PASSIVE SOLAR ARCHITECTURE IN CYPRUS

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Abstract - The principal element of this research was the design, construction and monitored inhabitation of an Experimental Solar House (ESH) at Lefkosia, taking into account the potential of the well established principles of Passive Solar Design when applied to the specific cultural, economic and climatic contexts of Cyprus. The research into thermal comfort concluded that, for Cyprus, an average 19.5-29°C is an acceptable temperature and an average of 20-75% is the acceptable range of relative humidity. It is concluded that it is impossible to accurately specify final temperatures and RH for the average person, because of the psychological, physiological and practical factors. It is concluded that the passive systems that are most suited for Cyprus are: Direct Gain, external insulation on walls (0.6W/m²K) and roof (0.3W/m²K), low emmisivity double-glazed argon-filled, interior thermal storage constructed from bricks and concrete, 5% north wall openings are sufficient for cross ventilation during summer nights, optimum of south wall openings 18%, permanent external shading devices, vegetation, use of natural ventilation and ceiling fans. Comparative annual energy use of the ESH versus traditional house, contemporary house and a low energy case was performed using computer simulation software Energy 10. The annual energy use of the ESH (121KWh/m²) is less than the contemporary house (368 kWh/m²) and the traditional (243 kWh/m²). Through monitoring the ESH the results show that all heating requirements are satisfied by solar energy, while natural ventilation or ceiling fans meet all the cooling needs, concluding that Passive Solar Design may be successfully applied in the design of modern buildings in Cyprus.

1. INTRODUCTION

This research is set out to demonstrate that passive solar architecture is a viable energy-saving concept that can be applied in the context of Cyprus. A principal aim of the research was to develop an understanding of the criteria for an appropriate passive solar architecture that is sensitive to both energy use and climatic conditions. The Experimental Solar House, supported by this research, is a pioneering project to Cyprus, and shows that passive solar architecture functions in an energy-saving manner is cost-efficient.

In the execution of the research the following parameters were studied:

- The climate of Cyprus
- The comfort zone of the average Cyprus person
- Examples of historical and traditional housing which can be shown to inform passive solar architecture in Cyprus
- The energy uses of the island.

The results of these studies show that passive solar design is an appropriate energy-saving strategy for Cyprus. The Experimental Solar House was constructed in order to put the theories developed in the research into practice. Monitoring the Experimental Solar House, led to various conclusions in relation to its performance and to indications for further development and improvement.

This research was fundamentally specified for Cyprus for the following reasons:

- Cyprus has no energy resources of its own. Therefore, more than 94% of the total primary energy is imported to the island of which 15.1% of total annual energy consumption comprises in the residential sector with electricity at 34%, creating not only ecological imbalance but also serious financial government credit.
- Cyprus's climate guarantees 100% energy saving potential and therefore is a suitable starting point for the Experimental Solar House.
- End uses of energy in households are minimized. Water heating from 50% to 0%, space heating from 18% to 0%, lighting 24% from to 0%, cooking 3%, electrical appliances 3%.

2. CLIMATE OF CYPRUS

The climate of Cyprus can be summarized as:

- Cyprus is within the Mediterranean temperate zone
- Hot summers rise to an approximate of 41°C in its warmest month
- Mild winters drop to an approximate of 5°C in its coldest month
- Average humidity of 40-60% (sustaining within the comfort zone limits)
- Large daily temperature range (up to 18 °C difference between night and day)

These findings defined the following conclusions, regarding passive solar architecture in Cyprus:

- The large amount of solar radiation which varies from 3.48 KWh/m²day in midwinter to 8.82

KWh/m²day in midsummer, result in the potential for solar energy usage in winter

- Due to the hot summers, passive cooling is needed in Lefkosia

3. QUESTIONNAIRE

A questionnaire survey of the satisfaction of Cyprus people living in contemporary buildings was conducted and showed the following:

- Residents felt cold in the winter (80%)
- Residents warm in the summer (87%)
- 64% needed artificial lighting
- 86% experience drafts from windows and doors
- 66% of the residences have no thermal insulation.

It is seen that residents in Cyprus experience many problems due to the climate and conditions of Cyprus. The amount of mechanical cooling and heating used in Cyprus is rising steadily. The best example to follow, as far as non-mechanical cooling and heating is concerned, are those of traditional homes, which were built without the use of energy-consuming devices.

