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DIPLOMARBEIT

THERMAL BEHAVIOR OF VERNACULAR STONE BUILDINGS IN GREECE

ausgeführt zum Zwecke der Erlangung des akademischen Grades einer

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ABSTRACT

Vernacular architecture as developed in the region of mountainous Greece under numerous, long-term modifications and adjustments is believed to embody several design strategies that contribute to the construction of energy efficient buildings. The example of the stone made houses is claimed to integrate empirical techniques that are able to confront the Mediterranean climatic data and provide comfortable internal conditions. The research presented focused on the stone mansions in the region of Pelion in Greece and produced a systematic analysis and simulation of their indoor thermal conditions under different ventilation scenarios applied in energy analysis and thermal load simulation software.

Keywords

Vernacular stone mansion, thermal behavior, ventilation, thermal comfort

Contents

1. Introduction

1.1 Overview

Due to observed climatic changes and waste of energy resources, there is nowadays an intensive interest on environmental issues linked to the building sector and especially to the housing activity as it constitutes one of the main factors for the improvement of peoples' living conditions which can simultaneously negatively impact the environment because of uncontrolled energy consumption in order for the users to achieve internal delight.

In Greece the building sector-residential and tertiary - consumes about 34% of the country's energy resources (Figure 1.1.1) and most of it is used for covering heating and cooling demands. The energy derived from fossil fuels is responsible for 40% of CO_2 emissions to the atmosphere, and presents an annual growth rate of 4.5% (Karatsiori 2008). According to these data it is understood that the housing industry affects the global and local environmental conditions and depletes natural resources.

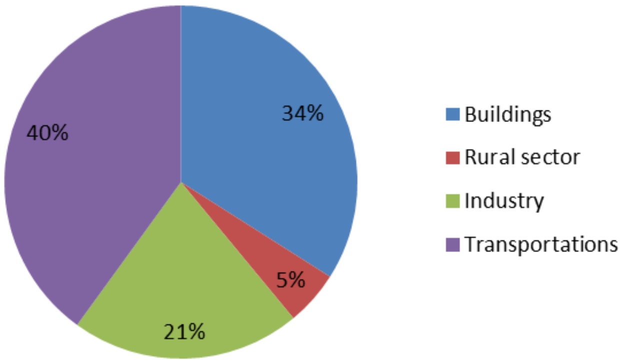


Figure 1.1.1: Distribution of Energy consumption in Greece. Source: YPEKA 2013.

A solution for the reduction of the negative impact from the construction and operation of buildings is the application of bioclimatic architecture principles. The use of local material resources and the involvement of geomorphological and climatological specific characteristics to the planning procedure are elements that may contribute to the insurance of internal thermal comfort with simultaneous minimization of energy consumption.

Traditional architecture worldwide provides numerous examples on the application of local data in the planning process with respect to the regional natural resources and climatic characteristics. Moreover, the fact that vernacular architecture evolved under the lack of technical means for the regulation of pleasant internal conditions indicates ways for the efficient function of a building.

In the Greek territory the stone made "Mansion House" as found in the region of Pelion reflects a complex vernacular residential structure which is nowadays believed to be able to integrate design features that can provide internal environmental delight. Therefore, after the completion of a detailed record of the structural elements and the functionality of this building type, the presented research focuses on computational simulations under specific residential and ventilation scenarios in order to examine whether the existing structures in their "passive" function can provide the user with a comfortable internal environment.

1.2 Research motivation

Vernacular architecture, which is not static but adapts to specific ways of living and exploits new technologies dependent on regional morphological peculiarities (Kalogirou and Sagia 2010), is believed to be a model of environmental - bioclimatic architecture. However, this hypothesis should not be considered as an axiom. The record of applied materials and the migratory living patterns which always characterize the use of these buildings (Sakarellou 2009) are not able to prove the assumption above. Further examination is necessary in order to define which vernacular features contribute to the achievement of internal thermal comfort and construction of sustainable buildings.

Under the assumption that the climate in the region of Pelion presents no great changes during the last century (Zerefos and Repapis 2011) the traditional-rural mansion of the 18^{th} century, whose structure is based only on natural, local resources and was built under the lack of improved mechanical techniques is the main objective of the presented research.

1.3 Research Outline

The aim of the presented research is to analyze the thermal behavior of the typical vernacular mansion as found in the mountainous region of Pelion in Greece and to determine if the applied features can become a source of technical knowledge for designing sustainable, ecological friendly buildings. The methodological approach is described in the following steps:

Step 1: Bibliographic survey and initial data evaluation

- A thorough literature investigation on information about building energy simulation software, Greek construction laws, climatic data, architectural characteristics of vernacular buildings, and relevant research studies was conducted and it is presented in chapter 1.4.

Step 2: Data Processing

The analysis was based on the following data:

- Climate data of the region
- Record of the sample buildings’ geometry and structure
- Physical properties of construction materials
- Information about the living habits of the users for the definition of operational scenarios
- Thermal comfort models

Step 3: Data input in appropriate software

- Simulation of the studied buildings by using appropriate energy performance software (Energy Plus)

Step 4: Results output

- Editing of data in Excel and Mat lab software.

Step 5: Data analysis

- Data analysis according to different comfort models.

1.4 Background

1.4.1 Overview

During the 18th century in the mountainous area of Pelion emerged the "Mansion House". It reflected the development of the trade in the construction activity and it was a symbol of power for the wealthier locals who regarded it as a suitable form of house for the protection of their property from raids and extreme weather conditions. The construction of mansions in the region lasted till to the 20th century when new legislations for buildings' seismic safety were introduced by the Greek State and declared the creation of buildings only by local-natural materials such as stone, clay and wood inappropriate.

To date there is extended research on the typology of structures appearing in Greek traditional settlements focusing on the historical, cultural and sociological facts that affected the development of this architecture and specific record of the structural characteristics of stone building envelops in mountainous regions (Kizis 1994). These studies are supplemented by assessments of the thermal properties of natural construction materials (Theocharopoulos 2009), while the study of their thermal behavior remains relatively unknown.

Assuming this building type is a characteristic example of the Greek vernacular architecture, a study of the regional geomorphology and microclimate in addition to a detailed record of the evolution of the mansions is made.

1.4.2 Geographic description of the region of study

Morphologically, Magnesia prefecture is divided into three sections: the mountainous region that covers 44.7% of the total area, the semi-mountainous region and the lowland. The mountainous part is formed of Pelion and Othris ranges, whereas the hilly areas with an average altitude of 200 to 800 meters are divided into croplands, pastures and to a limited extent in forests and residential areas (Figure1.4.2.1).

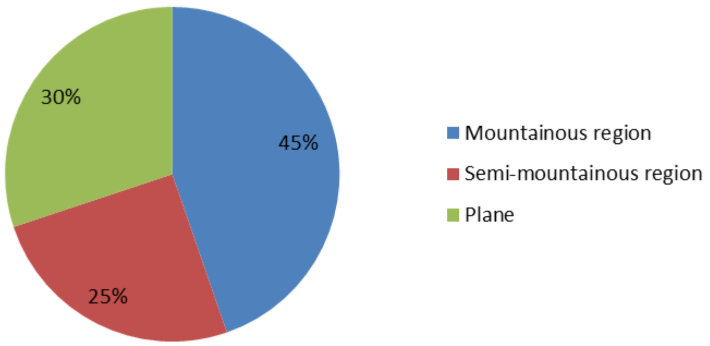


Figure 1.4.2.1: Ground morphology of Prefecture of Magnesia. Source: HSWMA 2013.

Mount Pelion is an L shaped peninsula which extends along the Aegean coastline of Magnesia (Figure 1.4.2.2). From northwest to southeast, mountain's length is approximately 44 km whereas the width varies from 10 km to the south to 25 km to the north part. The base of the peninsula turns in a right angle due to the west site of Pagasitikos Gulf. The main bulk of the mountain is in the north. Both the eastern and the western slopes are quite steep and the highest peak is at an altitude of 1.624 m. (5.354 ft.). Towards the south, altitude decreases and the slopes become gentler (Fotiadis 2010).

Figure 1.4.2.2: 3D Satellite view of Mount Pelion, Greece. Source: Nasa visible earth 2013. Makrinitsa village is marked with a red dot.

The presented research took place in the village of Makrinitsa, located in the northwest part of mountain Pelion, 6 km northeast of Volos. Its elevation is from 250 (820 ft.) to 550 m (1.804 ft.) as the settlement is developed by following the rapid elevation of the mountain. According to the population census of 2001 it has 898 residents. The first settlement was built during the 13^{th} century, evolved over the centuries and in the last years of Ottoman rule became one of the most important trade centers in Greece. As a result, construction flourished in the region and numerous public and residential buildings characteristic of vernacular Greek architecture appeared.

1.4.3 Climatic conditions in the region of study

The climate in the Prefecture of Magnesia presents several local variations because of the unique geomorphological characteristics of the region, but generally is characterized as predominantly Mediterranean. In the region of mountainous Pelion it is characterized by hot, relatively dry summers and mild winters. The bio climate dependent of the increasing altitude, varies from light middle-Mediterranean to Sub-Mediterranean (Fotiadis 2010).

The lowest temperature recorded in 2012 for the settlement of Makrinitsa was -3.5^{o}C in January and the maximum temperature was 35.8 ^{o}C in July. The highest rainfall event was recorded in February whereas in summer there was imperceptible precipitation. Wind direction was mostly SSW and SSE and is related to the placement of the village and the multifarious relief.

1.4.4 Historic evolution of the mansion house

The mansion house was established as a common type of building in the region of Pelion in the mid-18th to mid-19th century, when the area came to an economic and cultural acme. The resultant emergence of the bourgeoisie influenced the local construction industry as their needs for habitation, home handicraft, social promotion and protection led to the creation of mansion houses, which combined the rural building models with the urban architectural standards of the time. The old tower house of the 17th century which was the fortified residence of the Turkish landlords and it was characterized by solid, stone built trunk, very few windows, small lintels in the upper floor and simple interior organization (Kizis 1994) evolved to the mansion house of the age of Enlightenment (Figure 1.4.4.1).

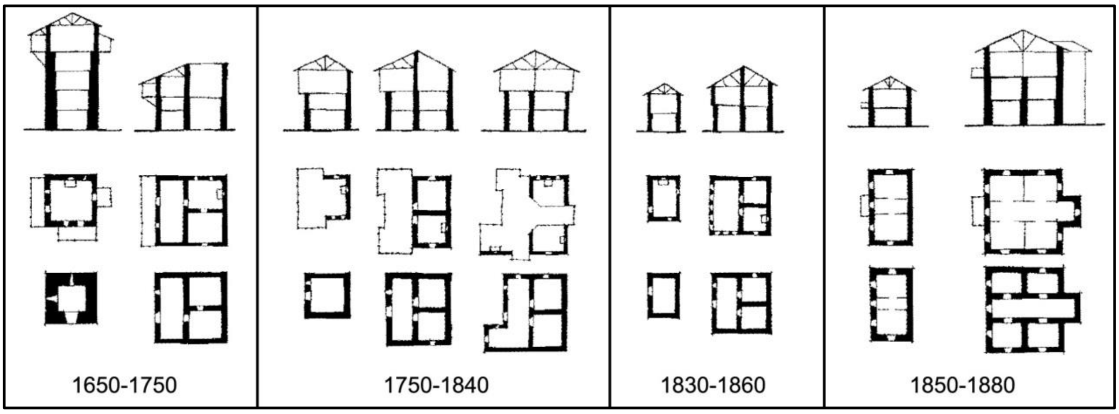


Figure 1.4.4.1: The typological evolution of the architectural from of the Mansion house in Pelion, Greece. Source: Kízis 1994

1.4.5 Architectural structure of the typical mansion

The mansion house maintained its fortified character through the tumor formation, by placing a ladder inside the building and by elevating the main living area on the first floor which gave to the occupants the ability to use the ground floor as a storage room.

These buildings were separated to 'outside' and 'inside' house, as they were deployed in zonal arrangement with private enclosed spaces involving the bedrooms, and food warehouses and semi transitional areas such as the staircase and the hayat (living room) which were the public spaces (Kizis 1994). Most of them were two or three story buildings and their plans formed L or Π- shapes.

The layout of the ground and first floor was the same. These two levels were characterized by a ‘rigorous’, minimal geometry, the openings were limited and the solid walls were made of rubble masonry (Baker 2011). The entrance hall and the living room were placed in the public zone, whereas the private zone included the bedrooms. These two levels were areas of main activity for the occupants and they were heated by open fireplaces in the bedrooms and wood stoves in the public zones (Sakarellou 2009).

The upper floor presented an architectural compositional freedom not only in the design but also in the way that it was built. The northern part was constructed again by rubble masonry whereas the south facade was a wooden bearing lightweight structure extended out of the prism and functioned as an enclosed perimeter balcony (saxnisi). It was mainly used for sericulture because of the numerous openings which offered to the user a chance to adjust the internal conditions without the use of heating or cooling systems.

The roof of the described buildings was composed of oak frame covered with schistose plates. It was extended out of the perimetric boundaries of the last floor and in this way it could also protect the vulnerable envelope from excessive sun gain, rainfall, and snowfall (Kizis 1994).

Another common feature of the mansion houses was their positioning and orientation. The local geomorphological characteristics, the microclimate and the need for protection from raids imposed specific restrictions on placing these buildings. They were constructed in naturally safe areas and their floor plan was crowned to specific orientation in order to protect them from cold drafts and to achieve the maximum solar gains. As a result most of these houses had “blind” sides to the north-northeast and perforated sides to the south and west.

2. Research methodology

2.1 Overview

The traditional stone mansions found in mountainous regions in central Greece are the main objective of this research. The sample set constitutes of “Chatzikosta mansion” in its initial and renovated form, whose documentation includes architectural drawings and a detailed list of the construction materials. In order to simulate the thermal behavior of the selected structure we reconstructed two and three dimensional digital models, defined the layout of the building (orientation in relation to sun and wind, aspect ratio), the spacing (site planning), the air movement and the openings (Vissilia 2008).

In addition, the internal spaces were divided into thermal zones according to their function and the floor plan arrangement; all the energy parameters were assumed to be constant over the zone. The climatic data of the region were extracted from Meteonorm v7.0 for year 2012.

The simulation was performed through Energy Plus software under the application of dwelling scenarios based on descriptions for the operation of these houses during the 18th century.

2.2 Sample buildings description

2.2.1 Mansion Chatzikosta, Makrinitsa, 37011 Pelion, Greece (initial form)

The initial model of the mansion will be referred to as C_I model.

- **General description**

This three story mansion built in 1896, is located in Makrinitsa with coordinates 22o 59' 12.28" E, 39o 24' 08.88" N and altitude 290m. Its floor plan is L shaped and the main facade has south-east orientation, while its total gross floor area is 184m^2. In its initial form the ground floor hosts the entrance hall and two storage rooms, whereas the living room and two bedrooms are placed in the first floor. Finally, the upper floor of the building which follows also the L shaped plan extended 40 cm beyond the perimeter of the prism to the south hosts an in-house workshop for silk production (Figure 2.2.1.1).

Figure 2.2.1.1a and b: External view before the renovation and living room of Chatzikosta mansion. Source: Stylianou 1992

The 3D model used for the simulation procedure is based on the initial architectural form of the building. It was created in Sketch Up software in combination with the Open studio Plug in (Open studio is a cross-platform collection of software tools to support whole building energy modeling using Energy Plus).

- **architectural plans and separation in zones**

Following the typical mansion architectural form the sample building is divided to 'outside' and 'inside' zones. This initial division was the basis for further separation of the structure to south (living) and north (sleeping) zones for the simulation (Figures 2.2.1.2 and 2.2.1.3). Each zone has independent internal climatic parameters, individual applied heating system and is expected to develop the same temperature in its entirety.

In this research we will focus on the first floor of the mansion as it hosts the main living and sleeping areas of the building.

