


Fig.1.60: The south façade of Kapitsinos war tower. (Saitas, 2001)

Another architectural type of tower constructions is the ***walled complexes***. The composite walled installations of the leading families, the heads of large *kapetanies* and the *beys "μπέηδες"* of the entire Mani Area, were located at selected sites of Mani and are dated to the last decades before the fall of the Ottoman Empire (*fig. 1.50-2, 1.62, 1.63, 1.64*).

Fig.1.61: Copper plate from 1805 of the walled complex at the anchorage of Kitries. It was built by the first bay Tzanetos Koutifaris. (Saitas, 2001)

These structures played an important role in local affairs, for the war councils, the administration of justice, the decision-making of war activities, festival on social and religious occasions, the serving of communal meals as well as the hosting of officials (*Saitas, 2001*; *Vasilatos, 2001*). During armed conflicts between the *kapetanoi "καπετάνιοι"* or against the Turks, difficult and heavy battles were waged at these fortifications with many soldiers and considerable military equipment. A basic characteristic of these complexes was the arrangement of the buildings around the circumference of the space, so that the buildings and the wall would form an enclosed, fortified courtyard, with one main and well-guarded gate (*fig. 1.50*). Usually, they occupied a total area of 700-1300 m^2 (*Saitas, 2001*). A strongly built and well-armed war tower or tower-dwelling of the kind commanded the whole walled area (*fig. 1.61, 1.62, 1.63*).

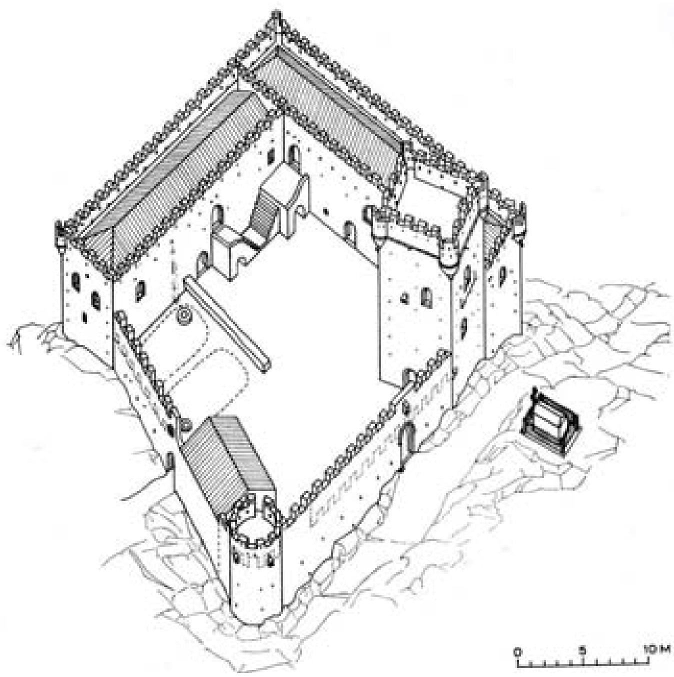


Fig.1.62: Axonometric drawing of the Kapetanakides complex at Trikotsova. (Saitas, 2001)

One or more large, imposing and fortified dwellings-reception buildings (with a length from 12-24 m) occupied a part or the total length of one or two other sides of the fortification (*fig. 1.50-2,3, 1.62, 1.66, 1.67*) (*Saitas, 2001*). The large, oblong reception hall frequently took up the entire main floor and had numerous windows, recesses and many *ntoufekotrypes*. The enclosure wall had a height of 3-4 m (*Saitas, 2001*), many *ntoufekotrypes* (*fig. 1.57*) arranged in two or three horizontal rows and sometimes ended in serrated battlements and at times it also had a raised walkway. Sometimes round corner turrets secured the protection on the sides (*fig. 1.50-2, 1.62*) while *foniades "φονιάδες"*, *katachystres* and guardhouses protected the gate. The church of the patron saint of the family was built inside (*fig. 1.50-2, 1.66, 1.67*) or next to the fortress installations where it was combined with the family cemetery (*fig. 1.66, 1.67*).

Fig.1.63: North view of the complexes of Mourtzinos and Petreas, lineages of Troupiani in Pano Kardamyli. (Saitas, 2001)

Fig.1.64: South view of the Kapetanakides complexes at Trikotsova. (Saitas, 2001)

Fig.1.65: The Christeas tower at Agios Dimitrios. The approach from the broken-lime stone stairway is via a retractable wooden bridge. (Saitas, 2001)

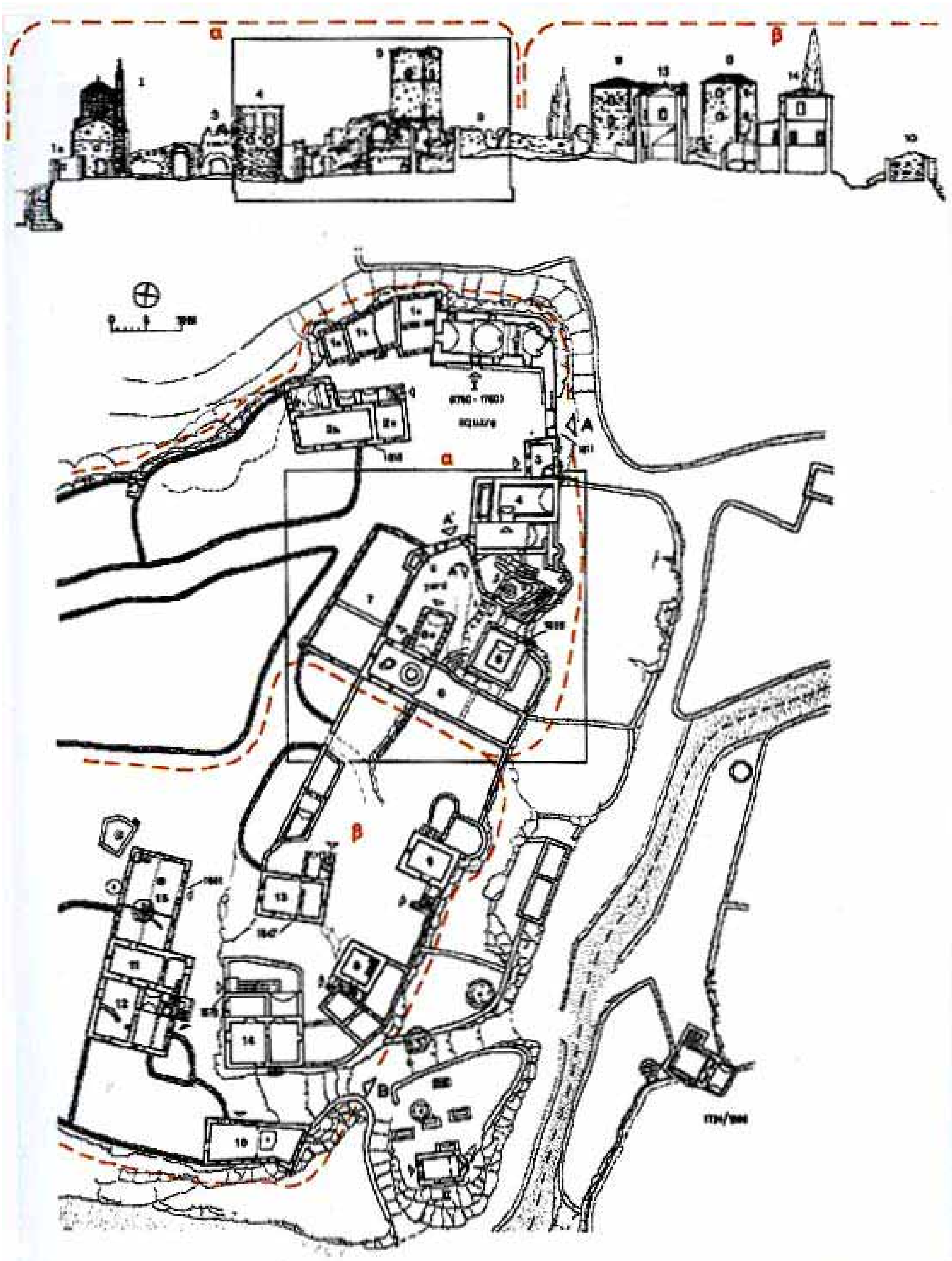


Fig.1.66: The Mourtzinos family complex (a) and that of Petreas (b). Above, west façade; below, ground floor plan. In the square, the main fortified nucleus of the kapetanios. I: the Agios Spyridon church, II: cemetery church of Agioi Theodoroi, f: fountain. A: main gate, B: secondary access. (Saitas, 2001)

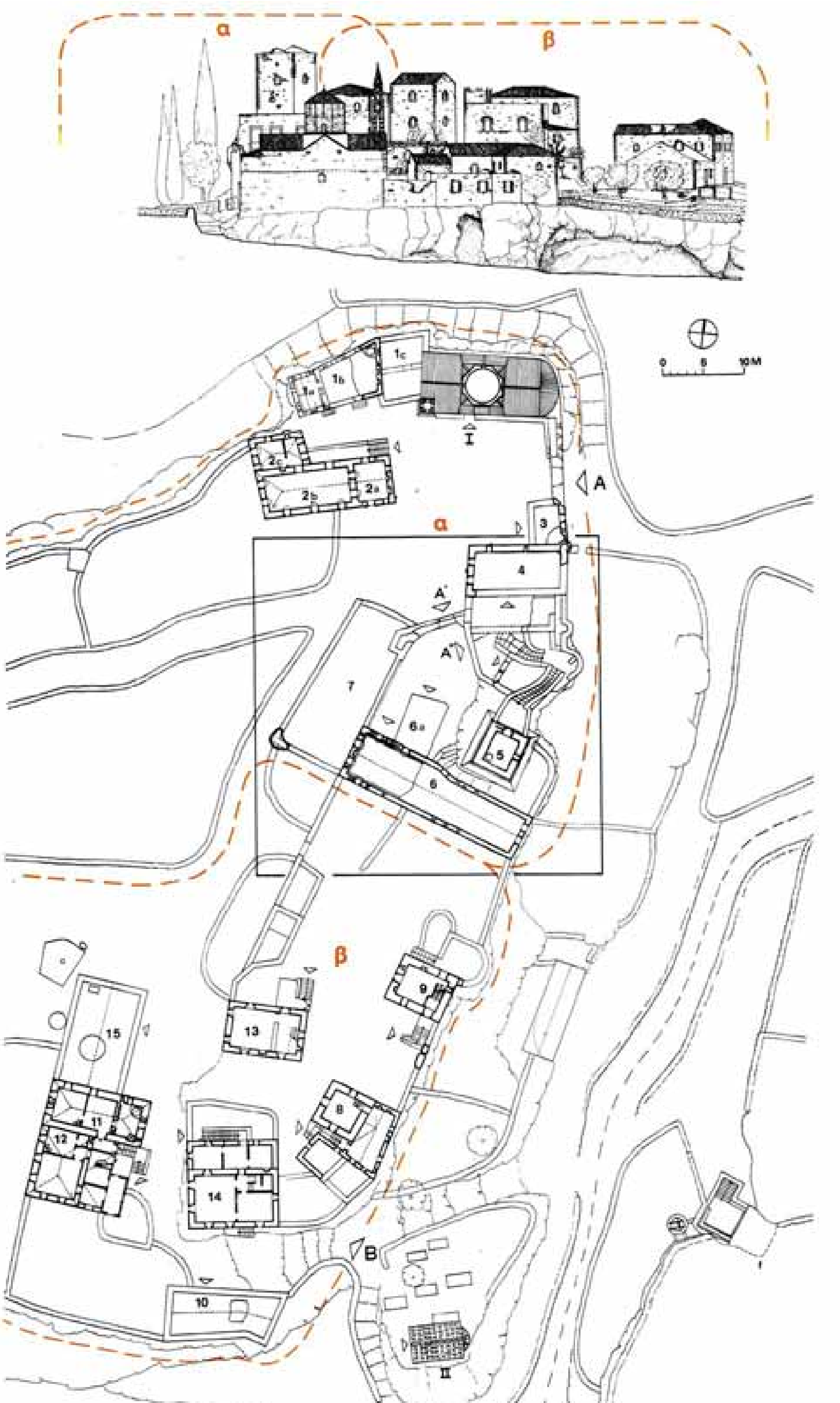


Fig.1.67: The Mourtzinos and Petreas complexes. Above, north façade; below,first floor plan.. (Saitas, 2001)

1.4 Hypothesis

Fig.1.68: Typical Tower-dwelling in Mani (Source: www.mani.org.gr)

Mani is one of the most traditional spots of Greece with protected traditional architecture and landscape legislation system due to its fortified monuments that are unique in Greece regarding the number, the oldness and stability of the structures, as well as the building innovative performance of the local builders. This monumental treasure derives from the culture and the daily older needs of local people, from the small civil internal conflicts and the continuous Turkish efforts for the total dominance in the Mani Area (*Vasilatos, 2001*).

The Area nowadays confronts the challenge of tourist industry introduction and relevant positive and negative assets that brings together. The local municipalities face the dilemma of correct management of the tourist construction activities and infrastructure. Mani due to its specific background and geographical isolation lead its inhabitants since now to live with sustainable and simple living standards. The challenge is to provide solutions for the increased tourist interest with sustainable and efficient manner that would reinsure the high quality of services for the tourist and high quality of living conditions for permanent inhabitants. Hence, some individual investment initiatives did not respect the environment and the topo-morphology of the Mani Area, which provoked the public negative belief and opinion for those activities. Therefore, there is a concern to introduce solutions that would advertise the Area for its natural and preserving beauty plus for the sustainable and alternative tourist services of high quality.

1.5 Methodology

1.5.1 Real project

Fig.1.69: Mauroeidakos Tower (Author)

In one of the municipalities of the Mani Area, municipality of Oitylo, there has been in progress a restoration and renovation of a Tower, owned by Mr. Mauroeidakos, designed by the company "*Oikomorphes*" and the author, with the use of materials same with traditional ones (*that is to say, same form of stonemasonry, same morphology of wooden frames internal and external ones, same timber for frames, ceilings, railings and same form for metal manufactures in window glasses*).

Fig. 1.70: Detail of hand-processed external corner stone-wall in Mauroeidakos Tower. (Author)

The materials used for the construction of the Towers are taken since nowadays from specific limestone deposits near the village. The surrounding landscape is extremely rocky and the surface of the ground without extended vegetation, making the excavation ease-accessible and the cost logical. The junction material between the stones was based on asbestos until 1950's but the dominant mortar nowadays is a mixture of cement, asbestos and local gravel sand. The stones that are taken by the limestone deposits are hand-processed until now in order to take square shape, are carefully examined by local experienced builders for their size, bulk continuity and stability. The width of the external walls in all Towers is 60-100 cm due to the height, the weight and the seismic background of the Laconia region. The stability of the Towers is reinsured by the big blocks of stones that are built in the corners of the external walls (*fig. 1.70*). Adequately, long continuous pieces of stone (up to 1.5m, width 0.3m) or arc hand-processed block of stone (*fig. 1.71*) *(Author)* are built over windows and doors to prevent cracking and demolishing phenomena during earthquake.

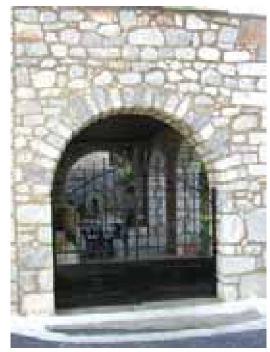


Fig.1.71: Detail of arc hand-processed block of stones in Mauroeidakos Tower. (Author)

The wood surfaces are scarce due to material scarcity over the Area, but nowadays easier transportation solved probable architectural dilemmas. Windows and doors are wooden according to the local decoration elements and practices of construction. The internal spaces are covered as well by limestone specially processed to avoid slippery surfaces. Internal stairs leading to upper stores are mainly wooden and transformed from circular (360°) to 180° formations according with available height and width *(Author)*.

1.5.2 Provision of hotel services

Fig.1.72: Renovation in the interior of a local traditional tower. (Author)

Transformations would be required for the creation of new spaces related to the initial operation. The project would achieve to a large extent very good solutions, without aesthetic and unnecessary intervention serving the new needs. Needless to say, the all furnishing and the equipment will exude the season and morphology of the first era of the building (early 1800's) (*fig. 1.72*). More analytically, in the ground floor the old living room would be changed in 3-bed room and the old bath in two ones. The small bedroom of ground floor would become reception hall. Also, in the ground floor and concretely under the exterior scale exists deposit 1.85m x 2.80m that would serve the needs of building. In the floor, the dining room would be changed in 2-bed room with its own bath. In the two levels of tower, they would become transformations in the stairwell so that are rendered the bedrooms independent. Also the last height in the loft from 2.10 m would become 2.40 m in order that with this process (change of plate) the loft would be insulated properly. Moreover, there would be changed all frames internally and externally, the floorings, wardrobes and cupboards of cooker, types of hygiene and ceramic tiles, colorations, furnishings etc.

1.5.3 Modeling of energy use and indoor climate

As it was referred during the brief description of the topo-morphology of the Mani Area and specifically for the area of the municipality of Oitylo, hot summer and cold winter throughout a year's time lead to special energy needs. The built-up of a model that would calculate the energy demand is needed for improvement of the total energy consumption, thermal comfort, indoor climate and house economy. The results of the model analysis that are going to be externalized could be stated as a baseline for similar projects that provide touristic services.

1.5.4 Set of applied technology

The modeling of the energy use and the indoor climate would provide the arithmetic values of energy that would help for the dimensioning and application of the mechanical system that would cover the Mauroeidakos Tower energy needs. This is going to be according to the impacts of the system on the energy use and the indoor climate, the cost-efficiency and the life-cycle performance.

1.5.5 Holistic solution

The results are going to suggest the tensions for the effectiveness and the applicability of the proposal that is going to be dealt in the study. The combination of the positive solutions that would be studied in the modeling of energy use and indoor climate and the applied technology performance should determine the final solution of the current project.

1.6 Purpose

The overall scope of the current study is a spherical solution for modeling the energy needs in traditional houses in the area of Mani, Greece for use in tourist industry development. The proposal of technologies that focus on sustainability is an aspect that is promoted to make familiar in the engineering society, that innovative solutions in Mani could be sustainable, feasible and more economic than others that are used widely nowadays.

CHAPTER 2

2 ENERGY SIMULATION AND DESIGN

2.1 Introduction

In the DIRECTIVE 2002/91/EC of the European parliament and of the Council of 16 December 2002 on the energy performance of buildings with appendices it is stated that the methodology of calculation of energy performances of buildings shall at least include the following:

- thermal characteristics of the building with air-tightness
- heating installation and hot water supply, including their insulation characteristics
- ventilation - natural ventilation
- built-in lighting installation (mainly the non-residential sector)
- passive solar systems and solar protection position and orientation - buildings air-conditioning installation
- indoor climatic conditions, including the designed indoor climate

The present standard ISO 13790:2004 "*Thermal performance of buildings -- Calculation of energy use for space heating*" is based on monthly balances and where building dynamics are accounted for by reducing the internal heat load by a so called utility factor based on the time constant of the building. The role of air tightness is also taken care of in a simplified way by expressing infiltration as a function of the air tightness at 50 Pa.

For compact heating or cooling systems with high temperature differences the interface between the heating system and the heated space and the function of the heated system can be treated in a simplified way. For low exergy systems, with integrated heating and cooling in the built structure, the processes become intertwined and a separation of the space temperature into surfaces and air temperatures becomes necessary. Also for more advanced heating schemes with night set back etc., an averaging method becomes to rough and the same applies for ventilation that can be varied with time. The treatment of solar radiation through windows and its impact on heating can be treated adequately with monthly averages through windows but its implication on cooling loads, indoor climate and day-lighting, calls for a higher resolution and a better modeling of the indoor space. It can be argued that computer software with all necessary complexity already exists on the market. But on the other hand a method which is meant to serve as basis for energy performance based specifications and an energy declaration of a building has to be simple to use and understand, based on as few input parameters as possible and be transparent for control in its different parts.

2.2 Consolis Energy Software

2.2.1 Level of modeling

Below is a description of the level of modeling chosen in this work together with a discussion and motivation on the different parts, as it is described by Professor Gudni Johannesson who has developed the software.

2.2.2 Timely resolution and climatic data

It is evident from the demands that a method that will meet the specifications of the directive will need a resolution corresponding to hourly calculations. The question is which periods are needed. The choice in the present approach has fallen on the use of three typical days for each month; the days have an average temperature which is the average for the month and for the actual location over a period of 30 years as given in climatic handbooks. One day is with clear sky, one with partly cloudy and one with full cloud covering. The temperature variation over the day as a function of the time t in hours is given by a synthetic algorithm based on cloudiness and solar radiation on a horizontal surface. The algorithm for the daily variation of the outdoor temperature T_e, K, has been found suitable for some Swedish locations but will probably have to be adjusted for other climates. T_{mav} is monthly averages for outdoor temperature and I_{Hdav} is the daily average for the horizontal radiation. Days with clear sky will consequently get more temperature variation than days with cloudy sky.

$$\mathbf{T_e = T_{mav} + (2.4 + 0.0162 \cdot I_{Hdav}) \cdot \cos[2 \cdot \pi \cdot (t-15)/24]}$$

The temperature for the ground under the floor construction is derived from the monthly heat flow given by EN ISO 13370. This temperature is constant for each month and is specific for each construction. The overall monthly result for heating and cooling loads will then be a weighted average based on the monthly cloudiness data generally available for most locations.

The main advantage is that the data set needed for each location is limited to 36 values which make it easily accessible for the user and easy to control. The data will basically be the same as for a normal calculation with EN ISO 13790 so that both methods can be run on the same data set for calibration. The method will however probably not save any computer time compared to a full year calculation. The possibility to study extreme periods in summer and winter is still not included, but such periods could be constructed from the data in a future development. It should however be noted that the chosen representation of thermal inertia in the modeling below is adjusted to the 24 hour period.

