PASSIVE SOLAR DESIGN CONSIDERATIONS FOR CYPRUS

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ABSTRACT

Passive solar systems offer simplicity, greater reliability, lower cost and a longer lifetime. Furthermore, the design of passive-solar systems comprises a part of the architectural design of the house, and thus, becomes an integrated element of the building's architecture. In choosing a system there are criteria of aesthetic or functional values. Some of the techniques described as passive solar systems for Cyprus can be incorporated in conventional building design and planning without adding considerable cost to the construction. All that is required is intelligent design. Taking into account the advantages and disadvantages of the passive solar systems the best systems that are advised to use in Cyprus are Direct Gain, Thermal Insulation, Thermal Storage, Low emissivity double-glazed, Solar Control (orientation, shading devices), Natural Ventilation (cross ventilation, stack effect, night ventilation and ceiling fans). Systems advised not to use are Trombe Walls and Sun Spaces. The results show that all heating requirements are covered through solar energy, while natural ventilation or ceiling fans cover all the cooling needs.

1. INTRODUCTION

Passive Solar architecture cannot persist without being as site-specific as possible. Climatic data is used in all the passive solar design considerations. The architect can make a competent assessment of the system's adaptation in the building's design without interrupting the function and normal use of the building. However, the economy and the performance of passive-solar systems hinges upon the type of system proposed. Therefore, it is necessary for the architect to be familiar with the types of passive-solar systems developed so far.

Cyprus's climate is within the temperate Mediterranean zone. It is however impossible to state a clarified comfort zone for any region, as psychological, physiological and practical factors are at hand. An average of 19.5°C – 29°C is the proposed temperature, within the comfort zone limits of Cyprus[1]. 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 need no extra heating or cooling. To achieve thermal comfort conditions, ventilation is required in the summer months (June, July, August and September). 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.

3. PASSIVE SOLAR STRATEGIES

Some of the techniques described as passive solar systems for Cyprus can be incorporated in conventional building design and planning without adding considerable cost to the construction. All that is required is intelligent design.

3.1. Direct gain

Advantages:

- o Direct Gain concerns the significant amounts of solar energy which may be collected in heated rooms through elements which would be found in the building, in the form of windows, clerestories, and roof monitors (skylights with vertical glazing) facing the sun. Roof monitors make it possible to provide direct solar gain to rooms that do not have direct solar exposure. Thus Direct Gain can be applied to single storey buildings, which do not have a sun-facing wall at all.
- o Direct gain is the simplest solar heating system and can be the easiest to build. The overall system can be one of the least expensive methods of solar space heating.
- o The large areas of glazing not only admit solar radiation for heating but also high levels of daylight and good visual conditions for the outside.
- o 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.

Disadvantages:

- o In any building heated by solar Direct Gain, the area of the southern windows would be much larger than in a non-solar building. Even if the glazing is completely protected in mid-summer from direct solar radiation, e.g. by an overhang, the diffused radiation from the sky and the reflected radiation from the ground may cause significant solar gain, in addition to the conductive heat gain. The risk of overheating is even greater in late summer (e.g. in September) when temperatures may still be high and the sun's lower elevation renders overhangs less effective.
- o The simplest protection from overheating caused by Direct Gain Glazing in Cyprus (due to its hot summers) is by the application of shading devices, which block most of the diffused and the reflected solar radiation, such as rollable or hinged shutters outside the glazing. Another option is to block the radiation by interior insulated panels, with their exterior surface painted white.
- o Large areas of glass can result in glare by day and loss of privacy at night.
- o Ultraviolet radiation in the sunlight will degrade fabrics, photographs and other contents of the building.
- o If large areas of glazing are used, large amounts of thermal mass will usually be needed to modulate temperature swings that can be expensive if the mass serves no structural purpose. If thermal insulation is increased the area of glazing required maybe reduced and, hence, the thermal mass will also be reduced.

3.2. Collecting/storage (Trombe) walls

Advantages:

- o The indoor temperatures are more stable than in most other passive solar systems.
- o If windows are provided alongside or within the solar wall then direct sun penetration provides light and quick heating of the space in the morning, while the mass is still cold.
- o Excessive sunshine does not penetrate into the building. Glare, privacy and ultraviolet degradation of fabrics are not a problem.
- o The time delay between absorption of the solar energy and delivery of the thermal energy to the living space can be more of an advantage for nighttime heating rather than for daytime heating.