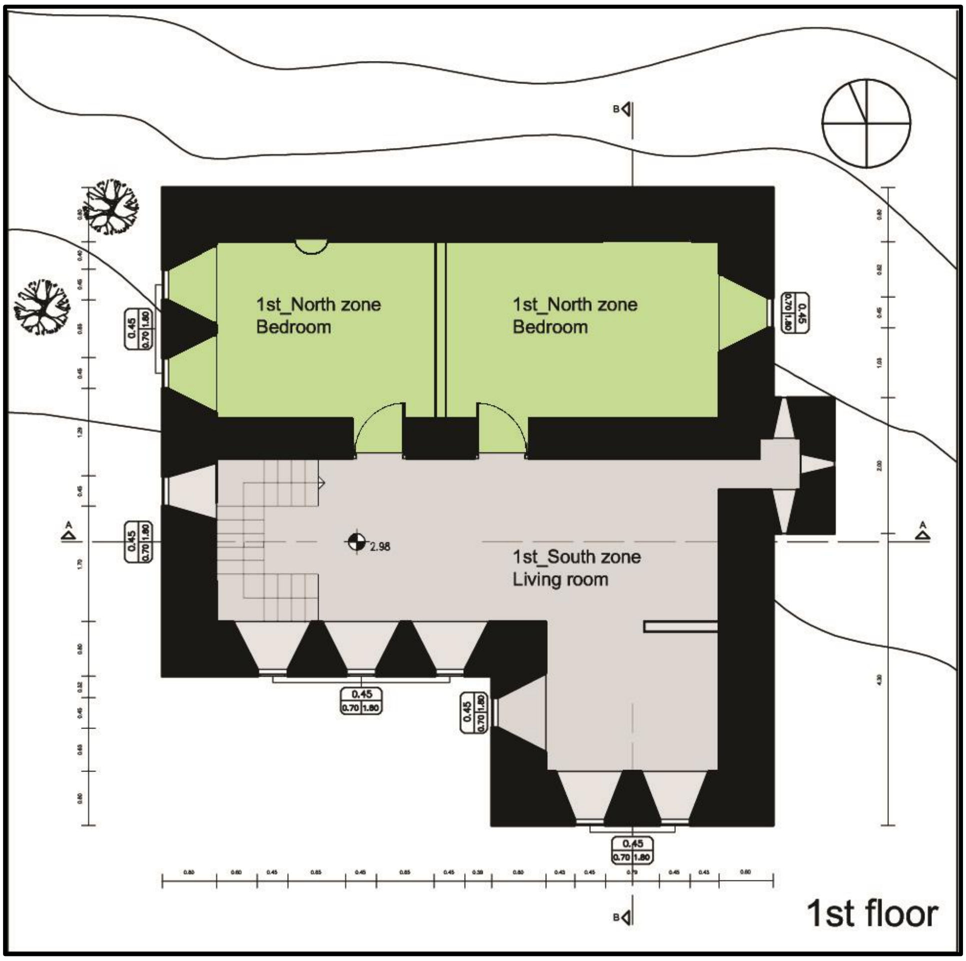


Figure 2.2.1.2: Floor plan of Chatzikosta mansion. Source of plan: designed by the author

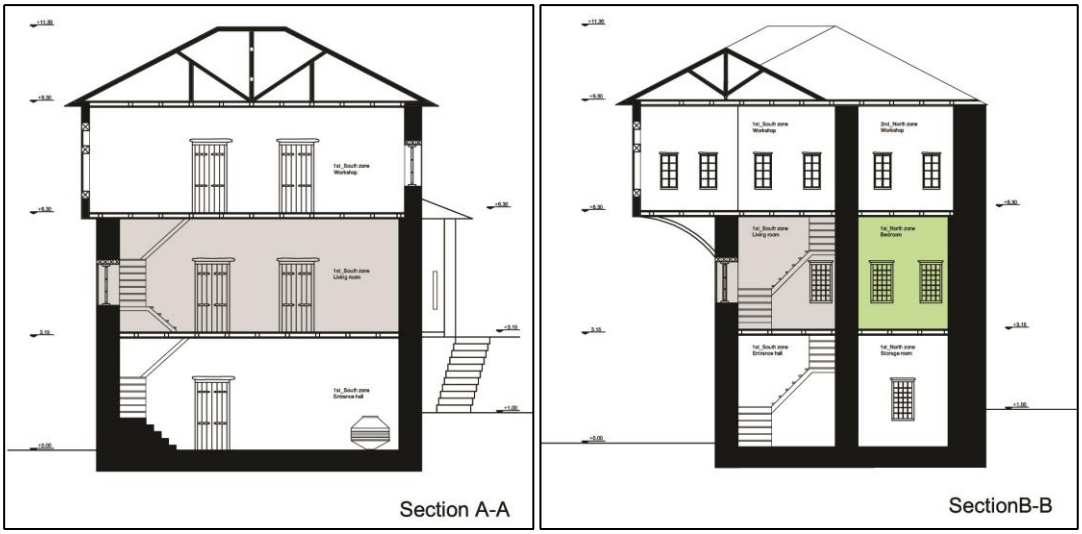


Figure 2.2.1.3a, b: Section A-A and B-B of Chatzikosta mansion. Source of plans: designed by the author

- **Structural documentation**

Transparent building elements:

The windows placed in the ground and first floor have dimensions 0.45x 0.95m and in the second floor 0.55x0.95m. Both of them are of oak frame and crown glass.

The U Value given to the whole window structure (glass and wooden frame) is $4.3Wm^{-2}K^{-1}$ based on the proposed U-Values of the English Heritage Organization (Wood 2009).

Opaque building elements:

The structural documentation in Table 2.2.1.1 stratifies the materials used for the construction of the mansion.

Table 2.2.1.1: Simulated materials of Chatzikosta mansion (C_I)

			Physical properties of simulated materials		
Building element	**Construction Materials**	**Thickness (m)**	**Density ($Kg \cdot m^{-3}$)**	**Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)**	**Specific heat ($J \cdot kg^{-1} \cdot K^{-1}$)**
External wall_ Stone masonry	Lime plaster mixed with wool fibers	0.025	1600	0.45	1000 (2)
	Limestone bedded in mud mortar	0.65	2200	1.7	1000(2)
	Lime plaster	0.025	1600	0.80	1000(1)
External wall _ Bagdati	Lime plaster	0.020	1600	0.80	1000(1)
	Wooden battens	0.020	700	0.18	1600(2)
	Mud	0.070	1500	1.5	2085(2)
	Wooden battens	0.020	700	0.18	1600(2)
	Lime plaster	0.020	1600	0.80	1000(1)
Internal wall	Lime plaster	0.25	1600	0.80	1000(1)
	Reed	0.10	250	0.05	1000(2)
	Lime plaster	0.25	1600	0.80	1000(1)
Ground floor	Marble plates	0.10	2800	3.35	1000(2)
Middle floor	Wooden plates (oak)	0.10	700	0.18	1600(2)
Roof	Schistose plates	0.03	2545	2.11	760(2)
	Mud	0.02	1500	1.5	2085(2)
	Wooden plates	0.03	700	0.18	1600(2)
Window frame and shutter	Wood (oak)	0.03	700	0.18	1600(2)
Internal &external doors	Wood (oak)	0.03	700	0.18	1600 (2)

Source: 1: Androutsopoulos 2010, 2: Papadopoulos 2000.

2.2.2 Renovation of Mansion Chatzikosta (renovated form)

The renovated model of the mansion will be referred to as C_R model.

After 1960 the owners of the building decided to restore its structural failures in order to make it a modern house that can cover their needs. The restoration program maintained the mansion in its original architectural and structural form and the materials used were from local sources as in the initial design. The reconstruction works repaired the damages of the bearing structure and ensured the static integrity with materials that closely resembled to the original.

The energy upgrade of the building was also an objective of the renovation. The task was to increase the heat gains and the reduction of the thermal losses in order to create thermal comfort conditions with the least possible involvement of energy-intensive mechanical systems.

The technical interventions that were applied in order to improve the thermal behavior of the reformed building related to the:

- Internal insulation of perimetric walls
- Replacement of the windows
- Thermal insulation of the roof
- Installation of exterior louvered shutters

- **Structural documentation after the restoration**

Transparent building elements:

The single glazed old windows are substituted from double glazing air filled (16mm gap) with wooden frame which have U-Value $2.7 Wm^{-2} K^{-1}$ as given from the producer.

Opaque building elements:

The opaque building elements are restored and stratified as shown in Table 2.2.2.1.

Table 2.2.2.1: Simulated materials of renovated Chatzikosta mansion (C_R)

			Physical properties of simulated materials		
Building element	**Construction Materials**	**Thickness (m)**	**Density ($Kg \cdot m^{-3}$)**	**Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)**	**Specific heat ($J \cdot kg^{-1} \cdot K^{-1}$)**
External wall_ Stone masonry	Lime plaster mixed with wool fibers	0.025	1600	0.45	1000(1)
	Limestone bedded in mud mortar	0.65	2200	1.7	1000(2)
	Mineral wool	0.08	40	0.040	840(1)
	Gypsum board	0.015	700	0.21	1000(1)
External wall _ Bagdati	Stucco plaster	0.018	800	0.16	840(1)
	Wooden battens	0.020	700	0.18	1600(2)
	Mud	0.070	1500	1.5	2085(2)
	Wooden battens	0.020	700	0.18	1600(2)
	Mineral wool	0.08	40	0.040	840(1)
	Gypsum board	0.015	700	0.21	1000(1)
Internal wall	Lime plaster	0.25	1600	0.80	1000(1)
	Reed	0.10	250	0.05	1000(2)
	Lime plaster	0.25	1600	0.80	1000(1)
Ground floor	Marble plates	0.10	2800	3.35	1000(2)
Middle floor	Wooden plates (oak)	0.03	700	0.18	1600(1)
	Rockwool	0.10	125	0.045	850(2)
	Wooden plates (oak)	0.03	700	0.18	1600(2)
Roof	Schistose plates	0.03	2545	2.11	760(2)
	Mud	0.02	1500	1.5	2085(2)
	Wooden plates	0.03	700	0.18	1600(2)
	Mineral wool board	0.1	40	0.040	840(1)

	Wooden plates(oak)	0.03	700	0.18	1600[(2)]
Window frame and shutter	Wood (oak)	0.03	700	0.18	1600[(2)]
Internal &external doors	Wood (oak)	0.03	700	0.18	1600 [(2)]

Source: 1: Androutsopoulos 2010, 2: Papadopoulos 2000.

2.3 Selection of the simulation tool

For the study of the internal conditions in the sample mansion, an hourly based simulation procedure through the use of Energy Plus software version 8.0.0 was applied. Energy Plus is a dynamic energy analysis and thermal load simulation software (Crawley et al. 2000). Based on the user's description of the building's physical make-up and associated mechanical systems, the heating loads necessary for the maintenance of thermal values during the winter period and the mean hourly internal temperature and relative humidity during summer are calculated.

The Energy Plus simulation followed the presented steps:

- Creation of an approximate 3D model of the sample buildings in Sketch Up software
- Materials' assignment to the models
- Division of the sample buildings in zones according to functionality
- Definition of the operational scenarios
- Selection and integration of weather data into the simulated model
- Extraction of hourly values of internal climatic parameters such as temperature and relative humidity

2.4 Operational scenario

The energy efficiency study required the application of operational scenario (Figure 2.4.1) in the simulation tool. The scenario followed in both sample buildings is based on descriptions about the living habits of the users. The assumptions made are:

- Both models (C_I and C_R) are used for domestic purposes and they are occupied during the whole year.
- There is no application of mechanical ventilation and air conditioning system.
- The shutters of the mansions during winter are in fully open position whereas during summer are remaining constantly closed.
- The dormers of the mansions are fixed glazed elements and as a result they are remaining constantly closed.
- The external and internal doors are considered as being constantly closed.
- The area studied is occupied by 4 people
- The internal occupancy sensible gains are considered to be 80 W/person.
- The lighting gains are considered to be $3.6Wm^{-2}$.
- Winter scenario from October to April.
- Summer scenario from May to September.

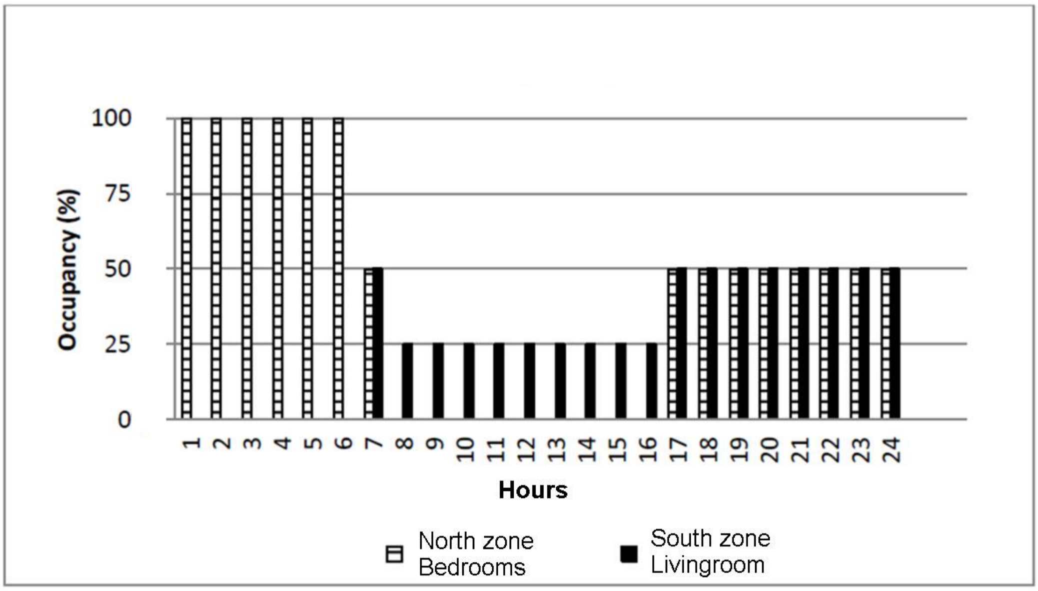


Figure 2.4.1: Operational schedule definition 24 hours

2.5 Ventilation scenario

In the sample mansion with no mechanical ventilation system, the exploiting of natural forces (created by temperature differences between the interior and exterior environment) and the winds are the main mechanisms for the adjustment and regulation of the internal conditions through the opening of the windows and doors.

For the conduction of this research the infiltration and ventilation scenarios defined for the building in its initial and renovated form are shown in Table 2.5.1:

Table 2.5.1: Ventilation and Infiltration values definition

Scenario		Factor	Daytime (08:00-22:00)	Nighttime (22:00-08:00)
Winter (October-April)	W1	Infiltration	0.6 h^{-1}	0.6 h^{-1}
		Ventilation	0.4 h^{-1}	-
Summer (May-September)		Infiltration	0.6 h^{-1}	0.6 h^{-1}
	S1	Ventilation	0.4 h^{-1}	0.4 h^{-1}
	S2	Ventilation	0.4 h^{-1}	2 h^{-1}
	S3	Ventilation	2 h^{-1}	2 h^{-1}
	S4	Ventilation	0.4 h^{-1}	8 h^{-1}

2.6 Mechanical heating system

In the sample buildings a hypothetical mechanical heating system of unlimited power is applied in the Energy Plus software, in order to calculate the energy demand which ensures comfortable thermal conditions by covering the difference of the indoor air temperature and the desired temperature for every month. The heating system operates from October to April is installed in all areas of the mansion except form the roof and the desired temperature is set at 20^{o}C.

2.7 Climatic data

2.7.1 Meteonorm v.7.0 function description

In order for Energy Plus to extract as accurate results as possible the mean hourly values of different outdoor climatic parameters are necessary. These values are extracted through the use of software for meteorological references Meteonorm v.7.0 of Meteotest for 2012.

The function of this program is based on the combination of numerous databases and computational models. The results consist of preexisting national and international climatic data, the recorded values of 8300 weather stations worldwide and data on solar radiation originating from satellites.

