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Guidelines for Bioclimatic Housing Design in Greece

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This paper details a set of guidelines for the design of thermally efficient houses in the generally temperate climate of Greece, using the common construction materials of Greek contemporary housing and employing simple passive design techniques. The guidelines should be of use to the designers of climate sensitive housing in Greece. The relationship between the heat capacity, levels of thermal insulation and size of openings are considered in detail. The Building Bioclimatic Chart devised by Givoni and the Energy Simulation Computer program ESP are the main tools of the study.

1. INTRODUCTION

IN THE RECENT PAST among the research community in climate sensitive building design, there has been a growing awareness of the need to develop design guidance beyond that of either hot or cold locations to complex climates, such as occur in temperate or Mediterranean regions. This fact was recognised by the organisers of the PLEA 88 conference "Energy and Buildings for Temperate Climates—A Mediterranean Regional Approach" held in Porto, Portugal, in July 1988. The papers [1] of this 6th International PLEA Conference give a review of the "state of the art" at this time. More recently, at the second EC conference on "Science and Technology at the Service of Architecture", held in Paris in December 1989, some authors saw the need to return to, and to develop, this theme. The papers, published in the conference proceedings [2], which deal specifically with bioclimatic design for complex climates, provide a background against which this present paper should be considered.

In temperate climates such as in Greece, although the climatic extremes may be less severe than elsewhere, distinct cold and hot seasons still exist. This was well understood in the design of vernacular buildings which respond well to seasonal changes and are adapted to the microclimate of the area where they were built. Contemporary housing in Greece, however, usually totally ignores the climate. This paper establishes guidelines for the design of new housing along bioclimatic lines and provides valuable general information for the use of designers of housing in Greece.

It is well known that there exist standard passive techniques for controlling the internal environment during both the underheated and the overheated periods of the year. The study provides guidelines for housing design so that the resultant internal thermal environment in winter and summer is as comfortable and as energy efficient as possible when the external building envelope is used as a passive system. Although Greece is the country under consideration in this paper, the methodology and conclusions (with appropriate modifications) could well be applied to other countries with a similar Mediterranean climate. Moreover, the findings can be used for comparison with the results of other researchers, in this way advancing the understanding of bioclimatic housing design in Mediterranean and similar climates.

Methodology

The passively created thermal environment in dwellings is the main focus of the study. The technique used for the investigation was first to establish thermal and climatic zones for Greece and then to test the effect of various design options (such as shape, orientation, heat capacity, thermal insulation and size of openings, in addition to colour of external surfaces, shading, shape of the roof and internal partitions) on the thermal performance for each of the climatic zones. The effect of the various design options was established by a computer simulation technique which predicted the internal thermal conditions.

The criterion used for selecting the most effective design feature was that it should produce internal *summer* conditions as close as possible to the upper limit of the comfort zone, but not above, so that in *winter* the energy used for heating will be a minimum. A feature, a combination of features or a total house design which achieves this has been rather loosely referred to as "optimum" in this study. It was found in all cases that features which establish the peak allowable summer conditions also result in the highest internal temperatures in winter in unheated dwellings.

Because of the large number of variables which affect internal thermal conditions and the impracticality of testing separately a range of options for each variable in combination with options of all the other variables, it

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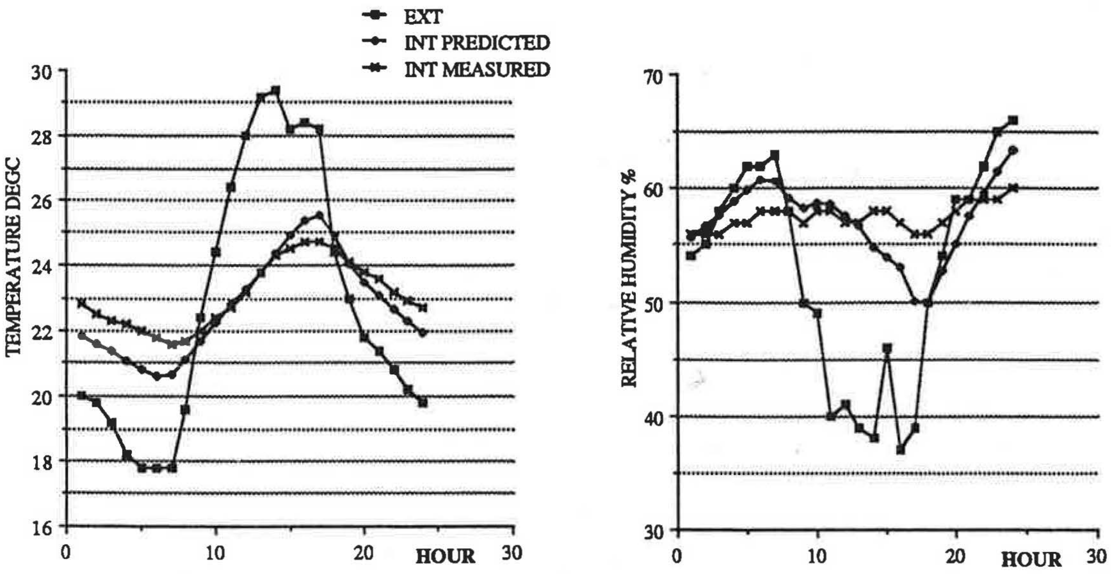

Fig. 1. Comparison between the external, internal predicted and internal measured temperature and RH, in summer. The data represent measured and predicted values for a contemporary Greek house in Tripolis [4].

