Thermal performance of a passive solar house for continental climate, in Florina, north-western Greece

Achilleas Stoios[1], Flora Bougiatioti[2] and Aineias Oikonomou[2]

[1]Architect
45, Sarantaporou St., Florina, GR - 53 100

[2]Architects, PhD students
Department of Architectural Technology, School of Architecture,
National Technical University of Athens
42, Patission St., Athens, GR - 106 82
email: fbougiatioti@yahoo.com, aineias4@yahoo.com

ABSTRACT: This paper presents the thermal performance of a single-family house in Florina, north-western Greece. As the winter thermal performance was analysed in a previous paper by the authors, this paper focuses on the thermal comfort conditions, which prevail in the house during the intermediate seasons (spring and autumn) and during the summer. This is achieved through two different approaches. First, in-situ measurements of the air temperatures were conducted during the year 2005. Second, the thermal analysis of the house is made with the use of the Ecotect software. The analysis of thermal comfort conditions is complemented by the reports of the users of the house. It is believed that the combination and the comparison of the results of the aforementioned approaches will provide an overall, comprehensive assessment of the design strategies, which guided the design of the house.

Keywords: passive solar design, temperature measurements, thermal analysis

1. INTRODUCTION

The incorporation of passive solar features, such as sunspaces, into the design of dwellings can significantly improve their thermal behaviour during the cold period. The accumulation of the sun's rays contributes not only to the conservation of energy for space heating, but also to the creation of favourable thermal comfort conditions in the living spaces of the house, which are in direct contact with the passive solar feature.

While, during the winter period, the existence of a sunspace can reduce the consumption of conventional energy for space heating, during the intermediate seasons, it can minimise the need for auxiliary heating. Nevertheless, even in areas with continental climate, problems may arise during the summer period. When the sunspace is not properly shaded [1], its thermal behaviour may result in the overheating of the living spaces of the house.

In this paper, an attempt is made to assess the thermal performance of a passive solar house, which is situated in the town of Florina, in north-western Greece, during the intermediate seasons and the summer period. As the winter thermal performance was analysed in a previous paper by the authors [2], this paper aims at completing this short-scale study with additional experimental and thermal analysis data. In this way, it wishes to address the issue of self-sufficiency during the intermediate seasons, and to explore the possible negative performance of the sunspace during the summer period.

2. GENERAL DATA

2.1 Overview of the topography and the climate of the area

The town of Florina lies in a mountain valley, which is crossed by a river from East to West. The longitude of the city is 21°23'59'', the latitude is 40°46'58'', and the altitude is 662 m. The house, which is analysed, is situated outside the city area, on the south slope of a mountain, at an altitude of 790 meters.

The climate of the area is continental, with long, cold, humid winters and short, warm, and dry summers. The hourly climatic data presented below (Table 1) were generated with the Meteonorm v4.0 software [3], and was then imported to the Weather Tool v1.10 software [4]. This data was used to derive the monthly heating degree-day (HDD) values for Florina, and to plot psychrometric charts for the area.

It can be seen that the mean minimum temperatures are below 18 degrees throughout the year, and heating may be required both in May and in October. Finally, the area is characterised by an extended snowing period, which starts from November and ends in April. [5]

Table 1: Monthly climatic data values for the spring and the summer for Florina. [4], [6]

	Mar	Apr	May	Jun	Jul	Aug
Mean Min Temp (C)	1.3	5.1	9.2	12.5	14.4	14.2
Average Temp (C)	6.7	11.6	16.8	21	23.1	22.5
Mean Max Temp (C)	11.8	16.7	22	26.2	28.8	28.7
Rel. Humidity (%)	70.9	64	63.4	59.8	57.4	58.3
Aver. Rainfall	57.9	57.9	58.9	37.3	34	31
Days of Rain	12.3	11.3	11.2	7.4	6.1	5.8
Wind Direction	W	W	W	W	N	N
Wind Speed	4.1	4.6	4.8	4.8	4.6	4.3
HDD (Tbase 19°C)	334	192	94	40	10	13

The psychrometric charts, which were generated for the spring and the summer period for Florina, demonstrate that even in the summer, climatic conditions may be way beyond thermal comfort (see Figs. 1, 2). The effect of three passive strategies (passive solar heating, thermal mass and natural ventilation) was plotted against the psychrometric chart, in order to explore their contribution to the thermal behaviour of a dwelling. It was seen that passive solar heating and thermal mass could significantly extend the thermal comfort range during the intermediate seasons (spring and autumn). The contribution of both thermal mass and natural ventilation during the hot hours of the summer months was also made clear.