2.2.3 Multiple zones

Energy calculations in buildings with uniform set point temperature will in most cases work fairly well by using one zone, either for the whole building or by calculation parts of the building separately. For buildings with zones heated to different set point temperatures or to calculate temperature variations and cooling loads, where parts of the building have different internal loads, window sizes and orientation calculations with a one zone model may have little to do with reality. The model chosen here includes two zones. Each zone is characterized by its thermal capacity at the surfaces and heat transfer coefficients between the temperature nodes which are T_e the outdoor air temperature, T_{a1} and T_{c1}, the air and surface temperatures in zone 1 and T_{a2} and T_{c2}, the air and surface temperatures in zone 2

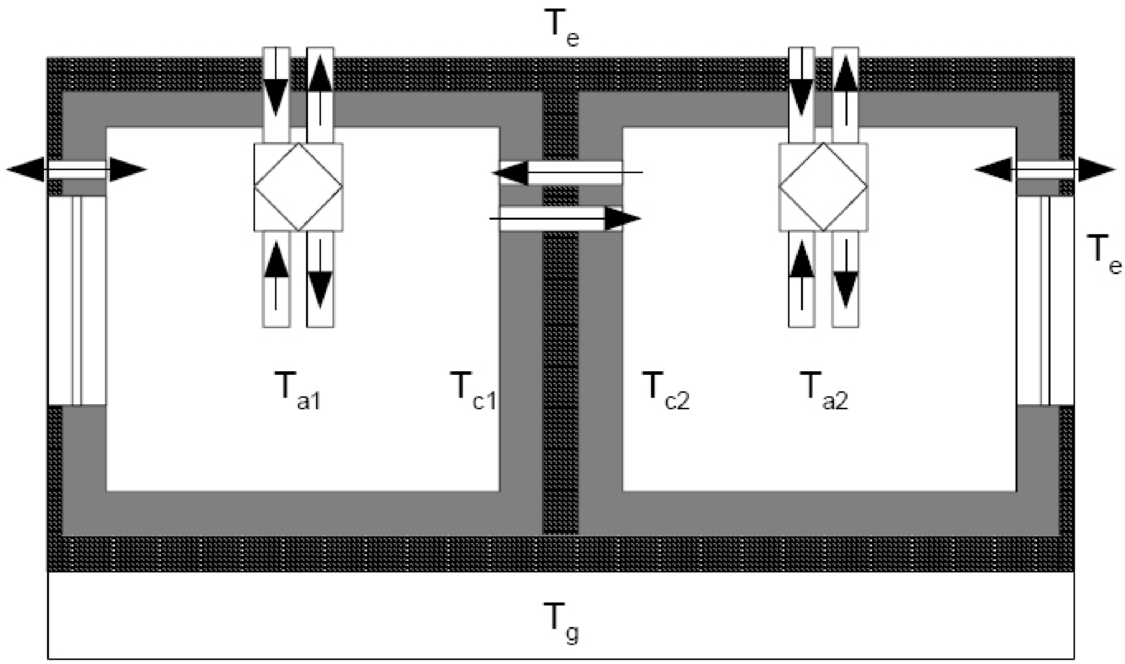


Fig. 2.1: A two zone model (source: Johannesson)

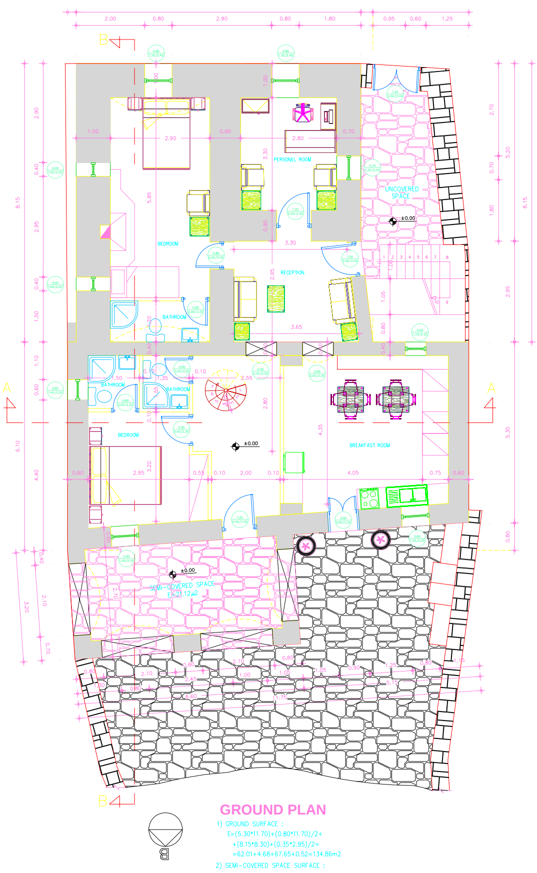
Each zone has an equivalent surface heat capacity that takes into account both internal and external surfaces. The air temperature is linked to the exterior temperature via the ventilation, infiltration and window heat transfer, to the air in the other zone via air flows and to the surface in the zone via convective surface heat transfer. The surface temperature is linked to the exterior and ground temperatures via transmission through opaque constructions, to the surface of the other zone via transmission through partitions and to the zone air. Arbitrary fractions of emitted or extracted heat in the zone can be directed towards the surface or the air. Ventilation flows in and out can be varied at will and an air to air heat exchanger function is included.

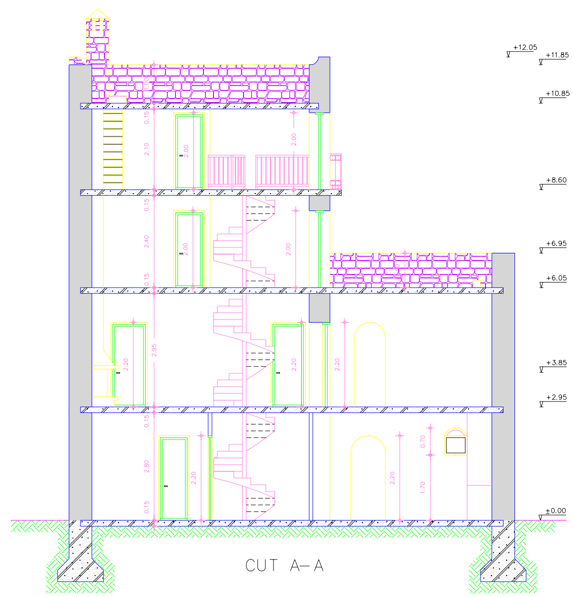
The model is geometric in a way as the solar radiation through the windows is based on the geometry and orientation of the windows. The most significant simplification is that all the surfaces in a zone have a uniform temperature and thermal capacity. This is justified by the fact that there is about twice as strong coupling by radiation between a surface and other surfaces in a room than by convection to the air.

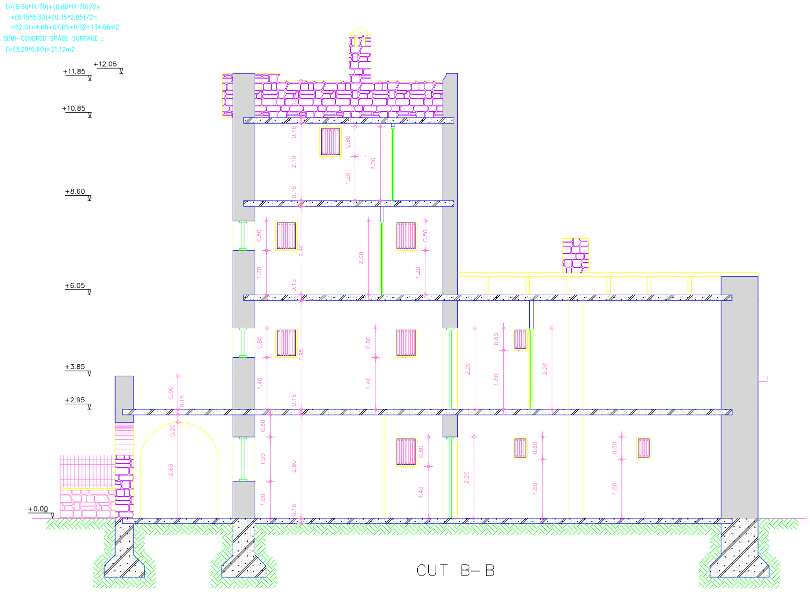
A further analysis of the model and the structure of the software are not in the scope of the current study, subsequently further information could be inquired by the responsible of the program, Professor Gudni Johannesson.

2.3 Model Analysis for Mauroeidakos Tower

The Mauroeidakos Tower has a typical architectural design of the kind of structures that are situated in the Mani Area. It is obvious that the energy simulation is based on the architectural plans and the materials used for the construction of the study building, climate and geographical information and well-defined theoretical analysis approach. The following characteristic architectural drawings are given so there could be seen clearly the details of the ground floor, of the cut A-A and of the cut B-B. (*Detailed architectural plans, cuts and aspects are shown in the Appendices A.1*)







The Hellenic National Meteorological Service ("*E.M.Y.*") provided the necessary information regarding climate data. Due to unavailability of data on the specific area of Mani, in Oitylo, the Service gave to author information obtained from three nearby areas, Gythion, Sparta and Kalamata. The author considered the information from the area of Gythion is more related to the one of Oitylo, due to smaller kilometric distance, nearer environmental conditions and coast formation (*Table 2.1*).

Table 2.1: Synoptic climate data

Preparation of climate data from monthly average temperatures and statements about cloudiness																
Cloudiness clear days				0.0	Cloudiness half-cloudy days			5.70	Cloudiness cloudy days			9.0				
																latitude
IN DATA FOR DISTRICT			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		36.46
Gythion	Ext.temp		9.6	10.0	11.6	15.4	18.8	22.8	25.7	27.3	23.8	21.8	16.8	10.2		Hor scr
Gythion1	Clear days		10.1	6.7	8.2	9.3	13.4	18.7	22.4	20.0	17.6	13.5	9.2	7.9		0.0
Gythion2	Cloudy days		7.3	6.3	6.4	4.2	2.0	0.3	0.1	0.1	0.9	3.3	6.7	7.4		
	Half-cloudy days		13.6	15.0	16.4	16.5	15.6	11.0	8.5	10.9	11.5	14.2	14.1	15.7		
District	Code	Storhet	Latitude	Longtitud	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gythion	110	Ext.temp	36.46	22.48	9.6	10	11.6	15.4	18.8	22.8	25.7	27.3	23.8	21.8	16.8	10.2
Gythion	111	Sol S	36.5	22.5	186.46	188.06	181.68	159.70	139.70	141.22	152.62	176.00	208.50	220.22	187.91	176.65
Gythion	112	Sol V	36.5	22.5	78.57	101.55	129.88	172.03	195.68	230.06	234.99	212.74	172.74	131.87	83.52	70.64
Gythion	113	Sol N	36.5	22.5	31.81	40.01	52.93	74.22	101.70	137.16	132.23	100.13	72.29	52.20	34.15	28.25
Gythion	114	Sol O	36.5	22.5	78.57	101.55	129.88	172.03	195.68	230.06	234.99	212.74	172.74	131.87	83.52	70.64
Gythion	115	Sol H	36.5	22.5	94.46	130.41	165.44	223.26	270.77	318.49	324.97	285.41	224.61	160.56	102.34	83.08
Gythion	116	Temp1	36.5	22.5	10	10	10	10	10	10	10	10	10	10	10	10
Gythion	117	Temp2	36.5	22.5	15	15	15	15	15	15	15	15	15	15	15	15

(Source: Consolis Energy +)

After the input of the climate information, it is important to supplement the general required data, responsible for the accuracy of the final calculations (*Table 2.2a; b*).

Table 2.2a: General data sheet

General data	**Part1**	**Part2**			
Temperature inside Min	**20**	**20**	^oC		
Max	**27**	**27**	^oC		
Hor solar screening angle	**0**	**0**			
Mean effect of internal heat load	**5**	**5**	**W/m²**		
Internal heat load profile	**1**	**1**			
Heated floor area	**320.79**	**320.79**	**m²**		
Ground area (Footprint)	**134.86**	**134.86**	**m²**		
Perimeter against the free	**51.15**	**51.15**	**m**		
Ventilation					
	Toward ambient atm		**Part1>>2**	**Part2>>1**	
Ventilation flow in	**100.00**	**100.00**	**0.00**	**0.00**	**l/s**
Ventilation flow out	**100.00**	**100.00**			**l/s**
Air leakage at 50 Pa q_{50}	**100.00**	**100.00**	**l/s**		
Temperature efficiency outlet air	**0**	**0.6**			
Temperature efficiency inlet air	**0**	**0.6**			

Table 2.2b: General data sheet

El consumption for property and household	**60**	**60**	**kWh/m2yr**
Energy consumption for hot water	**120**	**120**	**kWh/m2yr**
Internal conv heat transfer coefficient	3	**W/m^2K**	
Temperature control coefficients	Part1	Part2	
Surfaces temperature	0.5	0.5	
Air temperature	0.5	0.5	
Sun power distribution	Part1	Part2	
Surface	0.7	0.7	
Air	0.3	0.3	
Heating cooling power distribution	Part1	Part2	
Surface	0.5	0.5	
Air	0.5	0.5	
Internal power distribution	Part1	Part2	
Surface	0.5	0.5	
Air	0.5	0.5	
Climates **Option** Gythion	**Code**	490	

(Source: Consolis Energy +)

Before the supplementation of the construction data sheet, there is a need to estimate the effective heat capacity of the external walls and the roof (*Table 2.3*).

Table 2.3: Calculation of effective heat capacity

wall

	material	d	λ	ρ	c	R	κ
		m	W/mK	kg/m^3	J/kgK	m^{2}K/W	1/m
1	Limestone(greek)	0.60	2.50	2700.00	1000.00	0.24	6.27
2	Mineral wool	0.10	0.04	30.00	1000.00	2.78	5.50
3	Gypsum plasterboard	0.01	0.25	900.00	1000.00	0.05	11.44
4	VOID	0.00	1.00	1.00	1.00	0.00	0.01
5	VOID	0.00	1.00	1.00	1.00	0.00	0.01
6	VOID	0.00	1.00	1.00	1.00	0.00	0.01
7	VOID	0.00	1.00	1.00	1.00	0.00	0.01
8	VOID	0.00	1.00	1.00	1.00	0.00	0.01

Ceff from insideide J/m2K
13,421

Rtot **3.070** **m^{2}K/W**
Thickness **0.713** **m**

Ceff from outside J/m2K
304563

U-value **0.309** **W/m^{2}K**

roof

	material	d	λ	ρ	c	R	κ
		m	W/mK	kg/m^3	J/kgK	m^{2}K/W	1/m
1	Gypsum plasterboard	0.01	0.25	900.00	1000.00	0.05	11.44
2	Mineral wool	0.20	0.04	30.00	1000.00	5.56	5.50
3	Cement particle board	0.01	0.23	1200.00	1500.00	0.06	16.87
4	Plaster, cement /sand	0.03	1.00	1700.00	1000.00	0.03	7.86
5	Limestone(greek)	0.15	2.50	2700.00	1000.00	0.06	6.27
6	Ceramic tile	0.05	0.75	1750.00	1225.00	0.07	10.19
7	VOID	0.00	1.00	1.00	1.00	0.00	0.01
8	VOID	0.00	1.00	1.00	1.00	0.00	0.01

Ceff from inside J/m2K
#NUM!

Rtot **5.816** **m^{2}K/W**
Thickness **0.451** **m**

Ceff from outside J/m2K
#NUM!

U-value **0.167** **W/m^{2}K**

(Source: Consolis Energy +)

After the estimation of the effective heat capacities of the external walls and the roof, the construction data sheet is following whereas all constructions are inserted with properties and areas. For this case study, the external walls, the roof, the windows, the ground floor and the intermediate constructions are included respectively (*Table 2.4a; b; c; d; e*). The area values (in m^2) are obtained by the detailed architectural plan and cut drawings. (*There could be found in Appendices A.1*)

Table 2.4a: Construction data sheet

External walls

				Area Part1				Area Part2			
Number	Short Description	U-value	Ceff	Ext.temp	Ground tem	Temp 1	Temp 2	Ext.temp	Ground temp	Temp 1	Temp 2
1	Greek limestone wall 60 w 10 cm ins	0.31	14500	405.01	0	0	0	405.01	0	0	0
2	Greek limestone wall 60 w 10 cm ins	0.20	14500	0	0	0	0	0	0	0	0
3	Average heavy	0.23	100000	0	0	0	0	0	0	0	0
4	Average isolated light	0.23	25000	0	0	0	0	0	0	0	0
5	Bad isolated heavy	0.30	100000	0	0	0	0	0	0	0	0
6	Bad isolated light	0.30	25000	0	0	0	0	0	0	0	0
7	door	1.80	30000	0	0	0	0	0	0	0	0
8	SB 150 + 150 + 75	0.22	241000	0	0	0	0	0	0	0	0
9	Conc 70 min wool 250 CC 120	0.30	100000	0	0	0	0	0	0	0	0
10	Conc 70 min wool 250 CCt 120	0.30	100000	0	0	0	0	0	0	0	0

(Source: Consolis Energy +)

Table 2.4b: Construction data sheet

Roof											
				Area Par1				Area Part2			
Number	Short description	U-value	Ceff	Ex.temp	Ground tem	Temp 1	Temp 2	Ex.temp	Marktemp	Temp 1	Temp 2
1	Well isolated light	0.13	20000	39.12	0	0	0	39.12	0	0	0
2	Well isolated heavy	0.13	80000	0	0	0	0	0	0	0	0
3	Average isolated light	0.15	20000	0	0	0	0	0	0	0	0
4	Average isolated heavy	0.15	100000	0	0	0	0	0	0	0	0
5	Bad isolated light	0.30	20000	0	0	0	0	0	0	0	0
6	Bad isolated heavy	0.30	100000	0	0	0	0	0	0	0	0
7	SB HD + 300 mm 0.036	0.12	192000	0	0	0	0	0	0	0	0
8	Chipboard13min wool250plywood22roofing-	0.18	30000	0	0	0	0	0	0	0	0
9	Chipboard13min wool250plywood22roofing-	0.18	30000	0	0	0	0	0	0	0	0

(Source: Consolis Energy +)

Table 2.4c: Construction data sheet

Window													
Number	Short description	U-value		Area Part1					Area Part2				
				South	West	North	East	Hor	South	West	North	East	Hor
1	Two glass	2.80		2.88	6	11.24	3.84	0	2.88	6	11.24	3.84	0
2	Three glass 13 mm	1.80		0	0	0	0	0	0	0	0	0	0
3	Three glass 13 mm ii	1.40		0	0	0	0	0	0	0	0	0	0
4	Three glas LE and gas	1.00		0	0	0	0	0	0	0	0	0	0
5	Three glass 13 mm	1.80		0	0	0	0	0	0	0	0	0	0
6	Three glass 13 mm	1.80		0	0	0	0	0	0	0	0	0	0
7	Three glass 13 mm	1.80		0	0	0	0	0	0	0	0	0	0
8	Three glass 13 mm	1.80		0	0	0	0	0	0	0	0	0	0
9	Three glass 13 mm	1.80		0	0	0	0	0	0	0	0	0	0

(Source: Consolis Energy +)

Table 2.4d: Construction data sheet

Ground floor							
Number	Short description	R ValueF	Ceff	Area Part1	Area Part2	λ-ground	ρc-ground
1	Limestone floor	1.00	200000	134	134	3.5	2000000
2	Timber flooor structure	2.50	30000	0	0	3.5	2000000
3	Limestone floor	1.00	200000	0	0	3.5	2000000
4		4.00	100000	0	0	3.5	2000000
5		4.00	100000	0	0	3.5	2000000
6		4.00	100000	0	0	3.5	2000000
7		4.00	100000	0	0	3.5	2000000
8		4.00	100000	0	0	3.5	2000000
9		4.00	100000	0	0	3.5	2000000

(Source: Consolis Energy +)

Table 2.4e: Construction data sheet

Intermediate constructions							
Number	Short description	U-value	Area 1><2	Area 1><1	Area 2><2	Ceff 1	Ceff 2
1	Concrete wall	1.20	0	0	0	120000	120000
2	Gypsum wall	1.20	0	0	0	15000	15000
3	Concrete floor structure	1.20	0	250	250	150000	15000
4	Timber wood structure	1.20	0	0	0	30000	30000
5	Brick wall	1.20	0	111.09	111.09	60000	60000
6		1.20	0	0	0	50000	60000
7		1.20	0	0	0	50000	60000
8		1.20	0	0	0	50000	60000
9		1.20	0	0	0	50000	60000

(Source: Consolis Energy +)

The construction data worksheet is the most critical step in the energy simulation because the values that are supplemented should be calculated very carefully and according to the available architectural drawings, climate data and matrices obtained by national regulations. Then, the simulation is ready to begin and run the model for the selected scenario based on

ISO 13790 and the dynamic method. (*The values in the Tables are from the scenario 3, which is going to be proposed finally*)

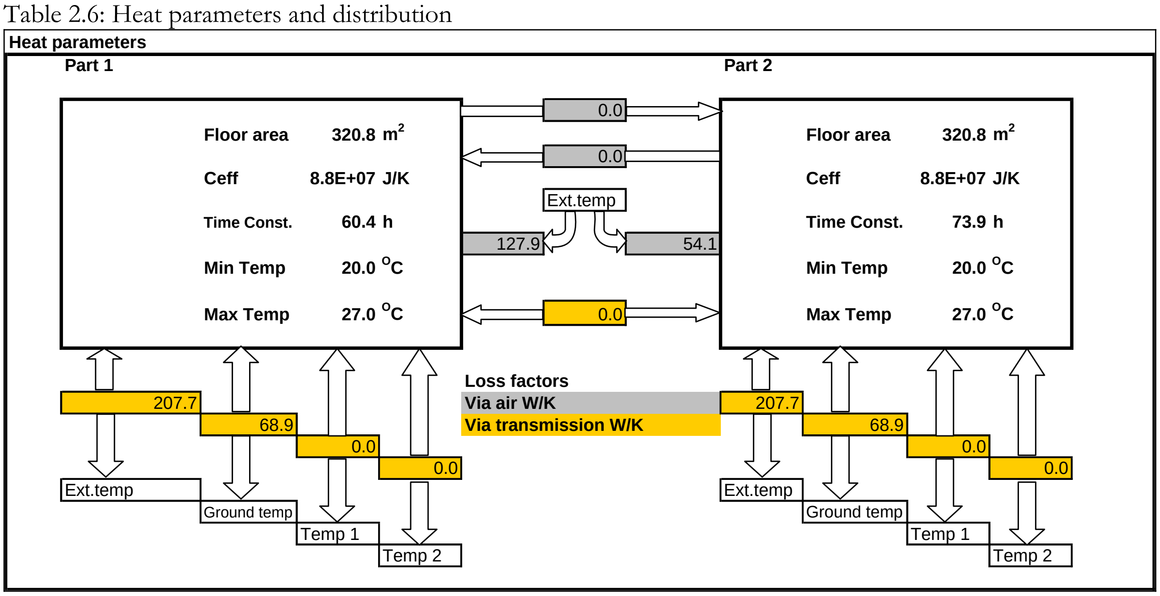
The result summary that comes out from the simulation is finalized in the form of tables and of several diagrams. The tables are following (*Table 2.5, 2.6*):

Table 2.5: Calculated yearly energy consumption

Calculated yearly energy consumption				
Testhus 6 vån 20x12x3				
Climat Gythion				
Calculation according to ISO 13790*				
	Part1		**Part2**	
Heated floor area	320.79 m²		320.79 m²	
Energy need for heating	3832 kWh/a	11.9 kWh/m²a	1920 kWh/a	6.0 kWh/m²a
Property- and household electricity	19247 kWh/a	60 kWh/m²a	19247 kWh/a	60.0 kWh/m²a
Hot water	38495 kWh/a	120 kWh/m²a	38495 kWh/a	120.0 kWh/m²a
Total	61574 kWh/a	191.9 kWh/m²a	59663 kWh/a	186.0 kWh/m²a
Surplus energy (indication)	6142 kWh/a	19.1 kWh/m²a	6876 kWh/a	21.4 kWh/m²a
Calculation according to the dynamic metod				
	Part1		**Part2**	
Heated floor area	320.79 m²		320.79 m²	
Energy need for heating	3325 kWh/a	10.4 kWh/m²a	1395 kWh/a	4.3 kWh/m²a
Property- and household electricity	19247 kWh/a	60 kWh/m²a	19247 kWh/a	60.0 kWh/m²a
Hot water	38495 kWh/a	120 kWh/m²a	38495 kWh/a	120.0 kWh/m²a
Total	61067 kWh/a	190.4 kWh/m²a	59137 kWh/a	184.3 kWh/m²a
Cooling energy	6435 kWh/a	20.1 kWh/m²a	7154 kWh/a	22.3 kWh/m²a

(Source: Consolis Energy +)

Table 2.6: Heat parameters and distribution



(Source: Consolis Energy +)

2.3.1 Background

The study that was carried out with the *Consolis Energy* + software contains the proposal and analysis of 6 possible scenarios/alternatives in the Tower energy simulation. These scenarios describe the degree of thermal insulation that should be implemented for the better energy efficiency of the whole structure. The results are critical for the final suggested solution that is going to be forwarded regarding the architectural restrictions and the cost-benefit analysis.

2.3.2 Alternative 0 *(No insulation)*

The Mauroeidakos Tower is renovated and rebuilt in the precise traditional construction style as it had been in 1890's when it was first built. There is no thermal insulation in the external walls and the roof so as the whole stone-structure plays the primary role in energy balance.