:o carry out the investigation in two parts. nd of simulations took a broad look at the tant variables to establish the basic par- thermally efficient design, while the second ·ously investigated the sensitivity of the basic ıanges in the most important variables.

,rnal climatic conditions, the house design and influence are the three factors affecting the ɔf the internal environment. The assumptions ,n studying these three interacting parameters in of the Greek climate, dwellings and people are d in Section 2.

,nain tool used for the analysis is the Environ- Systems Program (ESP) developed by the ,US Unit of the University of Strathclyde [3].

use of ESP and the notion of thermal comfort /ements raise two main questions: are ESP's pre- ıns accurate for Greek building practice and for its ıte and what are the thermal comfort limits for ıle acclimatized to the Greek climate?

ting ESP

'he first question, concerning ESP, was answered by nparing the predictions of ESP with physical data llected by monitoring a number of houses in Greece ıring the summer and winter periods. Vernacular and ɔntemporary houses in four locations were monitored or one week in winter and one week in summer. In :his way different construction materials and climatic conditions were investigated. The accuracy of the predictions was found satisfactory for both extreme seasons and for all the building types monitored [4]: for an example see Fig. 1.

Defining a thermal comfort zone suitable for Greece

The definition of a thermal comfort zone suitable for Greece was achieved by reviewing the literature on thermal comfort in dwellings for people acclimatized to moderate climates [5–9]. The resulting thermal comfort zone includes temperatures between 19 and 26°C with associated RHs between 30 and 80% for the colder part of the zone and lower RHs for the warmer part [4, 10] (Fig. 2). The high humidity–high temperature area is excluded as discomfort is usually observed when both these values are high. The lower part of the thermal comfort zone is particularly suitable for the winter period, because people are accustomed to the low outdoor temperatures and heavy clothing is worn even indoors (clo = 1.0). The upper part of the zone is best suited to the summer period when people are acclimatized to the high external temperatures and very light clothes are usually worn (clo = 0.5). The metabolic rate is assumed to be between 0.8 and 1.2 met, indicating sedentary or light activity as in dwellings and the air movement is taken as less than 0.2 m s^{-1} (still air).

If higher air movement is provided indoors, the summer thermal comfort zone can be extended because the air temperature in which one feels comfortable is also higher [5–8]. A limit of 28.5°C is set above which thermal comfort is not likely to be achieved by providing air movement without causing annoyance. Air velocities up to 1.5 m s^{-1} are likely to be acceptable indoors [4]. Humidities lower than 20% are excluded as dry air and high air movement can cause irritation. For the same reason as for the main thermal comfort zone, the high humidity–high temperature corner is also excluded. Air movement can be provided indoors using natural ventilation where possible. If the windows are closed, the air can be moved within rooms simply by using fans.

2. THE EXTERNAL CLIMATE, HOUSE MODEL AND USER INFLUENCE

This section is concerned with defining models of the climates, the house design and the users' influence for use

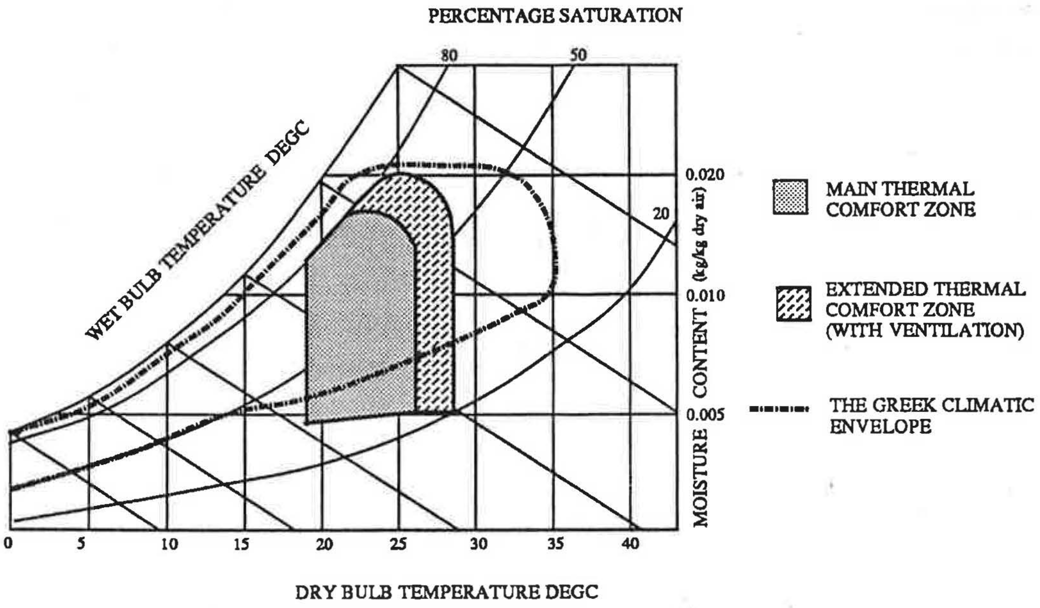

Fig. 2. The proposed main and extended thermal comfort zone suitable for Greece and the Greek climatic envelope.

in the study. It discusses how the models were derived and the assumptions made.