4. TECHNIQUES USED IN HISTORICAL AND TRADITIONAL HOUSES

The following techniques were used in historical and traditional houses, can be used through passive design today and are used for the design of the Experimental Solar House:

- Clear topographical clarifications
- The positions in orientation to the sun path either to avoid direct sunlight entering the building of the opposite.
- The exploitation of breezes for ventilation and cross ventilation in the room
- The awareness and exploitation of the nature of flora and its use for practical functions (e.g. medicinal plants, fruit-baring trees)
- A good insulation of walls (40-50cm width) and roofs,
- The small openings on the external walls for maximum insulation.

These elements can be found in constructions created since 7000B.C. Elements, which are now fundamentally used in passive architecture. Early examples include:

- The Solarium was predominant whether acting as an arched corridor, as a central axis or even when it evolved into a self-contained space.
- Courtyards, planted mostly with deciduous vegetation like grapevines, providing shade in the summer and admitting the sun in the winter
- Almost all openings placed on the south wall providing natural light and heat.
- Arseres (small openings located high on the external walls) allowed lighter hot air to go out of the house and be replaced by cooler air from outside in the summer
- Thymes (small dense bushes) blocked the arseres in the winter and provided thermal insulation.
- Roofs and floors were constructed in a typical insulating manner
- Courtyards were built to facing southwards, acting as a sunspace, receiving desired solar radiation in winter.
- The solarium admitted the rays from the winter sun to penetrate and so solar radiation could be utilized in winter.
- In multiple thermal modes and varied design, the courtyard and the solarium moderate high summer temperatures- their careful construction combined with the surrounding landscaping lower the temperatures around the building.

These examples, illustrate strong characteristics of historical architecture, which serve as fine examples of energy-saving architecture today and are used on the Experimental Solar House.

5. COMFORT ZONE OF CYPRUS

Using the psychometric chart, Olgyay's bioclimatic chart, Humphreys' comfort chart and Szokolays' equation, specifically adapted for Lefkosia, an average comfort zone was derived for application in Cyprus.

The following conclusions were made concerning thermal comfort in Cyprus:

- Thermal comfort zones depend on regional climate.
- An average of 19.5°C – 29°C is the proposed temperature, within the comfort zone limits of Cyprus
- An average of 20-75% is the proposed relative humidity, within the comfort zone limits of Cyprus.
- The best thermal comfort is achieved in the months of April, May, October and November. These months needed no extra heating or cooling. The results showed that to achieve thermal comfort conditions, ventilation is required in the summer months (June, July, August and September). In this case, natural ventilation actually occurs, or if there are no breezes, then ceiling fans are applied. In the months of December, January, February and March passive solar gains are used to achieve thermal comfort. It must be noted that steps should be taken to avoid over heating in the summer. The same is to be said for the passive cooling needs in the summer. The results show that all heating requirements are covered through solar energy, while natural ventilation or ceiling fans cover all the cooling needs.

The research also concluded that it is impossible to accurately specify final temperatures and relative humidity for the average person, because of the following factors:

- *Psychological:* It is impossible to define a person's psychology within the house indefinitely. For example, although one may be a little cold, a good view of the sun, and a sense of well-being may easily stray the specific individual from seeking heat.
- *Physiological:* It is impossible to define a person's body mass, temperature or amount of clothing he or she may be wearing.
- *Practical:* Passive solar design requires simple passive habits, which cannot be monitored mechanically. It is impossible for example, to be 100% sure that windows will be opened and closed, substantially enough, in order to preserve the required indoor temperature.

6. PASSIVE SOLAR SYSTEMS FOR LEFKOSIA

The development of passive solar systems is significant to the economic, social and political issues raised in this research. The best-known applications of passive solar systems were researched taking into consideration the advantages and disadvantages for Lefkosia were being researched and it is concluded that the passive systems that are most suited for Cyprus and used on the Experimental Solar House, are:

- *Direct Gain:* the simplest solar heating system and can be easiest to build. Areas of glazing not only admit solar radiation for heating but also high levels of daylighting and good visual conditions for the outside. Glazing is well researched and cheap and a material readily available. With adequate insulation of the building, it is possible to rely totally on direct gain as a passive solar system used in the case of Cyprus.
- *Shape of building:* rectangular but compact design (aspect ratio 1:1.33) with the longer axis pointing East and West.
- *Thermal Insulation:* position of insulation externally on walls and roof. Thickness 70mm expanded polystyrene. Overall U-value of walls and roof 0.6 W/m^2K.
- *Thermal Storage (Interior Mass):* The simplest heat storage approach is to construct the building of massive structural materials (reinforced concrete or brick blocks) insulated on the exterior, to couple the mass of the indoor space
- *Glazing:* For direct gain systems, south facing window area greater than about 10-12% of floor area require thermal mass, well distributed over floors, walls and ceilings to reduce temperature swings. 5% north wall openings are sufficient for cross ventilation during summer nights. Optimum of south wall openings 40% mountainous areas, 24% coastal region, 18% inland region. Types to be used: Low emmisivity glazing, argon-filled, double-glazed. South vertical glazing surfaces would intercept almost as much radiation during heating season as optimally sloped surfaces. Shading can be easily controlled for the non-heating season.
- *Solar Control:* By use of orientation (one of the long walls is facing south so that the available solar radiation is exploited in the winter), external shading devices, vegetation (shade deciduous trees are excellent for shade in summer while allowing sun through the winter.
- *Natural Ventilation:* By use of cross ventilation, stack effect, night ventilation and ceiling fans.

7. CONSTRUCTION DECISIONS

In order to establish the passive solar design targets, construction decisions were required at the design stages of the Experimental Solar House. While considering all aspects of Cyprus's climate, land and market, the following decisions were made:

- The high values of solar radiation falling on buildings in summer, and the moderate midday values of solar radiation coming from a clear sky in winter require that:
  - (i) The area of east and west walls was reduced to a minimum.
  - (ii) The windows should be placed in south walls and avoided in east and west walls. Small openings are provided in the north walls, mainly for natural ventilation purposes. Windows in the south walls should also be provided with shading devices that provide complete shading from direct solar radiation in summer but do not obstruct the low altitude sun radiation from penetrating building in winter.
  - (iii) Solar radiation absorbed by opaque building elements should be reduced to a minimum.
  - (iv) The surroundings of buildings should be appropriately treated in order to reduce the values of reflected solar radiation striking the walls.
- The high values of outdoor shade air temperatures during summer days, and the low values of these temperatures during winter days, together with the relatively low temperatures during summer and winter might require that:
  - (i) The area of the windows was reduced to a minimum in order to avoid any excessive convective heat gain or loss. Where large windows are required they should be provided with double-glazing, heat-reflecting and absorbing glass, blinds and curtains.
  - (ii) The windows be appropriately controlled during the day and night in order to make use of the cool outdoor air during summer night, and to avoid the high outdoor temperature during summer days, and moreover, to increase heat

gain from the sun during winter days and limit heat-loss during winter nights.

- The high values of both solar radiation and outdoor shade air temperature during the day in summer and most days in winter and the relatively low temperatures at night require that:

(i) Opaque building elements be of high thermal capacity and subsequently have an appropriate time-lag and low decrement factor, in order to reduce to a minimum the heat passing through, and in particular to prevent heat emission into buildings during the daytime in summer.

(ii) Alternatively, if opaque building elements cannot be well insulated in order to obstruct heat from penetrating. The insulation may also be only a cavity.

Upon constructing the Experimental Solar House, it was decided that the house should follow the most suitable combination of design parameters of a contemporary Cypriot home. These are:

- Wall construction type: 100x250x300mm brick and 70mm of expanded polystyrene on the exterior, with three layers of plaster on the interior and Adesilex FIS 13 on the exterior sides (U-value 0.296 W/m²k - Type 6), since it effectively insulates the whole structure and avoids thermal bridges where the columns and beams occur.
- Roof Type: 150mm concrete, 600mm air gap, 3mm water insulation and 100mm of expanded polystyrene on the exterior, with three layers of plaster on the interior and 50mm on the exterior (U-value – 0.28 W/m²k - Type 3), since it retains heat (thermal mass) and takes advantage of the reverse beam structure of the roof.
- External vertical louvers: Not used, as they are not 100% suitable, due to the high construction cost and permanent view obstruction of the east and west façade of the house.
- Permanent shading devices: The second floor bedroom windows on the southeast and south walls were recessed to prevent summer sun from entering, but allowing winter warmth to enter.
- Extreme overheated periods: Roof fans are used to assure no overheating would occur.