2.3.3 Alternative 1 *(Insulation in the roof)*

The main insulation material that could be applied in reasonable cost in the specific study is the mineral wool or the expanded polystyrene. Mineral wool is preferred in the analysis due to its environmental-friendly composition and large experimental usage in the software application. The roof analysis is divided in two parts according to the construction style of the building. In the first part, the roof which is in the top of the long high tower has a cement finishing and the heat insulation material (mineral wool) of 20 cm thickness is protected by a cement particle board (1-3 cm thickness). On the top of the roof, there is a series of flat limestones (15 cm thickness) that are space planned in such a design that leads rainwater to the pipe-system of water harvesting and offer thermal protection during summer.

The second part consists of the roof that is built in the synchronous tower-dwelling attachment next to the existing old Tower. The roof is typical of Mediterranean design and it is the dominant style in the South Greece Area. The framework is wooden and its foundations are established in the external stone-walls enabling secured antiseismic behavior. The framework is covered with flat timber pieces in both ways (upside and downside of the central frame) where in the middle created space is added the heat insulation material (mineral wool) of 20 cm thickness. The upside timber wood structure offers the ground where ceramic tiles of Byzantine type are going to be implemented, again securing maximum storm-water harvesting.

2.3.4 Alternative 2 *(Insulation in external walls)*

The heat insulation is attached to the external stone-walls and a material of 10 cm thickness is used for the analysis. The heat insulation is protected in the interior by gypsum plasterboard (1-3 cm thickness).

2.3.5 Alternative 3 *(Insulation in external walls and the roof)*

As it was described in the previous paragraph, the heat insulation is attached to the external stone-walls and a material of 10 cm thickness is taken into account for the analysis. The heat insulation is protected in the interior by gypsum plasterboard (1-3 cm thickness). The roof analysis is divided in two parts according to the construction style of the building (see Alternative 1). Now, the whole structure is thermally protected in both horizontal and vertical directions, due to the large surface that form the walls and the roof of the Tower and it is expected rather a more sophisticated thermal correspondence in the structure.

2.3.6 Alternative 4 *(Insulation in external walls, roof and use of 3-glass windows)*

As it was described in the previous paragraph, the heat insulation is attached to the external stone-walls and a material of 10 cm thickness is taken into account for the analysis. The heat insulation is protected in the interior by gypsum plasterboard (1-3 cm thickness). The roof analysis is divided in two parts according to the construction style of the building (see Alternative 1).

So far, 2-glass windows have been used for the simulation (with U-value of 2.80) and were the weak point for heat exchange in horizontal direction. In this Alternative, it is going to be used for simulation 3-glass windows of U-value equal to 1.0. Consequently, the heat transfer from windows frames is going to be decreased significantly.

2.3.7 Alternative 5 *(Insulation in the roof and use of 3-glass windows)*

In this Alternative, it is supposed that the external walls of the Tower are not covered in the interior by layer of heat insulation. The roof analysis as it has been mentioned is divided in two parts according to the construction style of the building (see Alternative 1) and heat insulation is adopted in both parts.

In this option, the windows are changing from 2-glass type (with U-value of 2.80) to 3-glass type (with U-value of 1.0) in order to find the tribute of the window openings in heat exchange neglecting external walls.

CHAPTER 3

3 GEOTHERMAL ENERGY

Energy storage technologies (*EST*) are of strategic and necessary part for the efficient utilization of renewable energy and energy conservation. It can technically substitute the fossil fuels by using stored heat or cold that would otherwise be wasted or useless or by using renewable energy resources. These energy sources can be used more effectively with the addition of short and long term energy storage. Thermal energy storage (*TES*) systems enable greater and more efficient use of these fluctuating energy sources by matching the energy supply with demand. By contributing to large-scale energy efficiencies, energy storage significantly reduces environmental impacts from energy activities, increases the potential uptake of some renewable energy technologies, increases the potential of sustainable energy development and subsequently leads to better energy security. Fossil fuel dominant energy situation in Greece gives a rise to economic, political, and environmental concerns same as the majority of countries (*IEA, 1998*). Unlike to other EU member-states, the gap between production and consumption of energy is growing and Greece becomes more dependent on expensive imported energy resources, especially to petroleum and nature gas (*IEA, 1998*). Therefore, new energy resources must be explored to alleviate these conditions, but energy conserving technologies are as important as exploring new resources.

3.1 Historical background

Since 1970's, air-source heat pumps set an alternative tool for heating purposes, because they had the advantage of no combustion, and thus no possibility of indoor pollutants like carbon monoxide. Heat pumps provided central air conditioning performing heating as well. Their competitive installation-cost regarding to a central combustion furnace/central air conditioner combination made many countries to adopt them in building sector.

Air-source heat pumps operate by moving or transferring heat, rather than creating it. During the summer, a heat pump captures heat from inside a closed space and transfers it to the outdoor air through a condensing unit. During the winter, the process is reversed where heat is captured from outdoor air, compressed, and released inside (*GHPC, 1997*). Much less electricity is used to move heat rather than create it, making heat pumps more economical than resistance heating. However, in all but the most moderate climates, the heating ability of the heat pump is limited by freezing outdoor temperatures, so electric resistance heat is used to supplement outdoor-air-source heat pump during the coldest weather, preventing "cold blow" (*GHPC, 1997*).

More recently, even more advanced and efficient heating and cooling systems have emerged using another innovative type of process. Sometimes called geothermal or ground-source heat pumps (*GSHP*), these systems move or transfer heat like the air-source heat pumps. However, they exchange heat with the earth rather than the outdoor air. Since earth temperature remains relatively constant throughout the year, GSHP systems operate more efficiently than air-source heat pumps and generally without the use of resistance heat. And because they are working from those constant earth temperatures, there are no blasts of hot air or "cold blow" as with other systems (*GHPC, 1997*).

Due to the climate of central and northern Europe, geothermal heat pumps there tend to be used for space heating and usually operate in the heating mode only, whereas in the US and southern Europe the use is primarily for conditioning. The size and cost of a GSHP system is highly dependent on the ground thermal properties. A good design requires certain site-specific parameters, most importantly the ground thermal conductivity, the borehole thermal resistance and the undisturbed ground temperature (*Poppei et al., 2006*).

In recent years the installation of GSHP in Southern Europe, in particular in Greece and Western Turkey, is on the way to exceed demonstration status, with the first pilot plant for GSHP with borehole heat exchangers (*BHE*) in Greece, installed with Swiss technical support, dating from around 1993 (*Papageorgakis, 1993*). This effort has led to the subsequent implementation of a project at the campus of the National Technical University of Athens, where the Mining Engineering Building is heated and cooled by the application of geothermal heat pumps combining a hybrid system of groundwater well and BHE and is meanwhile followed by others (*Sanner et al., 2003*). With the inclusion of larger commercial applications, requiring cooling, and the ongoing proliferation of the technology into Southern Europe, the double use for heating and cooling will become of more importance in the future.

3.2 GSHP technology status

Ground Source Heat Pumps (*GSHP*) or Geothermal Heat Pumps are systems combining a heat pump with a system to exchange heat with the ground (*fig. 3.1a, 3.1b, 3.2*).

The systems can be divided basically into those with a ground heat exchanger (closed loop systems), or those fed by ground water from a well (open loop systems). The means to tap the ground as a shallow heat source comprise:

- groundwater wells("open" systems)
- borehole heat exchangers (*BHE*)
- horizontal heat exchanger pipes
- "geostructures" (foundation piles equipped with heat exchangers) (*Sanner et al., 2003*)

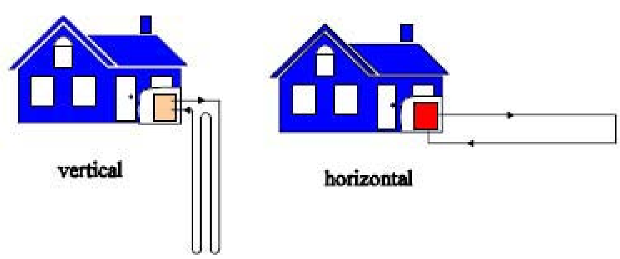


Fig. 3.1a: Closed loop heat pump systems (Lund, 2001).

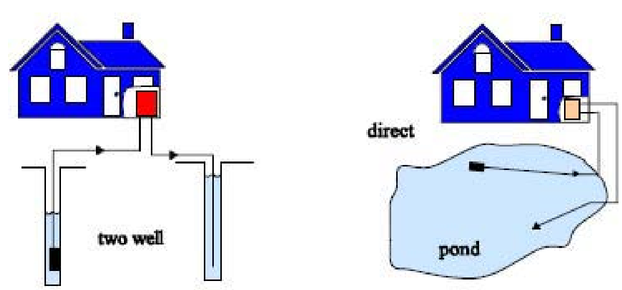


Fig. 3.1b: Open loop heat pump systems (Lund, 2001).

A typical GSHP with borehole heat exchanger (*BHE*) is shown in fig. 3.2. These systems use the earth as a heat source when operating in heating mode, with a fluid (usually water or a water-antifreeze-mixture) as the media transferring the heat from the earth to the evaporator of the heat pump, utilizing in that way geothermal energy (*fig. 3.3a*). In the cooling mode, they use the earth as a heat sink (*fig 3.3b*). For each kWh of heating or cooling output, they currently require 0,22 - 0,35 kWh electricity, which is 30%-50% less than the seasonal power consumption of air-to-air heat pumps, which use the atmosphere as a heat source/sink (*Sanner et al., 2003*).

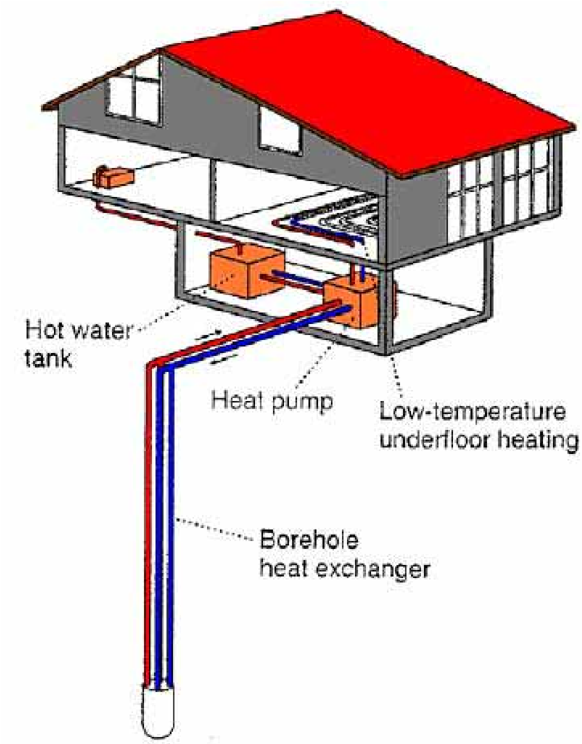


Fig. 3.2: Typical application of a BHE / heat pump system in a Central European home, typical BHE length ≥100 m (Sanner et al., 2003)

In the ground-coupled system, a closed loop of pipe, placed either horizontally (1 to 2 m deep) or vertically (50 to 100 m deep), is placed in the ground and a water-antifreeze solution is circulated through the plastic pipes to either collect heat from the ground in the winter or reject heat to the ground in the summer (*Rafferty, 1997*). The open loop system uses groundwater or lake water directly in the heat exchanger and then discharges it into another well, into a stream or lake, or on the ground (say for irrigation), depending upon local laws.

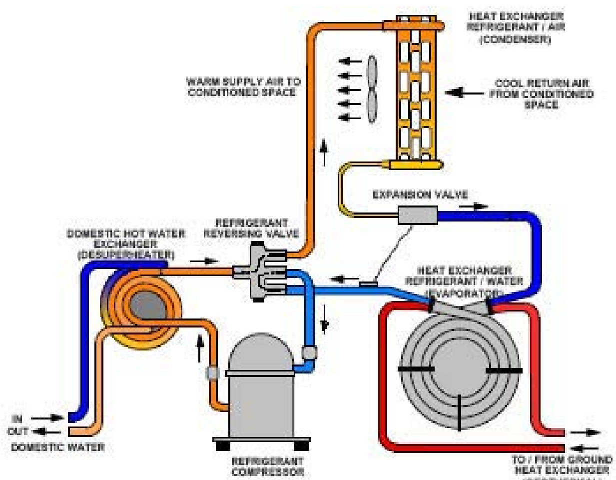


Fig. 3.3a: GHP in the heating cycle (Lund et al., 2004)

The efficiency of GHP units are described by the Coefficient of Performance (*COP*) in the heating mode and the Energy Efficiency Ratio (EER) in the cooling mode (*COPh* and *COPc*, respectively in Europe) which is the ratio of the output energy divided by the input energy (electricity for the compressor) and varies from 3 to 6 with present equipment (the higher the number the better the efficiency) (*Lund et al., 2004*). Thus, a COP of 4 would indicate that the unit produced four units of heating energy for every unit of electrical energy input. In comparison, an air-source heat pump has a COP of around 2 and is dependent upon backup electrical energy to meet peak heating and cooling requirements. In Europe, this ratio is sometimes referred to as the "Seasonal Performance Factor" and is the average COP over the heating and cooling season, respectively, and takes into account system properties.

3.2.1 European situation

Ground-source heat pumps (*GSHP*) can offer both heating and cooling at virtually any location, with great flexibility to meet any demands. In western and central European countries, the direct utilization of geothermal energy to supply heat through district heating to a larger number of customers so far is limited to regions with specific geological settings. In this situation, the utilization of the ubiquitous shallow geothermal resources by decentralized GSHP systems is an obvious option. Correspondingly, a rapidly growing field of applications is emerging and developing in various European countries. More than 20 years of R&D focusing on GSHP in Europe resulted in a well-established concept of sustainability for this technology, as well as sound design and installation criteria. These systems require currently for each kWh of heating or cooling output 0.22 - 0.35 kWh of electricity, which is 30 - 50% less than the seasonal power consumption of air-to-air heat pumps, which use the atmosphere as a heat source/sink (*Lund et al., 2004*).

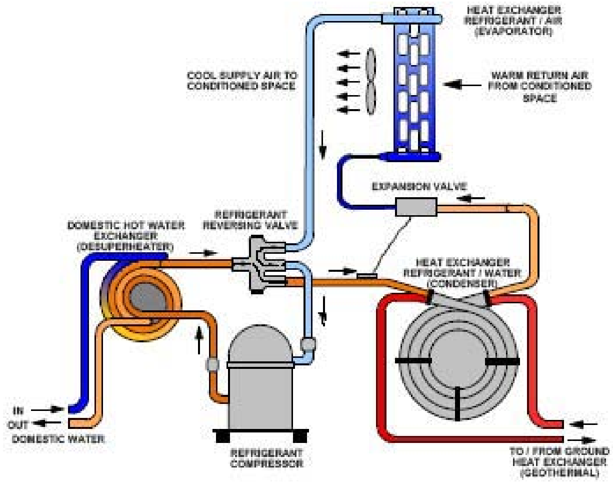


Fig. 3.3b: GHP in the cooling cycle (Lund et al., 2004)

The climatic conditions in many European countries are such that by far the most demand is for space heating; air conditioning is rarely required. Therefore, the heat pumps usually operate mainly in the heating mode. However, with the increasing number of larger commercial applications, requiring cooling, and the ongoing proliferation of the technology into southern Europe, the double use for heating and cooling will become of more importance in the future.

On the field of technical optimization, some developments of recent years should be mentioned:

• Thermal Response Test to determine the thermal parameters of the underground in situ;

• Grouting material with enhanced thermal conductivity; and

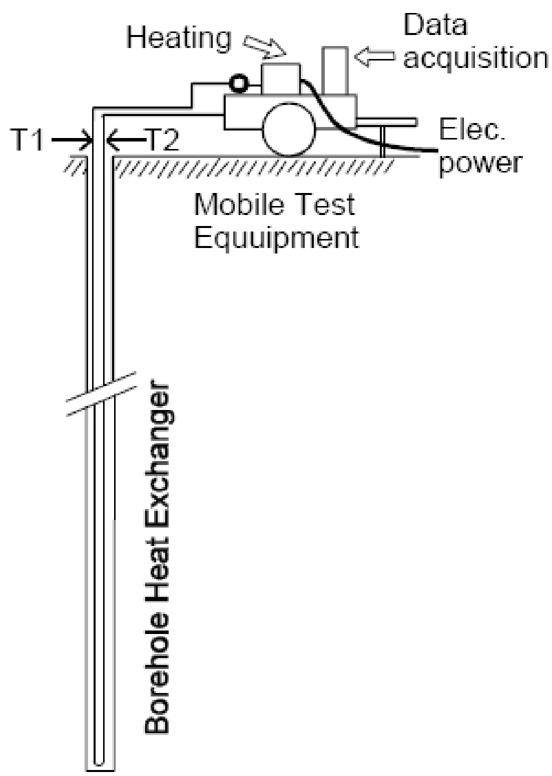


Fig. 3.4: Schematic of a Thermal Response Test (Poppei et al., 2006)

• Heat Pumps with increased supply temperatures for retrofit purposes (*Sanner et al., 2003*).

Thermal response tests (*TRT*) (*fig. 3.4*) offer a good method to determine the ground thermal properties for the total heat transport in the ground with groundwater and other disturbances automatically included. This is done by injecting a constant heat power into a borehole heat exchanger and measuring the temperature response (*Poppei et al., 2006*). Since the theory was established in the 1980s and the first mobile tests equipment was constructed in the 1990s the technique has developed and spread to several countries.

For a Thermal Response Test, basically a defined heat load is put into the BHE and the resulting temperature changes of the circulating fluid are measured which enable the determination of the following parameters:

• Mean underground temperature along a heat exchanger before and after the heating of the ground (*fig. 3.5, 3.6*);

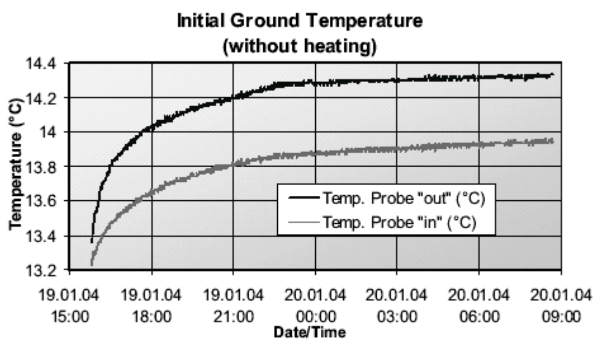


Fig. 3.5: Evolution of the initial underground temperature during the test (no heating) (Steinmann and Laloui, 2005)

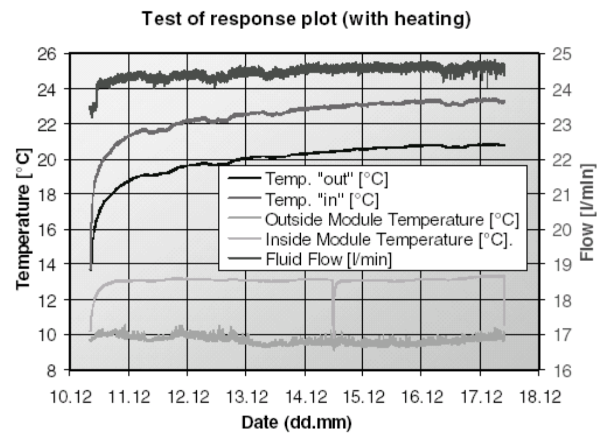


Fig. 3.6: Evolution of underground temperature and flow rate during the test (with heating) (Steinmann and Laloui, 2005)

• Thermal resistivity of the ground (*fig. 3.7*);

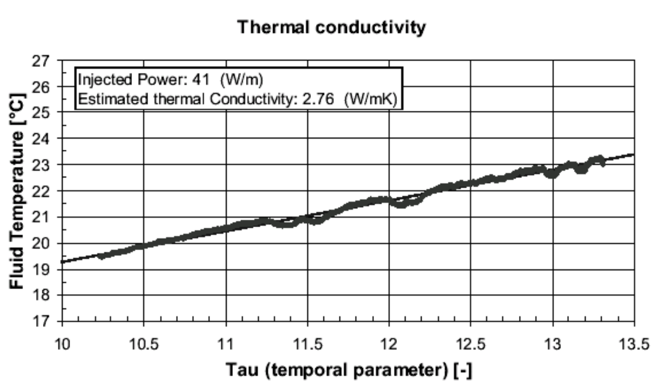


Fig. 3.7: Evaluation of the thermal conductivity of the underground (Steinmann and Laloui, 2005)

• Thermal conductivity of the ground along the heat exchanger (*fig. 3.8*) (*Eugster and Laloui, 2002; Steinmann and Laloui, 2005*).

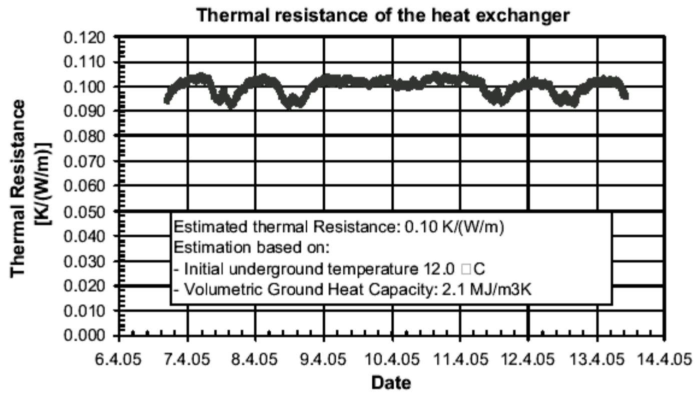


Fig. 3.8: Estimate of the thermal resistance (Rb) of the geothermal heat exchanger (Steinmann and Laloui, 2005)

3.2.2 Swedish Experience

Swedish ground-coupled heat pump installations are usually recommended to cover about 60% of the dimensioning load, which results in about 3500-4000 full-load hours per year. Electric heaters integrated in the heat pump cabinet cover the remaining load. There is a trend to increase the heat pump load fraction to 80 - 90% (*Zimmermann and Andersson, 1998*). It is estimated that about 80% of all installations are vertical (boreholes). In the residential sector, the average depth of vertical installations is about 125 m and the average loop length of horizontal installations is about 350 m. Single U-pipes (polyethylene tubes, diameter 40 mm, pressure norm 6.3 bars) in open, groundwater-filled are used in almost all installations (*Zimmermann and Andersson, 1998*). Double U-pipes are sometimes used when heat is injected into the ground. Thermal response tests have demonstrated that natural convection enhances the heat transfer in groundwater-filled boreholes compared with sand-filled (and grouted) boreholes. The popularity of ground-coupled heat pumps has raised concerns of long-term thermal influence between neighboring boreholes.

3.3 Mauroeidakos Tower case study

3.3.1 Theoretical background

The initial thought for solving the thermal needs of the structure was the choice of sustainable technology. The strict architectural limitations opposed the introduction of all the available conventional and environmental-friendly possible solutions in the decision-making phase, and from engineering point of view, it was preferred the study of the geothermal energy.

An indirect circulation system which is most common in major buildings of central Europe could be introduced, where the ground heat exchanger consists of a sealed loop of high-density polyethylene pipe containing a circulating fluid (usually a water/antifreeze mixture) pumped round the loop. Energy is transferred indirectly via a heat exchanger to the heat pump refrigerant. For the specific project, vertical collectors should be used because the tower occupied land area is limited. They could be inserted as U-tubes into pre-drilled boreholes generally 100 mm to 150 mm diameter and between 15 m and 120 m deep (*EST, 2004*). Vertical collectors are more expensive than horizontal ones but they have high thermal efficiency and require fewer pipes and less pumping energy as well as they is less possibility to suffer damage after installation.