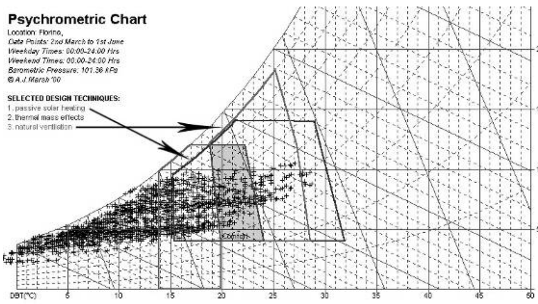

Figure 1: Psychrometric chart for Florina. Spring period data points. [4]

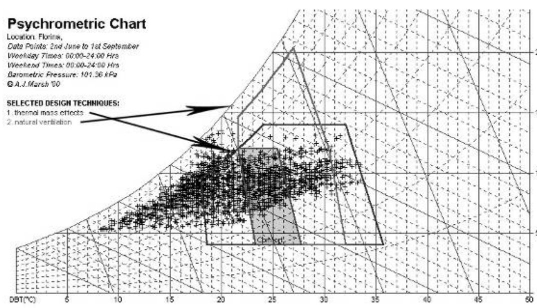

Figure 2: Psychrometric chart for Florina. Summer period data points. [4]

2.2 Overview of the design features of the house

Achilleas Stoios designed (1995) and supervised the construction of the building (1996-1997), which houses a four-member family. Its main bioclimatic feature is a south-orientated sunspace, which is attached to the living room and covers a significant part of the facade. All the south-facing rooms (master bedroom on the ground floor and children bedrooms in the attic) have extensive south-facing window areas for direct gain. The bathroom and the staircase are placed on the north in order to function as buffers for the main living spaces. (Fig. 3) Even though the area of the north-facing windows is minimised in order to reduce thermal losses, the staircase area has a window in order to enhance natural ventilation. For a more detailed description of the design of the house, as well as of its construction details, see [2].

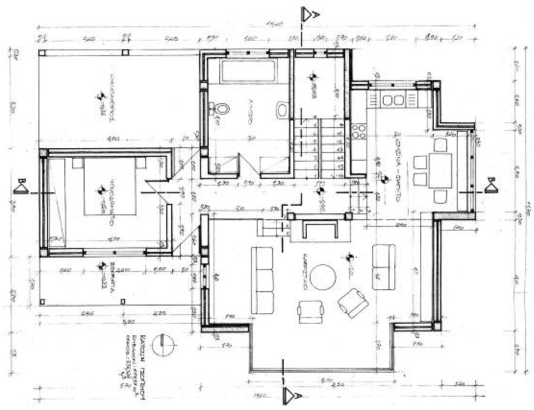

Figure 3: Plan of the house.

Figure 4: The main, southern facade of the house.

3. AIR TEMPERATURE MEASUREMENTS

3.1 Overview

In-situ air temperature measurements were carried out from March 1st to November 30th, 2005. (Table 2) The measurements were conducted with three dataloggers, which were placed outside on the northern part of the house, in the living room and at the staircase.

Table 2: Mean temperature values during the measurement period.