The accuracy of these generated data depends on the accuracy of the used stations' measurements, the distance to the next stations and the interpolation method (Botpaev et al. 2008). In the handbook of Meteonorm v7.0 as edited by METEOTEST it is mentioned that there are certain inconsistencies in the simulated results. The root mean square error in interpolating monthly radiation values and temperature is estimated to be 7 %, and 1.2°C respectively. There is an overestimate of the total radiation of inclined surfaces by 0–3 % (depending on the model) and the discrepancy compared to measured values is ±10 % for individual months and ±6 % for yearly sums (Remund et al. 2013).

2.7.2 Generated data from Meteonorm v.7.0

After applying the coordinates of Mekrinitsa village (22o 59' 12.28" E, 39o 24' 08.88" N and altitude 290m) in Meteonorm software v.7.0 we obtained data for the following values:

- **Outside temperature**

For the description of the climate conditions of the region one of the most important parameters that should be taken into consideration is the outside temperature. Figure 2.7.2.1 which was created after the analysis of the values exported by Meteonorm software gives us information for the mean monthly temperatures during the whole year and the minimum and maximum values recorded.

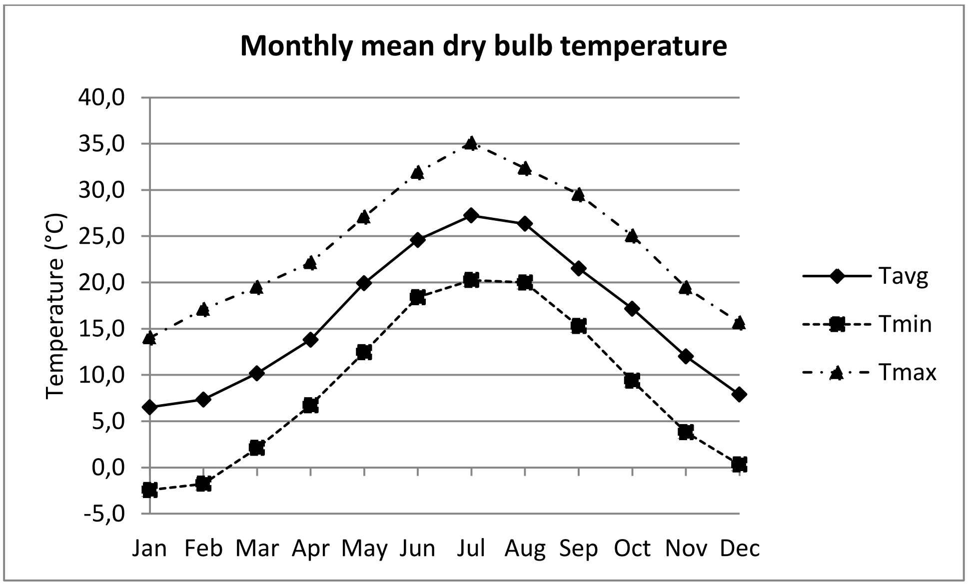


Figure 2.7.2.1: Mean monthly dry bulb temperature. Source: Meteonorm 2013

- **Relative humidity**

In Figure 2.7.2.2 the mean monthly values of outdoor relative humidity are presented. In December and January relative humidity ranges from 78% to 80%, whereas in July it reaches its minimum at 50%.

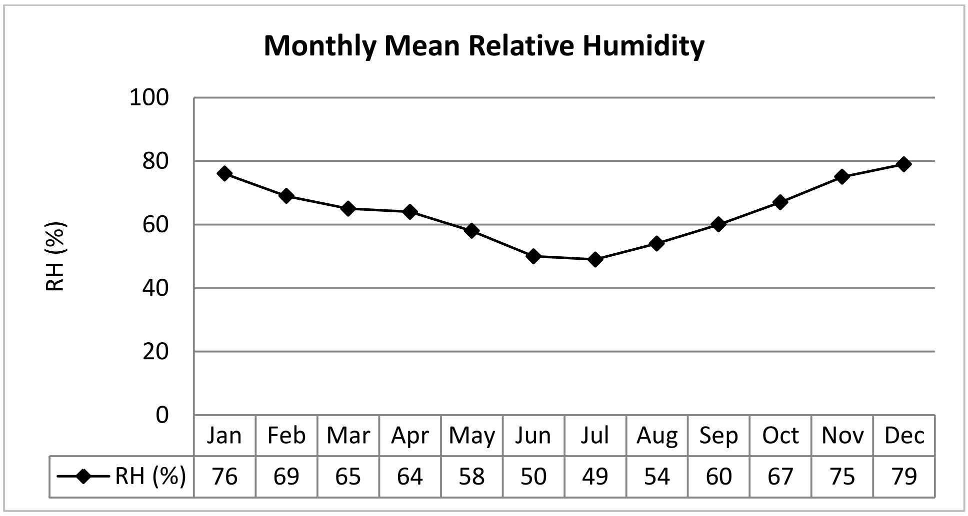


Figure 2.7.2.2: Mean monthly air relative humidity. Source: Meteonorm 2013

- **Solar radiation**

Meteonorm uses the recorded mean monthly values for solar radiation in order to calculate the monthly values of diffuse and global radiation. The results are shown as diffuse, direct and global radiation in Whm^{-2} with time in Figure 2.7.2.3.

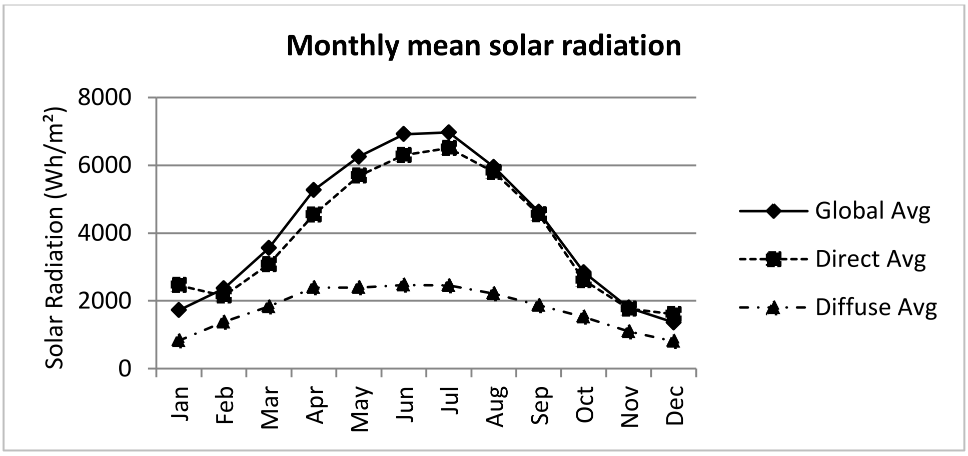


Figure 2.7.2.3: Mean monthly solar radiation. Source: Meteonorm 2013

2.8 Energy Plus results interpretation

After defining the internal air temperature values and relative humidity percentage developed in every zone of the studied buildings we examine whether comfort conditions are maintained during the summer months (from June to August) without the application of HVAC or other mechanical systems.

2.8.1 Thermal comfort models and comfort zones definition used for assessment of the results

2.8.1.1 Fanger PMV model and international comfort models

Fanger's thermal comfort is based on laboratory and climate chamber studies which suggest a seven step scale describing the subjective human reaction to the thermal conditions of a room, and then a correlation between the Predicted Mean Vote (PMV) of people that use this scale and an index that takes into account climatic variables such as the air temperature, the mean radiant temperature, the relative humidity, the air speed and two personal variables the clothing insulation factor and the activity level. For assessing comfort zones, ASHRAE Standard 55 and ISO are based on Fanger's PMV-PPD model. ISO 7730 uses the PMV values and defines three comfort categories, which are consistent with an ascending scale of predicted percentage of dissatisfied: category I ($-0.2<PMV<+0.2$, $PPD<6$), category II ($-0.5<PMV<+0.5$, $PPD<10$) and category III ($-0.7<PMV<+0.7$, $PPD<15$). These categories when referred to residential buildings are expressed by temperature limits: I (min Operative Temp. Winter > 21^oC, max Operative Temp. Summer < 25.5^oC), II (min Operative Temp. Winter > 20^oC, max Operative Temp. Summer < 26^oC), III (min Operative Temp. Winter >19^oC, max Operative Temp. Summer < 27^oC) (Olesen 2005).

For the purpose of this research the second category is taken into consideration as it corresponds to the 90% of occupants that feel thermally satisfied and it also meets the lower winter temperature and upper summer temperature limits of ASHRAE St.55.

Though, the thermal conditions obtained through the experiments for calibrations of the PMV and PPD equations are not comparable to those of residential buildings. The domestic scene is far from steady state as the activity level, the clothing value, the internal gains and the variation in occupancy will influence the required ventilation rate (Peeters et al. 2009). As a result a second calculation of the thermal comfort rate is made under the extended limits that Givoni proposed in his psychrometric chart.

2.8.1.2 Bioclimatic chart by Givoni B.

For the definition of the acceptable internal temperature limits it was also studied the psychrometric chart proposed by Givoni which presents boundaries of comfort zones, based on air temperature and air relative humidity; it is mainly applicable to residential buildings where heat gain is minimal (Givoni et al. 1998) and it correlates the maximum and minimum of the air temperature with the absolute humidity. As shown in Figure 2.8.1.2.1 in the proposed chart the identified zones are those of thermal comfort for winter and summer, natural ventilation 0.5m/s and 1m/s, high mass, high mass with night ventilation, evaporative cooling and a zone of possible comfort with inertia during summer. For the purpose of this research we use the limits of thermal comfort during summer. Air speed of 1m/s is also used.

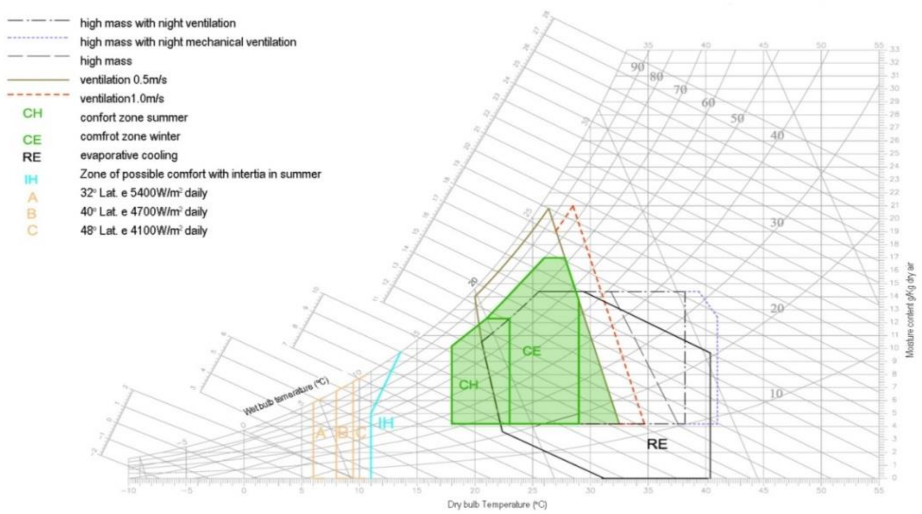


Figure 2.8.1.2.1: Psychrometric chart by Givoni B., Source: Lam et al. 2006

Givoni's research on comfort zones was conducted in the United States, Europe and Israel, which are regarded as developed countries. Though, he claims that the proposed comfort zones can be extended upwards by 2.0°K for people living in developing countries as occupants' comfort sensation depends also on their expectations.

3. Simulation results

For the studied buildings the results obtained after the completion of the simulation procedure and the processing of the initial data in the Microsoft Excel software are:

- Zone mean monthly and hourly air temperature ($^{\circ}$C)
- Zone mean monthly and hourly relative humidity (%)
- Zone monthly heating demand (J)

The questions that could be answered after the analysis of the obtained data are:

- Which are the structural elements that affect the thermal performance of the initial building?
- How do the different ventilation air change rates affect the thermal performance of the buildings?
- What is the role of natural ventilation in maintaining thermal comfort conditions inside each building?

In order to answer these questions:

- The data obtained from Energy Plus were analyzed for two periods: the winter period (October to April) which is defined also from the use of mechanical heating means and for the summer period from June to August ($T_{o\ average}$ >20°C).

The results are analyzed separately for the south (living) and north (sleeping) areas.

- For the winter period we created charts showing the heating energy demand (kWh.m^{-2}) for every studied zone both for the initial and renovated structure.

For the summer period where there is no application of mechanical cooling system:

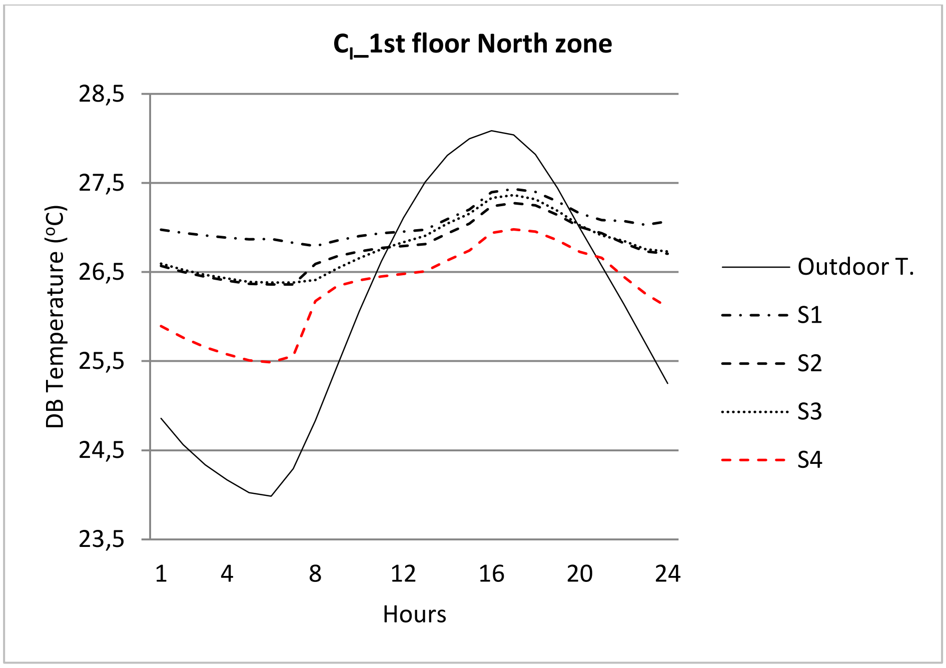
- The thermal performance of north and south zones is analyzed by calculating indoor mean hourly dry bulb temperatures under different natural ventilation scenarios, in accordance with the outdoor mean hourly temperatures. Moreover we calculated the overheating rates (percentage of hours with indoor temperatures T_o> 26°C) and the cumulative frequency of indoor temperatures.

- Indoor comfort rates are calculated for each zone under the two thermal comfort models selected for the analysis.
- The thermal comfort rates of the studied zones under different natural ventilation scenarios are mainly analyzed in reference to Givoni's extended comfort zone definition, since it is the only model which combines the effect of dry bulb temperatures and relative humidity levels while acknowledging the impact of the thermal adaptability of the body and user expectation on the subjective sensation of comfort (Aleksandrowicz 2010).
- Psychrometric charts with an outlined "comfort zone" based on Givoni's definition are used for the depiction of the correlation between indoor temperatures, relative humidity levels, and thermal comfort rates according to different ventilation scenarios.

3.1 Simulation results Chatzikosta mansion - Initial form (C_I model)

3.1.1 C_I_ Indoor mean hourly DB temperatures _summer period (June to August)

The mean hourly indoor temperatures during summer (Figures 3.1.1.1a and b), evidence that in both north and south oriented zones the increased ventilation rates of S4 scenario, result in lower indoor temperatures (both during daytime and nighttime). In addition, a substantial difference of indoor temperatures was recorded between the south-living and north-sleeping zones (under the same external conditions, ventilation and operational scenarios). The study of cumulative frequency charts (Figures 3.1.1.2a and b) shows also the same general trends.



