Paper No: 745 ZERO ENERGY HOUSE-INTEGRATED DESIGN AND THE HUMAN FACTOR

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Abstract

Through thermal analysis, optimization and evaluation of alternative design options and hypothetical data, previous research has concluded to the profile of the "Zero Energy House for Cyprus". It was found that it is possible to achieve indoor comfort conditions, for the Cyprus climate, without the need for mechanical energy for heating and cooling, through the use of compact shape and the optimization of insulation, internal mass and fenestration design.

However, peoples' responses are very important consideration in the creation of a zero energy house; but the occupants desired comfort level is not a manipulable input factor; people react differently to the thermal environment; even when the optimum environment for a given activity level and clothing is produced, not everyone is satisfied.

The study in this paper identifies the occupants' factors that influence the efficiency of building performance and the thermal environmental conditions of the "Zero Energy House". It analyses the intervention of the occupants in the design, which is reflected in the variable of fenestration. The analysis is carried out interdependently, in various combinations of shading and ventilation profiles, in computer simulations

As an integral part of the planning process, strategies are recommended and alternative solutions are given.

Keywords: Zero energy house, integrated design, Human factor, shading, ventilation, Infiltration.

1. Introduction

The study makes use of the optimisation studies of a specific house type, designed in an ideal environment, to the point of zero fuel consumption for heating and cooling with the aid of microcomputer programmes for thermal analysis. For these, initially simplified thermal calculations are carried out by using "Method 5000" a well established method used by the Commission of the European Community Handbook. These are followed by detailed hourly simulations of selected variants using dynamic simulation model "SERIRES".

The thermal calculations were analysed, a comparative assessment of results was drawn and design recommendations for new houses through economic analysis of the varied design measures were concluded. From those the profile of the "Zero Energy House for Cyprus" was outlined.

However, the house is not merely a container in which people act like robots and are placed to receive its thermal effects. There is a dynamic dialogue between building controls and building use. Furthermore, for the Mediterranean climate it is necessary that some of the employed passive systems for the optimisation must be activated by the users in order to be effective.

It was found from the study that the variable of fenestration houses those user interactive parameters which could be critical for the optimal performance of the 'Zero Energy House". These parameters are: Fenestration Shading and Ventilation.

The relative thermal effect of those parameters in many different combinations in building simulations was studied using thermal analysis programmes "AGRI" and "QUICK". The conclusions are outlined in the form of criteria for the selection of different design alternatives for "Zero Energy Houses" for Mediterranean.

2. The Zero Energy House

2.1 The Variables of the Zero Energy House

From the background studies the profile of the "Zero Energy House" was defined from analysis of the results of comparative parametric studies classified in four major variables:

- Shape
- Mass
- Fenestration
- Insulation

The effect of the most important parameters of these variables, on the thermal response of the building was assessed during both heating and cooling modes. The performance of the parameters was analyzed, their efficiency was compared with each other and their effectiveness was expressed in the constructional aspects for "Zero Energy House".

2.2 Integrated Design for Zero Energy House

The study through the comparative studies and the analysis of the results has concluded that thermal comfort can be achieved by many different combinations of optimized and effective variables in the "Zero Energy House".

- Compact Shape
- Internal Mass
- South Windows and Shading Devices
- Controlled Infiltration
- Summer Night Ventilation
- External Insulation

A change of one can frequently be compensated for by changes in the others. It is further observed from that one could locate a region of the optimum design.

This optimum region offers various combinations of effective parameters resulting to "Zero Energy House". Specifically the combinations of the optimized effective variables of glazing orientation, additional internal mass and envelope insulation, in the four tested shapes reduced their useful energy consumptions between 95% and 97%. Furthermore, introduction of additional measures or refinement of these optimized variables on the Square-shape, selected to investigate the sensitivity of the effective parameters, also concluded to nearly zero energy profiles. It is however important to incorporate in the design outline of the "Zero Energy House", such constructional characteristics so that it will have high market appeal and therefore should involve minimum departure from conventional construction. It should also be suitable for the life style of its inhabitants.

For this reason and in the process of establishing the design aspects for "Zero Energy House" it was apparent that the role of the human factor should be examined, comment on the practical implications of the "Zero Energy" design and purpose design recommendations for "Zero Energy House".