In order to determine the length of heat exchanger needed to meet a given load the thermal properties of the ground will be needed. The most important difference is between soil and rock as rocks have significantly higher values for thermal conductivity. The moisture content of the soil also has a significant effect as dry loose soil traps air and has a lower thermal conductivity than moist packed soil (*EST, 2004*). Low-conductivity soil may require as much as 50% more collector loop than highly conductive soil. Water movement across a particular site will also have a significant impact on heat transfer through the ground and can result in a smaller ground heat exchanger (*EST, 2004*).

Piping material

The used piping material affects life, maintenance costs, pumping energy, capital cost and heat pump performance. For indirect systems high-density polyethylene is most commonly used. It is flexible and can be joined by heat fusion. The pipe diameter must be large enough to keep the pumping power low, but enough to cause turbulent flow so as to ensure good heat transfer between the circulating fluid and the inside of the pipe wall. Pipe diameters between 20 mm and 40 mm are usual (*EST, 2004*).

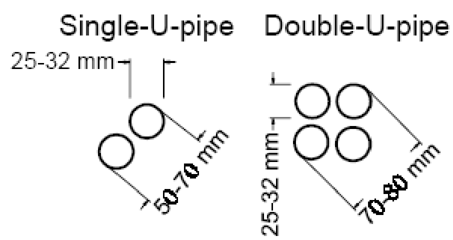


Fig. 3.9: Cross-sections of different types of U-borehole heat exchangers (Sanner, 1997)

Circulating fluid

The freezing point of the circulating fluid should be at least 5°C below the mean temperature of the heat pump (i.e. the average of the inlet and outlet temperatures).As the mean operating temperature of the heat pump may be as low as 12°C it is not necessary to add antifreeze solution to prevent freezing (*EST, 2004*). If it is proposed, the antifreeze should have good thermal performance. It is also important to make proper allowance for any change in properties of water/antifreeze mixtures as the loop temperature falls.

The ground loop circulating pump

The circulating pump should have a low electrical load requirement while still adequate to ensure turbulent flow is maintained in the ground loop. In general the pumping power should not exceed 50W per kW installed heat pump capacity (*EST, 2004*).

Installation and testing

Installation of the heat pump system and especially the ground heat exchanger needs to be carefully programmed and the time of installation depends on soil conditions, length of pipe, equipment required and weather conditions. Prior to any excavation, it is important to locate and protect any buried utilities, drainage pipes etc. The GSHP manufacturer's procedures must be followed. Vertical heat exchangers require highly specialist knowledge not just by the drilling contractor but also regarding pipe specification, joints, grouting etc. The ground heat exchanger should be installed by professionals who preferably have undergone training by manufacturers or other recognized authorities such as the International GSHP Association (*IGSHPA*).

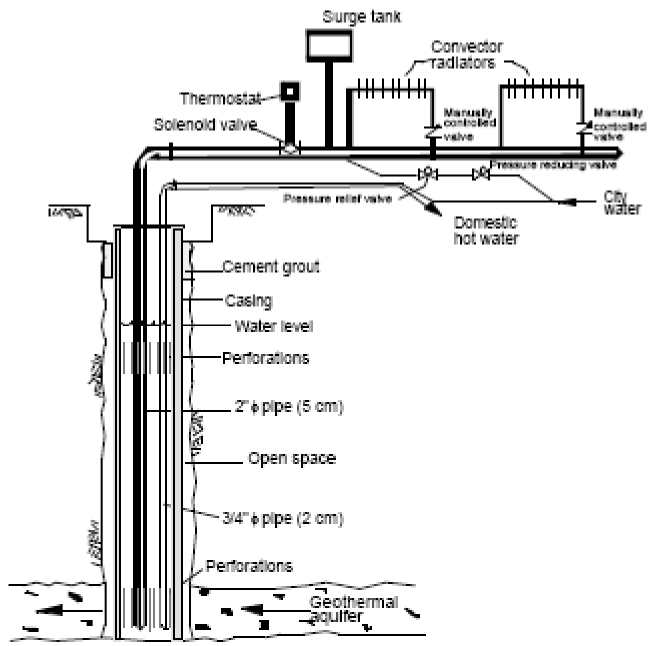


Fig. 3.10: Typical ground-source heat pump installation. (Lund, 2003)

The space between the borehole wall and the inserted pipes should be backfilled with a suitable grout material, for instance high conductivity bentonite grout, which is pumped from the bottom of the borehole. This provides not only good thermal contact but also prevents any vertical migration of groundwater. Any connections in high density polyethylene pipe should be made using heat fusion techniques in accordance with relevant standards. External pipe-work should be insulated within 1.5 m of any wall, structure or water pipes and sleeved where it enters the house (*EST, 2004*). When the heat pump is delivering heat the ground loop circuit will normally be operating below the building interior's dew point temperature. Good quality insulation and vapor sealing of internal pipe-work and fittings in this circuit is therefore essential to minimize the risks and the pipe-work should be configured so as to avoid potential damage if any condensation should still occur. Warning tape should be installed over all buried pipes. The ground loop should be pressure tested before installation in the ground (this may be done prior to delivery) and again after installation (*EST, 2004*). The loop should be flushed and purged of all air before being charged with antifreeze and pressurized ready for connection to the heat pump.

3.3.2 RETScreen Software

RETScreen International is a clean energy awareness, decision-support and capacity building tool developed on behalf of the Canadian Ministry of Natural Resources. The core of the tool consists of standardized and integrated clean energy project analysis software that can be used world-wide for free commercial and research purposes to evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various types of energy efficient and renewable energy technologies (*RET*). Each RETScreen technology model (e.g. Ground-Source Heat Pump Project, etc.) is developed within an individual Microsoft Excel spreadsheet "Workbook" file composed of a series of worksheets. These worksheets have a common look and follow a standard approach for all RETScreen models (*Retscreen International, 2007*).

3.3.3 Model Analysis

Having in mind the theoretical know-how and the limitations that are described in the previous paragraphs, the author has used the *RETScreen Software* for *Ground-Source Heat Pump Project Model* which calculates the system that is going to be performed, its capacity and finally its final cost and life-cycle performance. The proposed system is a vertical closed-loop system (*BHE* in Europe) which would be used instead of a conventional heating, ventilation and air conditioning (*HVAC*) system (heating provided by diesel-powered system and cooling provided by AC electricity-powered systems, typical use in Greece)(*Table 3.1*).

Table 3.1: Baseline system

Base Case HVAC System			
Building has air-conditioning?	yes/no	Yes	
Heating fuel type	-	**Diesel (#2 oil)**	
Heating system seasonal efficiency	%	70%	55% to 350%
Air-conditioner seasonal COP	-	3.5	2.4 to 5.0

(Source: RETScreen software)

The limited space of the Mauroeidakos Tower occupation land and its limestone bedrock imposed the usage of a vertical closed-loop system for the simulation as the more effective and less optical impact scenario.

The skeptic step for the model is the choice of the design criterion. This selection is used in the model to evaluate the size of the ground heat exchanger, the required groundwater flow, and to size the heat pumps. Since the energy simulation in the *Consolis Energy* + software showed that the thermal needs of the Tower after the implementation are extremely low for heating and average for cooling, the design criterion is based on the *cooling needs*. (*Table 3.2*)

Table 3.2: GSHP system

Ground Heat Exchanger System		
System type	-	Vertical closed-loop
Design criteria	-	Cooling
Typical land area required	m²	29

(Source: RETScreen software)

As part of the RETScreen Clean Energy Project Analysis Software, the Heating and Cooling Load Calculation worksheet is used to estimate the heating and cooling load as well as the energy demand for the building where the ground-source heat pump system is to be installed. The author entered the standard climatic and geographic information for the location of the GSHP project (*Table 3.3*). The software provided climate data for the area of Athens according to the information obtained by the Athens Observatory. The similarity of the weather conditions is summer season between Athens area and Mani area are justifying the engineering assumption that the former ones could be used and would not degrade the results.

Table 3.3: Climate and Geographical information

Site Conditions		Estimate	Notes/Range
Nearest location for weather data		Athinai(Athens) Observatory	See Weather Database
Heating design temperature	°C	3.1	-40.0 to 15.0
Cooling design temperature	°C	33.0	10.0 to 40.0
Average summer daily temperature range	°C	9.3	5.0 to 15.0
Cooling humidity level	-	Medium	
Latitude of project location	°N	38.0	-90.0 to 90.0
Mean earth temperature	°C	9.0	Visit NASA satellite data site
Annual earth temperature amplitude	°C	14.0	5.0 to 20.0
Depth of measurement of earth temperature	m	0.0	0.0 to 3.0

(Source: RETScreen software)

The choice of estimating the heating and cooling load by giving known load and consumption data are more precise instead of entering the building physical characteristics. The energy simulation calculations for the Mauroeidakos Tower gave annual heating and cooling energy demand of 1.5MWh and 7.0 MWh respectively (*Table 3.4*). The design heating load was estimated according to the thermal needs of the *coldest full-cloud day of January* and the design cooling load according to the thermal needs of the *hottest clear-cloud day of July* (*Table 3.4*).

Table 3.4: Heating and Cooling load

Building Heating and Cooling Load		Estimate	Notes/Range
Type of building	-	Residential	
Available information	-	Energy use data	
Design heating load	kW	1.5	
	million Btu/h	0.005	
Annual heating energy demand	MWh	1.5	
	million Btu	5.1	
Design cooling load	kW	7.0	
	ton (cooling)	2.0	
Annual cooling energy demand	MWh	7.0	
	million Btu	23,9	Return to Energy Model sheet

(Source: RETScreen software)

Before the calculation running step of the software, the author had to consider the average heat pump efficiency which could play significant role in the reliability of the results. Standard, medium and high efficiencies are steady state COPs and not seasonal values. These efficiencies are determined under standard test conditions as defined by the Canadian Standards Association (*CSA*) Standard 446 or the Air-conditioning and Refrigeration Institute (*ARI*) standards 325 and 330 (*Retscreen International, 2007*). (*Table 3.5*)

Table 3.5: GSHP efficiency

Heat Pump System		
Average heat pump efficiency	-	Standard
Standard cooling COP	-	3.50
Standard heating COP	-	2.80

(Source: RETScreen software)

Since GSHP systems are generally made up of a number of small to medium size heat pumps, the COP value represents the weighted average of all machines in the system. Selecting a higher efficiency level will reduce electrical consumption but increase the initial cost of the heat pumps. By using **Standard** average heat pump efficiency due to the research-orientation of the project, the following values of GSHP capacity were taken into account for the final calculations (*Table 3.6*).

Table 3.6: GSHP capacity

Total standard heating capacity	kW	5.9
	W	5,898
Total standard cooling capacity	kW	6.7
	W	6,724

(Source: RETScreen software)

CHAPTER 4

4 ARCHITECTURAL LIMITATIONS

4.1 Greek Legislation

The Ministry of Culture is the governmental body responsible for cultural heritage and the Arts in Greece. Its de-centralized departments (Museums, Ephorates of Prehistoric and Classical Antiquities, Ephorates of Byzantine Antiquities and Ephorates of Recent Monuments) (*Hellenic Ministry of Culture*) are spread throughout Greece while its administrative departments are situated in Athens. The major aim of the establishment of the Ministry of Culture is the development of a complete national cultural policy. It is the Unified Cultural Network, to which converge all the projects, all the networks of the Ministry, concerning either the cultural heritage of Greece or the cultural development (*Hellenic Ministry of Culture*).

The obligation of the state to support artistic creativity and protect cultural heritage stems from the Greek constitution *(COPENDIUM)*. Policy making, establishing cultural institutions and allocating funds for culture are the responsibilities of the Ministry of Culture as outlined in their organizational statutes. When appropriate, the Ministry of Culture co-operates with other Ministries (such as the Ministry for the Economy) to prepare and introduce legislation which is approved by the parliament and via presidential decrees.

Legislation related to heritage, culture and the arts originally consisted of an agglomeration of amendments to laws dating back to the 19th and early 20th century (*Hellenic Ministry of Culture*). After 1974, and especially since the 1980's, there has been a consistent attempt to modernize, bring together and systematize legislation within a smaller number of comprehensive laws.

The following pieces of legislation regarding culture should be noted *(COPENDIUM)*:

- *presidential decree no. 191/2003*, *Organization of the Ministry of Culture*, defining the organizational plan and responsibilities of the Ministry of Culture;

- *law no. 2121/1993, Copyright, Related Rights and Cultural Matters,* providing wide protection for the moral and economic rights of authors, and the related rights of performers, publishers, producers, etc., and stipulating the creation of an influential Copyright Organization under the auspices of the state;

- *law no. 2557/1997, Institutions, Measures and Actions for Cultural Development,* containing a wide range of legislation whose clauses include, among others, a new framework for national literary and other prizes, enforcement of a fixed book price, establishment of new national art galleries and museums, new statutes for the Thessaloniki Film Festival and the Greek Cinema Centre, provisions regarding music, cinema and arts education, establishment of a state-owned company entrusted with cultural heritage valorization and promotion through editions, audiovisual and multimedia productions and related activities (*Greek Culture Organization SA*), and several important terms related to intellectual property rights; and

- *law no. 3028/2002, For the Protection of Antiquities and Cultural Heritage in General,* broadening the notion and scope for the protection of monuments and works of all cultural traditions and historical periods, establishing legal provisions for the museum sector, introducing stricter controls to the provenance of works in private hands and the art market, stipulating the public right of access to cultural heritage (and the consequent obligations of the state, of archaeological research and of private collectors), defining regulations for archaeological research, including foreign archaeological schools operating in Greece, introducing fiscal incentives for the protection of cultural heritage, introducing stricter penalties for offenders, and making provisions for lending and exhibiting Greek cultural heritage objects abroad.

4.2 Cultural Heritage

Law no. 3028/2002 "*On the protection of antiquities and cultural heritage in general*" covers all the monuments that are part of the country's cultural heritage, irrespective of the religion or the ethnic origin of the people who created them or use them. The list of properties that comprise the country's cultural heritage is widened to cover the intangible heritage and the historic landscape. Special consideration is given to the accessibility of monuments and the educational role of heritage. *Law no. 3028/2002* regulates all aspects of cultural heritage protection and management, replacing a complex sequence of amendments to earlier pieces of legislation dating to 1932 and 1950. The provisions of the current legislation can be summarized as follows *(COPENDIUM)*:

- the concept of cultural heritage is broadened to encompass all cultural goods situated in Greece, including immovable monuments and sites, moveable cultural objects, and the intangible heritage (including oral traditions, myths, music, dances, skills and practices), regardless of cultural origin or tradition, and encompassing archaeological, ethnographic and broader cultural heritage;

- the notion of protection is broadened to cover, apart from physical preservation and conservation, the identification, research, documentation, access, and social, aesthetic and educational valorization of cultural heritage;

- the scope of the law covers cultural heritage of all periods, from prehistory to the present. A different degree of protection is afforded for different classes of cultural heritage objects. In general, all objects, moveable and immovable, before AD 1453, and all immovable monuments before AD 1830, are afforded the highest level of protection. More recent objects can also be placed on a higher level of protection if specifically characterized as containing special value;

- the law defines clear terms to recognize private collectors, outlines their special privileges, the terms of protection and access afforded by private collections, and for the operation of the art market;

- strict terms of protection are enforced through a system of zones. No building, quarrying etc. activity is permitted within a level A protection zone, while strict regulations apply over building and related activities within a level B protection zone;

- infringements relating to the protection of cultural heritage (such as theft, damage to monuments, illegal excavation, etc.) are defined in detail, and strong penalties have been introduced;

- the law defines the prerequisites for conducting archaeological research, including excavation, undertaken by the state archaeological service, academic institutions and foreign archaeological schools active in Greece, and stipulates the obligation of all researchers for the timely publication of their research;

- clear terms are defined regarding the rewards offered to those bringing hitherto unknown monuments to the attention of the state, as well as remuneration resulting from appropriation or limited use of privately owned land where monuments are found;

- measures are taken to strengthen control of legal provenance of cultural objects imported to the country or declared as part of a collection. Temporary export of cultural goods, in public or private custodianship, is explicitly allowed for exhibition, conservation, research or educational purposes; and

- specific requirements, concerning the purpose, the physical infrastructure, the staff, and the terms of operation, are defined to recognize private or public entities as a museum. All state museums, and non-state museums recognized by the state, are required to maintain specific collection management standards and to provide adequate access for research and public enjoyment of their collections; private museums are eligible to receive state subsidies. A national advisory council on museum policy has been established to offer advice to the Minister of Culture.

4.3 Mauroeidakos Tower case study

4.3.1 Mani Area

The Mauroeidakos Tower as it has been stated in the introductory part of this study is situated in the Municipality of Oitylo in the village of Xaria Pyrgou Dyrou. The whole area is protected according to the *Law no. 3028/2002,* for the following reasons (*European heritage network; Appendices A.3*):

- **Protection zones** (*article 10, 13, 17*)

Outside the boundaries of active settlements, towns or cities and around monuments and archaeological or historical sites, the Minister of Culture together with the other competent Ministers (Agricultural Policy and Environment, Physical Planning and Public Works) can delimit un-built zones (zone A). They can also regulate the land uses and prohibit all actions that could damage the monuments in any direct or indirect way. Such measures impose partial land use, restrictions on agricultural practices and farming, fishing or even on hunting. A second type of zoning (zone B), where special limitations on building, activities and land uses can be laid on, is also provided. For protection reasons, it is also possible to demarcate protection zones within the limits of historic settlements that constitute archaeological or historical sites. In those areas, the Services of the Ministry of Culture exert overall building control that encompasses building permits for new constructions, alterations and additions to buildings, small scale repairs, as well as demolition permits and attribution of new uses to the old buildings and their surrounding space. The guiding principle is to avoid altering the nature or the appearance of the individual monuments, as well as the architectural ensemble (*articles 13, 14, 17 of Law no 3028/2002 in combination with article 91 of Law no 1892/1990 (=article 184 of Code of Building Regulations)).*

- **Conservation Areas** (*articles 12-16*)

The Greek law on the protection of cultural heritage does not actually apply the term 'conservation area', but provides for the protection of archaeological and historical sites, which may be considered as the equivalent concept (*articles 13, 14, 16 of Law no. 3028/2002. See also, Protection zones*). In archaeological sites pre-dating 1453, building activity is not permitted in zone A, while it is regulated in zone B. In archaeological and historical sites dated post 1453, consent of the Ministry of Culture and special work authorization is required to build new houses (only reconstructions are permitted), or make any alterations to the existing ones. In all cases new interventions should not alter the character and appearance of the existing ensemble, or the spacing of structures and their relationship to each other.

4.3.2 Mauroeidakos Tower as structure

The Tower is a structure that dates back on 1800's and it follows the requirement of the *Law no. 3028/2002* for immovable monuments before 1830. Adequately, since the village area dates back before 1453 and many of its buildings have been constructed before 1830, the mentioned structure is protected and encountered as harmonized with the surrounding ones due to its historical, architectural and space-planning continuity. The whole structure is protected according to the *Law no. 3028/2002,* for the following reasons (*European heritage network; Appendices A.3)*:

- **Building license** (*articles 10-11, 40*)

A large part of the work of the regional services of the Ministry of Culture includes control of modern works carried out in the environs of monuments. Thus, any alterations proposed to their immediate surroundings, or within the limits of archaeological and historical sites, need the approval of the Ministry. The Ministerial Decision that confirms the license also states the exceptional conditions concerning the use of buildings together with the extent and character of any construction works taking place on them, as well as the conditions concerning conservation. Following this, it is the local town planning office that is responsible for checking the correct implementation of the terms of the building license, as well as the existence of the required authorization of other services, such as the Archaeological Service of the Ministry of Culture and the Committees for town planning and architectural control (*article 10 of Law no. 3028/2002 and Law no 3212/2003*).

Moreover, the Archaeological Service ("*Ephorate*") is also responsible for taking into account the construction phase of new buildings and inspecting the foundations of new buildings in areas of archaeological interest. In case of fortuitous finds during the works, further investigation in the form of sampling or rescue excavation may be required.

- **Restoration and conservation work** (*article 40, 43*)

Interventions to monuments conform to contemporary ethics of conservation as expressed not only through the provisions of the national legislative framework, but also the stipulations in Charters and international agreements on the protection of cultural property. They are carried out after the submission and approval of a detailed study and should provide for the preservation of the structural integrity of the building and its protection from natural destruction. They should also take into account the authenticity and historicity of the monument as well as the reversibility of the interventions. Full documentation of the monument in question is a prerequisite for the assessment of the study. Depending on the importance of the project, the study is either approved by the appropriate service of the Ministry of Culture after consultation of the local Council, or by the Minister of Culture after consultation of the Central Councils. The Ministerial Decision that confirms the approval of the project by the appropriate Council also states the extent and character of the intervention (*Article 40 of Law no. 3028/2002*).

CHAPTER 5

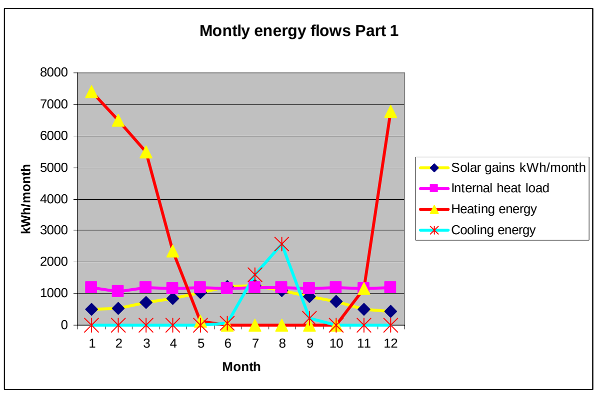
5 RESULTS

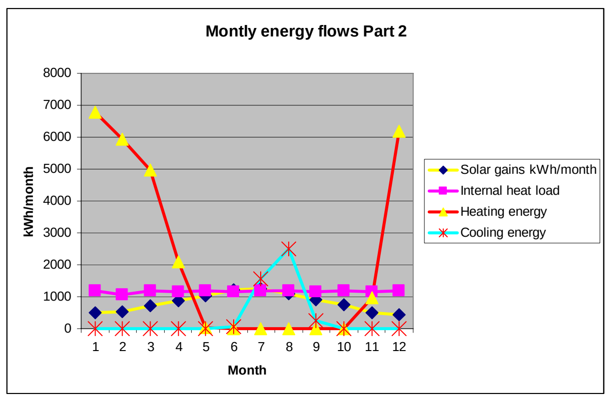
5.1 Energy optimal efficient approach

5.1.1 Alternative 0

As it is shown in the diagrams that are given after the analysis of the data, the thermal needs are high for the cold months of Mani Area and a lot higher than the internal heat capacity of the building. Nevertheless, during the summer months the amount of energy that is going to be used for cooling purposes is very low comparing to the average high seasonal ambient temperature.

The large width of the external walls (Greek limestone of 60 cm) enables a high amount of energy transition and heat exchange with the ambient air due to the construction style and the thermal conductivity of the building material. At the same time, the cooling sense of the stone-built structures in dry hot climates during summer is justified by the diagram indications and corresponds to the reasons mentioned before.