The external climate

In Greece as in any other region, the external climate rarely lies within the limits of the thermal comfort zone. The climate, which includes hot and cold seasons, spreads above and below the thermal comfort zone. The climatic envelope, shown in Fig. 2, was constructed by analysing data from 39 meteorological stations [11] selected across the country. It is possible to divide Greece into climatic regions [10]. This was done by the authors on the basis of which thermal building characteristics are predicted to produce the most effective passive control of indoor climate at meteorological stations throughout the country. The predictions are made, using the Building Bioclimatic Chart (BBC) devised by Givoni which has been slightly modified for direct application in Greece and by using ESP [4, 10].

It was found that Greece could be divided into four climatic regions (Fig. 3), named A1, A2, B1 and B2 and having the following main characteristics:

(A1) cold winter, mild dry summer
(A2) cold winter, hot dry summer
(B1) mild winter, mild humid summer
(B2) mild winter, hot dry summer.

Based on the climatic data of each of the four regions, a climatic model was constructed by averaging the mean daily maximum and minimum temperatures and relative humidities, average wind speed and predominant wind direction [11] for each meteorological station in the zone. The data for solar radiation were based on computed values using empirical equations [12, 13]. Using this model of external climate, the thermal performance of the houses was assessed for the most commonly occurring average conditions for each month of the year, i.e. mean daily maxima and minima. In addition climatic models based on mean monthly maximum and minimum temperatures in winter and summer were created to examine the thermal performance of the houses under extreme conditions. The thermal performance of the house model under a winter overcast sky was also examined.

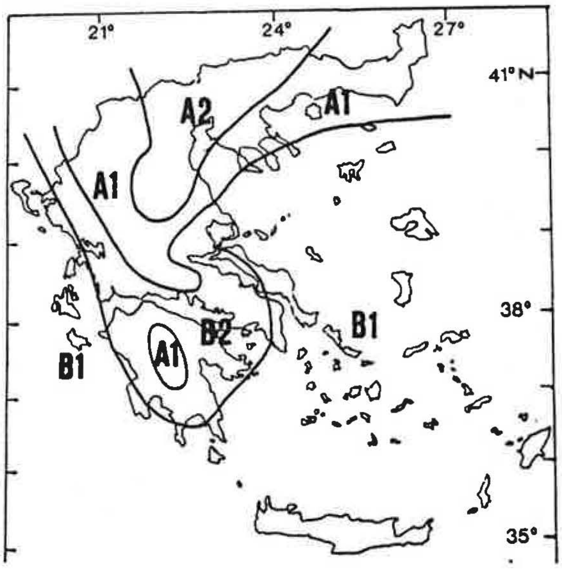

Fig. 3. The proposed climatic regions of Greece [4, 10].

The development of the house model

From the first steps of the study, it was decided to investigate the current situation in Greece with a view to finding ways of improving the thermal performance of

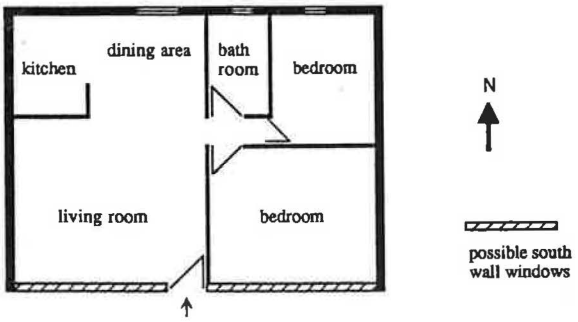

Fig. 4. Plan of the "standard" house model [4].

the housing currently being constructed. Further study therefore was necessary to create a "standard" house design upon which the effectiveness of the various design options could be tested. Reference [4] details the investigation which included a study of over 55 common house types. With regard to the *size* and *spatial layout*, the model is based on the typical four person Greek family house which usually has a relatively compact rectangular layout, a flat roof and a floor area of around 75 m^2 [4].

A *detached house* was used because this represents the worst arrangement from a thermal environment point of view. A detached house has greater heat losses in winter and heat gains in summer than terrace houses or blocks of flats, because all the external envelope of a detached house is exposed to the external conditions. Therefore, if care is taken not to obstruct the sun in winter and the natural ventilation in summer, terrace houses or blocks of flats should perform better thermally than detached houses. A plan of the derived house model is shown in Fig. 4.

The *materials* tested were those typically used in contemporary house construction [14]. A change of materials would obviously not alter the thermal performance of the houses if the *U*-values and the heat capacities are kept as proposed in the text.

In the initial stages of the research, four house-models were developed to correspond with the Givoni defined bioclimatic regions of the Greek climatic envelope (pp. 305–319 of [9]). Two models were developed for the cold side of the envelope, and 2 for the hot side. These Building Types were called BT1 : conventional house type (uninsulated), and BT2 : insulated conventional, for the cold side of the envelope, and BT3 : heavywieght and BT4 : lightweight, for the hot side.