	Mean outside T (*C)	Mean living room T (*C)	Mean staircase T (*C)
March	5.82	19.44	18.52
April	10.31	18.77	17.56
May	15.94	20.21	18.69
June	18.10	21.67	20.56
July	21.96	24.64	23.27
August	20.94	24.03	22.19
September	17.22	21.09	20.60
October	11.09	18.71	18.02
November	5.53	19.39	18.6

3.2 Analysis of the measurements

During March and April, outside temperatures were generally low, whereas the internal temperatures of the living room fluctuated between 17 and 22 degrees C, with a mean temperature of about 19.5 degrees C (March) and 18.5 degrees C (April). On May, the environmental temperatures start to rise, reaching 22 to 26 degrees C during the daytime and falling to 5 to 10 degrees C during the night. The living room air temperature fluctuation closely follows the outside one, reaching 22 to 24 degrees C during the afternoon, although the lowest temperatures do not fall below 18 degrees C, during the night. (Figs. 5-6)

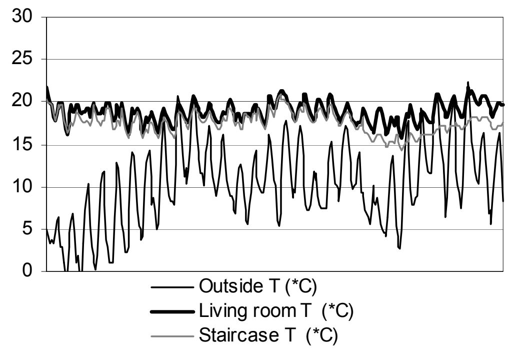

Figure 5: Measured temperatures for April.

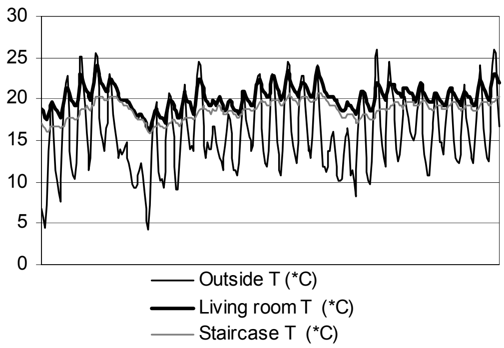

Figure 6: Measured temperatures for May.

During the summer months, the daily environmental temperatures were characterised by a significant daily fluctuation (from 12-14 ^{o}C to 26-28 ^{o}C on June, from 14-16 ^{o}C to 30-32 ^{o}C on July and from 12-16 ^{o}C to 30-34 ^{o}C on August). As a result, the mean outside air temperatures were between 18 and 22 degrees C. Throughout this period, the air temperature in the living room was relatively high (26-28 ^{o}C) during the afternoon hours. During a heat-wave, at the beginning of August, when the outside air temperature reached 34 degrees C, the living room air temperature surpassed 28 degrees C and nearly reached 30 degrees C. Nevertheless, during the night, when the environmental temperatures dropped steeply, the temperatures, which were measured in the living room of the house, were between 20 and 24 degrees C, depending on the month. (Figs. 7-9)

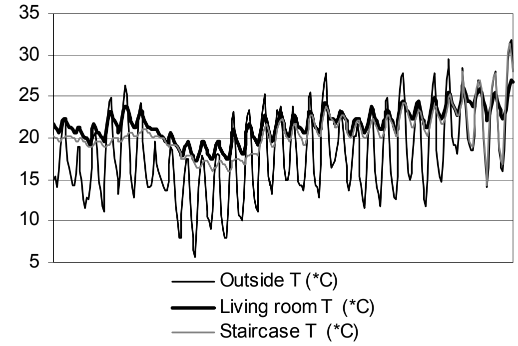

Figure 7: Measured temperatures for June.

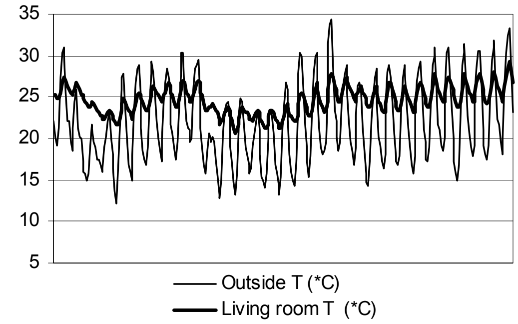

Figure 8: Measured temperatures for July.