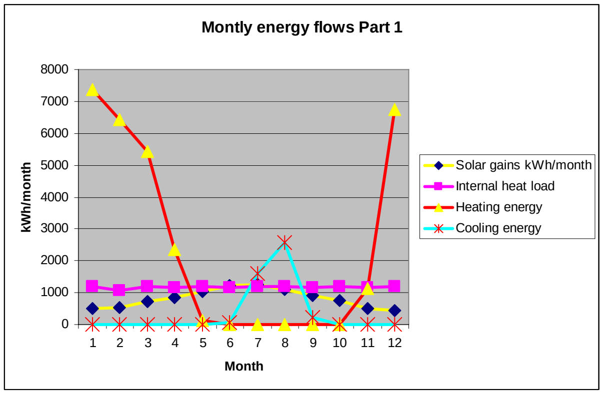


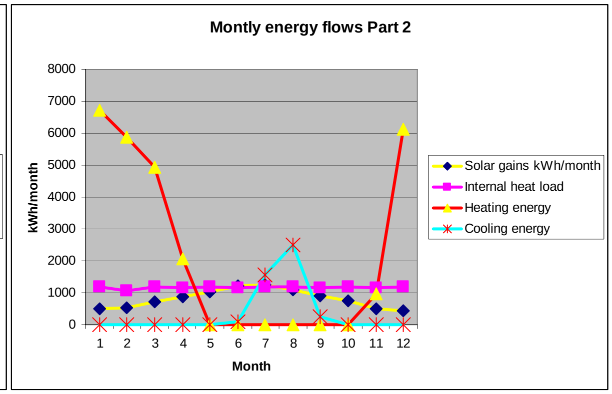


5.1.2 Alternative 1

As it is shown in the diagrams that are given after the analysis of the data, the thermal needs continue to be high for the cold months of Mani Area and a lot higher than the internal heat capacity of the building, despite the heat insulation of the roof. Nevertheless, during the summer months the amount of energy that is going to be used for cooling purposes is very low comparing to the average high seasonal ambient temperature.

The large width of the external walls (Greek limestone of 60 cm) and their formed surface area compared to the one of the roof still enables a high amount of energy transition and heat exchange with the ambient air due to the construction style and the thermal conductivity of the building material. The roof even if it manages to prevent vertical heat flows, cannot prevent the large heat exchange that takes place in the horizontal direction. At the same time, the cooling sense of the stone-built structure is not affected and the thermal comfort of tenants in upper floors during summer daytime is enhanced.

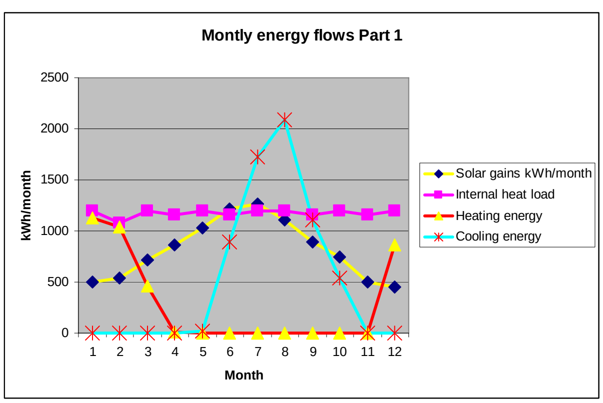


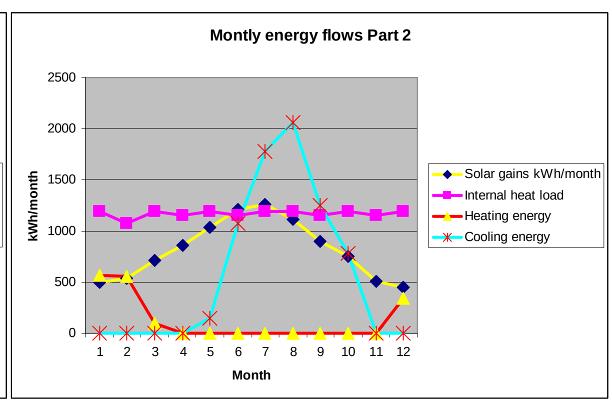


5.1.3 Alternative 2

As it is shown in the diagrams that are given after the analysis of the data, the thermal needs are dramatically decreased for the cold months of Mani Area and the internal heat capacity of the building is increased 50%. During the summer months the amount of energy that is going to be used for cooling purposes is very low comparing to the average high seasonal ambient temperature and remains a little lower than in the previous Alternative 0, 1.

The large width of the external walls additional to the insulation material enables a favorable condition in the structure concerning the energy transition and heat exchange with the ambient air. The massive wall structure offers a huge barrier for heat storage due to the material nature in winter but the heat insulation seems to correspond rather sufficiently in the conditions of the area. On the other hand, the wall structure during summer offers a large width of space which is not affected analogically by the dry hot conditions. Adequately to the insulation material, the cooling sense of the stone-built structure is enhanced and the energy needed is less than the one described in Alternative 0, 1.

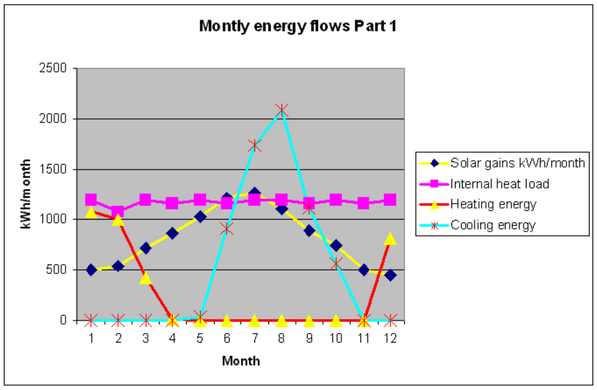


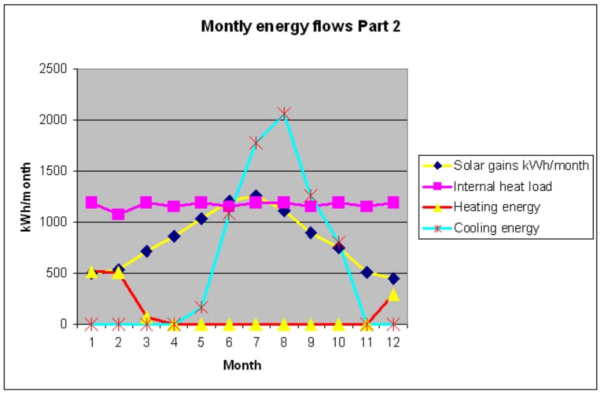


5.1.4 Alternative 3

As it is shown in the diagrams that are given after the analysis of the data, the thermal needs for the cold months of Mani Area are the same as in the Alternative 2 and the internal heat capacity of the building is in the same level. During the summer months the amount of energy that is going to be used for cooling purposes is very low comparing to the average high seasonal ambient temperature and remains a little lower than in the previous Alternative 0, 1.

As it is concluded, the roof type of the building, even with a very effective use of the insulation material, is not the critical one for the energy performance of the building. It seems that the roof's construction materials are activating well on the heat flows that happen throughout the year without any use of the heat insulation. The large width of the external walls is playing the dominant role in the heat transfer and exchange with the environment and the use of attached insulation material is critical.

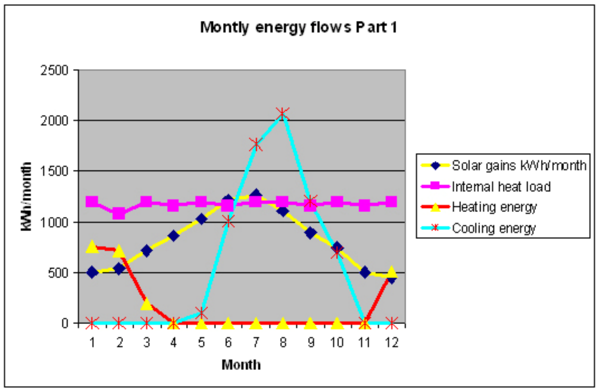


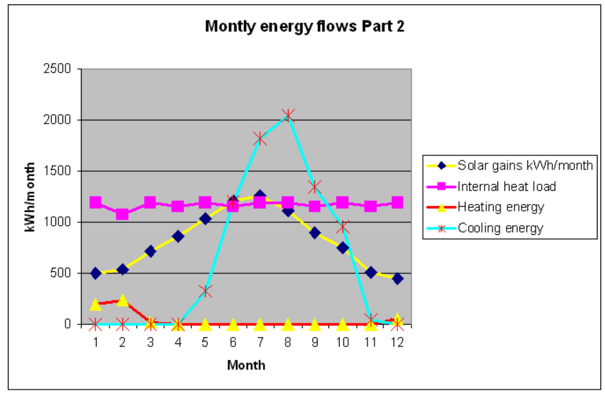


5.1.5 Alternative 4

As it is shown in the diagrams that are given after the analysis of the data, the thermal needs for the cold months of Mani Area decreased even more than Alternatives 2, 3 in a 30% decline. The internal heat capacity of the building remains in the same level, but it is obvious that in cold months (January, February) even solar gains from this heat planning are somewhat lower than the heating energy needs. During the summer months the amount of energy that is going to be used for cooling purposes is very low comparing to the average high seasonal ambient temperature and remains at same levels than in the previous Alternative 3.

As it is concluded, the window type is critical for the thermal balance and heat transfer of the Tower structure. Despite the fact that the large width of the external walls is playing the dominant role in the heat transfer and exchange with the environment, after the effective use of their attached insulation material, window openings were responsible for energy losses. The change of U-value corresponding to the different type of window installation decreased in a significant percentage the thermal needs and at the same time secured the thermal comfort during high seasonal temperatures of the summer.

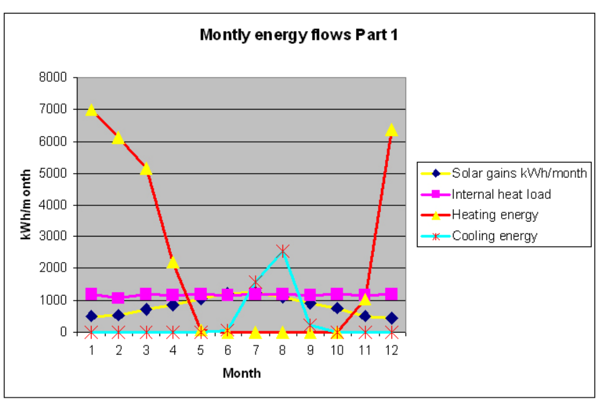


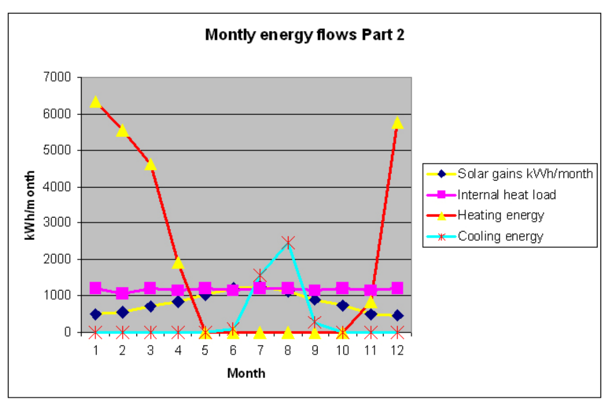


5.1.6 Alternative 5

As it is shown in the diagrams that are given after the analysis of the data, the thermal needs for the cold months of Mani Area are high but less than Alternative 0 and 1. The internal heat capacity of the building remains in the same level as the mentioned Alternatives, whenever during the summer months the amount of energy that is going to be used for cooling purposes is very low comparing to the average high seasonal ambient temperature and remains at same levels than in all the previous Alternatives.

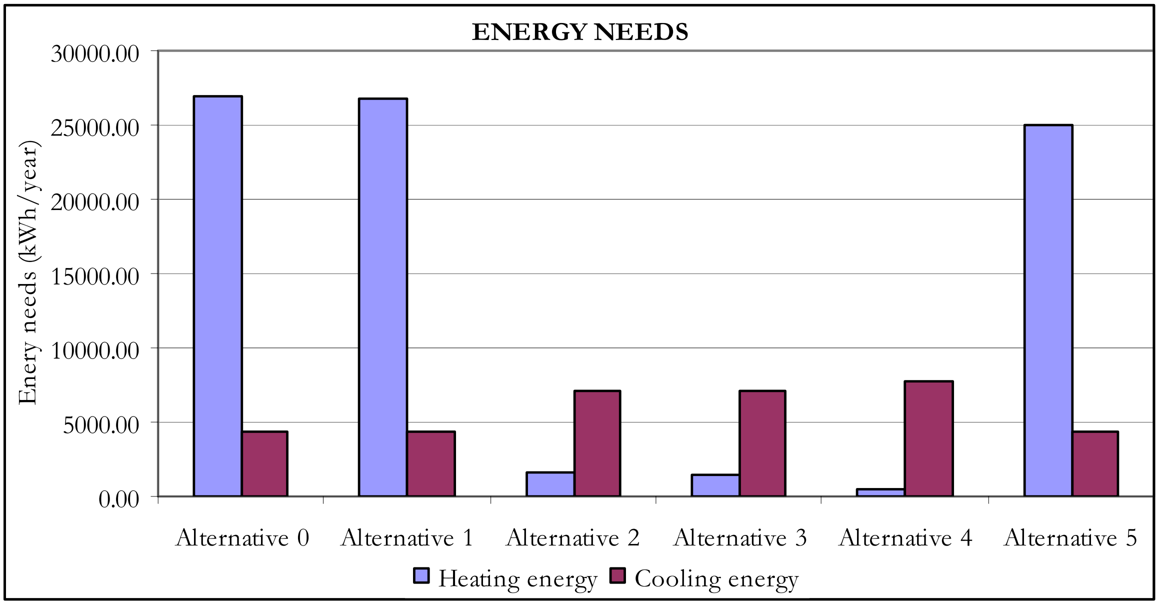
The large width of the external walls (Greek limestone of 60 cm) and their formed surface area compared to the one of the roof and more thermal-efficient windows enable a high amount of energy transition and heat exchange with the ambient air due to the construction style and the thermal conductivity of the building material. The roof even if it manages to prevent vertical heat flows and windows prevent heat flows cannot prevent the large heat exchange that takes place in the horizontal direction due to the stone-built of walls. At the same time, the cooling sense of the stone-built structure is not affected and the thermal comfort of tenants in upper floors during summer daytime is enhanced.





Synoptically, the quality characteristics of the heat insulation implementation in the Mauroeidakos Tower due to the energy simulation are weighted in the diagram that follows (*fig. 5.1*) and justify the initial estimations

Fig. 5.1: Summarized energy needs of all Alternatives



(Source: Author)

5.1.7 Cost Analysis

The energy simulation has shown in quality terms the scenarios that could be forwarded about the optimal thermal performance of the Mauroeidakos Tower. The energy design could be well-structured only when a feasible study is made for the applicable proposed solutions, which in the long run would reinsure the viability of the whole project. It is essential to clarify that this cost analysis contains only facts and assumptions made for the *heat insulation implementation* and its components in the structure. The baseline model (*Alternative 0 - no thermal insulation*) has considered that the Tower has 2-glass windows as in the other models in order that the cost analysis could be supplemented in equal terms.

The calculations for the initial costs of every alternative are shown in the Appendix A.2. The collection of the necessary values from the *Consolis Energy* + software regarding the heating and cooling needs and further calculations, would result in the presentation of concentrated information. In the Table 5.1, all the scenarios are presented according to their heating and cooling energy needs. The sum of Mauroeidakos Tower's energy needs in year basis is given in monetary value for practical reasons. This is done by considering that all the energy needs in kWh are provided by typical electrical devices consuming the same energy 24h/day. (*More analytical approach could separate heating needs provided by diesel-powered system and cooling needs by electrical air-conditioning, taking into account the differences in day and night electricity prices*)

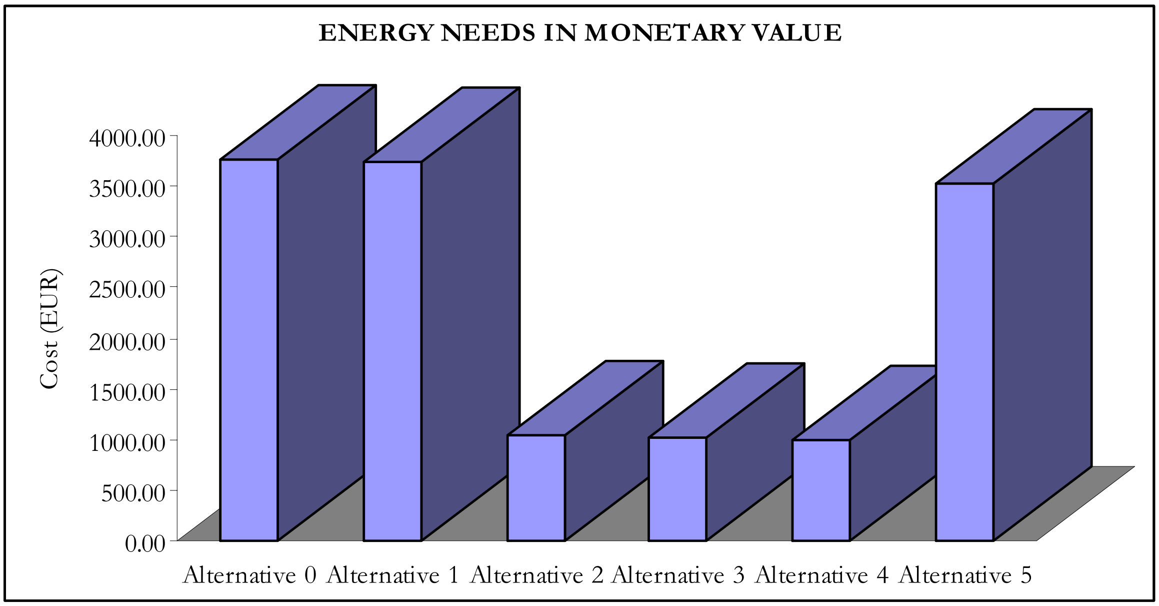
Table 5.1: Annual monetary value for energy

Simulation scenario	Heating enegy needs	Cooling energy needs	Annual electricity price (mean 0.12 EUR/kWh)
	(kWh/year)	(kWh/year)	(EUR)
Alternative 0	26899.84	4395.05	3755.39
Alternative 1	26698.85	4392.98	3731.02
Alternative 2	1556.64	7083.21	1036.78
Alternative 3	1395.22	7153.77	1025.88
Alternative 4	497.04	7731.16	987.38
Alternative 5	25048.75	4372.67	3530.57

(Source: Author)

The diagram that follows represents graphically the cost's large differences among Alternatives depending exclusively on the degree of thermal insulation. (*fig. 5.2*)

Fig. 5.2: Energy needs in monetary value



(Source: Author)

In general, mineral wool, apart from its excellent thermal performance, has a big life-cycle which justifies the preference that is been shown among constructors. The calculation of the total costs along its life-cycle performance is critical for the final proposed solution. It is estimated that for a period of 45 years, the mineral wool would provide thermal insulation in an accepted scientific approach. During this chronic distance, it is expected that some maintenance works are going to be done for the preservation of its high insulation ability. This is justified by other building materials' failure due to weather conditions and extreme temperature differences especially on the flat roof and less likely in the Tower interior. The author made the assumption for the 15 year period for every maintenance and costs that depend on material change, labor, staff transportation and daily needs.

The Table 5.2 that follows gives estimation on the total costs which would have been paid in energy (*heating* + *cooling*) for a 45 year life-cycle mineral wool performance and according to the degree of heat insulation.

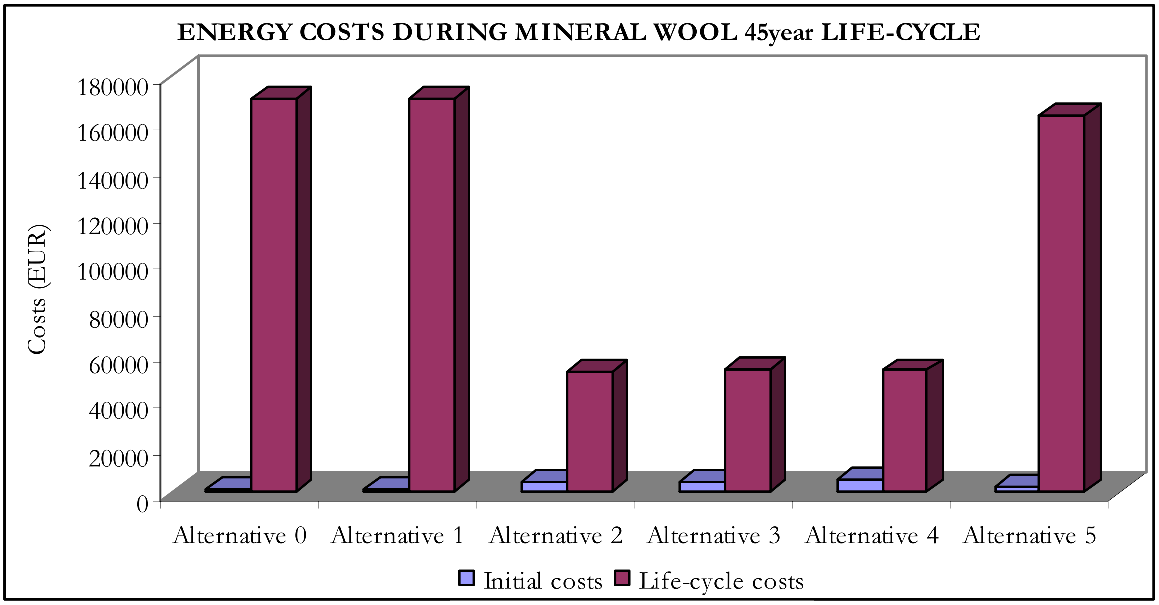
Table 5.2: Costs for energy during mineral wool's life-cycle

Simulation scenario	Initial costs	Maintenance costs (every 15 years)	Operation costs (end-life 45 years)	Total costs/ alternative
	(EUR)	(EUR)	(EUR)	(EUR)
Alternative 0	1200	0	168992.42	170192.42
Alternative 1	1786.8	300	167895.86	170582.66
Alternative 2	4184.92	500	46655.22	**52340.14**
Alternative 3	4771.72	800	46164.53	53336.25
Alternative 4	5251.72	1000	44432.30	52684.02
Alternative 5	2266.8	500	158875.66	162642.46

(Source: Author)

The diagram (*fig. 5.3*) shows graphically the energy costs in the life-cycle perspective of mineral wool

Fig. 5.3: Energy costs for mineral wool's life-cycle



(Source: Author)

Finally, the author made a comparison among the baseline model (Alternative 0) and each one Alternative respectively, in order that the saved energy would be estimated, both in terms of energy and monetary values. Additionally, there is an estimation of the pay-back period from the time that the whole project would have been implemented, based on the initial installation cost and the annual saved economy of each Alternative separately.