3. The Occupants and the Zero Energy House

It was identified that the occupants' factors that influence the efficiency of the building performance and the environmental conditions of the "Zero Energy House" is reflected in the variable of fenestration.

Therefore, in the study, the relative thermal effects of these parameters in various combinations in computer simulations are considered to understand the qualitative behaviour of the building fabric in use. The tested parameters are:

a) Use of shutters for shading

b) Opening and closing windows

Also, the possibility of introducing automatic shading and ventilating controls was investigated. This will lead to the optimal choice between different design alternatives based on flexibility, operational ease, and potential thermal efficiency.

As an integral part of the planning process, was intended to recommend strategies which, by reducing the operational constraints currently imposed upon buildings, secure an optimized, performance for "Zero Energy" houses in Mediterranean.

3.1 Shading and the Human Factor

From previous work [2] it has been concluded that the provision of shading devices is a very important fenestration parameter to combat overheating in the dwelling in the summer period.

It was also found that winter solar gains through fenestration reduce considerably (11%) fuel consumption for heating. The optimized fenestration shading strategies are summed up as follows:

- Summer: Shading between 07.00-19.00 hours.
- Winter: Unobstructed solar access between 07.00-17.00 hrs

However the introduction of manually operating shutters in order to provide summer solar control in occupied spaces (usual practice in Cyprus) may result in large energy penalties when misused by the occupants in either season to cause:

- In Summer : Overheating when the shutters are left open during the day.
- Winter: Solar losses by sun blinding when shutters are left closed

3.1.1 The Tests - Shading and the Human Factor

The misuse of shutters, in both seasons (winter and summer), and the effect on indoor temperature in free running buildings are examined through computer simulations with thermal analysis program "Quick".

This is done in a series of combinations of sun control on fenestration for the "Zero Energy House" derived in previous work {2}.The tested shading profiles are specified and outlined having as basis possible occupancy interference with the shading design objectives of the "Zero Energy House". These may range from maximum solar admission to total exclusion of direct radiation as a source of heat, depending on the season (winter or summer). Thus the simulations of shading combinations are classified for the two seasons as follows:

A. Winter

In this series of simulations the effect of window shutters left closed during the day, contrary to the optimized fenestration winter strategy, and consequently the drop of indoor temperature is examined.

B. Summer

In this series of simulations the effect of window shutters, left open during the day, contrary to the optimized fenestration summer strategy, on indoor temperature rise is examined.

3.1.2 The Results - Shading and the Human Factor

From the results it is evident that the occupants' interference and misuse of the manually operated window shutters could be counter-effective and might annul the optimized fenestration design for the concluded "Zero Energy House". The uncertainties associated with the shading variable and occupant behaviour can be large in occupied buildings. This occurs, where solar gains is a significant part of the design in achieving indoor comfort conditions without the need of mechanical energy, as in the case of the "Zero Energy House".

A. Winter

The results explicitly indicate that the counter-effect of misused south window shutters could be of vital importance for the maintenance of internal thermal comfort level in winter.

The optimized design for winter, in which all shutters are open, illustrates that while the ambient outdoors air temperature varies from 6.5 to 14.0 degrees Celsius, the swing in the inside temperature remains within the comfort zone, from 18.6 to 20.6 degrees only (Table 1, Cold Days, Optimised Design Strategy-All windows un-shaded).

Table 1: Results of Temperatures simulations of Shading Strategy- All windows un-shaded; for hot days (Counter-effective human intervention) and cold days (Optimised) [Degrees Centigrade].

Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	24.7	19.4	13	35.1	13.8	26.1	20.5
2	23.0	7.0	24.4	19.2	14	35.4	14.1	26.3	20.6
3	22.6	6.8	24.1	19.1	15	34.4	13.5	26.5	20.6
4	22.3	6.7	23.8	18.9	16	33.4	12.7	26.6	20.5
5	22.0	6.5	23.5	18.8	17	31.9	11.5	26.6	20.4
6	23.1	6.5	25.0	18.7	18	30.0	10.5	26.6	20.2
7	25.9	6.6	25.1	18.8	19	27.8	9.7	26.6	20.1
8	28.6	7.4	25.2	19.1	20	26.1	9.0	26.6	20.0
9	30.5	10.0	25.4	19.4	21	25.2	8.5	26.5	19.9
10	32.2	11.8	25.5	19.7	22	24.3	8.0	26.5	19.7
11	33.6	12.9	25.7	20.0	23	24.1	7.6	25.3	19.6
12	34.7	13.6	25.9	20.3	24	23.8	7.3	25.1	19.4

Depending on the extent and orientation of window shutters left shut during the winter day, a drop of indoor temperature ranging from 0.1 to 10.5 degrees Celsius occurs. If all window shutters are left shut, the internal temperature drops below outdoor, by 0.1 to 4.0 degrees. The largest drop occurs mainly between 09.00 to 18.00 hours. These results point out the reliance of the "Zero Energy House" on solar gains.