Following the design requirements of a contemporary Cypriot home the house was constructed as thus: concrete frame, floors and roof, brickwork on the exterior and interior walls. The house covered an area of 223m², and was rectangle (1:1.33) in shape.

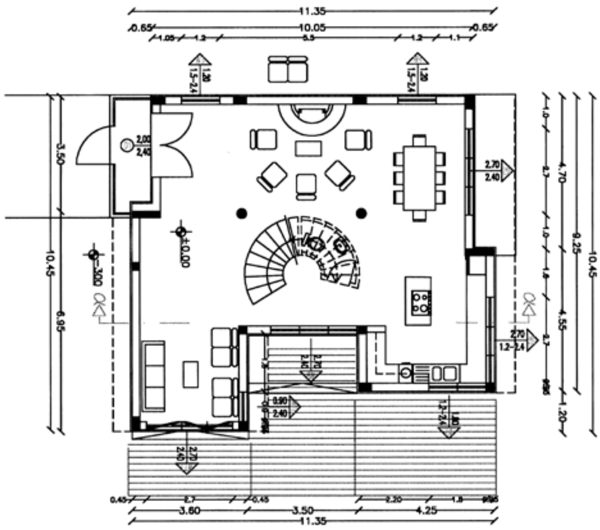

Figure 1. Ground floor plan of the Experimental Solar House.

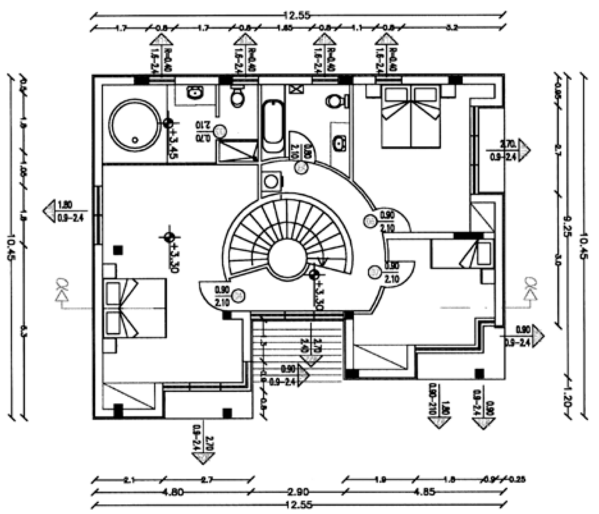

Figure 2. Upper floor plan of the Experimental Solar House.

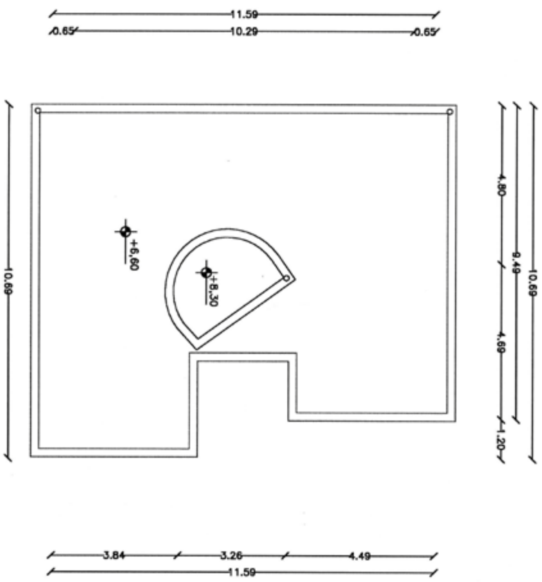

Figure 3. Roof plan of the Experimental Solar House

8. MONITORING OF THE EXPERIMENTAL SOLAR HOUSE

Upon construction of the Experimental Solar House, careful monitoring was pursued, in order to measure its performance in use. Through monitoring the house from the 27/11/1999 until 18/12/2001, using computer data loggers, the following can be concluded:

- The maximum temperature difference between indoor and outdoor temperatures, in the non-habitation period was 10°C
- The maximum temperature difference between indoor and outdoor temperatures, in the inhabitant period was 10-15°C
- The internal temperature and relative humidity throughout the year remained steady (within the thermal comfort limits), despite the instability of external temperatures and humidity percentages.
- Fans needed to be used from the 5th of July till the 20th of August (maximum internal temperature was 31ºC).
- Heating needed for 30 days between December and February (minimum internal temperature 17ºC). The only source of heating was the fireplace that proved satisfactory.
- Daytime ventilation (opening of windows and doors) during the summer caused indoor temperatures to rise unsatisfactorily (up to 36ºC, depending from the external temperatures)
- Once the pergola and the Venetian blinds were installed, temperatures remained at a steady and comfortable level (importance of shading devices)
- The house functioned properly with only a few minutes attention every day, in order to build fires, and operate windows
- Internal relative humidity daily swings were noted at 2-20% (within the comfort zone)
- The Experimental Solar House averages an average energy cost of £26 a month (much lower than that of a contemporary Cypriot house)
- Once the photovoltaic system was installed, this figure reduced to £13 a month.
- The domestic hot water needs were covered 100% by the solar hot water collectors.
- In order to cover cooling potential 100% the pergola and vegetation are necessary
- To cover heating potential 100%, various thermal storage techniques must be incorporated in order to excuse the lack of thermal mass through carpeting and wall coverings (artwork)
- A tent, vegetation or a permanent overhang is more suitable than the pergola, since they would allow shade in the summer, and solar radiation in the winter
- The spacing near the ceiling (around clerestory window) should be covered by building transparent coverings in the winter, in order to avoid a heat sink effect
- It is important to supervise construction closely, in order to ensure design is followed accurately.
- Once thermal mass effects, exposed mass and night purge ventilation, passive solar heating and natural ventilation, comfort percentages rise exceedingly higher than that of a contemporary home.
- The average total projected energy consumption of the experimental building developed in the research is 44 kWh/m2 per year. This is only about 25% of the typical consumption in residential buildings in Cyprus.
- The levels of daylight in the living spaces were very satisfactory.
- Overheating did not occur throughout the whole year.
- Condensation did not occur throughout the whole year

Figures 5 and 6 show the heating and cooling needs in the year 2000 and 2001. The dark line shows the internal temperatures throughout the year. Once this line drops below 19.5°C heating is needed (shown in light grey), and once the line rises above 29°C cooling is needed (shown in dark grey). The external temperatures are shown in a lighter black shade. Through these graphs the above results are further enhanced, as a clear distinction is noted between the years. There are moments during the heating and cooling seasons where the fireplace and fans are not needed, as temperatures rise and drop accordingly.

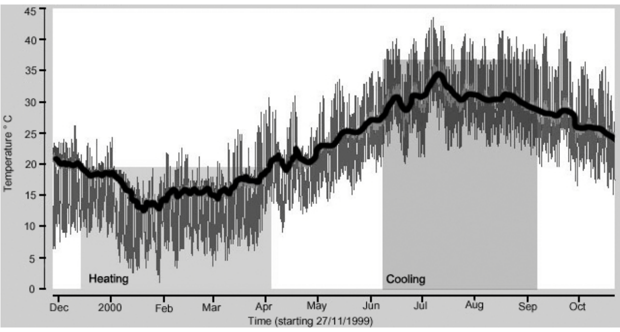

Figure 4. Internal and external monitored temperatures for the year 2000.

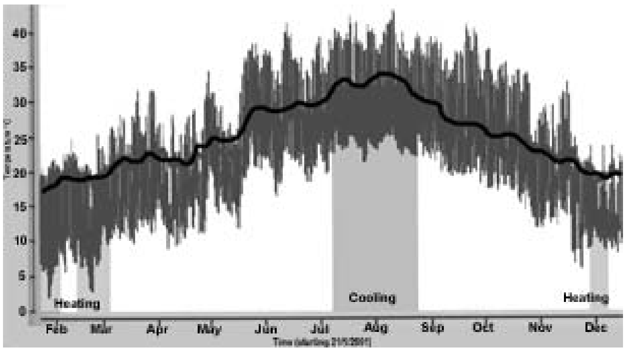

Figure 5. Internal and external monitored temperatures for the year 2001.