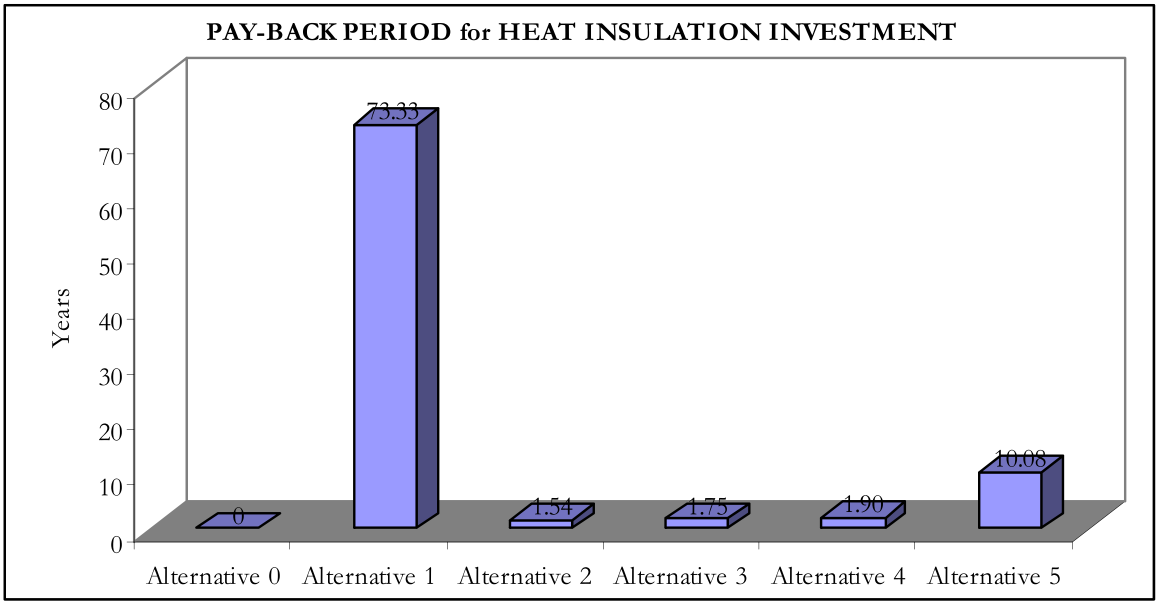
Table 5.3: Total saved energy and pay-back period

Simulation scenario	Saved Heating Energy	Saved Cooling Energy	Total Saved Energy	Annual saved economy	Pay-back period
	(kWh/year)	(kWh/year)	(kWh/year)	(EUR)	(years)
Alternative 0	0	0	0	0	0
Alternative 1	201.00	2.07	203.07	24.37	73.33
Alternative 2	25343.20	-2688.16	22655.04	2718.60	**1.54**
Alternative 3	25504.62	-2758.72	22745.90	2729.51	1.75
Alternative 4	26402.80	-3336.11	23066.69	2768.00	1.90
Alternative 5	1851.09	22.38	1873.47	224.82	10.08

(Source: Author)

The diagram (*fig. 5.4*) that follows represents in quality terms the pay-back time period for the thermal insulation initial investment:

Fig. 5.4: Pay-back time period for initial investment



(Source: Author)

5.2 GSHP system dimensions

5.2.1 RETSCreen Software model run

Taking into consideration the analytical steps that were made in the Chapter 3, the model was set for the calculation mode. The results are given below (*Table 5.4*):

Table 5.4: GSHP performance for Mauroeidakos Tower

Site Conditions		Estimate	Notes/Range
Project name		**Mauroeidakos Tower**	See Online Manual
Project location		**Mani, Greece**	
Available land area	m²	301	
Soil type	-	Light rock	
Design heating load	kW	1.5	Complete H&CLC sheet
Design cooling load	kW	7.0	

System Characteristics		Estimate	Notes/Range
Base Case HVAC System			
Building has air-conditioning?	yes/no	Yes	
Heating fuel type	-	**Diesel (#2 oil)**	
Heating system seasonal efficiency	%	70%	55% to 350%
Air-conditioner seasonal COP	-	3.5	2.4 to 5.0
Ground Heat Exchanger System			
System type	-	Vertical closed-loop	
Design criteria	-	Cooling	
Typical land area required	m²	29	
Ground heat exchanger layout	-	Standard	
Total borehole length	m	124	
Heat Pump System			
Average heat pump efficiency	-	Standard	
Standard cooling COP	-	3.50	
Standard heating COP	-	2.80	
Total standard heating capacity	kW	5.9	
	W	5,898	
Total standard cooling capacity	kW	6.7	
	W	6,724	
Supplemental Heating and Heat Rejection System			
Suggested supplemental heating capacity	kW	0.0	
	W	0	
Suggested supplemental heat rejection	kW	0.0	
	W	0	

Annual Energy Production		Estimate	Notes/Range
Heating			
Electricity used	MWh	1.0	
Supplemental energy delivered	MWh	0.0	
GSHP heating energy delivered	MWh	**1.5**	
	kWh	1,500	
Seasonal heating COP	-	1.5	2.0 to 5.0
Cooling			
Electricity used	MWh	2.1	
GSHP cooling energy delivered	MWh	**7.0**	
	kWh	7,000	
Seasonal cooling COP	-	3.3	2.0 to 5.5
Seasonal cooling EER	(Btu/h)/W	11.2	7.0 to 19.0
			Complete Cost Analysis sheet

(Source: RETScreen software)

5.2.2 Cost Analysis

The feasibility of the proposed solution is an issue of great importance because the budget for hotel facilities investments is always strictly defined. As part of the RETScreen Clean Energy Project Analysis Software, the Cost Analysis worksheet is used to estimate costs associated with the GSHP project. These costs are addressed from the initial, or investment, cost standpoint and from the annual, or recurring, cost standpoint. Due to lack of information for specific case studies in Greece and relevant costs for equipments, labor and national tax policy (GSHP installations are in embryo phase in Greece), a pre-feasibility study was made for cost estimation.

The initial costs in energy equipment, in the system balance and miscellaneous expenses such as training and contingencies costs are considered (*Table 5.5*).

Table 5.5: Initial costs

Energy Equipment									
Heat pumps	kW cooling	6.7	EUR	330	EUR	2,219		-	-
Well pumps	kW	0.0	EUR	-	EUR	-		-	-
Circulating pumps	kW	0.1	EUR	850	EUR	97		-	-
Circulating fluid	m³	0.02	EUR	2,600	EUR	57		-	-
Plate heat exchangers	kW	0.0	EUR	10.00	EUR	-		-	-
Trenching and backfilling	m	0	EUR	-	EUR	-		-	-
Drilling and grouting	m	124	EUR	12.00	EUR	1,488		-	-
Ground HX loop pipes	m	248	EUR	2.50	EUR	620		-	-
Fittings and valves	kW cooling	6.7	EUR	12.00	EUR	81		-	-
Other - Energy Equipment	Cost	0	EUR	-	EUR	-		-	-
Electric central heating system	Credit	1	EUR	20,000	EUR	(20,000)		-	-
Sub-total:					**EUR**	**(15,439)**	89.2%		
Balance of System									
Supplemental heating system	kW	0.0	EUR	-	EUR	-		-	-
Supplemental heat rejection	kW	0.0	EUR	-	EUR	-		-	-
Internal piping and insulation	kW cooling	6.7	EUR	60	EUR	403		-	-
Other - Balance of System	Cost	0	EUR	-	EUR	-		-	-
Credit - Balance of System	Credit	1	EUR	1,000	EUR	(1,000)		-	-
Sub-total:					**EUR**	**(597)**	3.4%		
Miscellaneous									
Training	p-h	14	EUR	70	EUR	980		-	-
Contingencies	%	15%	EUR	(15,055)	EUR	(2,258)		-	-
Sub-total:					**EUR**	**(1,278)**	7.4%		
Initial Costs - Total					**EUR**	**(17,314)**	100.0%		

(Source: RETScreen software)

There will be a number of annual costs associated with the operation of the GSHP system. These could include property taxes and insurance, O&M labor and travel and accommodation expenses (for specialized personnel in case of need). In addition, costs for electricity consumption and peak load demand (or credit, for cases where the peak demand is reduced) are incurred. Grey input cells are also provided to allow the user to enter a cost or credit item that is specific to the project and not included in the generic information provided. These costs are detailed below (*Table 5.6*).

Table 5.6: Annual costs

Annual Costs (Credits)	Unit	Quantity	Unit Cost			Amount	Relative Costs	Quantity Range	Unit Cost Range
O&M									
Property taxes/Insurance	project	0	EUR	-	EUR	-		-	-
O&M labour	m²	321	EUR	2.50	EUR	803		-	-
Travel and accommodation	p-trip	0	EUR	-	EUR	-		-	-
Other - O&M	Cost	0	EUR	-	EUR	-		-	-
Credit - O&M	Credit	1	EUR	3,500	EUR	(3,500)		-	-
Contingencies	%	5%	EUR	(16,035)	EUR	(802)		-	-
Sub-total:					**EUR**	**(3,499)**	114.3%		
Fuel/Electricity									
Electricity	kWh	**3,125**	**EUR**	**0.120**	EUR	375		-	-
Incremental electricity load	kW	**0.5**	**EUR**	**120**	EUR	63		-	-
Sub-total:					**EUR**	**438**	-14.3%		
Annual Costs - Total					**EUR**	**(3,061)**	100.0%		

(Source: RETScreen software)

Periodic costs associated with the operation of the system over the project life are also accounted. Grey input cells are provided to allow the user to enter the name of a periodic cost and periodic credit item. A periodic cost represents recurrent costs that must be incurred at regular intervals to maintain the project in working condition. The project may also be credited for periodic costs that would have been incurred over the project life of the base case, or conventional, energy system (*Table 5.7*).

Table 5.7: Periodic costs

Periodic Costs (Credits)		Period	Unit Cost		Amount		Interval Range	Unit Cost Range
Heat pump compressor	Cost	10 yr	EUR	5,000	EUR	5,000	-	-
Air-conditioner replacement	Credit	12 yr	EUR	6,000	EUR	(6,000)	-	-
					EUR	-	-	-
End of project life	Credit	-	EUR	2,000	EUR	(2,000)		Go to GHG Analysis sheet

(Source: RETScreen software)

The concentrated elements that are considered for the cost analysis are summarized in the financial summary that follows (*Table 5.8*):

Table 5.8: Financial Summary

Annual Energy Balance

Project name		Mauroeidakos Tower	Electricity required	MWh	3.1
Project location		Mani, Greece	Incremental electricity load	kW	0.5
Heating energy delivered	MWh	1.5			
Cooling energy delivered	MWh	7.0			
Heating fuel displaced	-	Diesel (#2 oil)			

Financial Parameters

Avoided cost of heating energy	EUR/L	0.060	Debt ratio	%	0.0%
			Income tax analysis?	yes/no	No
Retail price of electricity	EUR/kWh	0.120			
Demand charge	EUR/kW	120			
Energy cost escalation rate	%	2.0%			
Inflation	%	2.0%			
Discount rate	%	10.0%			
Project life	yr	25			

Project Costs and Savings

Initial Costs				**Annual Costs and Debt**		
Feasibility study	0.0%	EUR	-	O&M	EUR	(3,499)
Development	0.0%	EUR	-	Fuel/Electricity	EUR	438
Engineering	0.0%	EUR	-			
Energy equipment	89.2%	EUR	(15,439)	**Annual Costs and Debt - Total**	**EUR**	**(3,061)**
Balance of system	3.4%	EUR	(597)			
Miscellaneous	7.4%	EUR	(1,278)	**Annual Savings or Income**		
Initial Costs - Total	**100.0%**	**EUR**	**(17,314)**	Heating energy savings/income	EUR	12
				Cooling energy savings/income	EUR	240
Incentives/Grants		EUR	-			
				Annual Savings - Total	**EUR**	**252**
Periodic Costs (Credits)						
Heat pump compressor		EUR	5,000	Schedule yr # 10,20		
Air-conditioner replacement		EUR	(6,000)	Schedule yr # 12,24		
		EUR	-			
End of project life - Credit		EUR	(2,000)	Schedule yr # 25		

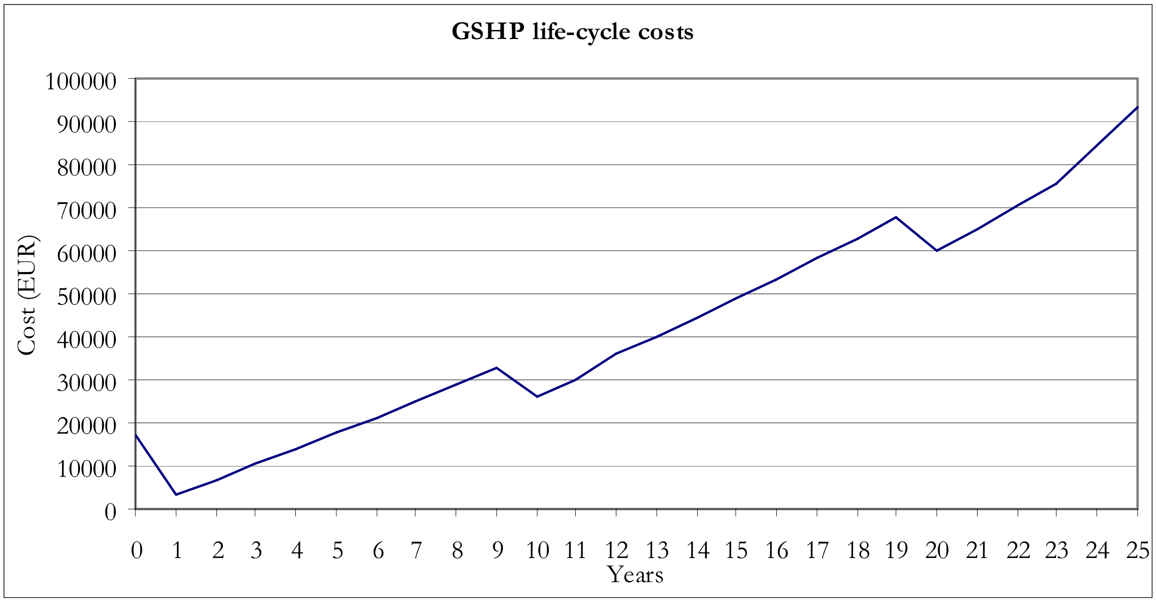
Financial Feasibility

Pre-tax IRR and ROI	%	#DIV/0!			
After-tax IRR and ROI	%	#DIV/0!			
Simple Payback	yr	(5.2)	Project equity	EUR	(17,314)
Year-to-positive cash flow	yr	immediate			
Net Present Value - NPV	EUR	53,415			
Annual Life Cycle Savings	EUR	5,885			
Benefit-Cost (B-C) ratio	-	(2.09)			

(Source: RETScreen software)

The values that are given in the financial summary could be understood in the synoptic GSHP life-cycle costs graph (*fig 5.5*).

Fig. 5.5: GSHP life-cycle costs



(Source: Author)

The pay-back period for the initial installation cost is estimated around 5.2 years from the commencement of the project. The positive cash flows are immediate and are calculated according to the interest rates which are shown in the financial summary.

The escalation in the graph is due to the maintenance and replacement costs that are considered every 10 and 12.5 years for the mechanical system.

CHAPTER 6

6 DISCUSSION and CONCLUSIONS

The scope of the current study was to analyze the perspective of a sustainable approach on the sensitive sector of tourism. Since the area that was chosen for studying is the famous Mani, in Greece, which has a great potential for further touristic development, the author tried to combine knowledge and experience in order to fulfill the initial objective. The initiative of Mauroeidakos family to renovate and change usage of its own Tower-dwelling set the line for the definition of the current report. The technical advice and study was given from the construction company *"Oikomorphes"* and helped Mauroeidakos family to activate in the hotel business. This brought to author the idea of the effective energy design and the application of renewable sources for meeting the building's basic thermal needs, as a step towards the better environmental preservation of Mani.

The Tower as a stone–made structure has adequate thermal needs that should be taken into consideration for the thermal comfort of the tenants, the overall economy and environmental concern. The acquisition of the necessary climate information from the Hellenic National Meteorological Agency gave the possibility to the author to start studying the model. The *Consolis Energy* + software which is developed by Professor Gudni Johannesson hosted the climate data, architectural-derived values, and different scenarios were analyzed to run over the model.

The externalized conclusions that were made by the solution of the different scenarios and the cost analysis promoted the optimal energy effective one for the Tower energy design. Based on the latter, geothermal energy was suggested as a renewable form of energy that could meet satisfactorily the new Tower needs. The *RETScreen Software* for *Ground-Source Heat Pump* was proposed as a tool that could approach practically the geothermal approach and could set the dimensions of the GSHP system which would cover Mauroeidakos Tower's energy demand.

6.1 Energy simulation conclusions

6.1.1 Heat Insulation performance

The analysis made in the software *Consolis Energy* +, supported the initial thought that the Tower's stone massive construction has a satisfactory thermal performance, even in the core of the winter and summer season. The bulk and the width of the external walls play the significant role in energy transitions rather than the roof, window shills and floors.

Nevertheless, the scope of the study was the highest energy efficiency and the problem was addressed to the proposed scenarios that were developed in the Chapter 2. The solution of mineral wool as heat insulation material was forwarded so as to be implemented in the interior of the massive stone-made walls. The energy simulation gave interesting results underling that the heat insulation dropped significantly the thermal needs of the structure, deteriorating them almost for hot water provision. At the same time, the cooling ones had increased in a small percentage, which is proved by the effectiveness of the mineral wool as insulation material. The sun radiation in summer increases the indoor Tower temperature and the heat is absorbed lower, something that suggests higher cooling energy for rejecting the heat to the ambient air.

6.1.2 Cost-efficiency

The Alternatives 2, 3 and 4 are the ones that are being promoted according to the results. The differences among them are small even after the cost analysis obtained information (*Appendix A.2*). Alternatives 3 and 4 have higher installation costs but the pay-back period and the saved energy are practically the same with Alternative 2.

6.1.3 Architectural continuity

Since the architectural limitations are strict as they are described in Chapter 4, the Alternative 4 with the 3-glass windows would pose problems in the exterior architectural continuity. The inadequate provision of such windows in Greece from big manufacture companies, and especially in the desired design formation according to the Archaeological Service, would lead owners to find solutions in local manufacturers with doubtful results. Since, the initial cost for installation is 1,000 EUR more than Alternative 2 and the thermal quality remains practically the same, Alternative 4 is rejected as the best energy scenario.

The Alternative 2 and 3 seem to fulfill most of the requirements that are made by the architectural limitations. The implementation of the mineral wool on the roof, both on flat and the escalated, is not posing architectural problems.

6.1.4 Best energy-efficient solution

Alternative 2 is the most economical scenario in absolute values and performs excellent even with no thermal insulation on the roof in relation to Alternative 3. The thermal insulation on the roof under the limestone large boards is estimated that increases the interior temperature in the upper floors during day on summer. But at the same time, this phenomenal floor difference becomes critical during winter, because the heat insulation prevents humidity and temperature punctuations due to north wind. This is translated to better thermal comfort for tenants in the loft floor for Alternative 3 in a typical Maniat winter day, similar to the comfort in the ground floor. Since the overall building performance is crucial for the promotion of high-quality hotel services and reinsure of tenant satisfaction, the scenario that should be promoted is ***Alternative 3***.

6.2 Geothermal Energy conclusions

6.2.1 GSHP system

The *RETScreen Software* for *Ground-Source Heat Pump Project* model was proposed in order to dimension the system that is going to take advantage the geothermy and cover the needs of the Tower. The approach is based on assumptions made by the author and his supervisor, since the model is developed in Canada and its local conditions. The model was based in the design criterion of *cooling load* that occurred from the energy simulation and built up on the specific climate conditions of Mani. The values that were used for the dimensioning, occurred by the ***Alternative 3*** scenario from *Consolis Energy* +.

Due to limited space land and for the better energy performance, a GSHP vertical looped system is promoted for modeling. This GSHP system is compared with a conventional HVAC one, typical for Greece (diesel for heating-electricity for AC) and the results are verifying in scientific acceptable manner the correlation between the values that occurred by the two software.

6.2.2 GSHP performance

The few heating needs of the Tower after the effective heat insulation are supplemented by the GSHP performance and meet the cooling needs posed by the *Consolis Energy* +. The viability of the system which is innovative for the Mani area stands on the accurate cost analysis and 25 year life-cycle. The *RETScreen Software* for *Ground-Source Heat Pump* has a worksheet that provides the information concerning the finance and it is critical to adjust the needed model values for the Greek reality. The financial summary that comes out from the cost analysis seems to estimate effectively the costs than expected. The pay-back period for the project is only ***5.2 years*** and the annual life-cycle savings about ***6,000 EUR***. Additionally, it is important to mention that the annual savings, regarding the operating annual costs of the HVAC conventional baseline system in case of implementation, are about ***3,000 EUR.***

6.2.3 Architectural continuity

The GSHP system operation method and installation does not require extensive architectural solutions for its visual members. The architectural limitations impose that the pipes which come out from the earth at the area of drilling holes should follow alongside the external walls covered from a limestone-built secured square space with the one side determined by the walls. Since the system unit that would provide the necessary heating and cooling needs is going to be set up in the old basement area, no external visual impact is estimated to destruct the Tower's architecture.

It is worth mentioning for comparison reasons that for the baseline HVAC system, the architectural dilemmas are sophisticated and often require expensive solutions for the neutralization of negative impacts. That is to say, the diesel-powered system for heating provision needs a high chimney for the fumes, which is often difficult to be hidden artificially. Simultaneously, this system has to be installed in contact to the Tower, in a space built only for its operation performance. In the meantime, the AC system poses also the architectural dilemma of the proper installation of the external units, which are far more difficult to solve regarding their big size due to the high cooling needs.

6.3 Recommendations

This study tries to initiate engineers in the area but also where is a similar need to, to face in a holistic approach all the themes concerning a traditional structure which addresses to tourists. Despite the mentioned scope of the thesis, the results and conclusions could be applied in traditional structures that remain under private usage and continue to accommodate family needs. The study has limitations and boundaries that are posed mainly by lack of specific climate and geographical data. The Hellenic National Meteorology Service provided information for nearby areas (*Gythion, Sparta and Kalamata*) which should be used with the necessary assumptions. Inadequate case studies in GSHP systems regarding Greece justify the lack of statistical values and prevent the more accurate cost-benefit analysis of the solutions, but without playing significant role on the final conclusions.

The Mauroeidakos Tower is a unique structure that corresponds to a continuous inhabited period of 200 years and at the same time, to a guard of a local worldwide heritage. The Tower belongs to a large family of construction complexes of the kind in Mani which are becoming more and more known abroad. The Maniat landscape, tradition and architecture charm the tourists and nowadays, there is high demand for touristic activities, even real estate business. The building and planning mistakes that have been made in Greece especially in islands coastline for the satisfaction of massive tourism threaten the local people and local authorities. Central and peripheral authorities should implement corresponding policies to the prototype of Toscana in Italy, in order to forward a regional economical development based on sustainability and mutual respect of human and environment.

As it was shown in the results of the study, energy simulation and design of a structure are playing dominant role in the thermal comfort, the energy saving and finally the household economy. Even by using conventional HVAC systems for the provision of heating and cooling, an effective energy design reinsures that energy savings will overwhelm initial installation costs in due time. In a building of the size, the construction style and the oldness of Mauroeidakos Tower, the proposed energy design dropped the energy needs 4 times. The pay-back period for the investment cost, after the hypothetical implementation of the mineral wool as heat insulation, is only 1.5 years. This suggests that the initial costs for thermal improvement of an existing building in Mani could be in the budget for the owner of average economic status. Additionally, the state could initiate a pilot program by giving different level motivation or financial support to owners of old traditional houses to start an energy design study and improve their thermal performance.