Disadvantages:

- o Summer overheating problems may outweigh winter benefits in Cyprus with mild winters and hot summers unless effective shading, also from radiation reflected from the ground, is provided[2].
- o The effective heating is felt only to a depth of about 1.5 times the wall's height, due to the limited depth of natural convection air currents and the decreasing radiant heat flux from the warm sun-facing wall[3].
- o Under optimal flow conditions, about 30% of the total energy flow in 'vented walls made of concrete about 30cm thick is by convection and 70% is by conduction. A vented wall exhibits a lower temperature in the air space and consequently less heat is lost through the glazing. Therefore the overall efficiency is higher by about 10% in systems with 'vented' walls as compared with un-vented walls[4].
- o In multi-story buildings problems with maintenance of the glazing may necessitate the provision of access balconies (such balconies can function as shading overhangs for the glazing below).
- o The external surface of the mass wall is relatively hot as conduction of energy through the wall is slow and can lead to considerable loss of energy to the external environment thus reducing efficiency.
- o Discomfort can be caused at either end of the heating season by overheated air from the Trombe wall during the day or uncontrolled thermal radiation from the inside surface of either type on warm evenings. Venting can reduce these effects.
- o The south wall needs to be part glazed and part massive (Trombe wall) in order to function effectively. This configuration can have certain space and cost disadvantages.The need for sufficient thermal mass must be balanced with the requirements for views from the living space and daylight.
- o Condensation on the glass can be a problem.
- o Practically, it is not easy to equip a conventional Trombe Wall with operable insulation or even to ventilate the air space in summer. Ventilation of that space introduces dust on the inner side of the glazing and on the dark surface of the wall, reducing the effective solar transmission and absorption. This dust cannot be removed. One way to overcome these problems is to design an accessible space, about 60cm wide, between the wall and the glazing. Such a space enables the installation of rollable winter insulation-summer-shade 'curtain' inside the protected space, which is accessible for maintenance, dust cleaning, etc. The extra cost of this additional space should be taken into account in considering this design detail[5].

3.3. Sunspaces

Advantages:

- o Sunspaces (Conservatories, Winter Gardens, Greenhouses, Sun Porches) are intermediate usable spaces between the exterior and the interior of the building. Being separated from the main spaces of the building, a much greater temperature swing, may be acceptable within sunspaces, more than can be tolerated in non-isolated Direct Gain spaces. The sunspace area itself can constitute an additional living space in the winter and in the transitional seasons. With appropriate provision of shading and ventilation in the summer, such spaces may be pleasant environments year round.

- They buffer the main spaces from extremes of exposure, thus reducing the potential temperature fluctuation, glare and the fading of fabrics and furniture, which may result from excessive indoor sunlight.
- They increase the heat collection potential of a given façade, by allowing a larger glazing area than is practicable and desirable with Direct Gain.
- The interior "climate" of the house can be greatly improved by the addition of a thermal "buffer" between the living space and the outside air. A sunspace can run the full width of the house and the full height - reducing fabric and ventilation losses.
- Sunspaces are readily adaptable to existing houses.
- Sunspaces can be easily combined with other passive solar systems.

Disadvantages:

- The overall cost is higher and the energy collection efficiency per unit area of glazing of sunspaces and the payback period of the investment in its construction is longer, as compared with Direct Gain.
- In Cyprus there are overheating problems, even on the mountains where the temperatures are lower[6].
- Sunspaces can experience large temperature swings making it unsuitable for living or growing plants unless some control is used.
- The glazed roof of the sunspace can be sufficiently cool at night to cause condensation on its internal surface.
- Thermal energy is delivered to the house as warm air, which is less easy to store heat from air than from direct solar radiation.
- The increased humidity caused by growing plants may cause condensation and discomfort in the building.