In testing the appropriateness of these 4 options in each of the four climatic zones of Greece (A1, A2, B1 and B2), it was found possible to reduce them to two basic types, namely BT2, the insulated conventional for regions A1 and B1 and BT3, the heavyweight for regions A2 and B2 [see 4 for details].

Once these two basic types had been established, they were used as the "building models" for the investigation of the "optimum" (as defined under methodology) *aspect ratio, size of openings and level of insulation, colour* and *shape of roof.* The following analyses, therefore, were carried out using these two "house-models". Table 1 gives the values of the important thermal properties of the two models. A detailed discussion of why these values were selected is given in Ref. [4].

Assumed use of the house

The users' behavioural patterns were based on the way Greek people usually use their houses during the winter and summer. It is important that occupants operate a thermally efficient house correctly, otherwise there is no point in designing it to bioclimatic rules. For example, a large glazed area on the south wall will be wasted if the window shutters are closed during sunny days in winter, while a movable shading device will serve no purpose if it is not in place during daytime in summer. Also the heat capacity of the external walls will not perform efficiently if the windows are open during hot summer days and closed during summer nights. In the simulations, it has been assumed that correct bioclimatic operation of the house was in use.

In Tables 2 and 3, the assumptions made in the simulations concerning the internal heat gains and the operation of the house in winter and summer are summarized.

In winter, the shutters of the windows are assumed closed between 22.00 and 08.00 h. In this way, the thermal insulation of the house is improved during the coldest period of the day and the air infiltration through window cracks is reduced. The shading devices are rolled up during the winter period, so that full exploitation of the direct solar heat gains through the windows and walls is made possible.

In summer, the shading devices are assumed in place between 08.00 and 21.00 h so as to avoid solar radiation during the hottest part of the day. During the same hours, the windows and shutters are also closed to exclude the penetration of heat into the interior.

The windows are assumed open and the shading devices rolled up between 21.00 and 08.00 h to allow night time cooling of the interior through natural ventilation and radiation.

3. RESULTS OF FIRST STAGE SIMULATIONS

Once the climate, "standard" house and users' behaviour models were set up, simulation work began using ESP. In each step of the investigation, one of the design parameters affecting the internal thermal environment was examined in each set of simulations for one day in the hottest month (August) and one day in the coldest month (January) of the year for the four climatic regions. In each successive step, the most effective solution (selected from the previous simulations) in terms of thermal comfort in winter and summer was used. This procedure was repeated until a complete design was formed. This was then examined throughout the whole year to ensure that no thermal conditions that were worse were likely to occur in any month.

At this point in the study, it was decided to postpone the investigation of the heat capacity of the structure on the internal conditions. Preliminary investigations showed that the effects were small, at least over the range likely to be found in any real buildings currently being constructed in Greece. It was considered it would be better to carry out the investigation of heat capacity

Table 1.

Building type	Avg. U-value ($W\ m^{-2}\ {}^\circ C^{-1}$)	Avg. heat capacity ($kJ\ m^{-2}\ {}^\circ C^{-1}$)	Percentage area of wall, glazed N	S	E	W	Shading
Insulated (conventional for A1 and B1)	0.58	340	10	18	0	0	walls and roof shaded
(heavyweight for A2 and B2)	0.48	530	8	10	0	0	walls and roof shaded

Note: aspect ratio 1:1.33, absorbtivity of external surfaces 0.50, flat roof, no internal partitions. (Preliminary studies showed that only small changes occurred with and without partitions when these do not obstruct the air movement.)

Table 2. Winter operation

		Start time	Finish time	Sensible heat gains (W)	Latent heat gains (W)
Occupancy:	1 person	8.00	15.00	95	45
	4 persons	15.00	08.00	380	180
Lighting		16.00	24.00	2300	—
		24.00	02.00	1000	—
		07.00	09.00	2300	—
Cooking		12.00	14.00	100	100
		20.00	22.0	50	50

Table 3. Summer operation

		Start time	Finish time	Sensible heat gains (W)	Latent heat gains (W)
Occupancy:	1 person	8.00	15.00	95	45
	4 persons	15.00	19.00	380	180
	4 persons	24.00	08.00	380	180
Lighting		24.00	02.00	1000	—
Cooking		12.00	14.00	50	50

as part of the sensitivity analysis in the second stage simulations, after the basic "optimised dimensions" had been established in the first.

The following issues were tested for the four climatic regions (four separate climatic models used) using the insulated conventional construction for the A1 and B1 zones and the heavyweight model for the A2 and B2 zones.

At the end of this first round of simulations, the four bioclimatic house designs were subjected to further "optimisation" in the second stage simulations, discussed in Section 4.

Aspect ratio

Three aspect ratios were tested, namely 1:1.33 as in Fig. 4, 1:2 and 1:3. In line with current knowledge, the long axis pointed E–W in all cases, so that more external surfaces were exposed to the direct effect of solar radiation for as long as possible during the winter. The east and west walls were kept without windows so as to avoid early and late solar penetration into the interior in summer, which is difficult to exclude by using simple shading devices. A rectangular plan allows for the internal spaces to be arranged in such a way that as many of the main spaces as possible receive direct solar radiation for most of the daylight time in winter. As this cannot be easily achieved in a square plan, this case was not studied.