List of Figures

List of Tables

List of Acronyms

AC	Air Conditioning
ARI	Air-conditioning and Refrigeration Institute
BHE	Borehole Heat Exchangers
CSA	Canadian Standards Association
COP	Coefficient of Performance
EER	Energy Efficiency Ratio
EST	Energy Storage Technologies
EU	European Union
GHPC	Geothermal Heat Pump Consortium
GSHP	Ground Source Heat Pumps
HVAC	Heating Ventilation Air-conditioning
IEA	International Energy Agency
IGSHPA	International Ground Source Heat Pump Association
ISO	International Organization for Standardization
RET	Renewable Energy Technologies
R&D	Research & Development
TES	Thermal Energy Storage
TRT	Thermal Response Test

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-***Additional information was acquired through the following Internet websites:***

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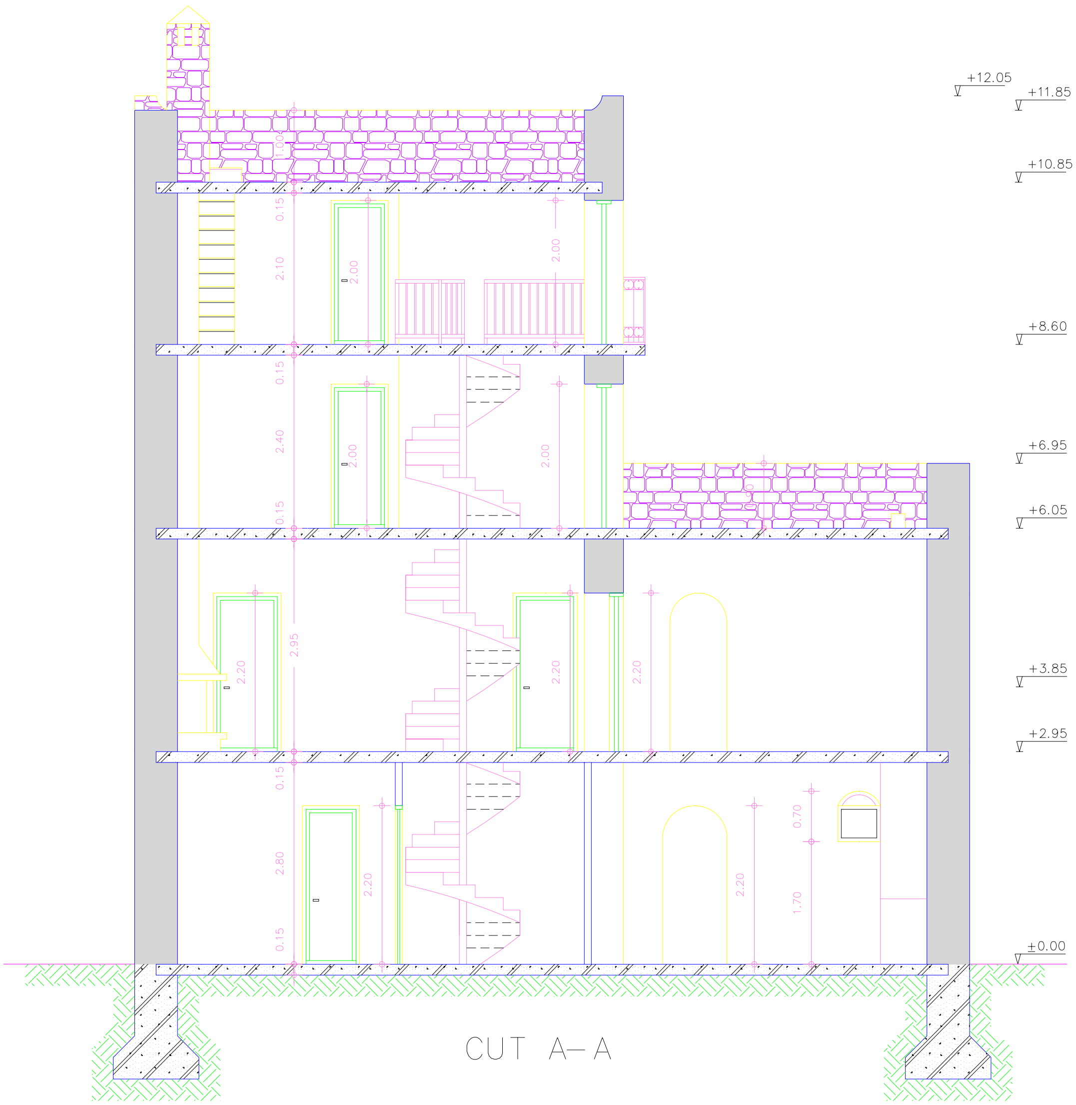
Mani, Hellas: www.mani.org.gr

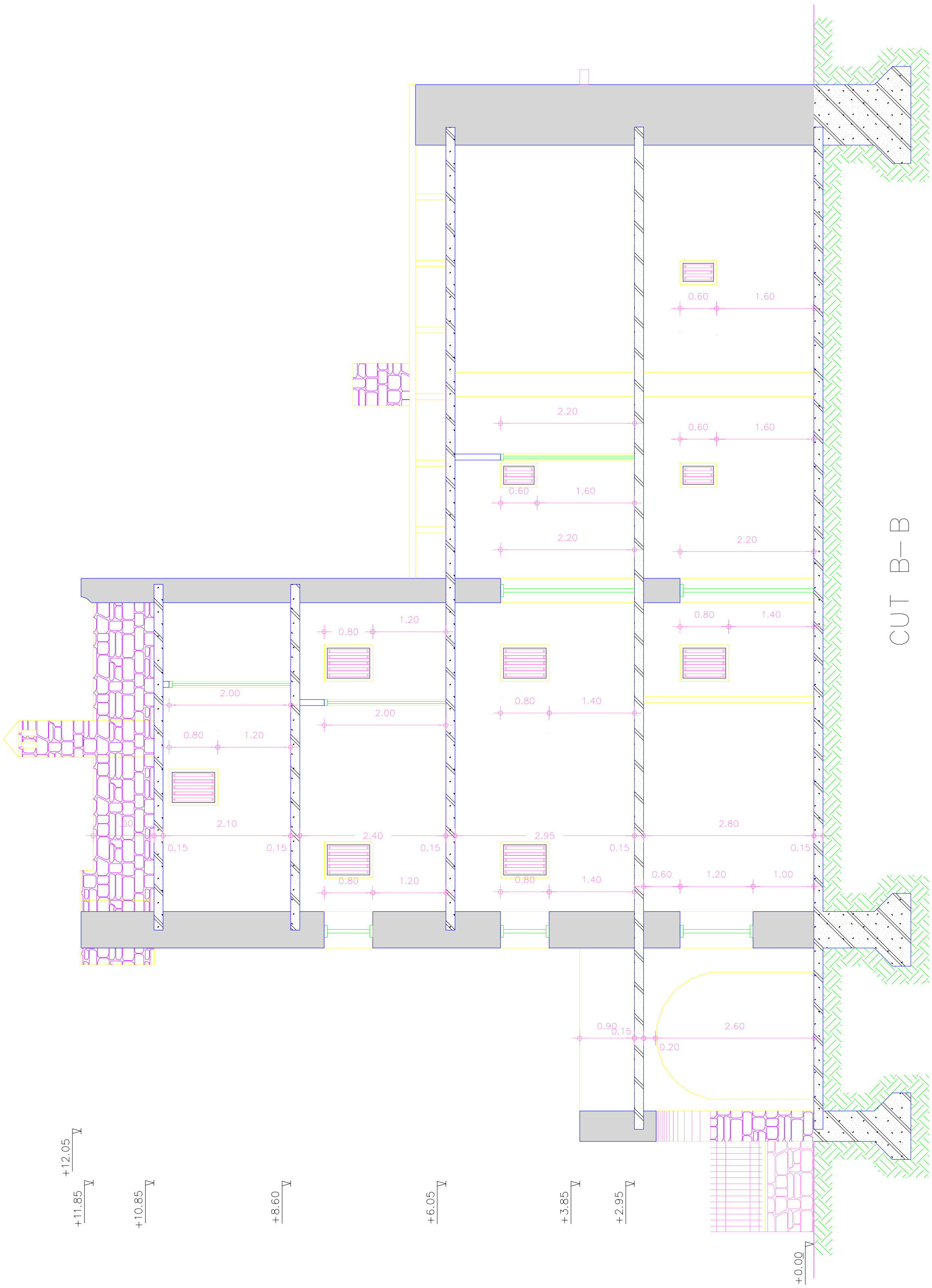
Dartmouth College:
http://projectsx.dartmouth.edu/classics/history/bronze_age/lessons/les/12.html

Context for Understanding Visual Art References and Resources:
http://www.noteaccess.com/APPROACHES/AGW/SanArchaeologicalS.html

Appendices

A.1 Mauroeidakos Tower architectural drawings

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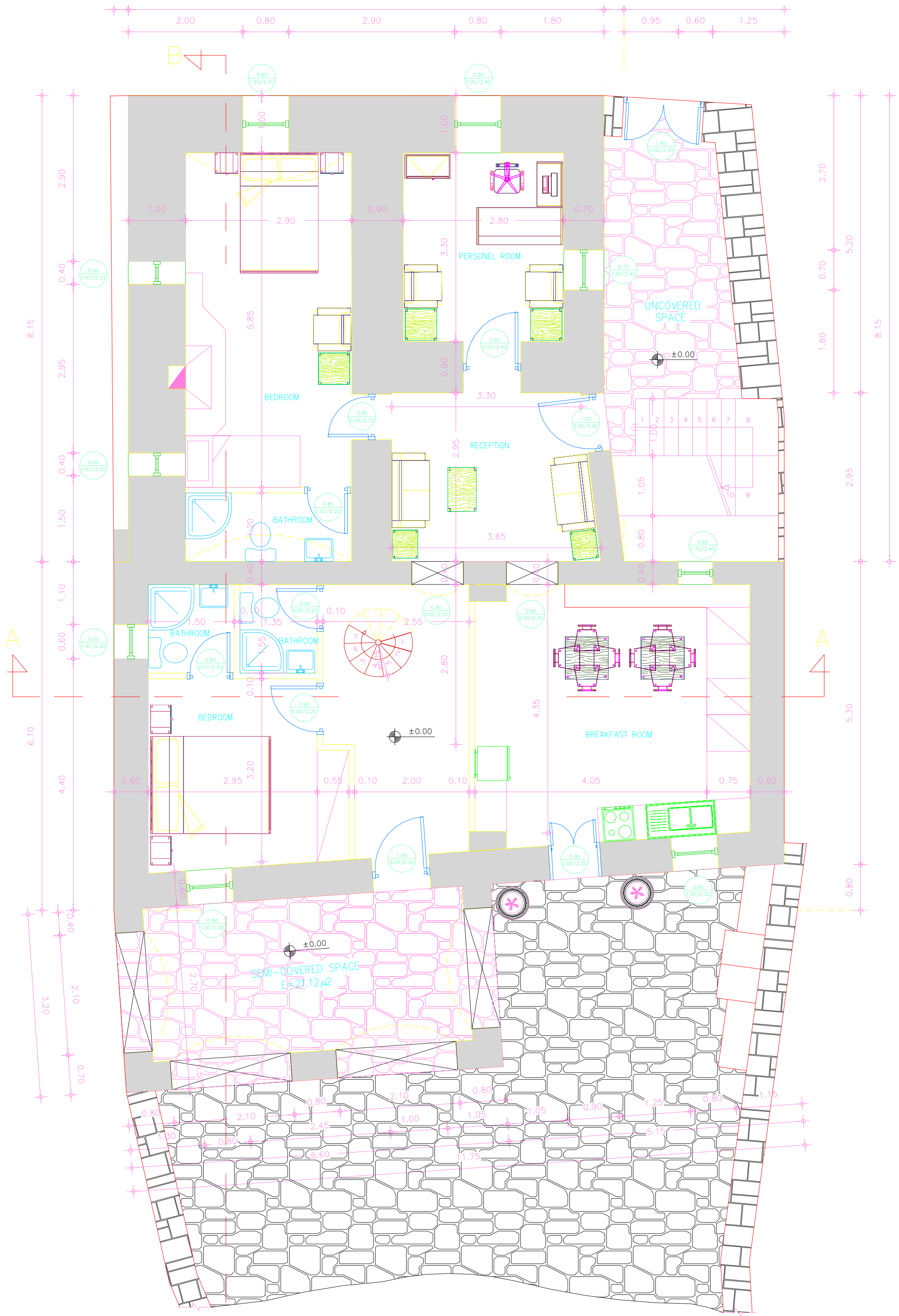


GROUND PLAN

1) GROUND SURFACE :

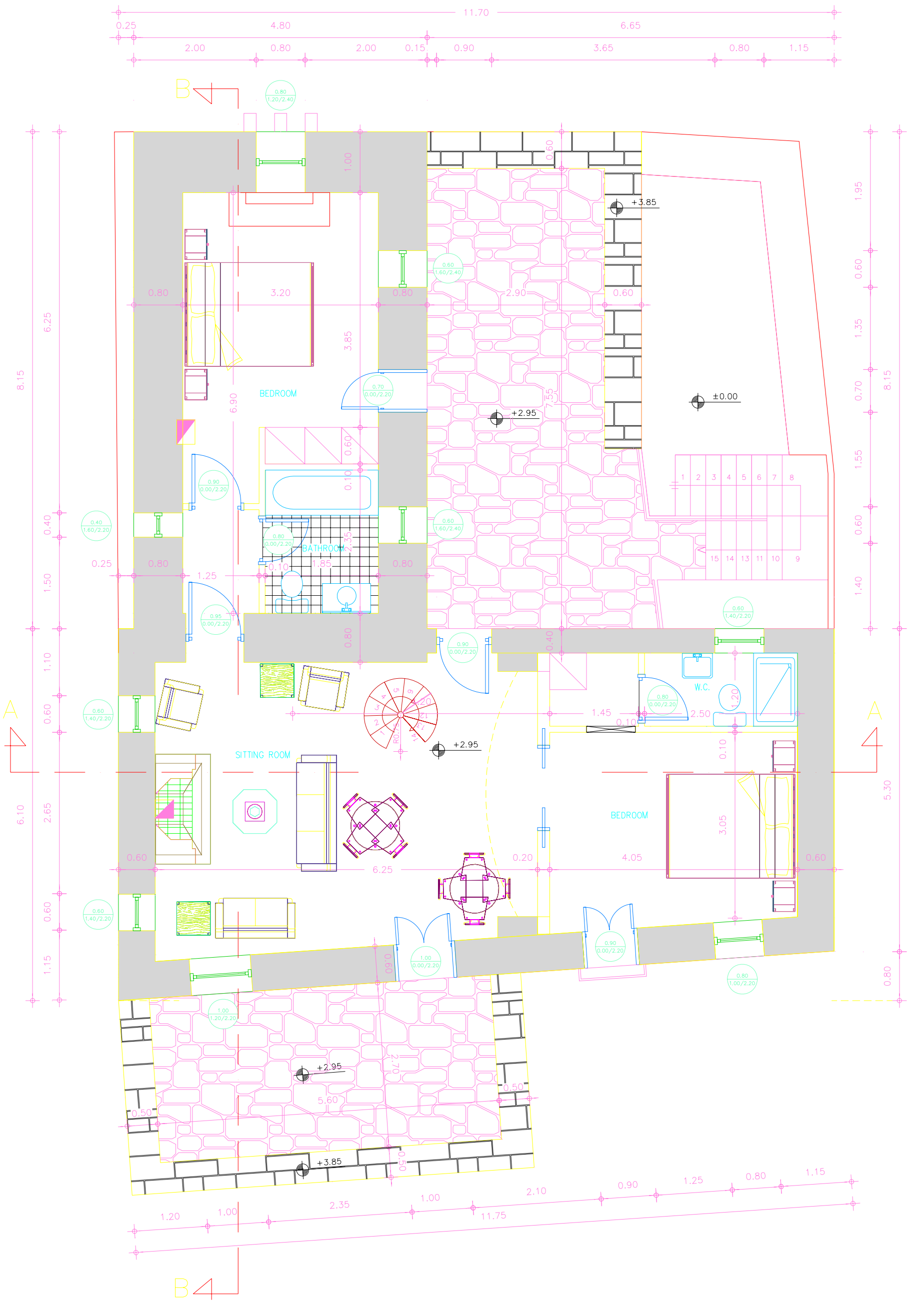
E=(5.30*11.70)+(0.80*11.70)/2+

+(8.15*8.30)+(0.35*2.95)/2=

=62.01+4.68+67.65+0.52=134.86m2

2) SEMI-COVERED SPACE SURFACE :

E=(3.20*6.60)=21.12m2



?' FLOOR PLAN

1) PLAN SURFACE :

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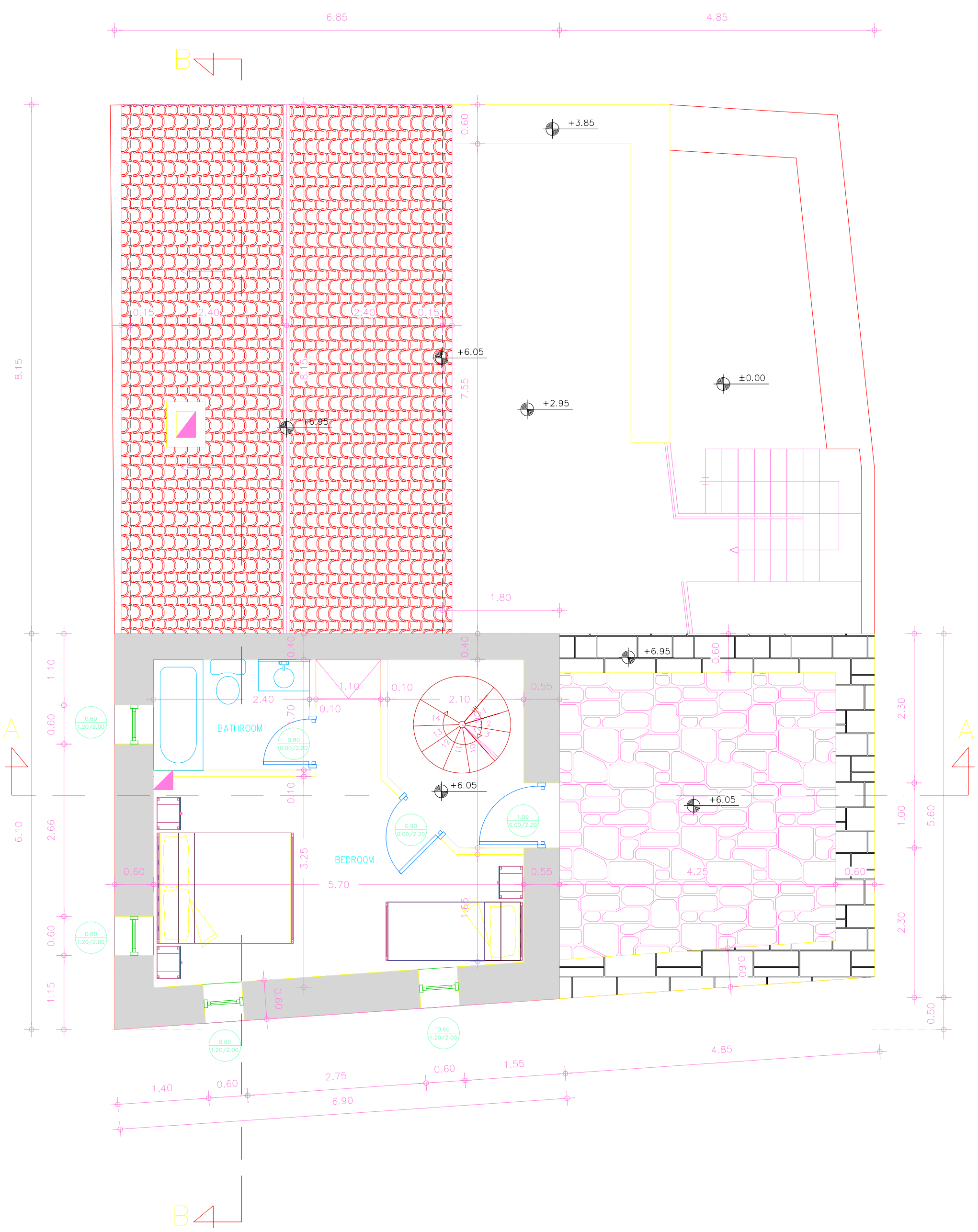
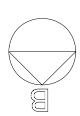
=62.01+4.68+39.12=105.81m2





B' FLOOR PLAN

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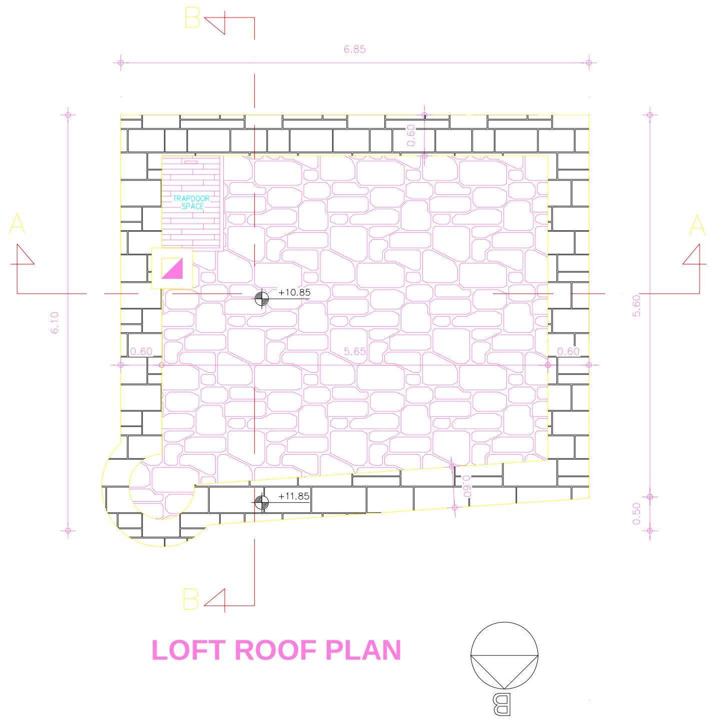
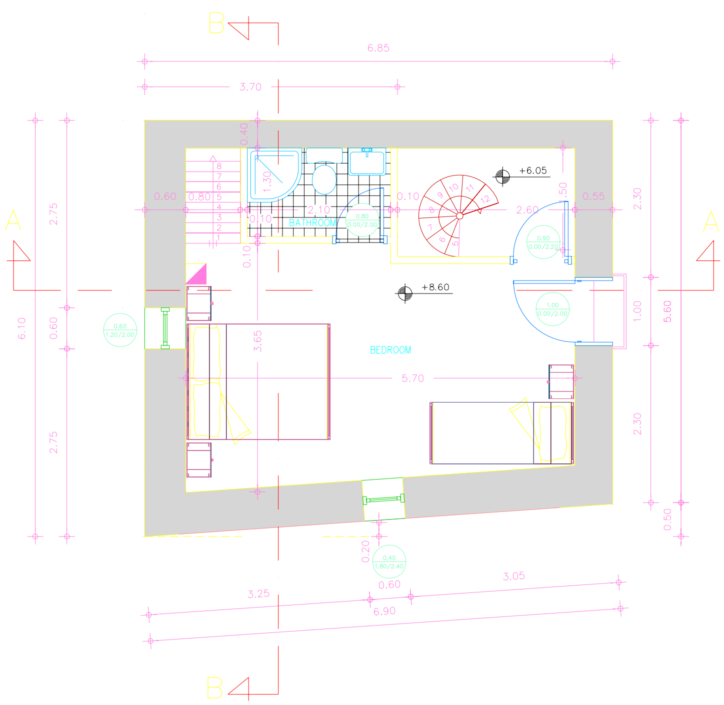
=38.36+1.70=40.06m2



LOFT ROOF PLAN



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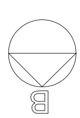

1) LOFT SURFACE:

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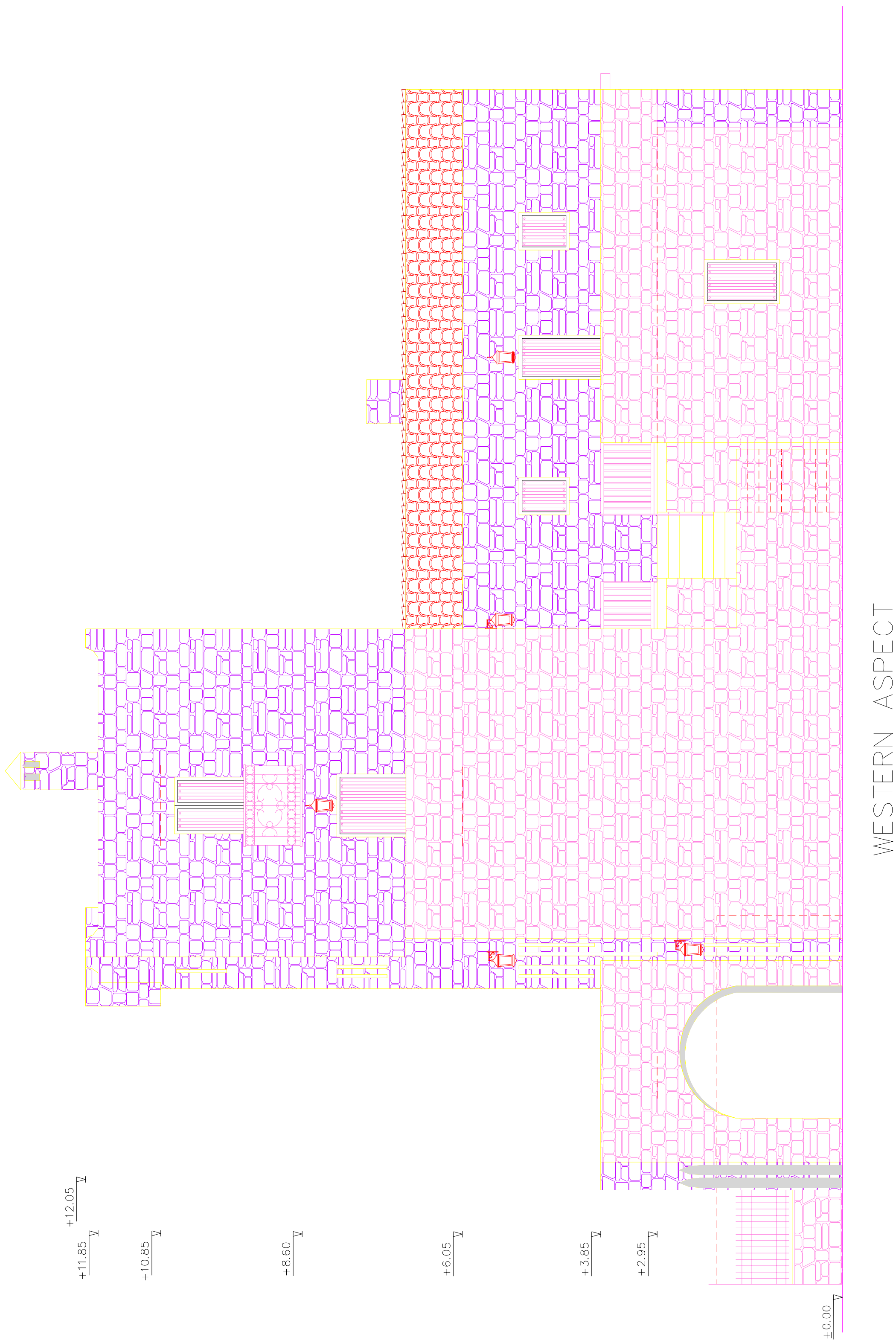
=38.36+1.70=40.06m2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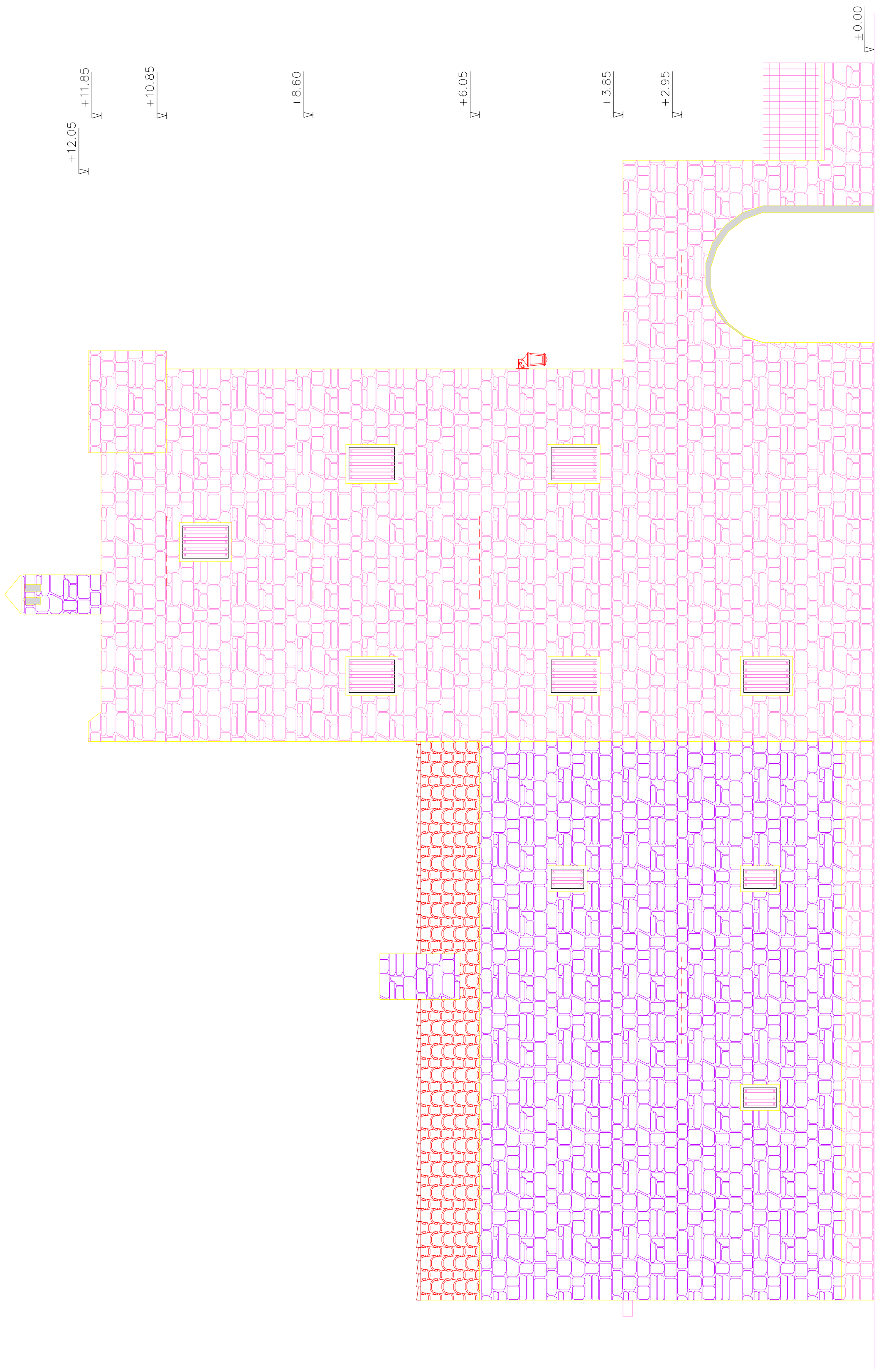
±0.00



EASTERN ASPECT

NORTHERN ASPECT

SOUTHERN ASPECT

A.2 Initial cost calculations for all energy simulation Alternatives

The prices that are given for the building materials in the tables are based on the study made by the Pan-Hellenic Association of Civil Engineers (*PACV; in Greek "ΠΕΔΜΕΔΕ"*) for the justification of market prices in Public Works. The prices for the electricity values are given from the Hellenic Public Power Corporation (*PPC; in Greek "ΔΕΗ"*).

Alternative 0

Construction type	Value	Mineral wool	Gypsum board	Cement board	2-glass compact	3-glass LE & gas	Total/type
	(-)	(4.17 EUR/m2)	(3.2 EUR/m2)	(7.63 EUR/m2)	(50 EUR/ piece)	(70 EUR/ piece)	(EUR)
External walls (m2)	405.01	-	-	-	-	-	0
Roof (m2)	39.12	-	-	-	-	-	0
Windows (piece)	24	-	-	-	1200	-	1200
							1200

Alternative 1

Construction type	Value	Mineral wool	Gypsum board	Cement board	2-glass compact	3-glass LE & gas	Total/type
	(-)	(4.17 EUR/m2)	(3.2 EUR/m2)	(7.63 EUR/m2)	(50 EUR/ piece)	(70 EUR/ piece)	(EUR)
External walls (m2)	405.01	-	-	-	-	-	0
Roof (m2)	39.12	163.13	125.18	298.49	-	-	586.8
Windows (piece)	24	-	-	-	1200	-	1200
							1786.8

Alternative 2

Construction type	Value	Mineral wool	Gypsum board	Cement board	2-glass compact	3-glass LE & gas	Total/type
	(-)	(4.17 EUR/m2)	(3.2 EUR/m2)	(7.63 EUR/m2)	(50 EUR/ piece)	(70 EUR/ piece)	(EUR)
External walls (m2)	405.01	1688.89	1296.03	-	-	-	2984.92
Roof (m2)	39.12	-	-	-	-	-	0
Windows (piece)	24	-	-	-	1200	-	1200
							4184.92

Alternative 3

Construction type	Value	Mineral wool	Gypsum board	Cement board	2-glass compact	3-glass LE & gas	Total/type
	(-)	(4.17 EUR/m2)	(3.2 EUR/m2)	(7.63 EUR/m2)	(50 EUR/ piece)	(70 EUR/ piece)	(EUR)
External walls (m2)	405.01	1688.89	1296.03	-	-	-	2984.92
Roof (m2)	39.12	163.13	125.18	298.49	-	-	586.8
Windows (piece)	24	-	-	-	1200	-	1200
							4771.72

Alternative 4

Construction type	Value	Mineral wool	Gypsum board	Cement board	2-glass compact	3-glass LE & gas	Total/type
	(-)	(4.17 EUR/m2)	(3.2 EUR/m2)	(7.63 EUR/m2)	(50 EUR/ piece)	(70 EUR/ piece)	(EUR)
External walls (m2)	405.01	1688.89	1296.03	-	-	-	2984.92
Roof (m2)	39.12	163.13	125.18	298.49	-	-	586.8
Windows (piece)	24	-	-	-	-	1680	1680
							5251.72

Alternative 5

Construction type	Value	Mineral wool	Gypsum board	Cement board	2-glass compact	3-glass LE & gas	Total/type
	(-)	(4.17 EUR/m2)	(3.2 EUR/m2)	(7.63 EUR/m2)	(50 EUR/ piece)	(70 EUR/ piece)	(EUR)
External walls (m2)	405.01	-	-	-	-	-	0
Roof (m2)	39.12	163.13	125.18	298.49	-	-	586.8
Windows (piece)	24	-	-	-	-	1680	1680
							2266.8

A.3 Law No. 3028/2002 on the protection of Antiquities and cultural heritage in General *(articles that are referred in the thesis)*

...

SECOND PART

INTERVENTIONS ON IMMOVABLE MONUMENTS AND THEIR SURROUNDINGS

Article 10

Activities on immovable monuments and their surroundings

1. Any activity on an immovable monument that may result directly or indirectly in its destruction, damage, pollution or disfigurement shall be prohibited.

2. The exploitation of quarries, the extraction of building material, the conduct of mineral exploration, the exploitation of mines as well as the designation of mining sites shall be prohibited without authorization by the Minister of Culture, following an opinion of the Council which shall be granted within three (3) months from the date of receipt at the Ministry of Culture of the application and the plans required by the legislation on minerals and mine:;. If the aforementioned time limit has elapsed, it shall be presumed that there are no prohibitive reasons, Authorization shall not be granted if, due to the distance from an immovable monument, the visual contact with it, the morphology of the ground and the nature of the activities for which authorization has been requested, the monument is threatened with direct or indirect damage.

3. The establishment or operation of an industrial, handicraft or commercial enterprise, the installation of telecommunications or other structures, the execution of any kind of technical or other work as well as building activity in the vicinity of an antiquity shall be permitted only upon authorization by the Minister of Culture, following an opinion of the Council. Authorization shall be granted if the distance from an immovable monument or the relationship with it is such that the monument is not threatened with direct or indirect damage due to the nature of the work or the type of business or the activity.

4. For any work, intervention or change of use of immovable monuments, even if the same does not result in any of the consequences referred to in paragraph 1, authorization shall be required pursuant to a decision of the Minister of Culture following an opinion of the Council.

5. In case of emergency and in order to prevent an immediate and serious danger, reparation work, provided that it does not disfigure the existing architectural, aesthetic and other related elements of the monument, may be undertaker, without the authorization required under paragraphs 3 and 4, after fully and promptly informing the Service, which in turn may stop the work upon providing notice thereon.

6. Where authorization is required pursuant to the preceding paragraphs, the same shall take precedence over all licenses issued by other authorities with respect to the businesses in question or the execution of the work and its particulars shall be recorded in these licenses upon penalty of nullity. Authorization shall be granted within three (3) months from the date of submission of the relevant application.

7. For the protection of immovable monuments, restrictions may be imposed on their use and function as well as on their building terms in derogation from existing provisions by a decision of the Minister of Culture, following an opinion of the Council.

8. By presidential decree, issued upon proposal by the Ministers of the Environment, Town Planning and Public Works, and Culture, following an opinion of the respective advisory bodies, special terms may be imposed on building and use for the purpose of protecting monuments.

Article 11

Duties of the owners, possessors or holders of immovable monuments

1. The owner, the possessor or the holder of an immovable monument or an immovable where an immovable antiquity is preserved, shall cooperate with the Service and follow its instructions for the preservation, enhancement and protection of the monument in general. He shall also allow periodic

or *ad hoc* inspection of the monument by the Service, following notification in writing and shall inform it without undue delay of every incident, which may endanger the monument.

2. The owner or the possessor of a monument shall be responsible for undertaking prompt conservation, consolidation or protection measures for a dilapidated monument without undue delay, at his own expense, under the supervision and instructions of the Service and in accordance with the provisions of articles 40 and 41. If the owner or the possessor takes no action, the holder shall be under the same duty and may turn against the owner or the possessor. If the Service considers that conservation or consolidation work has been delayed for any reason or has proved inadequate, it may take all the necessary measures, while reserving the right to recover the total amount or part of the expenses from the person liable in accordance with the provisions on the collection of public revenues. The State or local government agencies shall pa): the total amount or part of the expenses incurred for conservation, consolidation or other works for the protection of a monument which does not belong to them, provided that the expenses relate to a monument which has been determined to be accessible to the public by 21 decision of the Minister of Culture, following an opinion of the Council and exceed a reasonable amount of money, that the owner, the possessor or the holder shall not be responsible for the deterioration which the monument has suffered and the financial situation of the person liable does not allow him to defray the expenditure. In such a case, the owner, the possessor or the holder shall allow public access to the monument under certain conditions and for a time period to be specified by a decision of the Minister of Culture, following an opinion of the Council.

3. The owner, the possessor or the holder of an immovable monument or an immovable where an antiquity is preserved, shall facilitate its photography and study by the Service or by specialists who have been granted a relevant permit by the Service.

4. The provisions of the preceding paragraphs shall apply *mutatis mutandis* with respect to ther real property rights holders.

PART THREE

TERRITORIAL REGULATIONS

Article 12

Designation of archaeological sites

1. Archaeological sites shall be declared and designated or re-designated on the basis of data derived from archaeological research *in situ* by a decision of the Minister of Culture, issued following an opinion of the Council, accompanied by a topographic plan and jointly published in the *Official Gazette.*

2. If archaeological sites have not been designated within areas to be covered by pending General Town Plans or Territorial and Urban Organization of Open Cities Plans or other plans with territorial regulations, they shall be designated temporarily pursuant to a plan of a scale of at least 1:2000 prepared by the Service on the basis of adequate scientific data and in particular finds bearing witness to the existence of monuments, which shall be approved by the Minister of Culture by a decision published in the *Official Gazette.* The relevant act together with the plan shall be communicated to the competent authority within six (6) months from the date *of* receipt by the Service of the relevant request, and shall apply until the decision referred to in paragraph 1 has been issued.

3. lf there has been no delimitation of legally existing settlements, which is necessary for the application of articles 13, 14, 16 and 17, the Minister of Culture shall request the competent body, while sending the relevant plan, to proceed with absolute priority to the delimitation of the settlement to the extent that is necessary for the application of the aforementioned articles. Until this takes place, by a joint decision published in the *Official Gazette,* the Ministers of Culture, and Environment, Town Planning and Public Works shall delimit it temporarily to the extent above referred to and shall regulate any issue relating to the protection of the part of the archaeological site which falls within its temporary limits, such as suspension of building activities and issuing building licenses, or permissible activities.

4. The provisions of article 10, paragraphs 1 to *6,* apply *mutatis mutandis* to archaeological sites. Before issuing the decision referred to in paragraph 1, the opinion of the competent Minister *rarione materiae* shall be required for

existing activities falling under his competence, in order to determine whether and under which conditions they shall continue to operate within the context of article 10. This opinion shall be rendered within two (2) months from the day on which the relevant request was sent. If the aforementioned time limit has elapsed, the decision of the Minister of Culture shall be issued without this opinion.

Article 13

Archaeological sites; beyond settlements

Protection zones

1. In archaeological sites on land located beyond "city plans" or beyond the limits of legally existing settlements, agriculture, stock-breeding, hunting or other related activities as well as building activity may be carried out upon permit being granted by a decision of the Minister of Culture, following an opinion of the Council. The conditions for exercising agriculture, stock-breeding, hunting or other related activities may also be established normatively by a decision of the Minister of Culture.

2. Within the sites referred to in the preceding paragraph, an area may be designated, where building shall be totally prohibited *(Protection* Zone *A),* by a decision of the Minister of Culture, following an opinion of the Council and the conduct of a survey by some of its members or a committee composed of its members and specialists, accompanied by the relevant plan and jointly published in the *Official Gazette.* In this area, only the construction of edifices or additions to existing buildings may be allowed, where necessary for the enhancement of the monuments or sites as well as for facilitating their use, upon a decision of the Minister of Culture specifically justifying the *rationale* behind it, following an opinion of the Council. The same decision shall determine the location of the edifice within the zone or the part of the building where the addition shall be *made.* Within the sites referred to in paragraph 1, provided that they are extensive, an area may be designated by a decision of the Minister of Culture, following an opinion of the Council and the conduct: of a survey by its members or a committee established by it, accompanied by the relevant plan and published in the *Official Gazette,* in which or in a part of which special rules shall apply pursuant to tile joint decision referred to in the following section with respect to building terms, land use or permissible activities or all the aforementioned restrictions *(Protection Zone B).* A joint decision of the Minister of Culture and the *ad hoc* competent Minister, issued following an opinion of the respective advisory bodies, shall further determine special building terms, land uses, permissible activities, as well as the conditions under which the operation of existing legal activities may be continued. The joint decision shall be issued within three (3) months from the date that the Ministry of Culture sent the draft to the co-competent Ministries.

3. The limits of a protection zone may be re-designated by the same procedure on the basis of data derived from archaeological research and the conditions for the protection of archaeological sites or monuments. Immovable which contain visible antiquities and fall within a *Protection Zone A'*, shall be expropriated if they are subject to article 19, paragraph 3.

Article 14

Archaeological sites within settlements

Settlements constituting archaeological sites

1. In archaeological sites located within "city plans" or within the limits of legally existing active settlements, protection zones may be established in accordance with the provisions of article 13. In non-active settlements or in their parts which are located within "city plans" or within the limits of legally existing settlements which constitute archaeological sites, subject to the preceding section, it shall be prohibited to erect new buildings, while it shall be permitted to restore ruined edifices and to demolish 1 hose which have been characterized as dilapidated under the conditions provided for in paragraphs 2(b) and (c) of the present article respectively. In all other respects, the remaining provisions of paragraphs 2 , 3, 4 and *5* of this article shall be applicable.

2. In active settlements constituting archaeological sites or in their parts, any intervention impairing the character and the urban web of the buildings or disrupting the relationship between the buildings and open spaces shall be prohibited. Upon permit being granted by a decision of the Minister of Culture, following an opinion of the respective advisory body, it shall be allowed:

a) to erect new edifices provided that they are compatible in terms of size, structural material and function with the character of the settlement;

b) to restore ruined edifices provided that their original form can be established;

c) to demolish existing edifices provided that the character of the settlement shall not be impaired or that they have been characterized as dilapidated pursuant to the provisions of article 41 ;

d) to execute any kind of work on existing edifices, private unbuilt spaces and spaces of common use always taking into account the character of the settlements s an archaeological site;

e) to use an edifice and/or its free spaces, provided that such use **is** in harmony with their character and structure.

3. In case of emergency and to prevent an immediate danger, reparation work may be undertaken without the aforementioned permit after informing the Service, which in turn may stop the activities upon providing notice thereon.

4. The permit required under the preceding paragraph shall be issued prior to all licenses by other authorities relating to the execution of the work and, in any case, within sixty (60) days from the date of submission of the relevant application, its particulars being recorded, upon penalty of nullity, in these licenses. The permit for a change of use shall be issued within ten (10) days.

5. In the aforementioned archaeological sites, all activities and uses of the edifices and their free spaces or spaces of common use which are not in harmony with the character and structure of individual edifices or spaces or the settlement as a whole shall be prohibited. For the determination of the use of an edifice or its free space or space of common use a permit shall be granted by a decision of the Ministry of Culture, following an opinion of the Council.

6. Within archaeological sites which are active settlements, special rules shall apply with respect to restrictions to ownership, land use or use of buildings, building terms or permissible activities pursuant to a presidential decree, issued upon proposal by the Ministers of Culture, the Environment, Town Planning and Public Works and any other *ad hoc* co-competent Minister.

…

Article 16

Historical sites

Upon decision of the Minister of Culture, issued following an opinion of the Council, accompanied by a delimitation plan and jointly published in the Official Gazette, areas or combined works of man and nature pursuant to the more specific distinctions of article 2(d) shall be designated as historical sites. In historical sites, the provisions of articles 1 2, 1 3, 1 4 and 1 *5* shall apply mutatis mutandis.

Article 17

Protection zones around monuments

1. Around monuments, a *Protection Zone A'* may be established in accordance with article 13.

2. The designation of a site in an area beyond "city plans" or legally existing settlements as Zone A' shall entail its compulsory expropriation if its original use is suspended.

3. Around monuments, a Protected Zone B' may also be established in accordance with article 13.

…

SECOND PART

WORKS FOR THE PROTECT ION OF MONUMENTS

Article 40

Works on immovable monuments

1. Works on immovable monuments and in particular conservation, consolidation, restoration, anastylosis, interment, installation of protective sheds, landscape designing, as well as works directed at rehabilitation or re-use, shall aim at the preservation of their material existence and authenticity, their enhancement and protection in general. They shall be carried out pursuant to a study approved by the Service, following an opinion of the Council or, if the works are of major importance, by a decision of the Minister of Culture, following an opinion of the Council. For the approval of the study, prior documentation of the monumental character of the immovable shall be required.

2. Emergency conservation and consolidation work shall be carried out care of the Service without undue delay and without further formalities.

3. If the works referred to in the present article and in articles 41 and 42 are to be carried out by the Service, no building license shall be required.

4. The specific rules governing the elaboration of studies and the execution of works falling within the ambit of the present article shall be determined by a decision of the Minister of Culture. More specifically, they shall refer to recording, listing, documentation and survey of monuments, elaboration of the relevant architectural, structural and diagnostic studies, as well as studies for the preservation, protection, restoration, enhancement, management and the integrated use of monuments, application of quality control systems in conservation and restoration work and any other relative issue.

…

Article 43

Conservation works on monuments

1. Conservation works on movable monuments and on items of sculpture, paintings, decorations or other elements that form an integral part of immovable monuments, shall be carried out by the Service or by persons listed in the Registers of Conservators of Antiquities and Works of Art mentioned in article 9, paragraph 6 of Law 2557/1997 *(Official Gazette* A' *271)* under the supervision of the Service, pursuant to a study approved by it or, if it is; of primary importance, by a decision of the Minister of Culture, following an opinion of the Council. For the approval of the study, prior documentation of the monumental character of the movable or the immovable shall be required.

2. In case of emergency, conservation works shall be undertaken *in situ* by a conservator appointed by the Service without undue delay and within o further formalities.

3. The specific rules and principles governing the conservation works referred to in the previous paragraphs shall be determined by a decision of the Minister of Culture, following an opinion of the Council.

4. A decision of the Minister of Culture shall specify the terms and conditions for the establishment and operation of laboratories of conservation of antiquities and works of art.

Remarks

The Translation of the Greek Law 3028/2002 from the Greek language to the English one was held on Athens, the 17th September 2004 under Mr. Stelios Kondylis. All the document of the Law 3028/2002 translation is accessible through the website: http://www.culture.gr/8/index.html