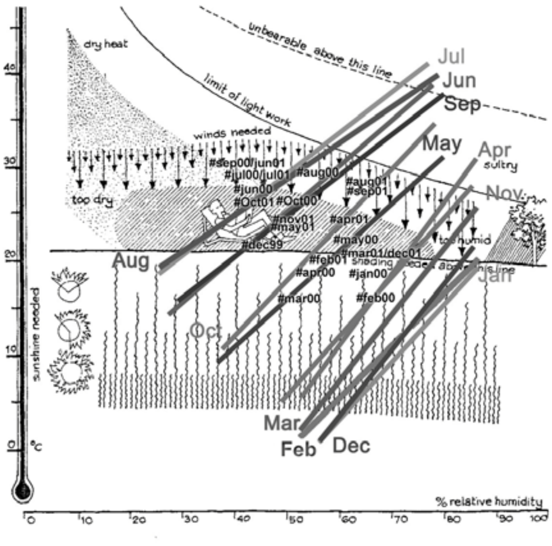

Figure 6. Olgyay Comfort Chart with the monitored mean monthly internal temperatures and relative humidity

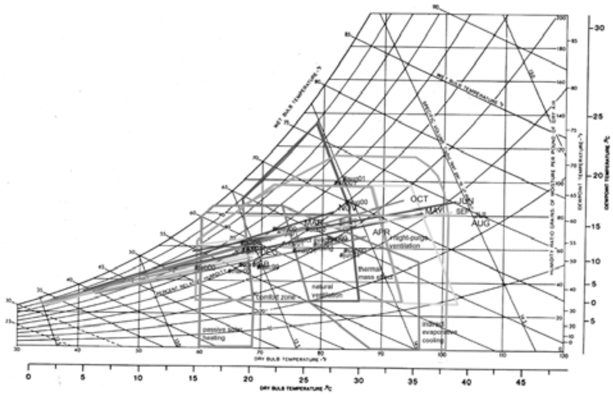

Figure 7. Psychometric Chart with the monitored mean monthly internal temperatures and relative humidity.

Through monitoring, a few problems, or errors were also noted. These include:

- Ventilation problems arose sometimes in the summer. This was because there was insufficient breeze during the summer period. The solution was to operate the ceiling fans at specific times.
- Overheating occurred on a few summer days. The main reason is the lack of shading on the ground floor, since one of the shading devices is vegetation. The trees have not grown enough to provide adequate shade.
- Internal Venetian blinds were placed in the east and west windows. External blinds would have been more efficient.
- The glass door of the entrance broke in the winter and cold draughts were formed through the wooden entrance door. It took two months to replace the glass door.
- To achieve sufficient heating in the bedrooms in the winter the doors of the bedrooms have to be kept open, which results in the lack of privacy of the occupants. The same happens in the summer. A grill can be placed on the doors, to allow sufficient natural cross ventilation, and sustaining optic privacy.
- The sunspace in the lobby was not entirely successful. In the summer months the sunspace overheated. Fan induced ventilation is needed or the glass door should always be kept open in the summer.
- Constructors did not follow accurate design, thus creating problems on matters such as the size of windows. Tight on-site supervision is particularly important in low-energy buildings.
- The monitored temperature and relative humidity of the Experimental Solar House showed that they are within the thermal comfort zones proposed by the charts.
- Comparative annual energy use was performed using computer simulation software Energy 10.
- Contemporary house (368 kWh/m²) versus Traditional (243 kWh/m²)

- Experimental Solar House (121 kWh/m²) versus a low energy case (102 kWh/m²).
- Experimental Solar House (121 kWh/m²) versus contemporary house (368 kWh/m²)

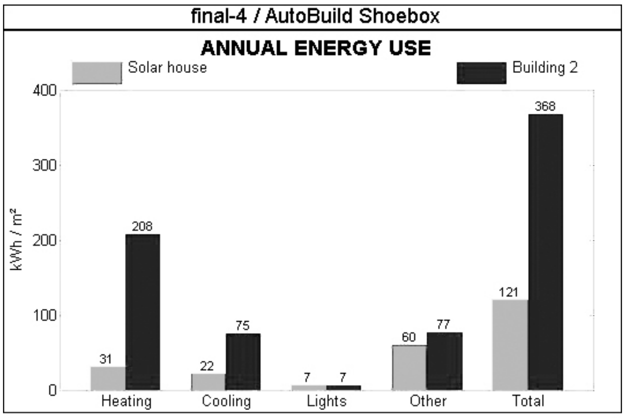

Figure 8. Comparative Barographs Energy.
Total annual energy use, plus breakout by heating, cooling, fan, and "other" uses (everything else)

