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Bioclimatic desert house
A critical view

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Abstract

The paper presents a bioclimatic house in the Negev Desert, Israel, as a case study through which it attempts to present a comprehensive and critical view of bioclimatic architecture, desig support tools, and appropriate details vis-a-vis common construction technologies and practices, assessing their relative impact and limitations. A number of topics are examined from different aspects, such as insulation and thermal mass, window systems incorporating double glazing, insulated shutters and window screens, vis-a-vis solar gains, ventilation and infiltration. Although interesting in themselves, topics such as desert gardening, runoff harvesting, soil types and graywater recycling, are not dealt with in this paper.

INTRODUCTION

Geographical location and climate

The Meir house was built (1992-4) in the first solar neighborhood in Israel, situated on the Negev Desert Highlands. The site is located at 30 ° north latitude, and an altitude of 470 meters. The climate of the region is defined as arid, with hot and dry summers, and cold winters. Summer daily average temperatures range between 32 and 17.3°C in July and August, but maxima of 42-43°C occur in May and June (hot spells called "sharav" in Hebrew, or "hamsin" in Arabic). Relative humidity during these months may drop as low as 24% at 1400 hours, with extreme conditions reaching as low as 5-15%, whereas at night and early morning it may reach 65-90% . Winter temperatures range between 15°C and 5-3.5°C, with below 0 temperatures near ground surface. There are over 1017 Heating Degree Days per year on average. Yearly average precipitation is below 90 mm. Winds are north and north-westerly in the early noon and evening hours, whereas at night and early morning they may turn north-east by south-east. Average maximum spee s range between 40 km/h in winter and 30 km/h in summer (absolute maxima above 100km/h have been registered) [1].

Historical and vernacular precedents

Traditional construction materials in the Negev and other arid regions are of high specific weight (stone, mud). Their limited strength in tension and the scarcity of wood, have led to the evolution of building types with thick walls, small apertures and domed roofs. Monitoring of vernacular buildings in deserts, as well as current research, highlight the importance of heavy building envelopes, and that of certain morphological solutions, in internal microclimate modification [2,3]. However, it should be noted that vernacular solutions do not stem solely from bioclimatic considerations, and are not necessarily better than the contemporary ones.

Planning framework

The Newe Zin solar neighborhood was designed in the 1980s by the Desert Architecture Unit, as a prototype toward the creation of energy conserving building codes in Israel. Although bioclimatic design is optional, the local building code ensures the protection of solar access rights [4]. An additional step toward bioclimatic design is the prohibition of chimneys, thus prohibiting the use of combustion heaters. Other issues dealt with by the building code are greenhouses and sunspaces, shading devices and building morphology ensuring visual homogeneity. Insulation standards are defined by the Israel Standard 1045 for the insulation of residential buildings [5]. The national building code enforces the use of solar water heaters for residential buildings, and final permit is dependent on the installation of such a heater.

Within this framework, houses in the Newe Zin neighborhood are designed by individual architects according to the specific clients' briefs.

HOUSE DESIGN

Brief

The Meir house is a single family building. The ground floor, with an overall area of appr. 150 m^2, includes four bedrooms, living and dinning spaces, kitchen, facilities and storage, whereas a 37 m^2 library and study is arranged on an internal balcony over the living room. A 20 m^2 garage adjacent to the ground floor functions as a separate space. The master bedroom, with adjacent bath and walk-in closet, is located at the western end of the house, and children's rooms and facilities are located at the eastern end, with the living room between them. The house also includes a number of verandas and balconies in different orientations. An open plan approach was taken both for functional and energetic reasons.

Environmentally responsive layout

Considering the site's geometry and climatic constraints, among them solar angles, air temperatures, and wind directions, it was decided to position functions along an east-west axis, with all bedrooms and the living room to the south. The second floor is exposed to all four directions. The kitchen, baths and laundry room are located at the northern part of the plan, and the garage serves as a western buffer. All of the spaces (except for the garage) were designed as a single thermal zone. Main fenestration is placed to the south, with smaller openings to the north for cross ventilation. However, all rooms have openings in two directions to ensure appropriate ventilation. There are practically no openings to the west (except for recessed small ones).

Early design decisions and tools

The preliminary plan was simulated as a single thermal zone with QUICK [6]. Simulation runs included different wall sections and materials, fenestration size and orientation, ventilation potential, as well as finish hues. As a result, decisions were made regarding the use of building materials for the envelope, and some minor changes were made to the plan and the overall fenestration area.