3.4. Thermal Insulation

Thermal insulation should be provided to reduce heat losses in winter and heat gains in summer. Savings from energy conservation increase on as insulation moves from the internal side to the external surface of the envelope, for both cooling and heating. It should be placed as externally as possible because the part of the wall or roof inside of the insulation determines to a large extent the effectiveness of the heat capacity[7] [8]. Energy savings do not increase proportionally with the increase of the thickness of thermal insulation[9]. Application of 25 mm insulation causes 20% reduction of energy consumption both in heating and cooling. Doubling of the insulation thickness (50mm) causes only 6% more reduction of energy consumption both in heating and cooling (Total 26%). Tripling of insulation (75mm) causes only 3% more reduction of energy consumption both in heating and cooling (Total 29%).

3.5. Thermal storage

Thermal storage is an essential component in the effective use of solar energy in buildings.[10] It acts like a reservoir that absorbs and releases intermittent sources of energy like solar radiation (or large diurnal temperature swings) to assist in providing human comfort. Although many types of solar heating systems use remote storage (such as liquid storage tank, rock-beds, air core systems or phase change materials), this section will address those storage techniques that are directly coupled to the interior space of buildings. These are typically surfaces of the interior building structural elements themselves. The heat capacity of interior furnishings and other contents must also be considered.

The aspects relating to mass are of particular significance for Cyprus due to the large diurnal fluctuations (15 to 25 ºC), and the potential possessed by mass for large solar contribution in winter and cooling in summer. Addition[11] of internal mass yields to 5% reduction of cooling as well as heating load, while addition of external mass increases energy consumption by 40%. Whereas masonry provides good heat storage medium within a space, it readily passes this heat to the outside when added on exterior walls. Heavy weight construction is suitable for all the climatic regions of Cyprus. An average heat capacity of 300 kJ/m²K is proposed as optimum for economic reasons[12]. Using 215mm reinforced concrete or 195mm perforated brick blocks produces this heat capacity. The concept of addition of mass is presented as acceptable modification of the walls construction in the Cyprus market. Centralised masses in highly solar-driven spaces have not been shown to reduce temperature swings effectively. However, spreading out thinner layers of heat storage materials up to about a 12-to-1 ratio of storage layer area to glazing area provides better results. A 6-to-1 storage-to-glazing ratio is thought to be most effective.[13]

There have been examples of follow-up owners covering over heat storage walls thereby eliminating its storage function. Placement of thick carpet over heat storage floors and hanging too many plants in sunspace windows are other examples. Occupants of passive buildings must be well informed of the necessity for exposure of thermal storage components to direct sunlight, or to secondary gains via reflection and convection. One way to prevent this kind of intervention is to provide a storage mass that is aesthetically acceptable.

3.6. Shape

The shape of the house[14] (i.e. aspect ratio) affects only slightly its thermal performance when average weather prevails and it is designed and used in an "optimum" way. A rectangular but compact design (aspect ratio 1:1.33) with the longer axis pointing East and West is preferable because it is less sensitive to changes in weather and in design decisions than a rectangular but longer shape[15] (aspect ratio 1:3).

3.7. Solar control

Clearly, the greatest and most immediate source of heat gain to a building's interior is the solar radiation entering through a window. Windows provide essential benefits, such as view, ventilation, and a psychological (and sometimes physical) connection to the outdoors. Perhaps more importantly, windows are architectural elements that can set the style of a building. Any new glazing alternatives must provide all these benefits to be accepted in the marketplace. Today's commercially available argon-filled low-emissivity (low-e) windows can attain performance about midway between the extremes of the other glazing materials. The use of double-glazing is an effective means of controlling heat losses and therefore reducing energy consumption[16]. Replacing north single glazing with double results to 6% savings. Replacing all single glazing with double results to 48% savings.

If solar overheating is a problem, as it is in Cyprus, there are methods available for the reduction of solar heat gain through windows. These variables are within the designer's control. It is preferable that one of the long walls of the building is facing south so that the available solar radiation is exploited in winter. If the site prohibits this, additional energy is required for heating[17]. Trees and shrubs provide the simplest way of protecting a low building (or part of it) from solar radiation. Deciduous trees are especially valuable, as they do not cut out winter sunshine. The main negative factor is the time they need to grow.

Internal blinds and curtains are not very effective means of solar control, especially in Cyprus. It is true that they stop the passage of radiation, but they themselves absorb the solar heat and can reach a very high temperature. Blinds are most effective when fitted between sheets of double-glazing. Internal shades are very often of the venetian blind type and for these to give most benefit, they should be adjusted so that they reflect the rays of the sun back to the outside and so that no direct rays pass between the slats into the room. Under such conditions, only 53% of the direct and sky radiation normally incident upon a window is transmitted to the room.