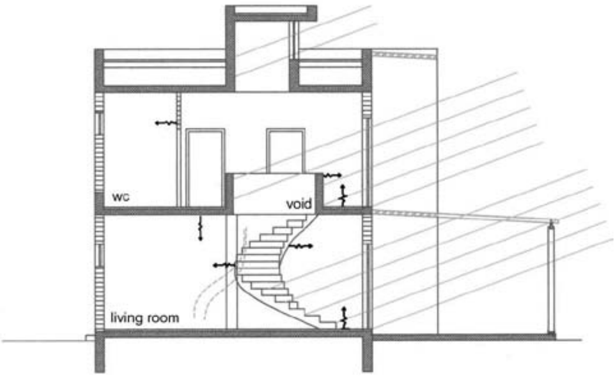

Figure 9. Winter design considerations (north-south section through the staircase)

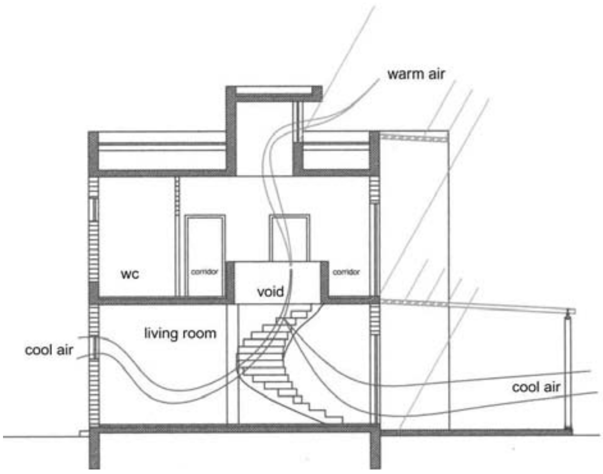

Figure 10. Summer design considerations (north-south section through the staircase)

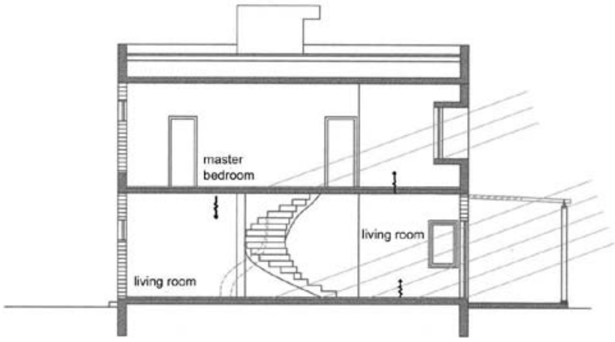

Figure 11. Winter design considerations (north-south section through the master bedroom)

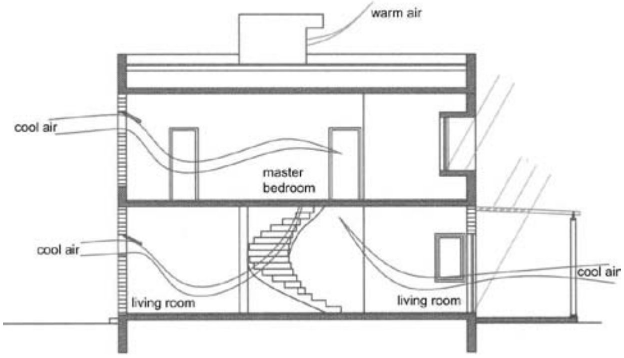

Figure 12. Summer design considerations (north-south section through the master bedroom)

Photo 13. Staircase and clerestory window

Photo 14. Staircase bottom


Photo 15. The twin pergola is used for both levels to protect from the southern summer sun. West and south facade


Photo 16. South and east facade


Photo 17. Interior originally painted with warm colours. Later the author decided to re-paint all white to ensure better dispersion of light

9. CONCLUSION

Because of Lefkosia's climate, passive solar architecture works to its full capacity. This means that, a passive solar house has 100% energy saving potential. This theory has not remained at its conceptual stage as the Experimental Solar House has demonstrated it in practice.

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