Thermal mass and insulation

The wide diurnal temperature fluctuations characteristic of the desert climate dictate the use of thermal mass, both for internal temperature damping and for energy storage. The common building techniques in Israel use concrete and its by-products both for envelope and internal partitions. This results in heavy buildings with ample thermal mass. Simulations and monitoring showed that the roof mass plays a definitive role in the modification of indoor temperatures. Insulation, and especially its relative position in the envelope section, has long been discussed. Based on the simulation results, which showed marginal differences between different wall sections (due to the high internal mass) it was decided to build the walls with cellular concrete blocks 25 cm thick, with a specific weight of 650 kg/m^3 and 0.2 Watt/m°C conductivity. Thermal bridges were insulated with 5 cm thick cellular concrete blocks, positioned in the moulds before concrete pouring.

These decisions stemmed primarily from the wish to refrain from combined, sandwich wall sections, or external insulation demanding precision in construction and suffering of relatively low strength to concentrated pressure and impact.

Floors are suspended, made of reinforced concrete poured over cardboard moulds, in order to prevent mechanical problems due to swelling soils, and corrosion problems due the local soils' high salinity. Roofs are made of cast reinforced concrete, covered by extruded polystyrene, aerated slopes cement and waterproofing, with an overall insulation value of appr. 2.22 m^2°C/Watt. Internal partitions are made of hollow concrete blocks. The staircase and structural elements are made of poured concrete.

Fenestration

Climatic conditions and termites excluded the use of wooden frames. Aluminium was the obvious choice. The relative advantages of single and double glazing were considered. Acoustical considerations (proximity to a high school dormitory) finally dictated double glazing. Mosquito mesh screens - a necessity in such areas - were included in all windows and doors. All windows (and glazed doors) are fitted with external rolling shutters using aluminium louvers filled with expanded polyurethane insulation, and internal vertical or horizontal venetian blinds.

Finish materials

External walls were painted with a latex-base paint to avoid cracking, common to the cement stucco finish in climates as dry as the one in discussion. The colour chosen was ochre, with an estimated absorptivity factor of 0.4. This was decided in order to minimise glare in the adjacent open spaces and to avoid aesthetic problems due to dust deposition. The latter would have increased the absorptivity of white paint in a matter of months, due to the frequent storms. Internal walls were whitewashed to increase light intensity. Floors were paved with terra cotta tiles to facilitate heat absorption. Balconies were paved with light coloured terrazzo tiles, and roof waterproofing membranes were chosen with a reflective coating.

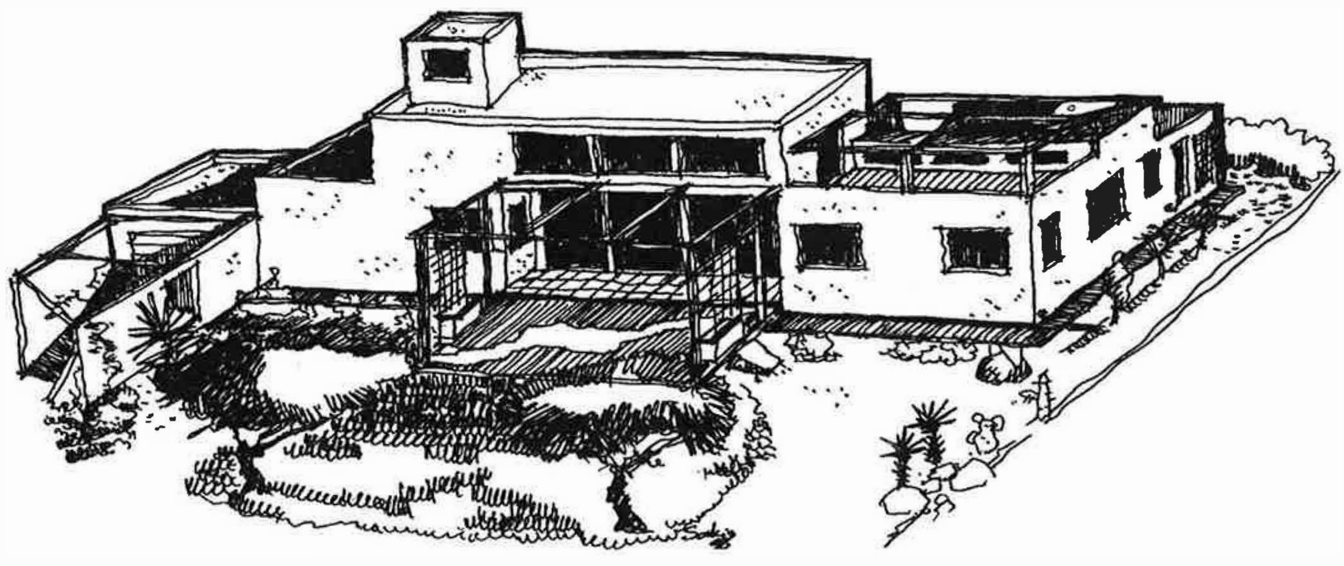

Figure 1. The Meir house - view from south.