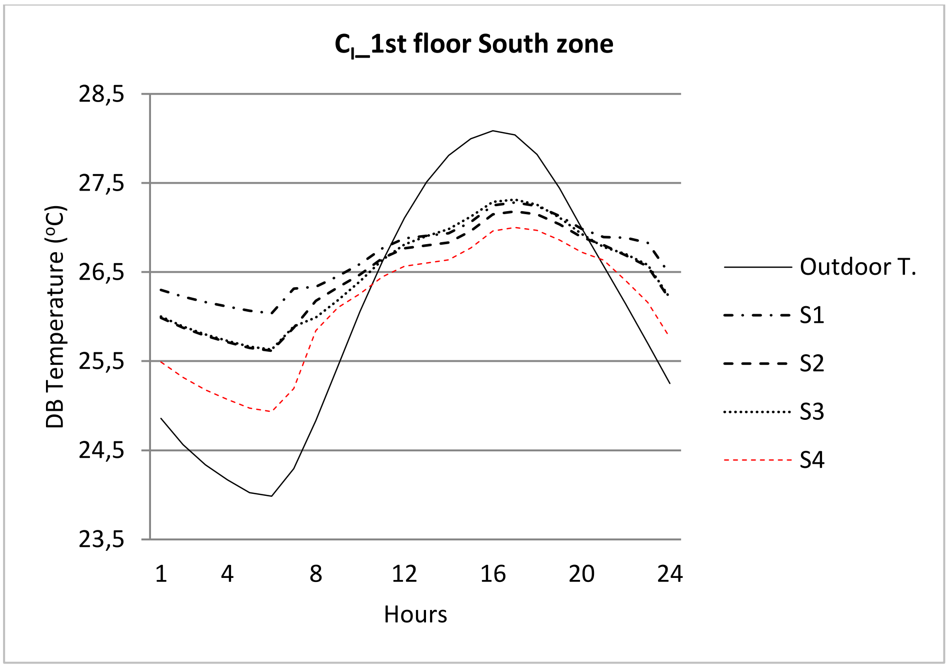
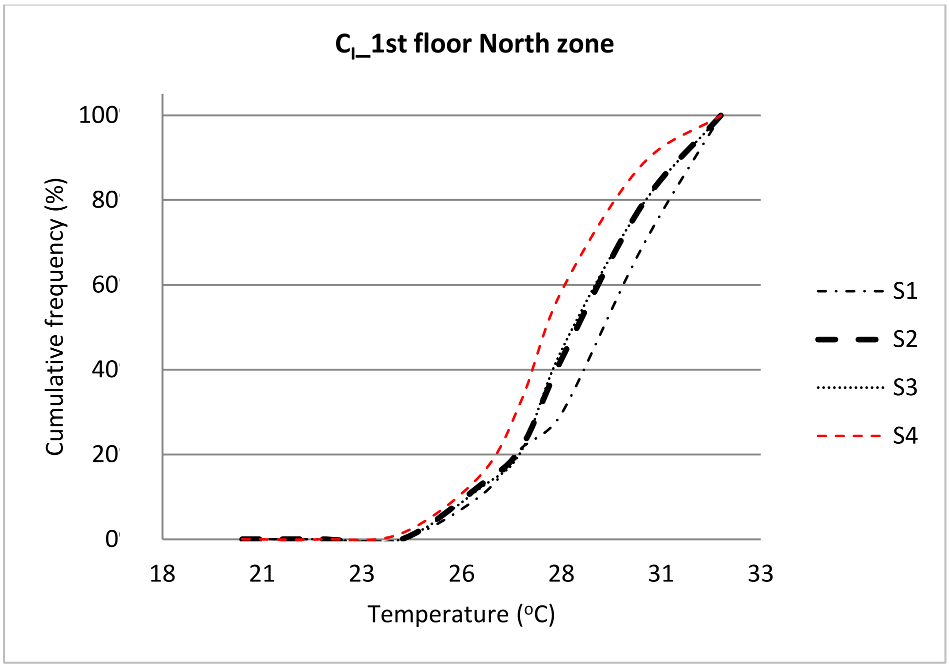


Figure 3.1.1.1 a and b: C$_I$ model 1st floor north and south zones mean hourly dry bulb temperatures for three month period (June to August) under different ventilation scenarios



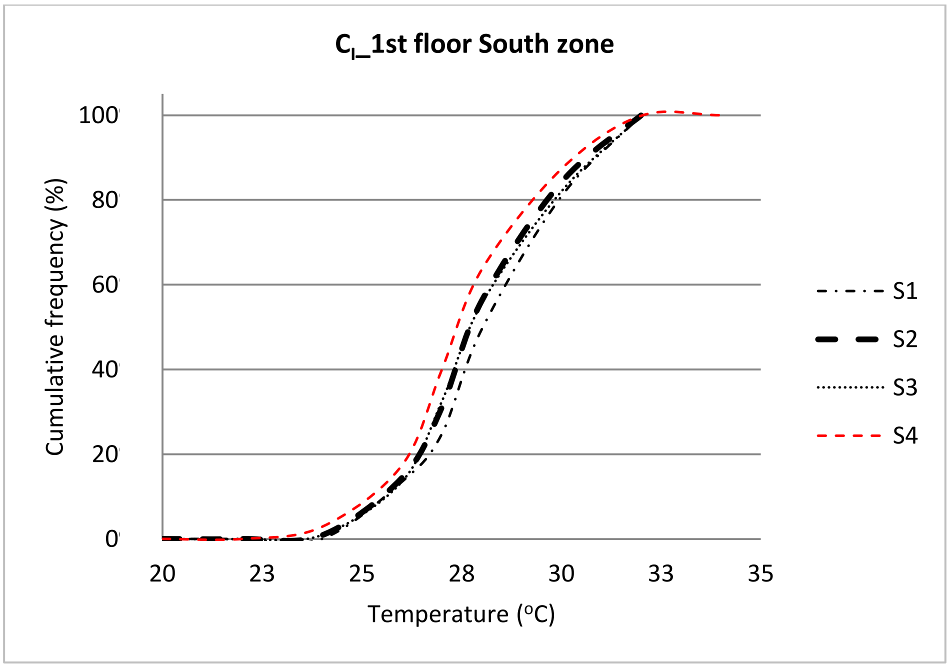
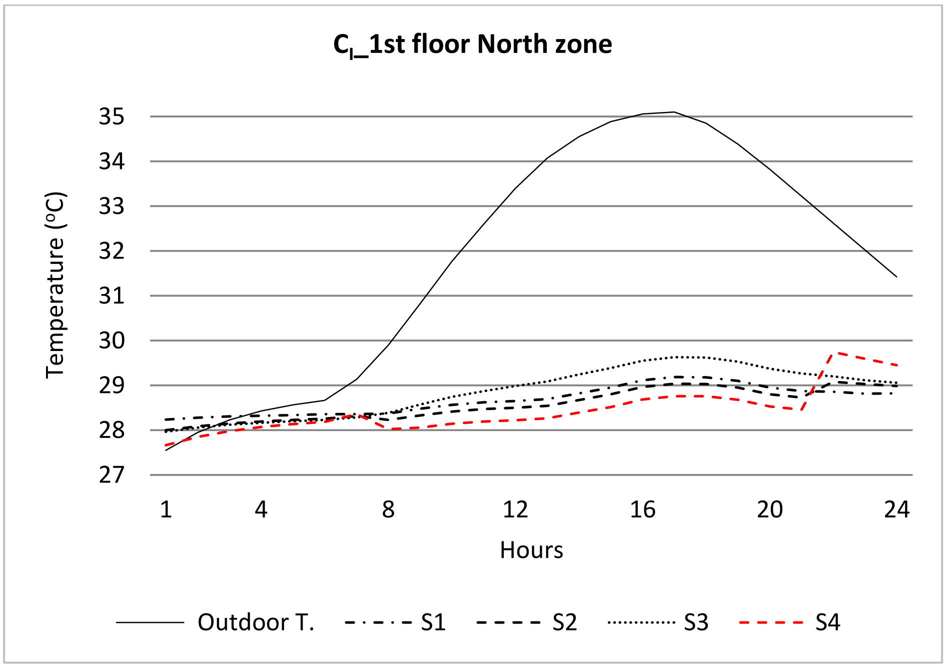


Figure 3.1.1.2 a and b: C$_I$ model 1st floor zones cumulative frequency of indoor temperatures for three month period (June to August) under different ventilation scenarios

The indoor temperature fluctuation during the warmest day (21st July) of the year studied is presented in Figure 3.1.1.3. The data show that high rate nocturnal ventilation results in rise of the internal temperature during nighttime.



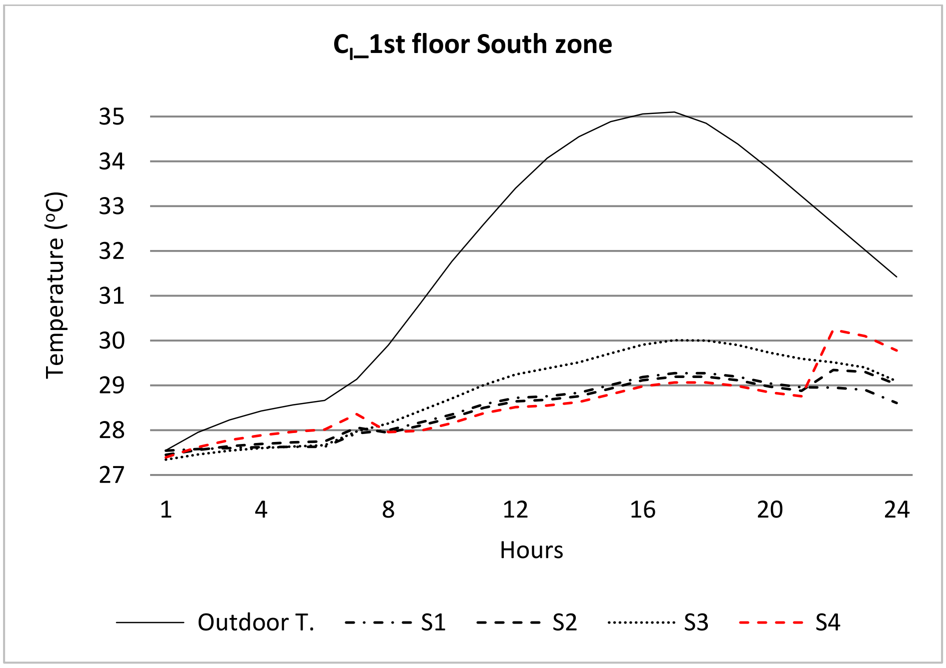


Figure 3.1.1.3 a and b: C$_I$ model 1st floor north and south zone mean hourly dry bulb temperatures for 21st July (highest outdoor temperature value recorded) under different ventilation scenarios

3.1.2 C_I_ Indoor overheating rate and thermal comfort according to different comfort models _ summer period (from June to August)

The comparisson between the overheating rate (T_{in} >26^oC) of the zones studied (Figure 3.1.2.1) indicates that the sleeping areas remain warmer under all ventilation scenarios examined. Moreover, the application of different comfort models for the three-month period studied (from June to August) show substantial differences in the resulting comfort rates (Figure 3.1.2.2).

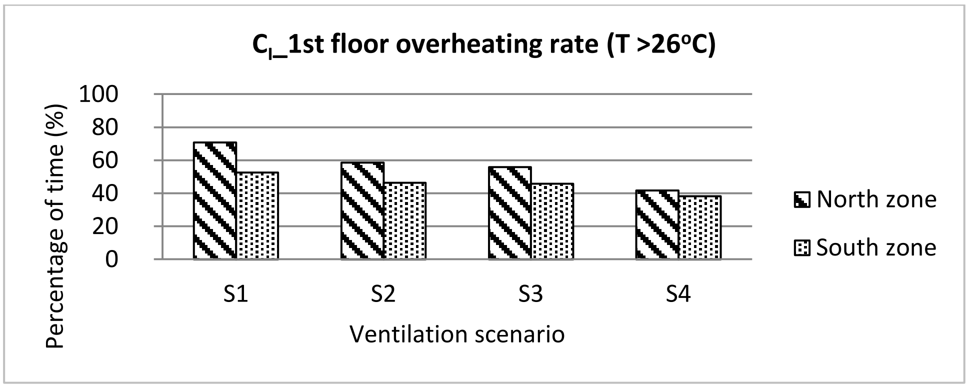
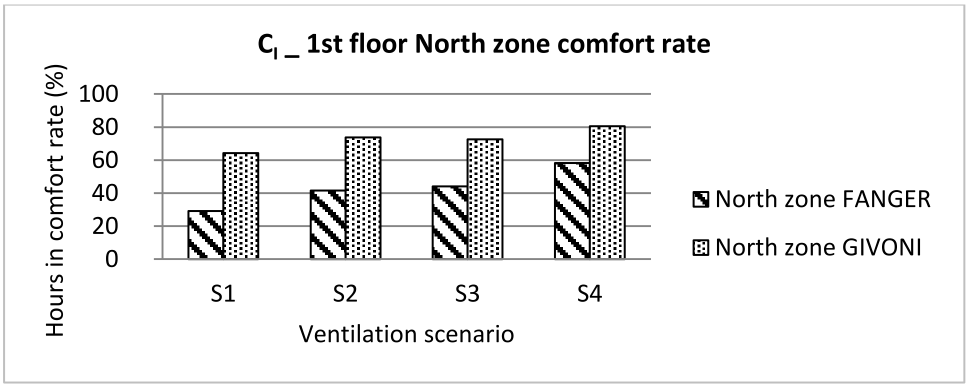


Figure 3.1.2.1: C_I 1st floor north and south zone overheating rate (T >26^oC) for three month period (June to August) under different ventilation scenarios



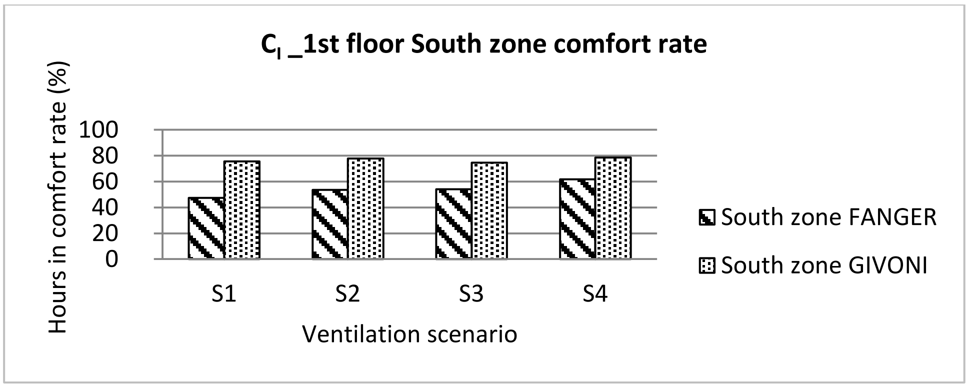
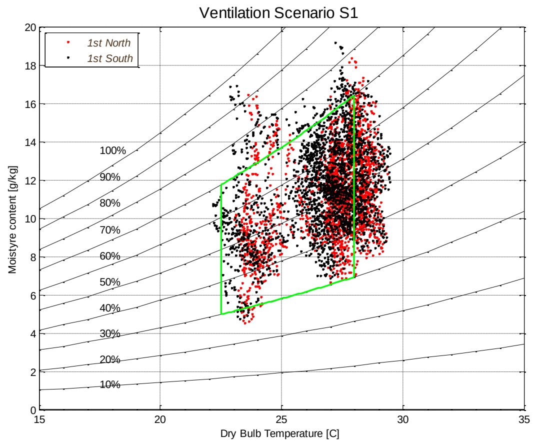
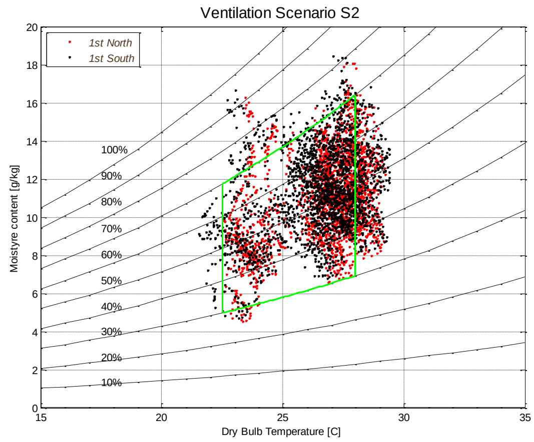


Figure 3.1.2.2 a and b: C_I 1st floor north and south zone thermal comfort rate for three month period (June to August) under different ventilation scenarios

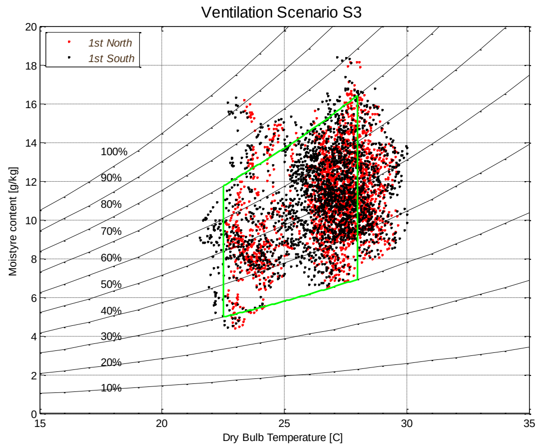
3.1.3 C_I_ Indoor thermal comfort according to Givoni's extended comfort zone

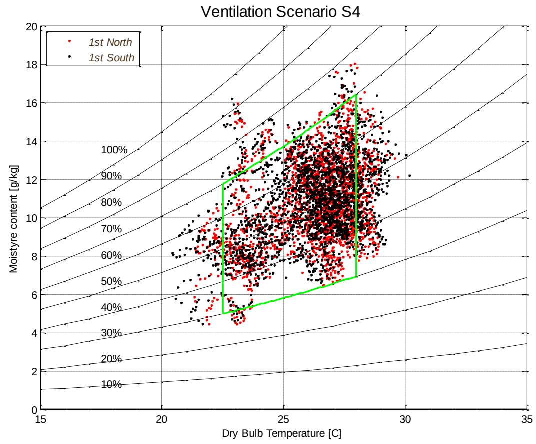
Phychrometric charts according to Givoni's extended comfort theory were created (Figure 3.1.3.1) through the use of Mat lab software for all ventilation scenarios studied during the three-month summer period (from June to August).