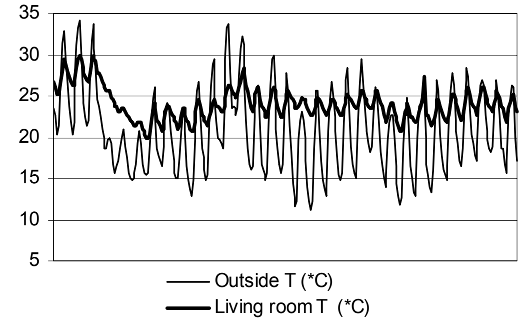

Figure 9: Measured temperatures for August.

On September, the outside air temperature starts to fall (daily fluctuation from 10-15 ^{o}C, during the night, to 20-25 ^{o}C, during the day), while on October the maximum environmental temperatures do not exceed 20 degrees C and the minimum are lower than 10 degrees C. Finally, on November, the outside air temperatures drop significantly, reaching 15 degrees C during the daytime and falling to 0-5 degrees C, during the night. Throughout the autumn, the interior temperatures of the house fluctuate between 15 and 20 degrees C, although on some September days the maximum air temperatures of the living room rise up to 25 degrees C. (Figs. 10-11)

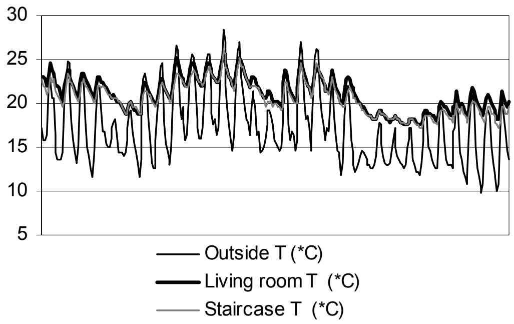

Figure 10: Measured temperatures for September.

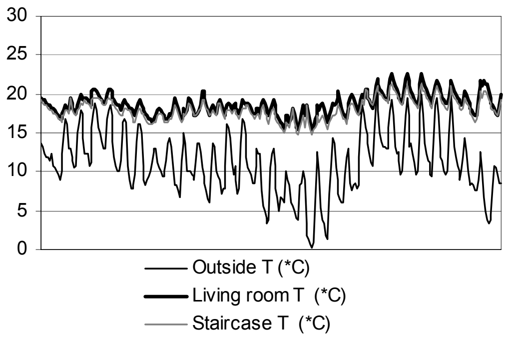

Figure 11: Measured temperatures for October.

The in-situ measurements clearly underline the positive contribution of the sunspace to the thermal budget of the house during the months of March to May and September to November, when the air temperatures during the day and the solar radiation allow it to function as a heating element. Furthermore, it is seen that the diurnal internal temperature range of the house is relatively small. This underlines the efficient thermal behaviour of the building fabric. It also denotes the energy-conscious behaviour of the users, in periods during the spring and the autumn months when the use of active heating was necessary in order to maintain thermal conditions within the comfort range.

4. THERMAL ANALYSIS USING SOFTWARE

4.1 Overview

The thermal analysis calculations were performed with the software Ecotect v5.2 [7] (Fig. 12). The aim of this analysis is to obtain a representative picture of the passive thermal behaviour of the house, namely its behaviour without the active heating systems, during the period that the house is on a free-running regime.

The thermal modelling was based on a series of assumptions:

- The terrain was assumed to be suburban.
- The spaces of the house were represented with different zones.
- The winter comfort band was set to 15 to 22 degrees C, while the summer comfort band was set to 20 to 26 degrees C.
- The sunspace enclosure was designed with a slightly higher U-value, from 18:00 in the afternoon until 08:00 in the morning, in order to account for the effect of internal blinds on the reduction of thermal losses.
- Even though the sunspace zone is not physically separated from the living room, its thermal behaviour was simulated separately, due to the radically different characteristics of its construction and thermal mass. Nevertheless, the boundary between the sunspace zone and the living-room zone was assigned as a void. In this way, typically, the two zones are thermally linked.
- The occupation of the house was represented with different schedules. During the week, it was assumed that the house was occupied after 14:00, whereas during the weekends and the holidays, that it was fully occupied.