BIOCLIMATIC FEATURES AND OPERATION

continuous internal space enables free air circulation. her windows provide solar access to the northern parts he plan, whereas the different height spaces enhance k ventilation and exhaust hot air from the upper strata.

Interior

COOLING: NIGHT VENTILATION

th and south facing windows enable cross ventilation ing summer nights, when ambient air temperature may :h levels below thermal comfort. The ventilation rate is ned by the overall windward fenestration area of appr. m², or 62.5% of the leeward fenestration area. Mesh :ens (in both inlet and outlet openings) play a definitive : here by cutting wind speed down to about 20-25% of ernal wind speeds, depending on wind incidence angles. asurements carried out in the house comply with research ılts [7,8]. The existence of windows on different levels in same space enhance ventilation by enabling different ration modes (cross, stack, suction).

HEATING: DIRECT SOLAR GAIN

overall area of 24 m² of south glazing (appr. 30% of the th facade, or appr. 14.5% of the floor area) functions as primary heating source (together with an additional 8 m² east facing windows). This is located so that high itioned windows allow solar access to the deeper parts of plan. With solar radiation exceeding 4.6 kWh/m² day a south facing vertical plane in January), this accounts over 110 kWh/day. To reach such values, shutters have be appropriately operated. Dust accumulating on the ıdow panes, as well as on mesh screens, may cut solar ns by as much as 30-50% and even more. Hot air :ulates freely through louver openings over room doors. ısed shutters during the night minimise heat losses, ıough poor window construction enhances infiltration.

ADDITIONAL FEATURES

:eiling fan was installed over the two storey living room ıce, so that windows may remain sealed during summer ernoon, when air movement is desired, but ambient ıperature is usually still higher than desired. A high iciency (7,000 kcal) solar collector and a 150 lt. water ıter were placed in a concealed part of the roof in order to nimise their aesthetic impact.

Adjacent open spaces

ree such spaces have been designed: south and north randas and a south-eastern balcony.

The southern veranda is open to the garden and the sert. Protected by the mass of the building to the north, d by the garden wall to the west, it provides wind otection and sun exposure during winter days. For summer otection a pergola has been designed that will incorporate ovable fabric shading.

The northern veranda is partly covered by the second ry and is protected to the east and west by the building ss. Thus, it is shaded in whole, or part, throughout most the warm and hot months of the year. Vegetation and the jacent buildings provide protection from hot afternoon nds.

The south-eastern balcony is primarily used during hot mmer nights. Its location exposes it to south-eastern eezes.

MONITORING

Monitoring was undertaken during the summer of 1995 and the winter of 1995-6. Ambient data were received from the Ben-Gurion National Solar Energy Center (located on the northern edge of the site). Monitoring included air temperatures measured at four locations within the house, surface temperatures, relative humidity, air velocity and occasional light intensity measurements.

Summer monitoring

Windows and shutters were closed from about 0630-0700 till after sunset. During monitoring ambient maxima reached around 34°C at 1400. Internal temperatures ranged from about 25.5°C at that time to an absolute maximum of 27.1°C with a delay of 5 hours. However, the real building lag was estimated to about 26-28 hours. While ambient night minima reached 13.8°C, the internal absolute minimum temperature was 22.3°C. Maximal temperature span between all internal spaces and surfaces (including glazing) seldom exceeded 1.5°C at any given moment. Exterior wall surface temperatures reached maxima of 44.3°C (marginally lower than the roof waterproofing membrane). The air space between the insulated roller shutter and the outer pane of southern windows was cooler by 5.5°C than the ambient at 1400. Windows positioned in the windward and leeward direction of the stairs tower enabled efficient ventilation even with relatively low wind speed. Shutters on the ground floor were partially closed at about midnight for security reasons.

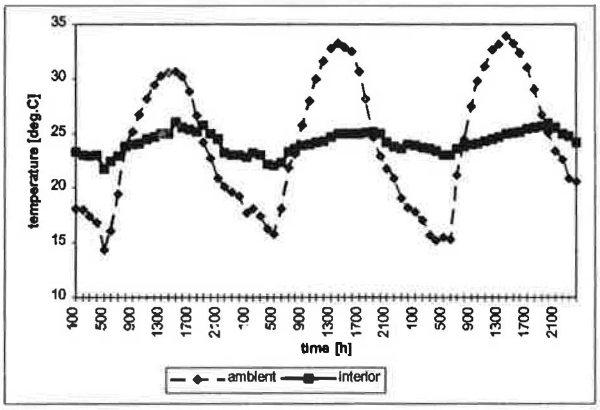

Figure 2. Typical summer period (June 18-20, 1995).