As might be expected the simulations showed that the compact shape (1:1.33) performed better in winter, while the more elongated shape (1:3) performed better in summer. The maximum difference in conditions, however, was less than 0.5°C in all cases, an almost negligible difference. The shape which gave the best summer condition was selected as the one to go forward to the next stage of the investigation. The data carried forward, which needed adjustment due to the change in aspect ratio, now become as shown in Table 4.

Size of openings and level of insulation

It has been long recognized that thermal insulation should be provided in buildings in an attempt to reduce heat losses in winter and heat gains in summer. It is also known that it is better if the insulation is placed as near to the exterior as possible in naturally conditioned buildings because the part of the wall or the roof on the inside of

Table 4.

Building type	Avg. U-value (W m^{-2} °C^{-1})	Avg. heat capacity (kJ m^{-2} °C^{-1})	Percentage area of wall, glazed				Shading
			N	S	E	W	
Insulated (conventional for A1 and B1)	0.568	312	6.5	12	0	0	walls and roof shaded
(heavyweight for A2 and B2)	0.46	509	5	6	0	0	walls and roof shaded

Note: aspect ratio 1:1.33, absorbtivity of external surfaces 0.50, flat roof, no internal partitions.

the insulation determines the effectiveness of the heat capacity and so affects the internal thermal conditions.

The issue which was investigated in detail was the provision of the best combination of thermal insulation and size of openings. For this, various combinations of thickness of thermal insulation and size of window were examined. The selection of the proposed values was made according to the following three criteria:

(1) The predicted internal conditions in summer must
be below the upper limit of the thermal comfort
oid the need for artificial cooling under
ummer weather. However, the situation
e internal summer conditions were just
e comfort zone were accepted as ideal as
ter conditions were then at their highest,
previous definition of "optimum".
ermal insulation must be such that the aver-
/-value of the dwelling is lower than the
mum permitted by the Greek Thermal Regu-
ns for Buildings.
largest windows possible should be selected
ause in this way direct solar gains are promoted
winter and natural ventilation in summer.

s between 0.2 and 1.0 W m^{-2} °C^{-1} and per-
s of south wall glazing between 6 and 48% were
ed. Table 5 lists the alternative values which
the first two criteria, while the underlined values
y all three. The underlined values were used in the
set of simulations.

our of the external surfaces

ight colours should be used for the external surfaces
all zones. Simulations showed that in summer, the
ternal temperature is reduced by 2°C if the absorbtivity
f the external surface is reduced from 0.9 to 0.1.
owever, as 0.1 absorbtivity corresponds to pure white
which is difficult to maintain and can possibly cause glare
if used for large surfaces, a value of 0.25 absorbtivity of
external surfaces was chosen for the following simulations.

Shape of roof

Simulations indicated that pitched roofs as against flat roofs have little impact on internal conditions if these are properly ventilated. Pitched roofs should therefore be constructed where precipitation levels require them, i.e. A1, B1 (apart from the central Aegean sea area) and the western part of the B2 climatic region (Fig. 3).

As the choice between pitched and flat roofs is not critical from the thermal performance point of view, flat roofs are used for the four climatic zones in the second step of simulations as these are more common than pitched roofs throughout the country.

Table 5.

Climatic region	U-value (W m^{-2} °C^{-1})	South openings (%)
A1	$\underline{0.20}$	$\underline{40}$
	0.40	24
	>0.40	*
A2	0.20	24
	$\underline{0.40}$	$\underline{27}$
	0.60	6
	>0.60	*
B1	0.20	9
	0.40	12
	0.60	15
	0.80	20
	$\underline{0.90}$	$\underline{24}$
	1.00	20
B2	0.20	12
	0.40	15
	$\underline{0.60}$	$\underline{18}$
	0.80	12
	1.00	*

* If these U-values are used, the average U-value of the house is higher than the maximum allowed by the Greek Building Regulations, even with very small openings.

4. RESULTS OF SECOND STAGE SIMULATIONS

Once the "optimum dimensions" of *aspect ratio*, *opening size*, *insulation levels*, *colour* and *shape of roof* had been established for the 4 climatic zones of Greece, the four variations of the two standard building models, (conventional insulated and heavyweight), were further investigated to test the sensitivity of the designs to changes in *heat capacity*. Another issue of importance in terms of sensitivity is the aspect ratio of the dwelling. More compact forms will probably be less sensitive to changes in other variables and to more extreme weather conditions. It was therefore felt necessary to investigate the sensitivity of the four designs to variations in aspect ratio.