Vertical devices are most effective when the sun is to one side of the elevation, such as an eastern or western elevation. For a vertical device to be effective when the sun is opposite to the wall considered, it would have to give almost complete cover of the whole window.

Horizontal devices can consist of roof overhangs, canopies, balconies, horizontal louver blades or externally applied Venetian blinds. Projecting slabs are also common forms of horizontal screening. These are more effective when the sun is opposite to the building face and at high angle, such as for south facing walls. To exclude a low angle sun, this device would have to cover the window completely, permitting a view downwards only.

The introduction of shutters to intercept the summer sun, incurs considerable reduction of cooling[18]. Cooling savings are 42% while the heating load is increased by 10%. The introduction of shutters as solar protection method achieves higher energy conservation than re-orienting fenestration; the unwanted summer solar radiation is intercepted, whilst the desired winter solar gains are almost unaffected, thus reducing considerably the cooling load. The introduction of shutters and addition of overhangs and side-fins also concludes to considerable reduction of cooling. The total savings are 20% for both heating and cooling. There is 5% reduction of the heating load that is attributed to the loss of useful solar gains intercepted by permanent overhangs and side-fins. There is 5% loss of cooling savings that is attributed to the retention of heat by the additional external mass of overhangs and side-fins.

3.8. Ventilation

Throughout history, people in Cyprus have relied upon natural ventilation for comfort in buildings during the summer. When natural ventilation does not occur some type of mechanical device is needed to provide adequate ventilation. Fans and ventilators are an effective way to enhance air circulation. This forced ventilation can supplement or even replace air conditioning. With ceiling fans, the thermostat setting can be raised up to 5ºC from the thermal comfort level[19] (depending on the occupants' preference).

Designers in Cyprus should commonly practice stack effect ventilation. During the summers in Cyprus, daytime ventilation is impossible and the building gradually heats up during the day. The stack must terminate above the roof peak so that the stack top is always under suction compared to the lower inlet level. Otherwise, a wind coming from the opposite direction can introduce the hot stack air into the room.[20 21]

Solar chimneys use the sun to warm up the internal surface of the chimney. Buoyancy forces due to temperature difference help induce an upward flow along the plate. The chimney width should be close to the boundary layer width in order to avoid potential backward flow[22].

Wind towers draw upon the force of the wind to generate air movement within the building. The wind-scoop inlets of the tower oriented toward the windward side capture the wind and drive the air down the chimney. The air exists through a leeward opening of the building[23 24]. The airflow is enhanced by cold night air. Alternatively, the chimney cap is designed to create a low-pressure region at the top of the tower, and the resultant drop in air pressure causes air to flow up the chimney. A windward opening should be associated with the system for air inlet. Both these principals may be combined in a single tower providing both admittance and exhaust of air.

4. EXPERIMENTAL PASSIVE SOLAR HOUSE

At the initial stages of the experimental passive solar house[25] all that have been discussed were taken into account and implemented in the construction. The construction was decided to be a heavy weight construction, as the typical Cypriot contemporary houses (concrete frame and floors and roof, 250mm brick work with plaster on the interior and exterior of the walls). 70mm expanded polystyrene was used to cover the whole building, including walls, concrete beams, columns and roof. In this way thermal bridges were excluded.

The ground level has an open plan in order to facilitate a constant indoor temperature and natural ventilation. It was also a personal decision on the author's behalf. It was also considered that if walls divided the ground floor, it was ensured that all the rooms would have south openings for the sun penetration and small north openings for the north summer breezes. A circular staircase was located centrally facing south providing a thermal mass storage which radiates heat in the winter evenings. On top of the staircase are the clerestory windows, which create a stack effect for ventilating the interior space in the summer, and allowing the winter sun in the winter.

When the fireplace is used the warm air rises through the open staircase and enters the bedrooms (stack effect) on the top floor. Naturally the inside temperatures of the bedrooms were lower (1-2ºC) than the living room.