North zone	64,2%	**North zone**	73,8%
South zone	75,5%	**South zone**	78,1%





North zone	72,5%	**North zone**	80,4%
South zone	74,6%	**South zone**	75,4%

Figure 3.1.3.1: C_I model_ psychrometric charts with Givoni's extended comfort zone for July-August (north and south zone) under different ventilation scenarios. Red dots represent the north zone values, black dots represent the south zone values

3.1.4 C_I_ Heating demand _ winter period (October to April)

Figure 3.1.4.1 presents the average heating energy demand ($kWh.m^{-2}$)for maintaining the internal temperature on desired levels ($T \geq 20^oC$) in the examined zones during the winter period.

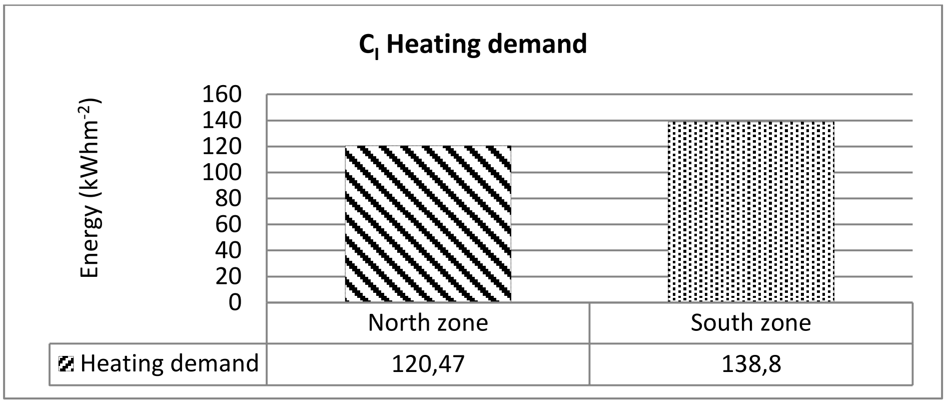


Figure 3.1.4.1: C_I model 1st floor heating demand for north and south zone for the winter period (October to April)

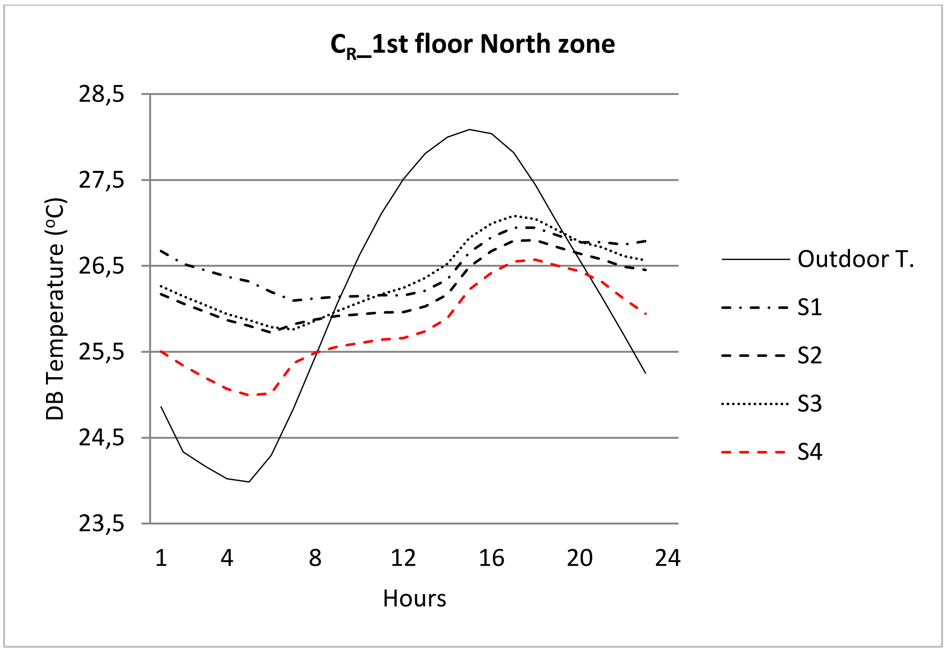
A list of findings for the C_I model is summarized below:

- During nighttime the mean hourly temperatures recorded are higher than the outdoor temperatures under all ventilation scenarios examined.
- During daytime and especially the peak hours (13:00-17:00), all scenarios produced lower average temperatures, compared with the outdoor temperatures.
- During summer, highest overheating rates are recorded under the S1 ventilation scenario both in south and north zone.
- In all zones, the lowest nocturnal mean hourly dry bulb temperatures are recorded under the S4 ventilation scenario and the highest daily values under scenario S1 for the north and scenario S3 for the south oriented zone.
- In both north and south zones, during the warmest summer day (21st July) highest mean hourly nighttime temperatures are recorded under scenario S4.
- In all rooms, smallest diurnal range of temperature is recorded under ventilation scenario S2.
- Scenarios S2 and S3 produced almost similar temperatures to the examined south zone during nighttime, whereas during daytime the temperatures recorded under the S3 scenario are presenting a slight decrease (difference less than 0.5°C).
- During winter the heating demand of the south oriented zone is increased by 15% in comparison with the north zone.

3.2 Simulation results Chatzikosta mansion - Renovated form (C_R model)

3.2.1 C_R Indoor mean hourly DB temperatures _ summer period (June to August)

The mean hourly indoor temperatures during the three-month summer period (Figures 3.2.1.1a and b), evidence that all zones under high ventilation rate (S4 scenario) obtain lower indoor temperatures; a trend which is also proved by studying the cumulative frequency charts (Figures 3.2.1.2a and b).



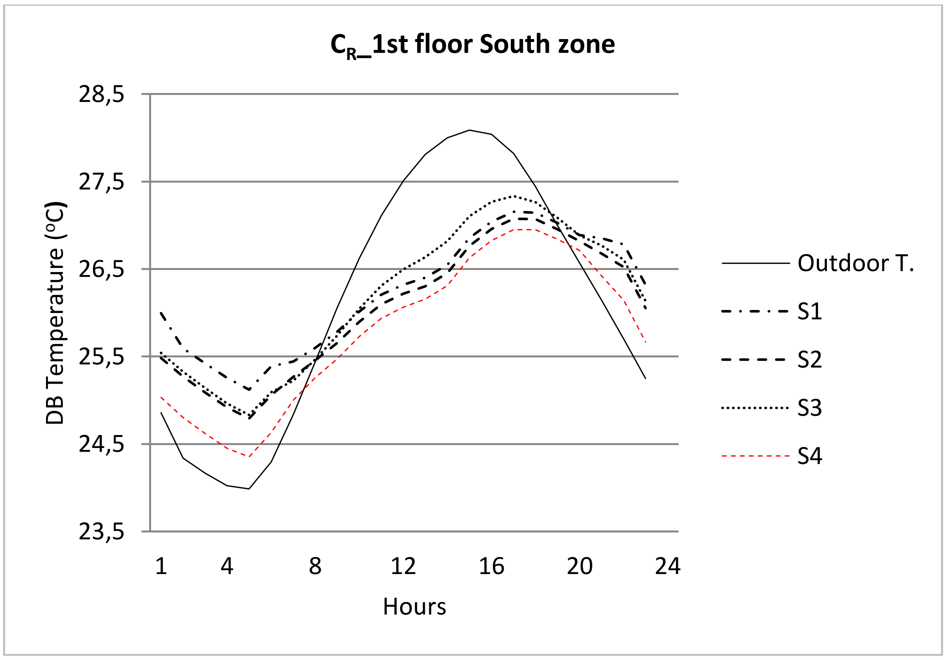
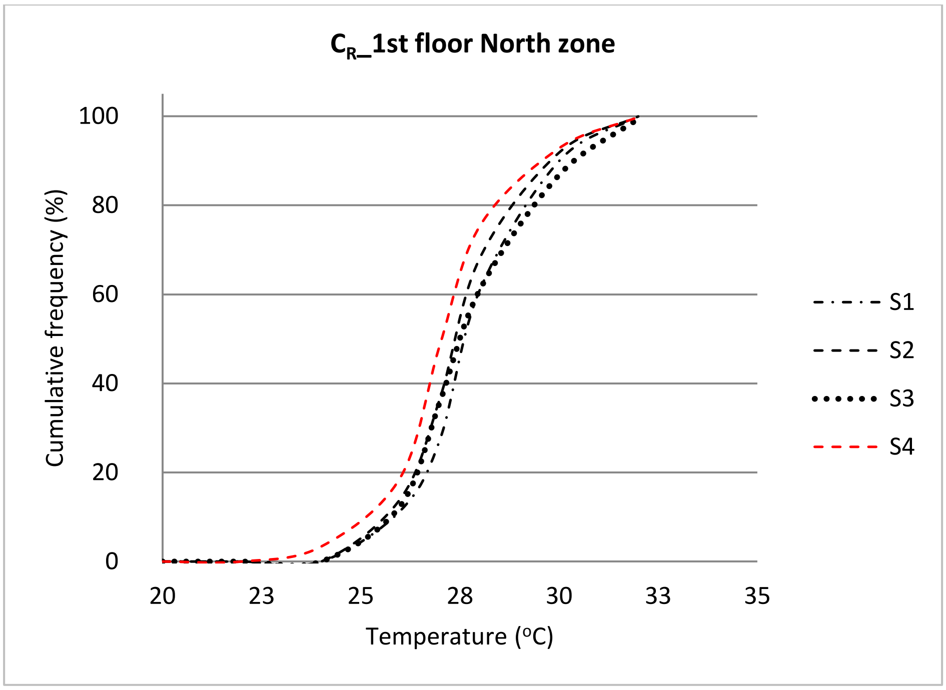


Figure 3.2.1.1 a and b: C_R 1st floor zones mean hourly dry bulb temperatures for three month period (June to August) under different ventilation scenarios



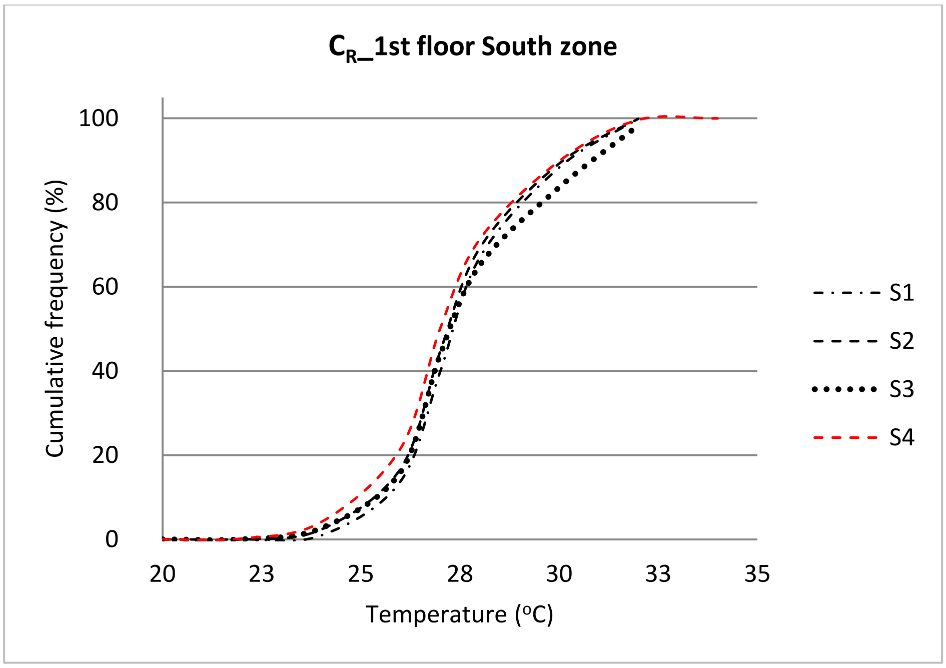
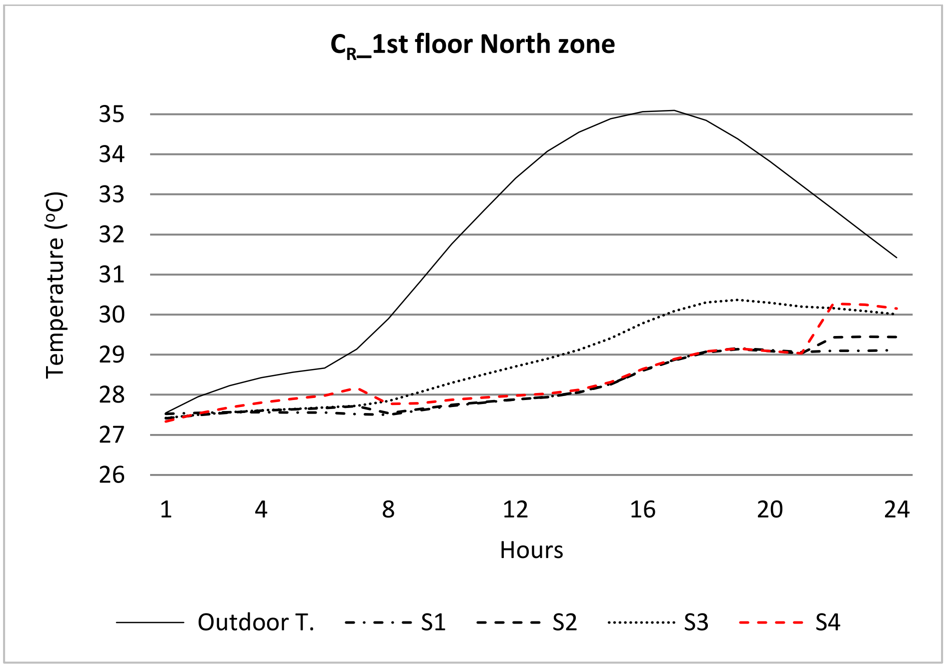


Figure 3.2.1.2 and b: C_R 1st floor zones cumulative frequency of indoor temperatures for for three month period (June to August) under different ventilation scenarios

The internal temperature fluctuation during the warmest day (21st July) is presented in Figures 3.2.1.3 a and b; the data show that high rate daytime ventilation can lead to temperatures higher than 30°C both in the living and sleeping zones.