Furthermore the small extent of deviation of temperature, incurring when shutters are left shut on the house elevations other than south, confirm the validity of the optimization of fenestration distribution and orientation on the "Zero Energy House".

B. Summer

The optimized design for summer, with all shading closed, when the outside temperature reaches a maximum of 35.0 degrees Celsius achieves an inside temperature of only 25.5 degrees (Table 2, for Hot Days, Optimised Design Strategy-All windows shaded).

Table 2: Results of Temperatures simulations of Shading Strategy- All windows shaded; for hot days (Optimised) and for cold days (Counter-effective human intervention) [Degrees Centigrade].

Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	24.2	10.0	13	35.1	13.8	25.1	10.1
2	23.0	7.0	24.0	10.0	14	35.4	14.1	25.2	10.2
3	22.6	6.8	23.7	9.9	15	34.4	13.5	25.3	10.2
4	22.3	6.7	23.5	9.9	16	33.4	12.7	25.4	10.2
5	22.0	6.5	23.3	9.8	17	31.9	11.5	25.4	10.2
6	23.1	6.5	24.3	9.8	18	30.0	10.5	25.4	10.2
7	25.9	6.6	24.4	9.8	19	27.8	9.7	25.4	10.2
8	28.6	7.4	24.4	9.8	20	26.1	9.0	25.4	10.2
9	30.5	10.0	24.6	9.9	21	25.2	8.5	25.4	10.1
10	32.2	11.8	24.7	9.9	22	24.3	8.0	25.3	10.1
11	33.6	12.9	24.8	10.0	23	24.1	7.6	24.8	10.1
12	34.7	13.6	24.9	10.1	24	23.8	7.3	24.6	10.0

Examining the results of the counter-effective human intervention on the manually operated window shutter on the "all-shaded" optimized shading profile for summer, it is noted that this poses no significant conflict on solar control. Comparing the free thermal behaviour of the building under the optimized summer strategy (Table 2, Hot days) with the less than optimized shading profiles, incurring a rise of 0.4 to 1.0 degree Celsius of internal temperature indicated for some configurations presents no serious problem. Even when all window shutters remain open during day the internal temperature does not deviate from the comfort zone (Table 1, Hot Days, shading strategy-All windows un-shaded).

Over the complete period of investigation the deviation did not exceed 1.00 degree Celsius; indicating at least for the shading variable, the efficient performance of the fixed shading devices of overhangs and vertical extended walls on the southern orientations for the summer season.

3.1.3 Comments - Shading and the Human Factor

The above results show that although window shutters contribute to limiting thermal gains in the summer, by reducing indoor temperature up to 1.3 degrees Celsius, their negative effects of misusing them in winter might defeat the optimized performance of the "Zero Energy House" to the extent of dropping indoor temperature below outdoor during winter.

The results also indicate that the combined effect of the optimum design of fenestration distribution and orientation and permanent shading devices, overhangs and vertical extended walls provide sufficient sun control without the need of the manually operated shutters and its possible counter- effects.

Even so, if design fenestration aspects such as orientation, size, distribution, and sun control devices, differ to those developed for the "Zero Energy House", the application of shutters for shading could be the only solution. For example, the fixed overhangs do not work for windows facing east or west, since the sun is low in the sky in the morning and afternoon. In such cases the introduction of automatic controls is imperative in order to eliminate the negative effects of the manually operated shutters misuse presented above.

3.2 Ventilation-Infiltration and the Human Factor

From previous work [2] it was found that the combination of controlled infiltration rate in both winter and summer days (0.5ac/h) and increased ventilation in the summer nights (10 ac/h) results to the significant reduction of cooling and heating load of 32%). The adopted infiltration rate of 0.5ac/h assumes good weather stripping, whereas the increased ventilation value of 10ac/h assumes encouraged airflow through window apertures (Table 3, Optimized Ventilation-Infiltration).