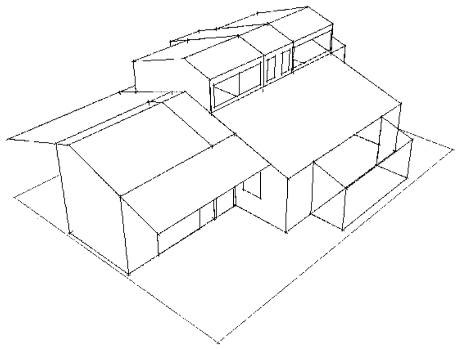

Figure 12: Model of the house constructed with Ecotect [7].

4.2 Hourly Temperature Profiles

On the hottest day of the year (July 12th), the outside temperatures range from about 15 to about 33 degrees C. The measured and the calculated air temperatures of the living-room show a very good agreement (less than 1 ^{o}C difference). (Fig. 13)

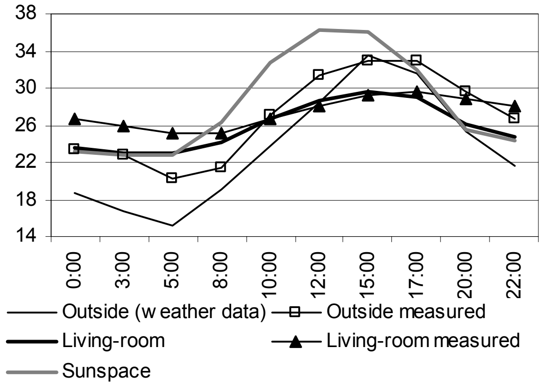

Figure 13: Hourly temperature profile of the main zones of the house (12/07).

For a one-week period at the beginning of May (May 1st to May 7th) the monitored data were plotted against the data, which were modelled by Ecotect [7]. The measured ambient temperatures had the same diurnal variation with the ones used by the software, but were significantly higher (2 to 5 °C).

It can be seen that the modelled internal temperatures for the living room are similar to the monitored ones, but significantly lower (by 2 to more than 5 °C). Only during the first day the maximum daytime temperatures of the simulation and the measurements coincide, whereas for the rest of the week the maximum living room temperatures are very close to the calculated sunspace temperatures. (Fig. 14) The above-mentioned inconsistencies can be explained by the differences between the weather data file, which was used by the software, and the actual air temperatures. Furthermore, it is possible that the software analysis can not fully account for the thermal inertia of the house. This may be the reason why the actual air temperatures during the night do not fall as steeply as do the modelled ones.

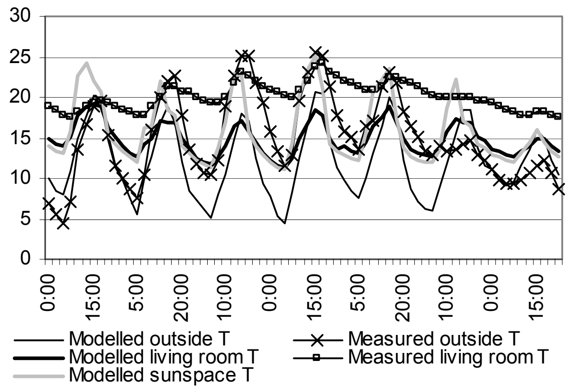

Figure 14: Diurnal temperature variation for the living room space during 1 week in the spring (1/5-7/5).

For a one-week period in the middle of the summer (July 28th to August 3rd) the monitored data were plotted against the data, which were modelled by Ecotect [7]. The measured ambient temperatures were, for most days, fairly close to the ones used by the software. It can be seen (Fig. 15) that the modelled internal temperature variation for the living room is similar to the monitored ones (up to 2 °C difference), during the daytime, but significantly lower (by 2 to 5 °C) during the nigh. This fact can be attributed to the lower night-time environmental temperatures of the weather data file, which was used by the software. From the graph, it is also evident that the air temperature of the sunspace is very high during the daytime, reaching, and even surpassing, 34 degrees C round noon.