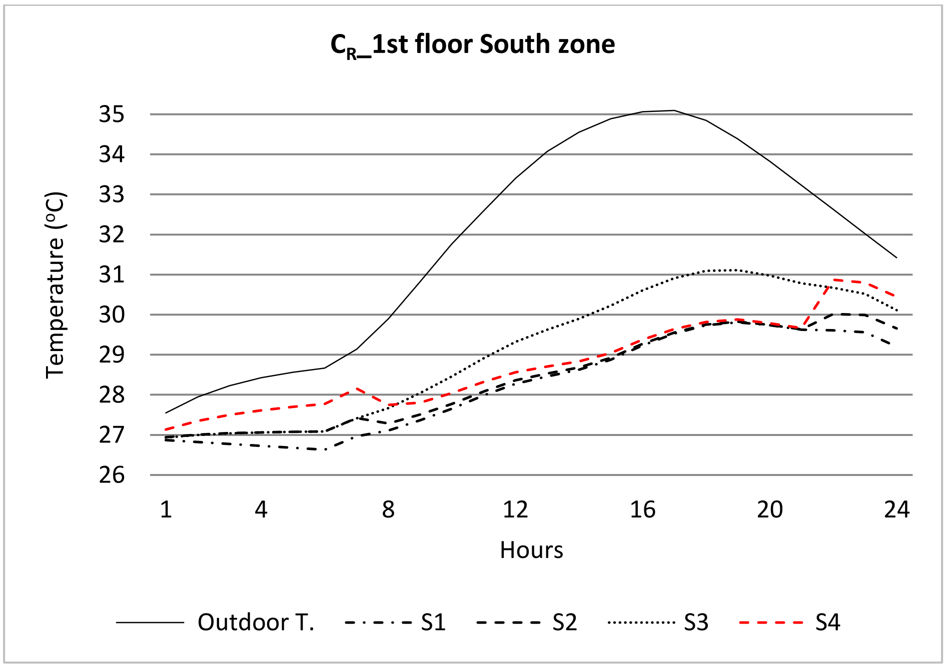


Figure 3.2.1.3 a and b: C_R 1st floor zones mean hourly dry bulb temperatures for 21st July (highest outdoor temperature value recorded) under different ventilation scenarios

3.2.2 C_R_ Indoor overheating rate and thermal comfort according to different comfort models _ summer period (June to August)

Comparisson between the overheating rate (T_{in} >26°C) of the zones studied (Figure 3.2.2.1) indicates that high rate daytime ventilation leads to higher internal temperatures. Furthermore, Figures 3.2.2.2 a and b show that comfort rates occuring after the application of different comfort models for the period studied (from June to August) present clear differences.

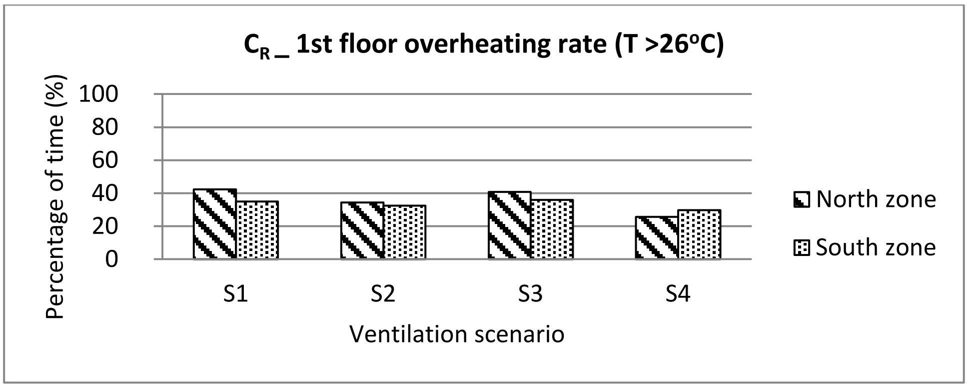
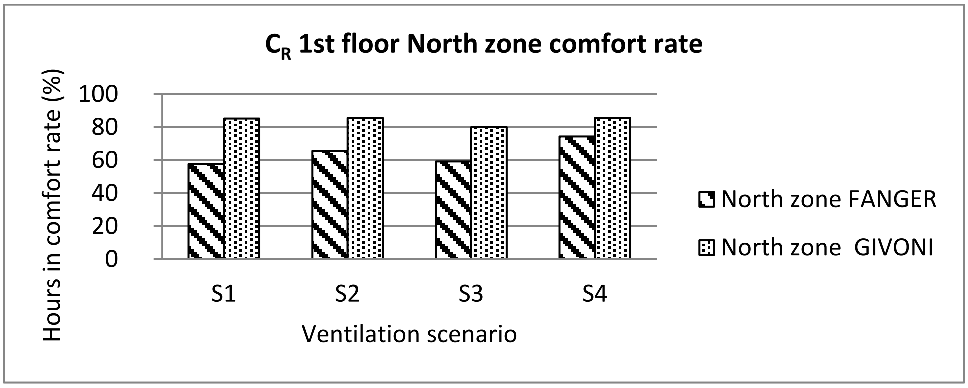


Figure 3.2.2.1: C_R 1st floor zones overheating rate (T >26°C) for three month period (June to August) under different ventilation scenarios



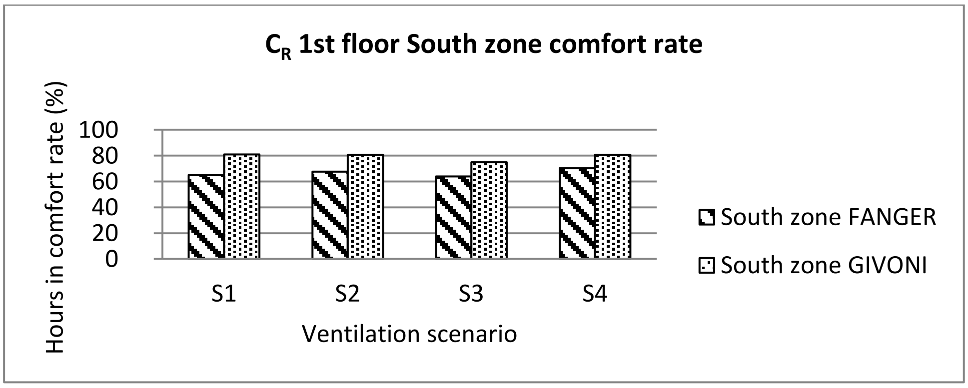
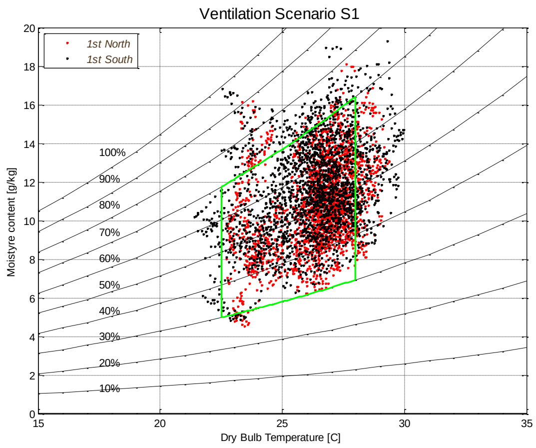
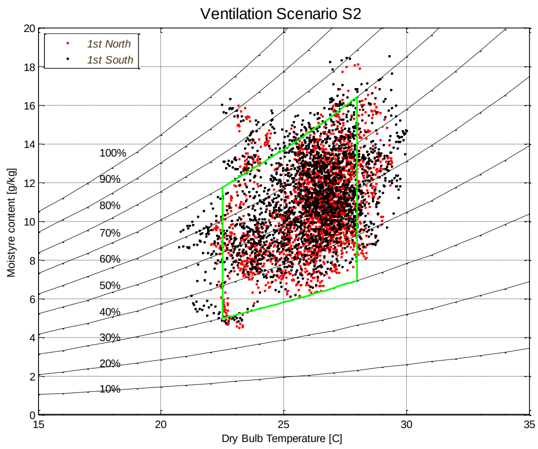


Figure 3.2.2.2 a and b: C_R 1st floor north and south zone thermal comfort rate for three month period (June to August) under different ventilation scenarios

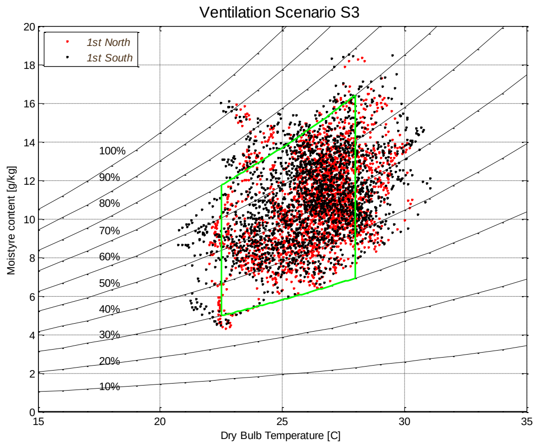
3.2.3 C_R_ Indoor thermal comfort according to Givoni's extended comfort zone

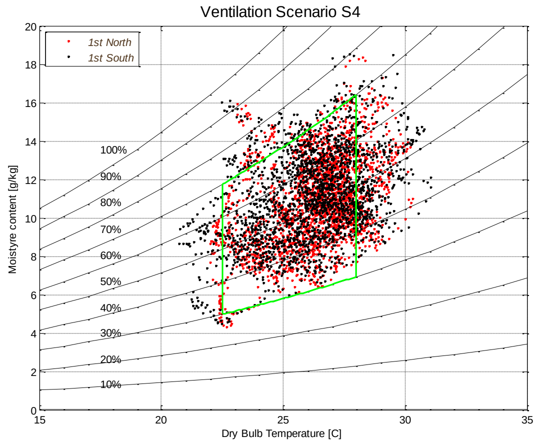
Phychrometric charts according to Givoni's extended comfort theory were created (Figure 3.2.3.1) through the use of Mat lab software for all ventilation scenarios studied during the three-month summer period studied.





North zone	85,2%	**North zone**	84,7%
South zone	80,9%	**South zone**	80,7%





North zone	79,9%	**North zone**	84,3%
South zone	74,9%	**South zone**	80,8%

Figure 3.2.3.1: C_R model psychrometric charts with Givoni's extended comfort zone for July-August (north and south zone) under different ventilation scenarios. Red dots represent the north zone values, black dots represent the south zone values

3.2.4 C_R_ Heating demand _ winter period (October to April)

Figure 3.2.4.1 presents the average heating energy demand ($kWh.m^{-2}$)for maintaining the internal temperature on desired levels (T≥20^oC) in the examined zones during the winter period (from October to April).

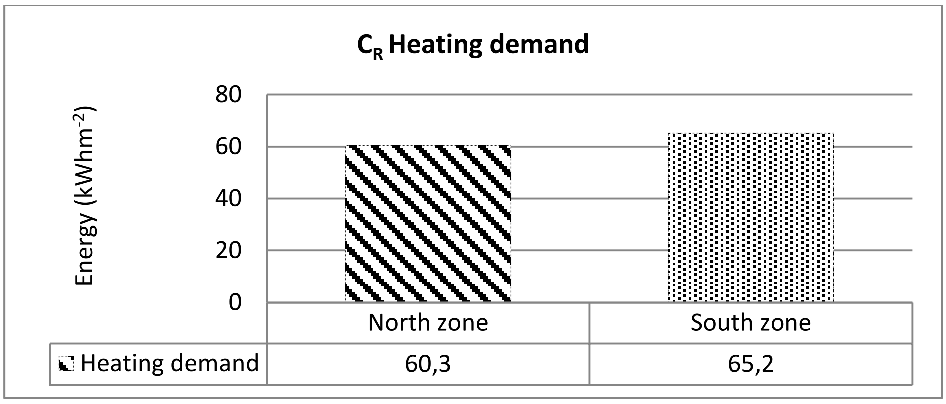


Figure 3.2.4.1: C_R model heating demand for north and south zone for the winter period (October-April)

A list of findings for the C_R model is summarized below:

- During nighttime the mean hourly temperatures recorded are higher than the outdoor temperatures under all ventilation scenarios.
- During daytime the average internal temperatures remain constantly lower than the outdoor temperatures.
- In all zones, the lowest nocturnal mean hourly dry bulb temperatures are recorded under the S4 ventilation scenario and the highest daily values under scenario S3.
- Ventilation scenario S4 during the warmest summer day (21st July) produced the highest mean hourly nighttime temperatures in both north and south zones.
- In all rooms, smallest diurnal range of temperature is recorded under scenario S2.
- Scenarios S2 and S3 produced almost similar temperatures to the examined zones during nighttime, whereas during daytime the temperatures recorded under the S3 scenario are presenting a slight increase.
- The north oriented zone presents higher indoor overheating rates than the south zone under ventilation scenarios S1, S2 and S3.
- The S1 ventilation scenario resulted in the highest overheating rate to the north zone, whereas the S3 ventilation scenario to the south zone.
- During winter the heating demand of the north oriented zone is decreased by 7.5% in comparison with the south zone.

4.0 Discussion

4.1 Thermal performance of the structure

The clear thermal performance of the structure, independently of the way that natural ventilation affects the internal conditions, could be described by identifying repeated similarities in the average daily indoor temperature range under the different ventilation scenarios applied (see section 3).

Regarding the initial structure of the building (C_I model) it is observed that:

- The stone walls while producing poor thermal insulation (assumed conductivity of 1.7 Wm^{-1} K^{-1}), has high density and heat capacity which delays the heat flow from outdoor and results in relatively low difference between the highest and lowest temperatures during the day.
- During summer this delay of heat flow is also responsible for keeping indoor temperatures lower than the outdoor during daytime peak hours (13:00-17:00) and higher during nighttime even when the ventilation applied is relatively low ($0.4h^{-1}$).
- During winter the limited thermal insulation provided by the stone wall in its initial form is responsible for the large average heating demand in the examined zones (129.7 $kWh \cdot m^{-2}$).

Regarding the renovated form of the studied building (C_R model) the following observations can be made:

A reduction of the average heating demand by 51.6% in comparison with the C_I model is witnessed (Figure 4.1.1). This improvement of the thermal behavior of the structure results from:

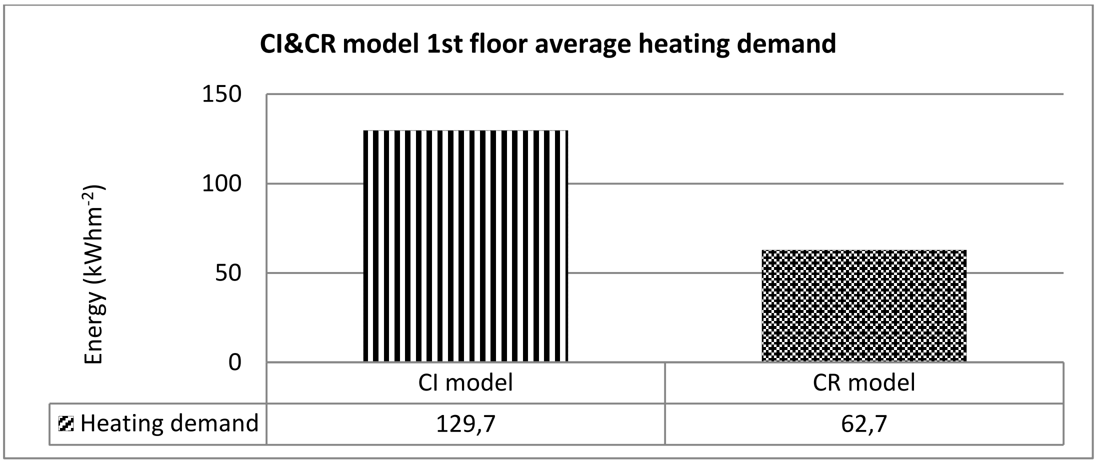


Figure 4.1.1: C_I and C_R model 1st floor average heating demand for October-April

- The improvement of the thermal conductivity of the stone walls after the addition of isolation (mineral wool layer) to the structure which reduced the average thermal losses through conduction for the zones studied.
- The replacement of the windows is another factor that contributes to the reduction of the energy demand for maintaining the internal temperature on desired levels (≥20^oC) as the new double glazed windows applied (U-Value $2.7Wm^{-2}K^{-1}$) increased the heat gain rate (despite the fact that the transmitted solar radiation was decreased) as the losses to the outdoor environment are reduced.