Table 3: Results of Outdoor&Indoor Temperatures of Optimised Ventilation-Infiltration Strategy. Summer: Days-All windows closed. Nights-All windows open. Winter: All windows closed 24hrs [Deg. Centigrade].

Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	24.6	18.7	13	35.1	13.8	26.1	19.8
2	23.0	7.0	24.3	18.5	14	35.4	14.1	26.3	19.9
3	22.6	6.8	24.0	18.4	15	34.4	13.5	26.5	19.9
4	22.3	6.7	23.7	18.3	16	33.4	12.7	26.6	19.8
5	22.0	6.5	23.4	18.1	17	31.9	11.5	26.6	19.7
6	23.1	6.5	24.9	18.1	18	30.0	10.5	26.6	19.5
7	25.9	6.6	25.0	18.2	19	27.8	9.7	26.6	19.4
8	28.6	7.4	25.2	18.4	20	26.1	9.0	26.6	19.3
9	30.5	10.0	25.3	18.7	21	25.2	8.5	26.5	19.2
10	32.2	11.8	25.5	19.0	22	24.3	8.0	26.5	19.0
11	33.6	12.9	25.7	19.3	23	24.1	7.6	25.3	18.9
12	34.7	13.6	25.9	19.6	24	23.8	7.3	25.0	18.8

The optimized infiltration and ventilation strategies are summed up as follows:

- Summer Nights: All Windows Open for Maximum Ventilation
- Summer Days: All Windows Closed for minimum Heat Gain
- Winter: All Windows Closed for minimum Heat Loss

However the manually operated purpose openings for the provision of ventilation may result in large energy penalties when misused by the occupants in either season to cause:

- In summer: Overheating when windows are left open during the day or closed during the nights.
- In winter: Heat losses when windows are left open during the days or nights.

3.2.1 The Tests – Ventilation & Infiltration and the Human Factor

In this chapter the misuse of openings, in both seasons (winter and summer), and the effect on indoor temperature in free running buildings are examined through computer simulations with thermal analysis program "AGRELEK". This is done in a series of combinations of open windows on the "Zero Energy House". The programme used for the simulations has the facility to calculate either the infiltration or ventilation rates.

The tested ventilation and infiltration profiles result from opening and closing the windows and are specified and outlined having as basis possible occupancy interference with the ventilation and infiltration design objectives of the "Zero Energy House". These may range from maximum intentional airflow to an airtight profile depending on the season (winter or summer) and period (day or night).

The human intervention in the ideal use of windows for optimum ventilation and infiltration rates is studied in counter-active patterns of the optimized design for:

Summer Night Ventilation

Summer Days and Winter Infiltration and Ventilation

3.2.2 The Results – Ventilation & Infiltration and the Human Factor

From the results it is evident that the occupants' interference and misuse of the manually operated windows could be counter-effective and might annul the optimized fenestration design for "Zero Energy House". The uncertainties associated with the window variable and occupant behaviour can be large in occupied buildings. This occurs, where prevention of heat losses is necessary in winter; also where ventilation is a significant part of the design in achieving in the summer indoor comfort conditions without the need of mechanical energy, as in the case of the "Zero Energy House". It is summed up as follows:

A. Summer

In the optimized design strategy for summer, with all windows closed during the day and open at night and when the outside temperature reaches a maximum of 35.0 degrees Celsius, the inside reaches only 26.6 degrees.

a) Summer Night Ventilation

The results conclude to the effectiveness of night ventilation which retains the building structure cool, throughout the day (Table 3).

They also indicate the necessity of having openings on the ground as well as on the upper level of the house, in order to activate high ventilation rates through stack effect (Fig.1 and Fig 2). It is found that two open windows, of an area of 1 square meter on different levels reduce operational constraints of windows. Automatic controls can ensure the two windows to be kept open for the provision of sufficient ventilation in the summer nights, in order to maintain thermal indoor comfort (Table 4).

Table 4: Results of Outdoor & Indoor Temperatures. Open Window area: 1m2 - ground level, 1m2 2nd floors, between 00.00 – 24.00 hrs.

Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	28.7	18.6	13	35.1	13.8	30.0	19.5
2	23.0	7.0	28.6	18.5	14	35.4	14.1	30.2	19.6
3	22.6	6.8	28.4	18.4	15	34.4	13.5	30.3	19.6
4	22.3	6.7	28.2	18.3	16	33.4	12.7	30.3	19.5
5	22.0	6.5	28.1	18.2	17	31.9	11.5	30.2	19.4
6	23.1	6.5	28.2	18.1	18	30.0	10.5	30.0	19.3
7	25.9	6.6	28.5	18.2	19	27.8	9.7	29.9	19.2
8	28.6	7.4	28.7	18.4	20	26.1	9.0	29.6	19.1
9	30.5	10.0	28.9	18.6	21	25.2	8.5	29.4	19.0
10	32.2	11.8	29.2	18.9	22	24.3	8.0	29.2	18.9
11	33.6	12.9	29.5	19.1	23	24.1	7.6	29.1	18.8
12	34.7	13.6	29.8	19.3	24	23.8	7.3	28.9	18.7

b) Summer Days

Examining the results of the counter-effective human intervention in the use of windows, on the "all-shut" optimized profile for summer days, it is noted that this poses no significant conflict on heat gains control. This is provided there is no interference with the night ventilation strategy described above.

Comparing the free thermal behaviour of the building under the optimized summer strategy with the less than optimized, the rise 0.1 to 1.0 degree Celsius of internal temperature indicated for some configurations presents no serious problem. Even when all windows remain open during summer day the internal temperature does not deviate from the comfort zone. Over the complete period of investigation the deviation did not exceed 1.00 degree Celsius, indicating at least for the ventilation variable, the efficient performance of the night ventilation for the summer season. This is confirmed by a test in which all windows are kept closed at night and a window area remains open during the day; the indoor temperature increases at much higher rates than when windows are kept open at night (Table 5).

Table 5: Results of Outdoor&Indoor Temperatures. Counter-Effective human Intervention: All windows closed 00.00-24.00 hrs (summer & winter).

Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	31.7	19.5	13	35.1	13.8	32.1	20.6
2	23.0	7.0	31.6	19.3	14	35.4	14.1	32.2	20.7
3	22.6	6.8	31.5	19.2	15	34.4	13.5	32.3	20.7
4	22.3	6.7	31.4	19.0	16	33.4	12.7	32.4	20.6
5	22.0	6.5	31.3	18.9	17	31.9	11.5	32.3	20.5
6	23.1	6.5	31.3	18.8	18	30.0	10.5	32.3	20.3
7	25.9	6.6	31.4	18.9	19	27.8	9.7	32.2	20.2
8	28.6	7.4	31.5	19.2	20	26.1	9.0	32.1	20.1
9	30.5	10.0	31.6	19.5	21	25.2	8.5	32.0	19.9
10	32.2	11.8	31.7	19.8	22	24.3	8.0	31.9	19.8
11	33.6	12.9	31.8	20.1	23	24.1	7.6	31.8	19.7
12	34.7	13.6	31.9	20.4	24	23.8	7.3	31.8	19.5

The results emphasize the significant role of maximum summer night ventilation on the thermal performance of the "Zero Energy House" as proposed above for the "Summer Night Ventilation".

B. Winter

The results explicitly indicate that the counter-effect of misused windows could be of vital importance for the maintenance of internal thermal comfort level in winter.

In the optimized design for winter, in which all windows are kept closed it was concluded that while the ambient outdoor air temperature varies from 6.5 to 14.0 degrees Celsius, the swing in the inside temperature remains within the comfort zone, from 18.1 to 19.9 degrees only.

The ventilation and infiltration tests indicate a drop of indoor temperature ranging from 0.1 to 10.0 degrees Celsius, depending on the level, area and orientation of windows left open during the winter day. If all windows are left open, the internal temperature drops below outdoor, by 0.2 to 0.7 degrees. The largest drop occurs mainly between 10.00 to 15.00 hours.

These results point out the reliance of the "Zero Energy House" on an airtight structure, and the necessity of keeping all windows closed. A way of ensuring closed windows in the house is by incorporating in the design an alarm system to warn occupants of windows left open, and/or by providing mechanical ventilation.