Even though the preliminary analysis showed that the air temperatures of the sunspace zone are way beyond thermal comfort during the hot hours of the summer months (Fig. 15), the users of the house did not mention such a problem. For this reason, an extra series of calculations were run for the examined summer period (28/7 to 3/8), but this time the sunspace zone was defined as ventilated. (Fig. 16) It can be seen that the air temperatures in the sunspace zone remain within the summer comfort range, when it is ventilated.

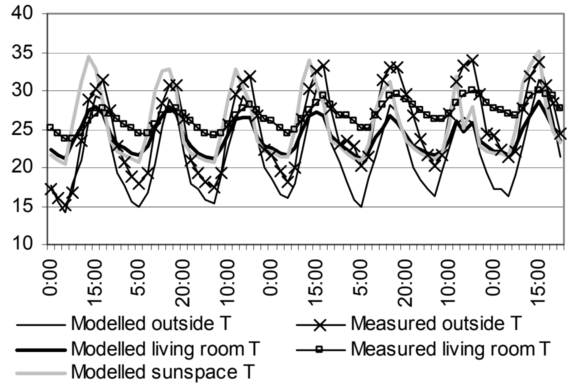

Figure 15: Diurnal temperature variation for the living room space during 1 week in the summer (28/7-3/8).

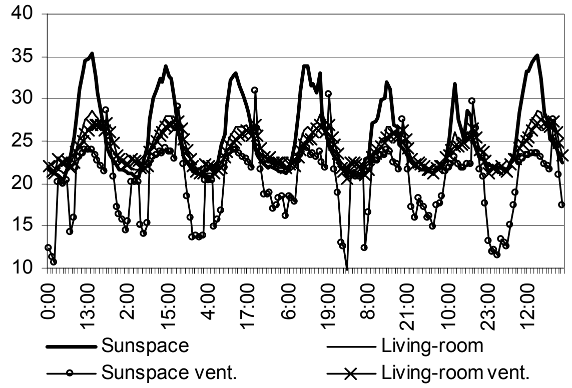

Figure 16: Modelled diurnal temperature variation for the sunspace and the living room zones during 1 week in the summer (28/7-3/8) with and without ventilation. [7]

The thermal behaviour of the sunspace zone was further explored with the calculation of the temperature distribution. This calculation showed that the air temperatures there exceed the defined upper comfort limit (26 °C) for less than 100 hours. Air temperatures in the sunspace reach 28 °C for 31 hrs and 0.9% of the year, 30 °C for 20 hrs and 0.6% of the year, 32 °C for 15 hrs and 0.5% of the year, 34 °C for 11 hrs and 0.3% of the year, etc.

4.3 Other aspects of the thermal analysis

After having confirmed a relative agreement between the simulation analysis and the experimental measurements, other aspects of the thermal analysis are also explored.

The hourly gains of the different living spaces of the house were calculated for different days during spring, summer and autumn. The thermal analysis showed significant direct solar gains through the southern openings and the sunspace (Fig. 17). During the summer months, the direct solar gains of the sunspace are also significant due to its lack of shading (see Table 3 for the calculation for the hottest summer day).

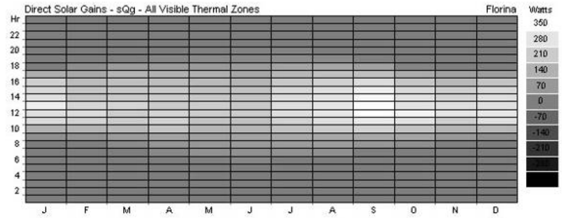

Figure 17: Direct solar gains of the whole house derived with Ecotect [7].
Figure legend:
Horizontal axis: months from January to December
Vertical axis: hours of the day from 0:00 to 24:00
Shade ranges: from +350 W (white) to -350 W (black)

Table 3: Direct solar gains of the different spaces of the house during the hottest summer day (July 12th).