4.2 Natural ventilation and shading effect on thermal comfort (summer period)

As seen in section 3, natural ventilation affects the indoor temperatures (and thus relative humidity and comfort levels). The general recorded tendency evidence that during the warmest months, high rate nocturnal ventilation resulted in lower indoor temperatures during the day and that the north oriented bedrooms were always warmer than the south oriented living rooms.

Both for the C_I and C_R model it is observed that:

- The combination of high rate nocturnal ventilation and limited daytime ventilation results in lower temperatures during the whole day.
- High rate daytime ventilation ($2h^{-1}$) increases the internal temperature and thus the overheating rate. Therefore, blocking daytime ventilation leads to cooler indoor environment.
- During nighttime the best way to release the added heat is by enabling high rate air flow in the building.
- During the warmest days ($T_o \geq 30\ ^oC$) high rate nocturnal ventilation results in rise of the internal temperature because of the warm air mass introduced into the building.

Regarding the initial form of the building (C_I model) it is observed that:

- The relatively low overheating rate of the north oriented zones results from the heat capacity and width of the walls and the limited area of the openings which disable high solar gains.
- The overheating rate difference between north and south oriented zone range from 18.3% for the S1 to 3.5% for the S4 ventilation scenario which proves that natural ventilation is of great importance for cooling the internal environment of the south oriented zone as being the area with the greatest solar gains.
- The above tendencies are also proved by the PMV comfort model where the difference on thermal comfort levels between the two zones is reduced under incremental increase of nocturnal ventilation rate.

- The comfort rates occurred from the analysis of the data in accordance with Givoni's extended comfort model are significantly higher than those of the PMV method. Indicatively in the north zone a difference of 35% in comfort hours is recorded under the S1 ventilation scenario.
- By comparing the comfort hours of every zone according to Givoni's proposed limits and under different ventilation scenarios we observe that the higher indoor temperatures recorded, especially during nighttime (scenario S1) do not significantly decrease the comfort rates because they simultaneously decrease the humidity levels (as the air moisture content doesn't change).

Regarding the renovated form of the building (C_R model) it is observed that:

- The difference between the overheating rate of north and south zones is reduced when the rate of incoming air is higher. This indicates that the envelope of the renovated model is not able to release the heat added into the building from daytime ventilation.
- The above result occurred due to the upgraded wall construction where the isolation material (layer of mineral wool) delays the heat flow from inside to outside when the outdoor temperature falls.
- The addition of louvered shutters on the windows of both north and south oriented zones lead to decreased mean hourly night temperatures in comparison with the initial model as they reduce the heating gain rate by solar radiation during the day.
- The aforementioned element affected also the difference between the comfort rates in south and north oriented zones which present now a slight difference (between 4.26% and 4.98%) under Givoni's temperature limits.

From the above findings it is clarified that the renovation program applied to the initial structure contributed to the improvement of the thermal behavior of the building without altering its architectural form and that nocturnal ventilation is of great importance for insuring comfort indoor living conditions to the users.

Although, it is important to remember, that the original users’ sense of comfort in the building was never documented and as a result Givoni's model may not describe it accurately. Admitting that it is hard to determine whether Givoni's results convey an accurate representation of the expected reaction to the assumed examined conditions, we can still infer, that it is a suitable comfort model for the analysis of the data obtained through the Energy Plus software as it produces more plausible results in comparison with the PMV model**.**

5. Conclusion

The Mansion as a characteristic building type of Greek vernacular architecture had lasting prominence along the mountainous region of Pelion during the 18^{th} century. The presented research aimed at examining and analyzing its thermal performance during the whole year by simulating the indoor conditions developed in an existing structure in the settlement of Makrinitsa in its initial and renovated form.

The outcome of the research is that it offers to the designers and engineers the required information regarding the indoor comfort conditions developed in vernacular dwellings found in Pelion. Factors that affect the energy gains and losses through the envelope which is constructed under the limited material sources of the region are also analyzed.

Regarding the thermal performance of the structure, it can be argued that the studied building in its initial form is not able to cover the modern living requirements of the occupants during winter without the application of mechanical heating system. The overall energy performance of the building in relation to the applied living pattern shows that the first users with their basic knowledge and limited material resources, tried to construct houses that operate naturally and effectively throughout the year.

During winter, the residents' primary need was to keep the internal temperature constant and their property safe from adverse weather conditions and raids. As a result, the design of the external envelope of the ground and first floor were adjusted to a luminous internal environment but minimized the heating demand and the energy losses through the building envelope.

The applied architectural design features such as the mobile wooden shutters, and the trapdoors when combined with nocturnal ventilation, effectively prevented the building from overheating and provided the best possible living conditions in summer.

From the analysis of the obtained results and by comparing the basic model with the upgraded form it is made clear that the thermal behavior of the mansion can be improved with simple interventions that do not alter the form and structure and obey to the laws for protection of this type of buildings as examples of the traditional Greek architecture.

The application of appropriate thermal insulation and change of the single glazing with double reduces the energy required for heating by 50% which is indicative of the level of energy savings that can be achieved by the residential sector if considering that the 79% of buildings in the Greek territory were constructed before 1980 (before the introduction of regulations for the isolation of the building envelope by the Greek State).

Moreover, it is proved that natural and nocturnal ventilation strategies for the analyzed building are suitable for achieving high rates of internal comfort conditions during summer according to the adaptive comfort theory of Givoni. From the results obtained it is illustrated that cross natural ventilation in combination with the thick stonewall construction can be effective under the climatic conditions prevailing in the studied region.

Furthermore, a key finding of this research is the need for implementation of specific renovation proposals in protected buildings in order to enhance their thermal behavior, but also to reduce the adverse consequences of increased energy consumption.

Since this research is based on computer simulations further on site measurements are needed for obtaining certain results regarding the thermal performance of this type of buildings. Though, the thermal computational simulations in this study demonstrate the potential of applying techniques of the past in modern structures in order to reduce the energy consumption in the domestic sector.

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Appendices

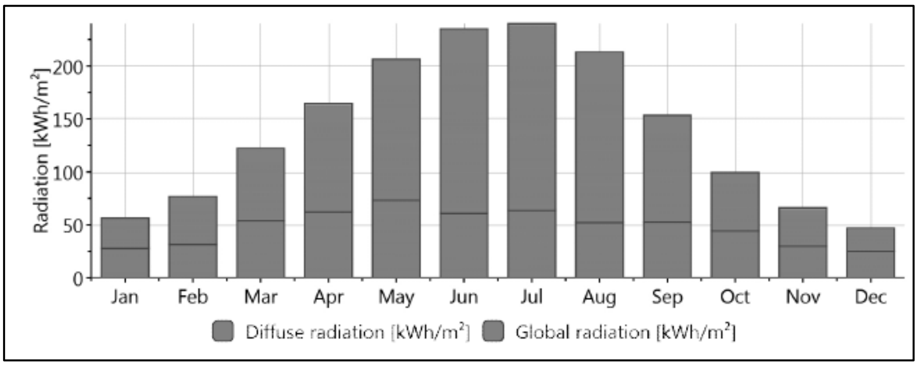
1. Meteonorm data

Name of site = Makrinitsa GR
Latitude [°] =39.402, Longitude [°] = 22,986, Altitude [m] =300, Climatic zone IV1
Radiation model = Default (hour); Temperature model = Default (hour)
Temperature period = 2000-2009
Radiation period = 1986-2005
Uncertainty of yearly values: Gh = 6%, Bn = 11%, Gk = 8%, Ta = 1,5 °C
Trend of Gh / decade: -
Variability of Gh / year: 3,8%
Radiation interpolation locations: Satellite data
Temperature interpolation locations: KOZANI (CIV/ARMY) (143 km), Larissa(55km), LAMIA (75 km), KASTORIA AIRPORT (186km), SKIATHOS ISLAND (51 km), Skiros Is. (146 km)

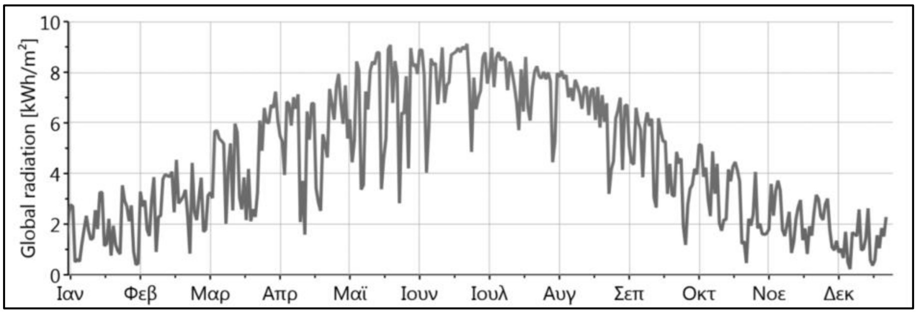
Month	H_Gh	H_Dh	H_Gk	H_Dk	H_Bn	Ta
[kWh/m^2]	[kWh/m^2]	[kWh/m^2]	[kWh/m^2]	[kWh/m^2]	[kWh/m^2]	[C]
January	56	28	97	34	79	4,7
February	76	31	115	38	96	5,9
March	122	54	150	58	123	9,9
April	165	62	174	65	167	13,4
May	206	73	186	72	198	19
June	235	61	198	62	247	23,7
July	240	64	209	66	254	26,5
August	213	52	210	58	249	26
September	153	52	180	60	168	20,6
October	99	44	136	50	111	15,9
November	66	30	109	36	92	10,2
December	47	25	80	30	63	5,8

H_Gh: Irradiation of global radiation horizontal
H_Dh: Irradiation of diffuse radiation horizontal
H_Gk: Irradiation of global rad., tilted plane
H_Dk: Irradiation of diffuse rad., tilted plane
H_Bn: Irradiation of beam
Ta: Air temperature