In order to address the problem of summer overheating, several applications of passive solar systems were considered and it was decided to employ the following. The author chose to recess the second floor bedroom windows on the southeast and south walls so as to prevent summer sun from entering, but at the same time allowing winter warmth to enter. They are used as permanent shading devices so as to avoid movable shading devices. The recessed windows create a hollow space from the inside of the room, above and below the window frame, which can be converted to storage space. Roof fans are used to assure that no overheating would occur in the extreme overheated periods. It is actually one of the best active ventilation systems, since the indoor comfort temperatures are not high.

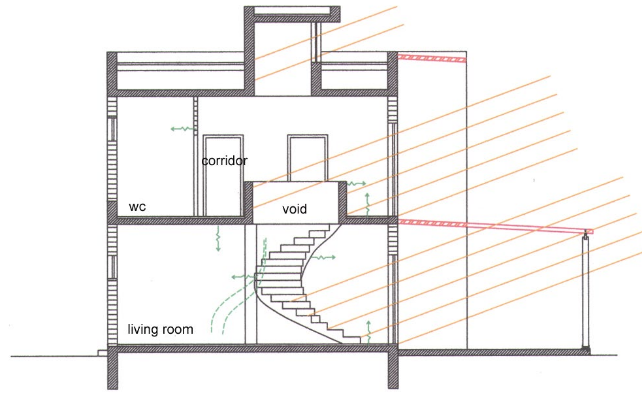

fig. 1 Experimental passive solar house. Winter

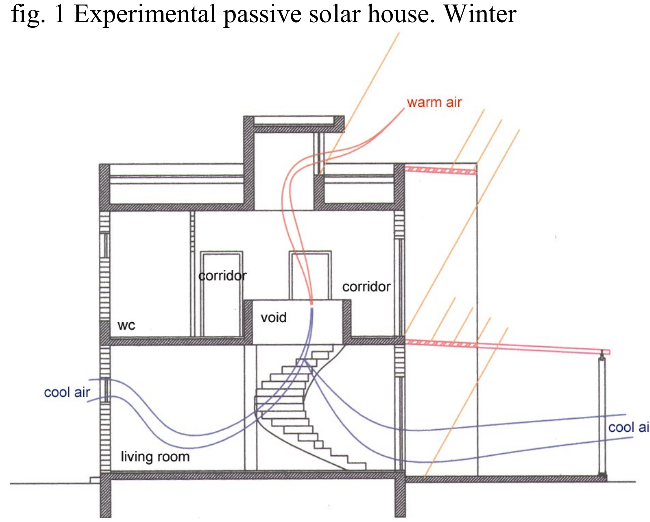

fig. 2. Experimental passive solar house. Summer

The monitoring results (21/1 - 18/12/2001) of the internal temperature and relative humidity throughout the year remained steady, despite the instability of external temperatures and humidity percentages.

Problems occurred during the heating and cooling periods. It was concluded that 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 movable shading device or vegetation is more suitable than the pergola, since they would allow shade in the summer, and solar radiation in the winter. The space at the ceiling (by the clerestory window) should be covered in the winter by placing a transparent covering in order to avoid heat sink. It is important to supervise construction closely, in order to ensure design is followed accurately. The Passive Solar House, not only functions successfully, but functions better than the average contemporary house.

5. CONCLUSION

Many buildings in Cyprus are designed with no recognition of passive solar design principles, and as a result they become uncomfortable inside and require unnecessary energy to artificially overcome the effects of inappropriate design, even when the outside climatic conditions are comfortable. Taking into account the advantages and disadvantages of the passive solar system it is concluded that the best systems which can be used for Passive Solar Houses in Cyprus are Direct Gain, Thermal Insulation, Thermal Storage (Interior Mass), Low emmisivity double-glazed, Solar Control (orientation, shading devices), Natural Ventilation (cross ventilation, stack effect, night ventilation and ceiling fans). The systems that are advised not to be used are Trombe Walls and Sun Spaces

The results of the experimental solar house show that all heating requirements are covered through passive solar energy, while natural ventilation or ceiling fans cover all the cooling needs. However, preliminary recommendations regarding the above-mentioned passive solar means may not be adequate to state that a particular building will not be overheated in the summer or underheated in winter. A proper assessment regarding such decisions cannot be made without calculations that involve a suitable prediction method of indoor air temperatures and numerical external and internal design data.

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