Zone of the house	Direct solar gains (kW/day)
Sunspace	35.749
Bedroom 1	0.686
Bedroom 2 (attic)	1.082
Bedroom 3 (attic)	1.082
Hallway (attic)	0.386

Furthermore, the thermal analysis showed that because of the harsh climate of the area, the house has thermal losses due to conduction throughout spring and autumn, whereas the conduction thermal gains are confined to the months from June to August. Nevertheless, throughout the examined period, the conduction losses and/or gains are reduced due to the improved U-value of the wall elements and the roof structure. (Fig. 18)

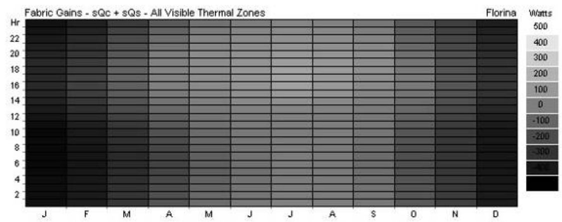

Figure 18: Fabric gains and losses of the whole house derived with Ecotect [7].
Figure legend:
Horizontal axis: months from January to December
Vertical axis: hours of the day from 0:00 to 24:00
Shade ranges: from -500 W (white) to +500 W (black)

5. CONCLUSION

This short-scale study lead to some interesting conclusions concerning the assessment of the thermal behaviour of the passive solar house. First of all, it proved that for the cold continental climate of Florina, the applied passive solar strategies have a very positive contribution to the thermal behaviour of the house during the intermediate seasons (spring and autumn), when heating can be minimised with correct architectural passive solar design. Secondly, similar to the previous study by the authors [2], it made evident that for the harsh, cold climate of Florina, the effect of the sunspace and the south-facing windows for the exploitation of direct solar gains cannot in any case eliminate the need for active heating. Thirdly, it proved that even though the negative contribution of the sunspace to the thermal balance of the house during the summer period is significant, it is eliminated with the use of passive cooling strategies, such as ventilation. Nevertheless, the most efficient way of preventing summer overheating problems in the sunspace is an exterior shading device, such as moveable louvers, or a pergola with deciduous plants.

It should be noted that, similar to the previous study [2], this one clearly demonstrated the importance of the behaviour of the occupants concerning the overall thermal performance of passive solar houses. Even though the air temperatures during the intermediate seasons may call for active heating, it is the energy-conscious behaviour of the users, which minimises energy consumption through the definition of a low set-point temperature for the auxiliary heating system. Furthermore, during the hottest days of the summer period, the users of the house use ventilation in order to remove the excess heat from the sunspace, during the daytime. They also use night ventilation in order to cool the mass of the building, during the night and to prevent it from overheating during the daytime.

The behaviour of the occupants of the house enhances the bioclimatic performance of the passive solar features, which the architect incorporated in the design. In this way, throughout the year, the interior air temperatures remain within the comfort range, with the comprehensive use of conventional energy.

ACKNOWLEDGEMENT

The authors would like to thank the occupants of the house, Giannis Daikopoulos, Eleni Nikolaou, and their children for their co-operation and understanding, during the course of this study.

REFERENCES

[1] R. Colombo, et al., Design Handbook. Passive Solar Architecture for Mediterranean area, Joint Centre of Research, Brussels-Belgium (1995).
[2] A. Stoios, et al., "Design and post-occupation evaluation of a passive solar house for continental, cold climate, in Florina, north-western Greece ", Proc. 22nd PLEA Conference, Beirut-Lebanon (2005), 565-570.
[3] Meteonorm software v4.0, Meteotest, J. Remund, et al., Bern - Switzerland (1999).
[4] Weather Tool software v1.10, Square One Research PTY Ltd., Dr. A. Marsh, http://www.squ1.com
[5] G. Daikopoulos and E. Mavrikaki, "Changes in the physical environment of Florina", Proc. Conference Florina 1912-2002. History and culture, Florina-Greece (2004), 699-712.
[6] http://www.emy.gr/hnms/english/climatology/
[7] Ecotect Tool software v5.2, Square One Research PTY Ltd., Dr. A. Marsh, http://www.squ1.com