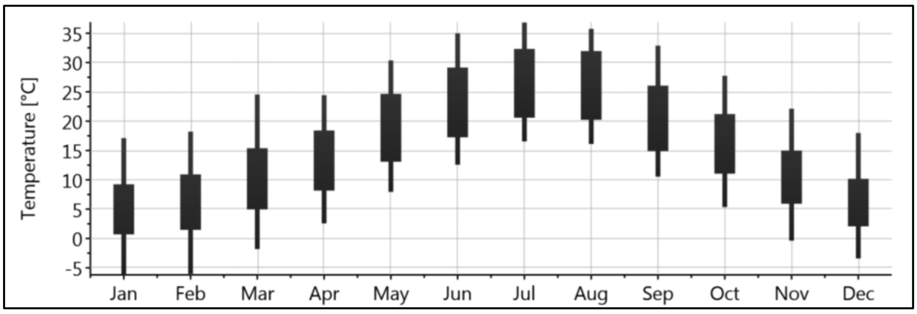
Monthly radiation



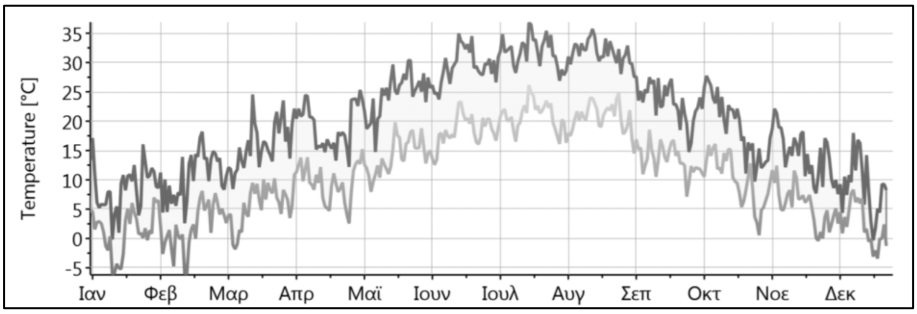
Daily global radiation



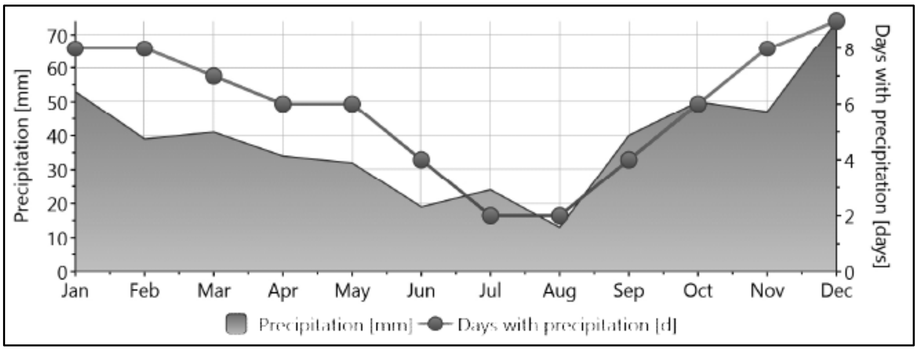
Monthly temperature



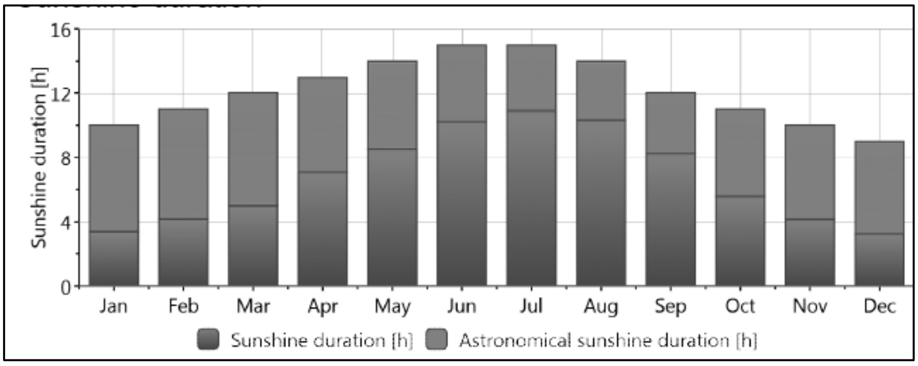
Daily temperature



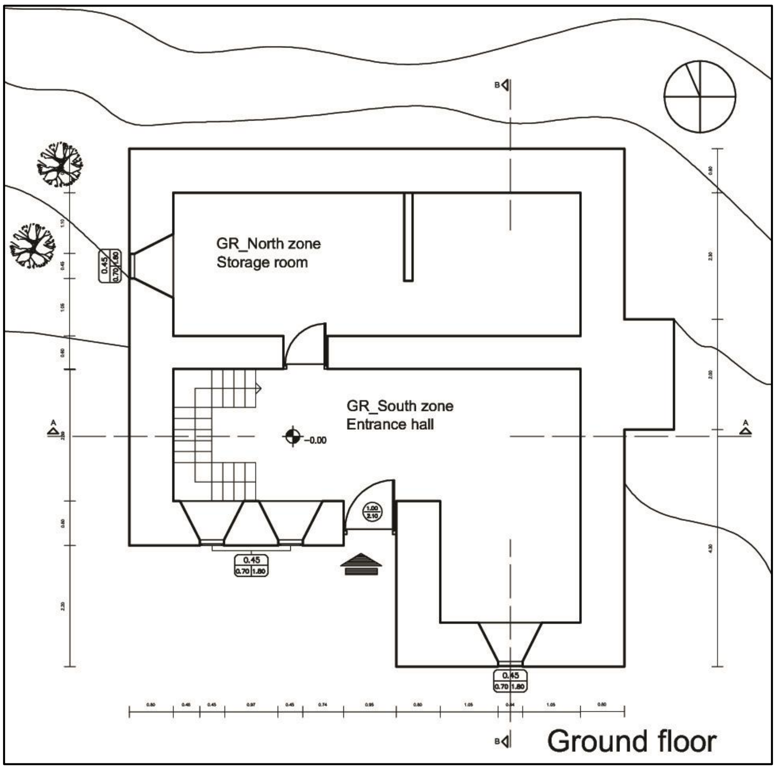
Precipitation

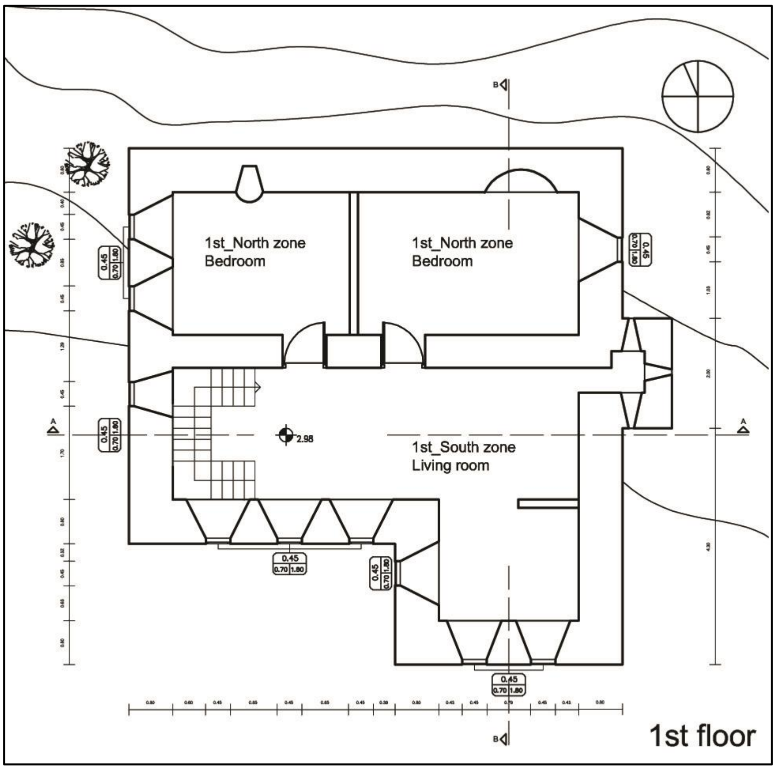


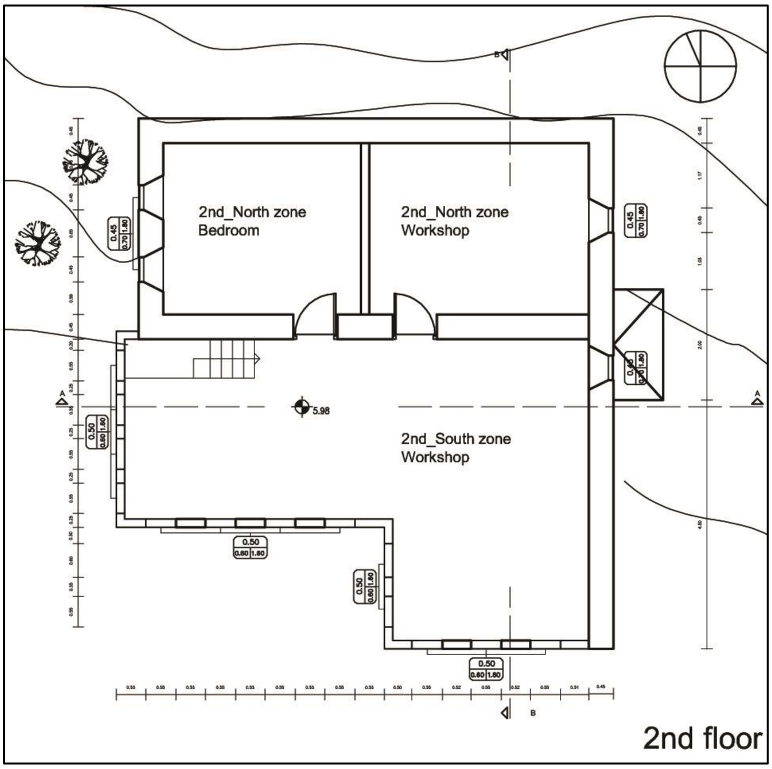
Sunshine duration

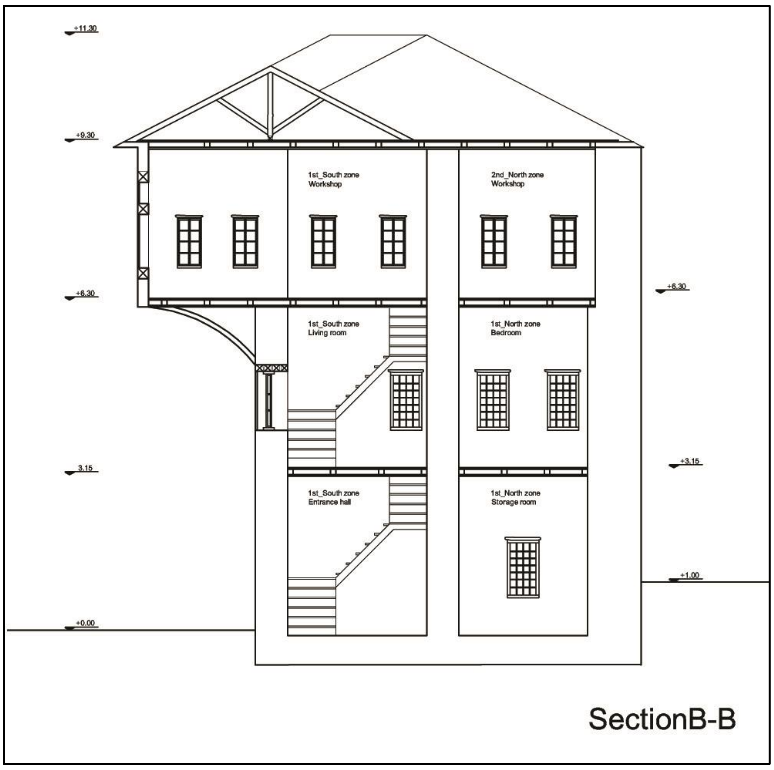


2. Architectural plans of the sample building





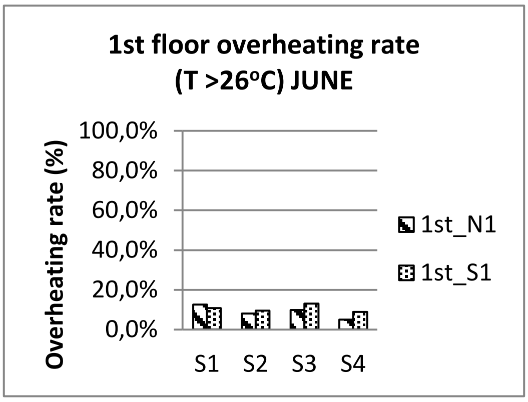

2nd_North zone
Bedroom
2nd_North zone
Workshop
2nd_South zone
Workshop
5.98
2nd floor

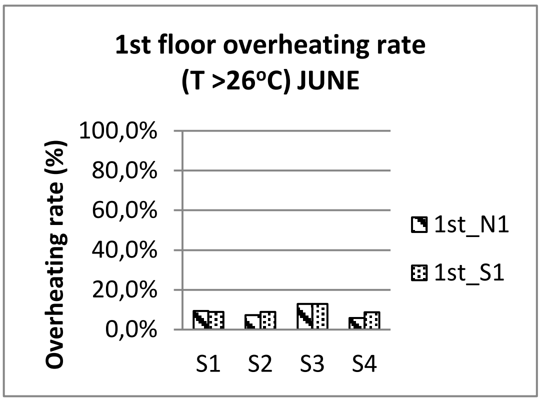

+11.30
+9.30
+6.30
3.15
+0.00
+6.30
+3.15
+1.00
1st_South zone
Workshop
2nd_North zone
Workshop
1st_South zone
Living room
1st_North zone
Bedroom
1st_South zone
Entrance hall
1st_North zone
Storage room
SectionB-B

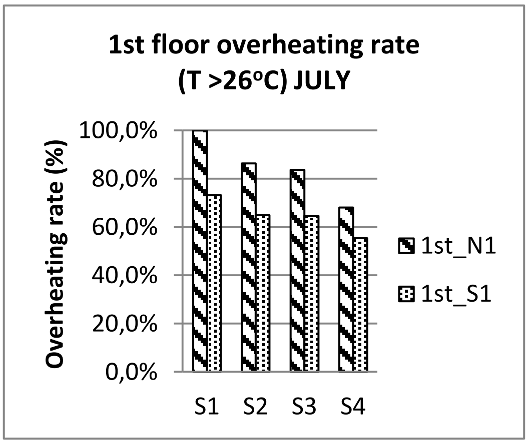
3. **Monthly overheating rate for C_I and C_R model_ summer period** (June to August)

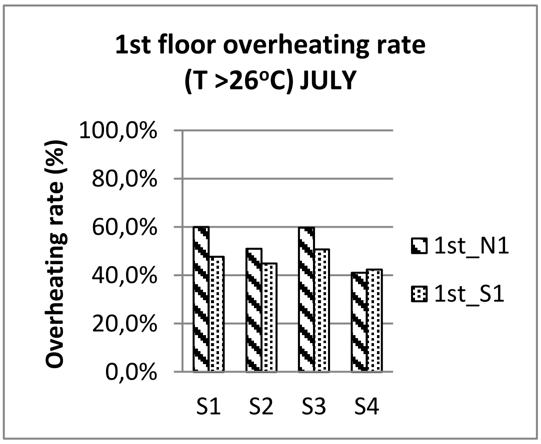
C_I model

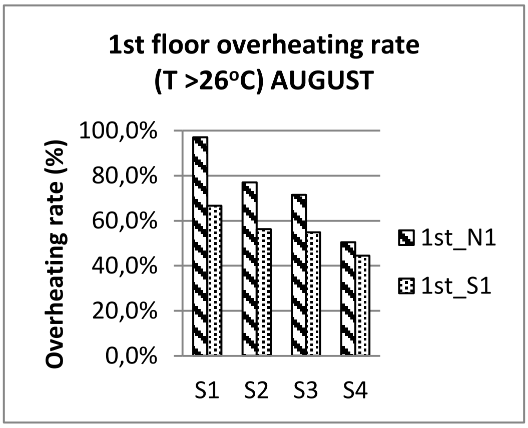
C_R model

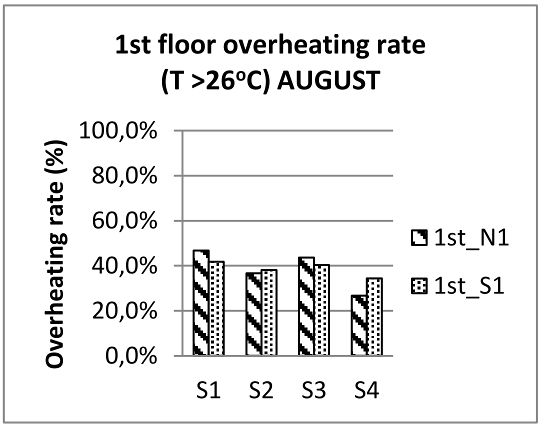




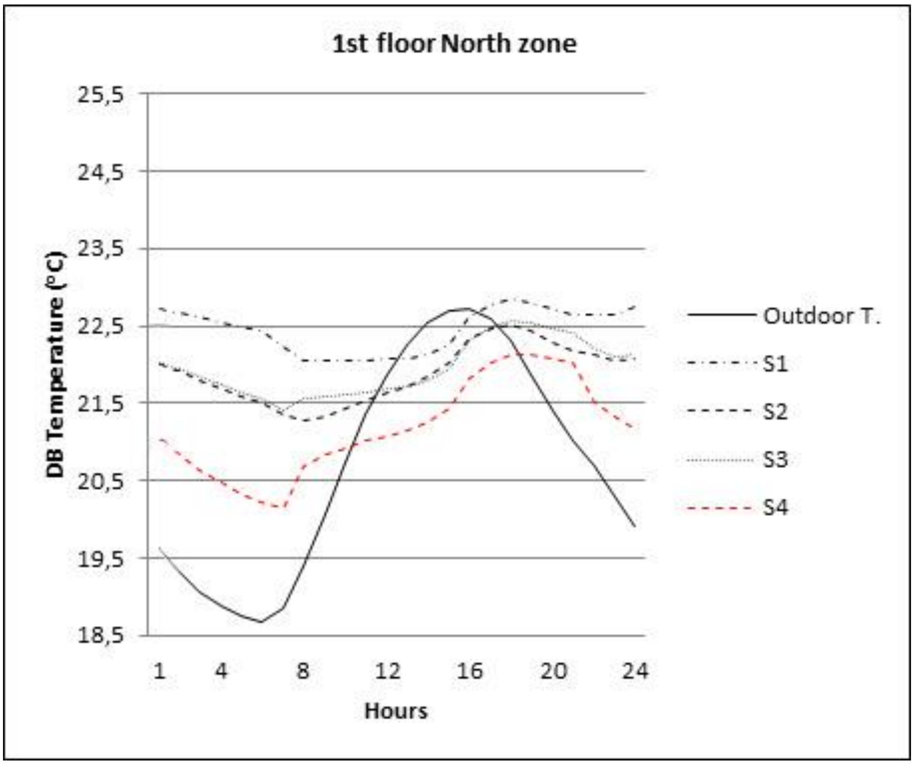


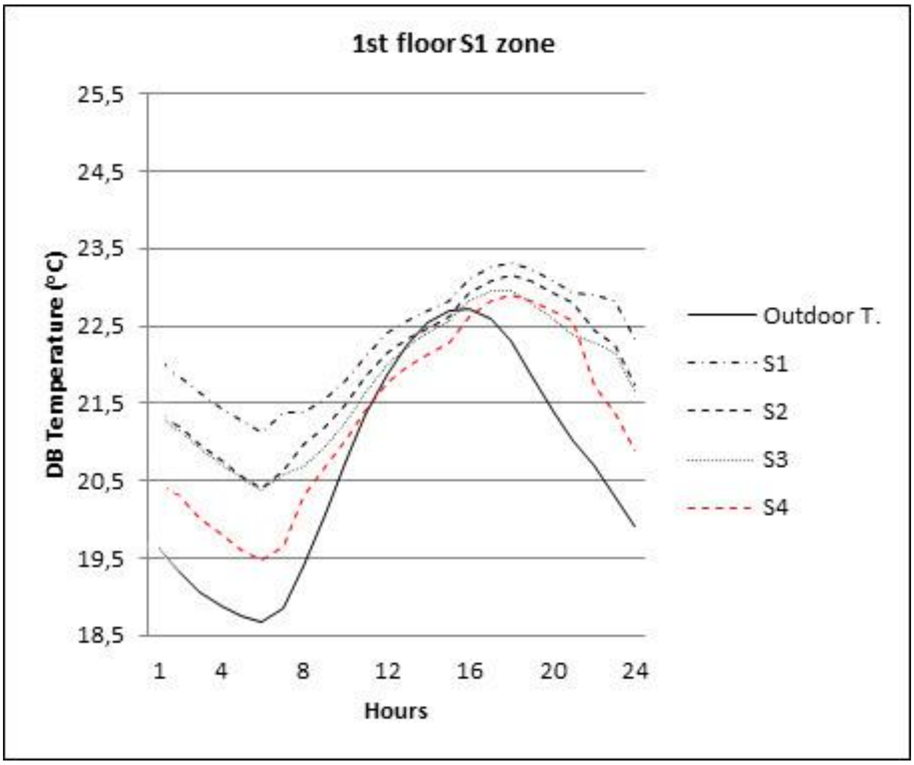






4. **Mean monthly DB temperature for C_I and C_R model_ summer period** (May and September)





5. **Monthly overheating rate for C_I and C_R model_ summer period** (May and September)

C_I model **C_R model**