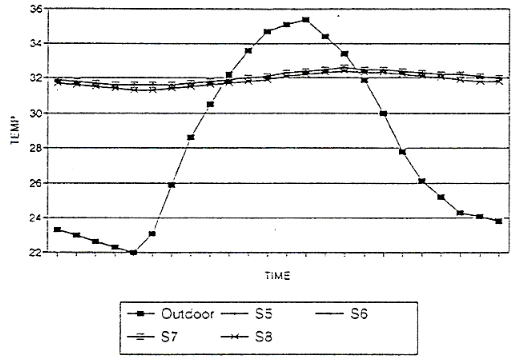

Fig. 1 Outdoor & Indoor Temperatures: Window area 2 m2 open at the same level.

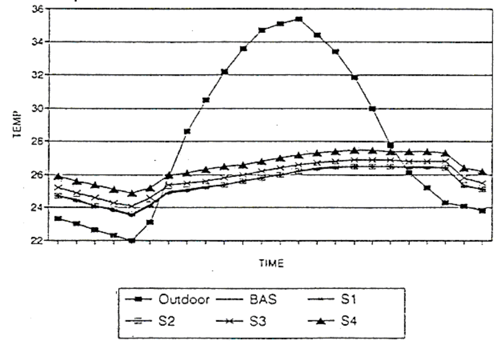

Fig. 2 Outdoor & Indoor Temperatures: Window area 2 m2 open at different levels.

3.2.3 Comments – Ventilation & Infiltration and the Human Factor

The above indicate that the counter-effect of misusing windows in either season might defeat the optimized performance of the "Zero Energy House" to the extent of dropping indoor temperature below outdoor during winter or raising it above outdoor in the summer.

The introduction of automatic controls could eliminate the negative effects of the manually operated windows. These devices may serve well even when residents are away during holidays or weekends. It is possible to generate cooling air flows in the summer nights by the strategic placing of windows with automatic controls (preferably thermostatically operated) and use of stack effect.

In the "Zero Energy House", for the summer season, the open bathroom windows on the upper floor and the toilet or kitchen windows on the ground, maintain comfort conditions indoors. In winter an alarm system could be used as warning when windows are left open.

4. Conclusions of Fenestration and the Human Factor

4.1 Shading

For Shading it was concluded that optimized design of fenestration overhangs and side-fins, without shutters could best provide sufficient summer sun control in order to maintain thermal indoor comfort. The results do not dispute the effectiveness of the manually operated window shutters, especially in cases in which the design concern in buildings extends beyond the thermal and physical determinate and the decision to use shutters is dominated by considerations other than energy and thermal comfort. The application of shutters is often circumscribed by a number of design considerations environmental as well as architectural, economic and behavioural. The function of solar control might then be carried as a secondary function and shutters might be installed primarily for privacy, security night insulation, or as a traditional semantic feature. The role of the shutters as such might then prevent the occupants from availing themselves of the potential of free solar gains to the amounts illustrated by the results.

4.2 Ventilation

Maximum summer night ventilation is derived as the most appropriate cooling ventilation strategy. This could be ensured by embodying in the windows, opening automatic devices which could be activated at specific hours (20.00-07.00). A simple alarm system incorporated in fenestration could also ensure closed windows in winter.

Even so, if automatic devices are not part of the solution and the control of the fenestration is left upon the occupants, it is concluded from the study that this poses no problem during the day in the summer. During the night due to low external temperatures opening windows has immediate effect in cooling the indoors space.

Furthermore as it is demonstrated in the ventilation tests the inherent intuitive approach of Mediterranean people in appropriately activating passive design strategies seems to work well in securing optimal performance of “Zero Energy House”.

5. Final Conclusion

The study in establishing the “Zero Energy Houses” simulation profile has identified and quantified the principal factors that determine its practical efficiency. The resultant “Zero House” does not require unfamiliar construction techniques or untried technology and no major changes in the inhabitants’ life style are expected. It is suitable for normal urban and suburban sites and it employs different sets of options.

It is found from the study that the designer has several design options which offer him a considerable latitude in selecting design combinations for zero energy load, it is also concluded that the adoption of strategies to achieve comfort conditions in houses by the use of passive, manually or automatically operated techniques on the one hand and the willingness and ability of building users to use corrective intervention on the other hand are very powerful tools. The suitable choice of techniques for the inhabitants is also imperative. These should enable sufficient degree of interaction in terms of flexibility between climate on the one hand and the building and its users on the other hand. Therein lays the potential for the successful creation of comfort conditions without the use of mechanical energy demand.

6. References

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