Heat capacity

In order to find a heat capacity value most suitable for dwellings in Greece for summer, designs with different

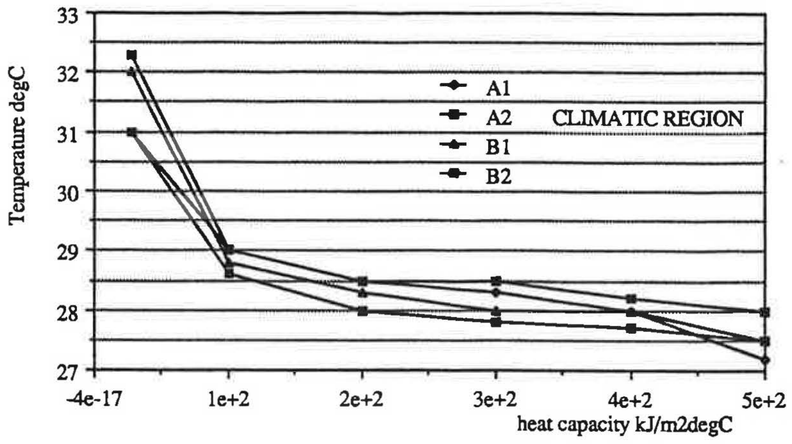

Fig. 5. Heat capacity effect on the internal maximum temperatures in summer.

average heat capacities were examined for each of the climatic regions. The results are presented in Fig. 5.

The x-axis is average heat capacity and the y-axis represents the maximum temperatures established indoors in summer. It can be seen that in all cases the curve flattens for heat capacities above 200 kJ m^{-2} $°C^{-1}$ and thermal comfort is established in all cases for heat capacities somewhere between 200 and 300 kJ m^{-2} $°C^{-1}$. However, a very welcome reduction in internal temperature occurs as the heat capacity increases even further but the thickness of the walls become impractical economically. For example, while a 150–220 mm concrete or 130–200 mm perforated brick wall can achieve a heat capacity of 200–300 kJ m^{-2} $°C^{-1}$, the thickness would increase to 350 mm for a heat capacity of 500 kJ m^{-2} $°C^{-1}$.

However, there is an inter-relationship between the heat capacity, U-value and size of openings in terms of the resultant internal thermal conditions. If the heat capacity changes, either the U-value or the size of openings, or both, should change to maintain the criteria set out above, namely that thermal comfort is ensured in summer and optimum conditions are established in winter, i.e. internal temperatures are on the upper limit of the comfort zone in summer and maximum temperatures are achieved in winter, and the average U-value is not greater than the Greek Building Regulations. Further, the heat capacity should not be lower that 200 kJ m^{-2} $°C^{-1}$ (for thermal comfort reasons) or greater than 500 kJ m^{-2} $°C^{-1}$ (for economic reasons). In Table 6 the alternative combinations of heat capacity, U-values and size of openings are presented as well as the average U-value of the dwelling to produce "optimum" internal conditions in winter and summer. This table provides guidance for designs of new bioclimatic housing in Greece. It is suggested, however, that an average heat capacity of 300 kJ m^{-2} $°C^{-1}$ is used as it represents a compromise between thermal comfort requirements and economy of construction. If this value is used, it can now be said that the conventional insulated house type is the sole "correct" building type for all the climatic zones of Greece, and in the rest of the study the underlined values are used in the simulations.

Aspect ratio

In order to test the sensitivity of the designs to different weather conditions and changes in orientation and shading when the aspect ratio is altered, two shapes were examined; a rectangular but relatively compact plan with an aspect ratio of 1:1.33 and a longer plan with aspect ratio of 1:3.

The first design, Rectangular Compact is abbreviated to RC, and the second design, Rectangular Long is abbreviated to RL.

Figures 6–8 present the results of simulations for winter (January) in terms of the heating energy required to maintain 19°C indoors, throughout day and night. The effect of changes in climatic conditions, shading arrangement and orientation were examined. Each figure includes the daily heating requirements for the fully solar exposed south orientated, RC and RL designs under mean daily external temperatures and average radiation values.

Figure 6 shows that, as expected, for the same shading arrangements and orientation, but under more extreme external temperatures (mean monthly) and solar radiation (overcast sky), more energy is required to maintain similar internal conditions. In this case, however, the RC design appears to be less sensitive to weather changes, requiring significantly less energy than the RL design.

Changes in the heating energy due to changes in shading arrangements are shown in Fig. 7. Three cases were investigated; fully exposed, partly shaded and fully shaded. The partly shaded design has been chosen to represent the situation when the building model is shaded by surrounding buildings of equal height, while the fully shaded dwelling represents the situation when it is surrounded by buildings three times its height. In both cases the surrounding volumes have been arranged in a distance of 2.5 m from the east and west side. This corresponds to the minimum distance allowed by the Greek Regulations in a free-standing urban arrangement. On the south side a street of 10 m wide is assumed, this being a typical street width.

Figure 7 shows that there is little difference between the fully exposed and the partly shaded cases. However, considerably more energy is required for a fully shaded

Table 6. Relationship between heat capacity, U-values and openings

Climatic region	Heat capacity (kJ m^{-2} °C^{-1})	U-value (W m^{-2} °C^{-1})	South wall openings (%)	Average U-value (W m^{-2} °C^{-1})
A1	200	0.20	40	0.554
	300	0.20	40	0.554
	400	0.20	48	0.618
	500	0.20	48	0.618
A2	200	0.40	27	0.610
	300	0.30	27	0.530
	400	0.30	30	0.553
	500	0.30	38	0.616
B1	200	0.90	24	0.989
	300	0.90	24	0.989
	400	0.80	24	0.909
	500	0.80	30	0.951
B2	200	0.60	18	0.704
	300	0.60	18	0.704
	400	0.60	24	0.748
	500	0.50	24	0.671

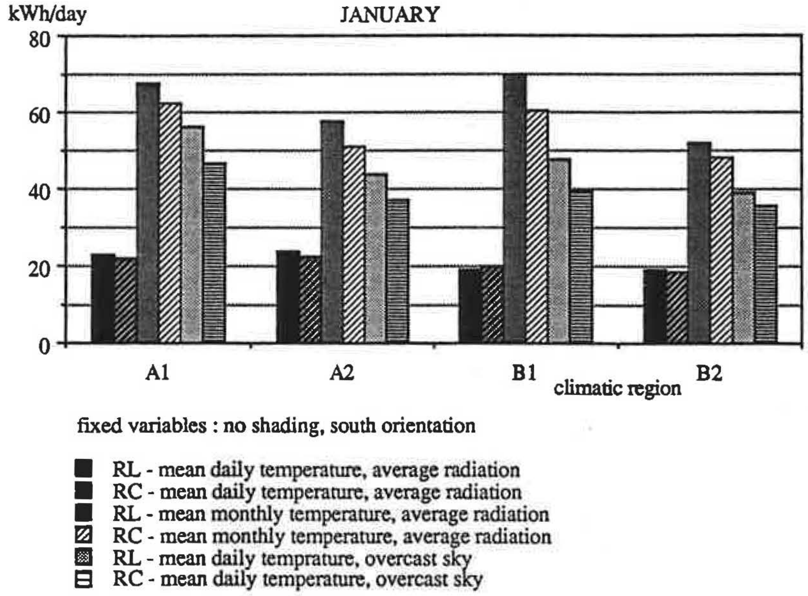

Fig. 6. The daily heating requirements in winter for the RL and RC designs under average and extreme weather.

dwelling. Also shown is the fact that the RC design is less sensitive to shading arrangements than the RL design.

Figure 8 presents the daily heating requirements when the designs are subject to changes in orientation. Three cases were examined; in the first the wall with most openings faces south, in the second south-east and in the third south-west. It can be seen that the S orientation requires least energy, with the SW requiring most. Also, the RC design requires less energy than the RL, with the maximum difference in the SW case.

With regard to the summer period (August), Fig. 9 presents the daily cooling requirements when the RC and RL designs are exposed to extreme summer temperatures (mean monthly). It can be seen that the RC design performs slightly better than the RL requiring less energy for cooling. It should be noted that no cooling is required under average temperatures (mean daily).

In Fig. 10, the maximum established internal temperatures in August for a fully shaded and a fully exposed design are presented. The difference between the RC and RL designs is very small with the RC design performing slightly better in the A1 and A2 climatic regions and the RL better in B1 and B2.

In summary, it can be said that a rectangular but compact form (aspect ratio 1:1.33) with the long axis pointing E and W, fully shaded in summer and fully exposed in winter, is preferable to a rectangular shape with a larger aspect ratio (1:3), because it is less sensitive in winter to changes in the weather and other design decisions, while in summer the differences are negligible.

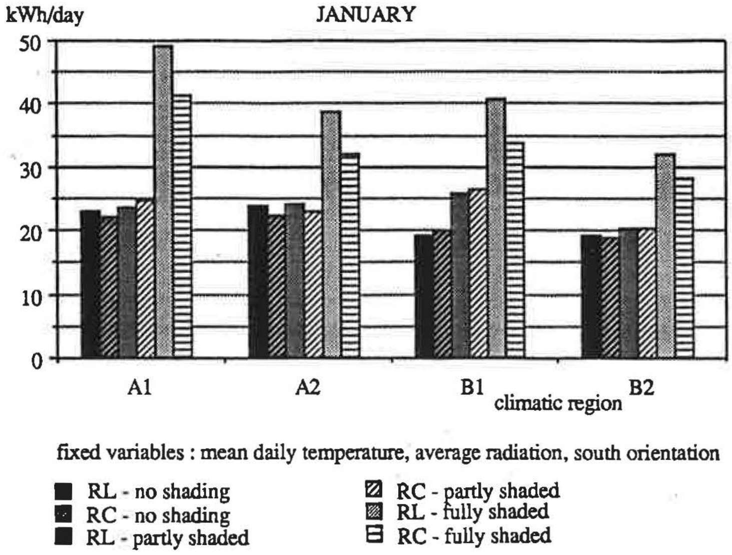

Fig. 7. Daily heating requirements in winter for fully exposed, partly shaded and fully shaded designs.

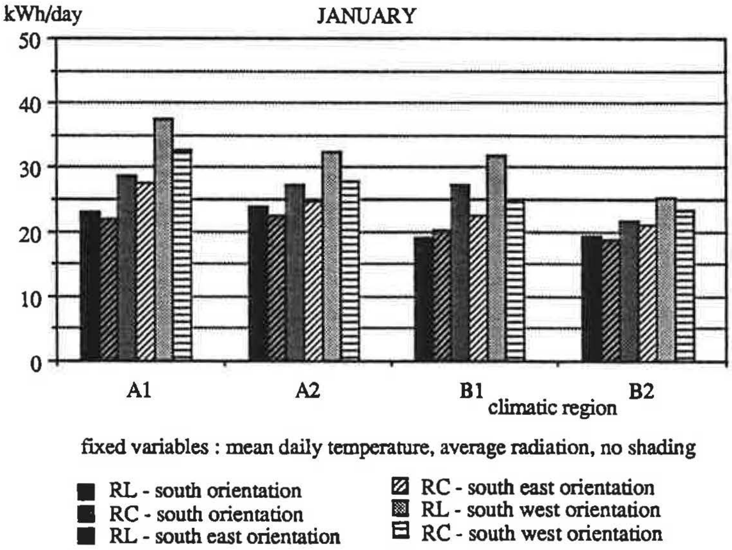

Fig. 8. Daily heating requirements in winter for south, south-east, and south-west orientated designs.

5. CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

The investigation of the thermal effectiveness of various design options for dwellings in the moderate climate of Greece has shown that it is possible to design a dwelling which complies with the current building regulations, which does not require cooling in summer under average climatic conditions and in which the winter heating requirements are less than in typical insulated dwellings currently being built in Greece. However, some form of artificial cooling is still required for summer days when more extreme temperatures prevail.

It has been shown that a rectangular but compact design is less sensitive to weather extremes, shading arrangements and orientation than a more elongated shape in winter (Figs 6–8), and that light coloured external surfaces are preferable as they then absorb less heat in summer, thus preventing the rise of internal temperatures. A southerly orientation has been shown to provide the best exploitation of winter solar radiation. In addition, the investigation has shown that movable shading devices are necessary, so that the dwelling can be fully shaded during the summer but fully exposed to solar radiation in winter.

The relationship between heat capacity, insulation level and size of south openings, has been shown to be of great importance in the creation of internal conditions. The most effective combinations of these three building properties for the 4 climatic regions in Greece are given in Table 6.

It is clear that further work should be carried out in continuation of the present study, especially in assessing the effect of the various assumptions adopted on the

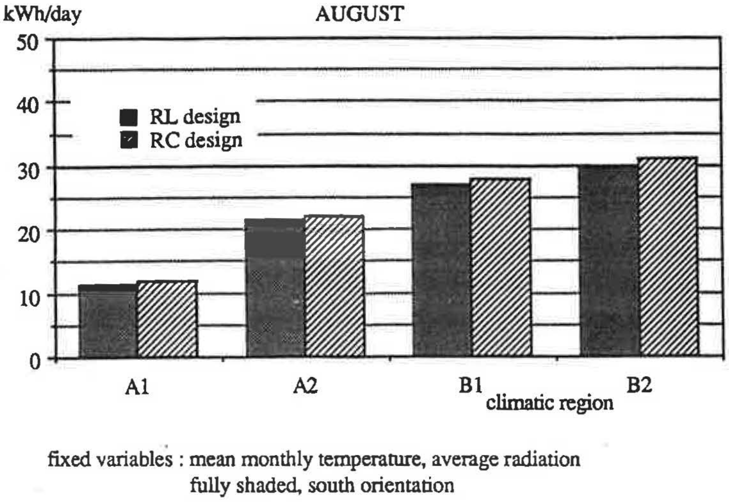

Fig. 9. The daily cooling requirements in summer for the RL and RC designs under mean monthly temperatures (no cooling is required under mean daily temps).

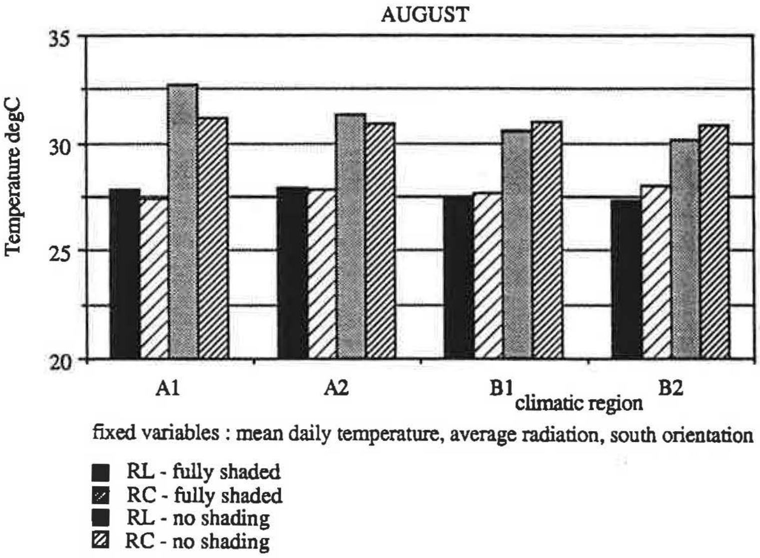

Fig. 10. Maximum internal summer temperatures in shaded and non-shaded designs in average summer conditions (mean daily temperatures).

internal summer conditions and winter energy use. The sensitivity of the "optimum" designs to these assumptions should also be investigated. If lower temperatures are preferred in summer at the expense of larger heating bills in winter, this could be achieved by selecting lower U-values and/or smaller south facing wall openings. Further work needs to be carried out to quantify the trade-offs possible.

A full economic study of the capital and running costs of the proposed housing would also add much to current knowledge in the field.

Finally, the construction, and subsequent monitoring, of a test house in each of the climatic zones would yield much useful information and would help towards the acceptance of the findings of this study.

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