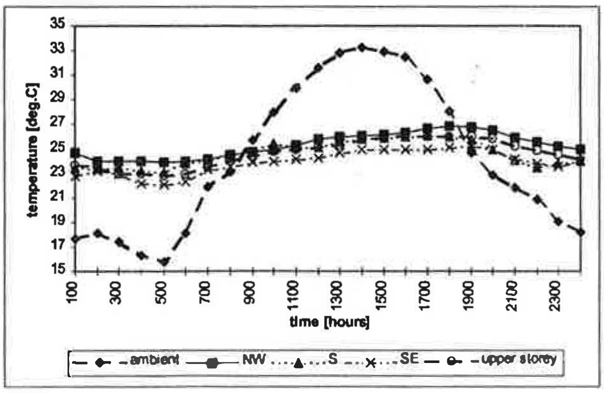

Figure 3. Daily temperature fluctuation at four locations within the house - typical summer day.

Winter monitoring

Shutters were kept closed between sundown and 0700. During the day south windows were exposed to the sun, whereas during exceptionally sunny days, northern shutters were also opened so that reflected radiation from whitewashed adjacent buildings could also be exploited. Solar gains and storage were sufficient to maintain internal temperatures at about 19-20.5°C during the day and 16.5-17.5°C by 0600, whereas ambient minima reached 1°C during monitoring. After a period of 7-8 cloudy days auxiliary heating was needed to maintain such temperatures, at an average rate of 10.9 kWh/day, or an equivalent of appr. 0.06 kWh/m^2 day (this does not include electricity used in showers when in use). Here, again, maximal temperature span between all internal spaces and surfaces (including glazing) seldom exceeded 1.5°C at any given moment. Stratification of hot air never exceeded a maximum span of 0.5°C. The air space between the insulated roller shutter and the outer pane of northern windows was hotter by 5-5.5°C than the ambient at 0030.

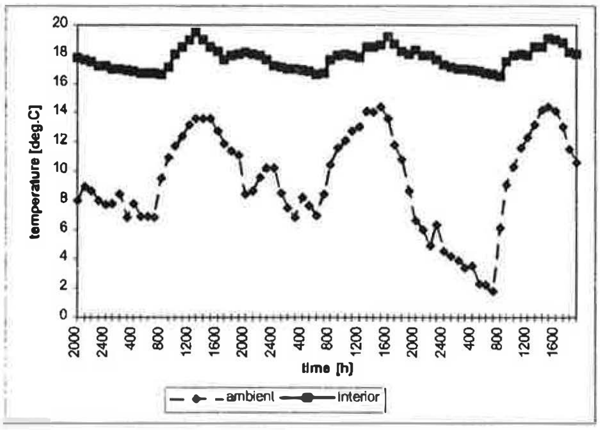

Figure 4 Typical winter period - cloudy (Dec. 11-14, 1995).

CONCLUSIONS

Monitoring showed that preliminary design assumptions and QUICK simulation results were rather accurate: the use of a medium weight material for the envelope walls did not alter the thermal performance of the building significantly, while it simplified construction by far in comparison with other wall sections adopted by other architects in the same neighborhood [9]. Thermal mass and insulation are sufficient and the time lag was satisfactory. Higher ratio of south glazing to floor area would have increased solar gains, but this might be at the cost of higher infiltration (estimated by the crack length method to about 0.44 m^3/sec) due to poor fenestration construction, as well as functional and privacy problems. Mesh screens in windows and doors, a vital necessity, proved to be problematic, as they interfere with ventilation and solar gains. Closing ground floor shutters during summer nights reduces cooling, but is necessary because of security reasons and the existence of snakes, scorpions and other pests.

The open plan concept proved to be correct as far as heat transfer and air circulation are concerned. However, it has created certain problems in regard with acoustics, and smells from the kitchen to other parts of the house. The concept of varying heights within a continuous space proved to be advantageous in the case of summer night ventilation, but during winter nights also created air movements due to buoyancy differences, which may prove unpleasant.

The ceiling fan proved to be insufficient, primarily due to the large volume and complex geometry of the space within which it operates. This was corrected by the addition of a smaller fan in the ground floor space. The solar collector provides ample hot water for the five people living in the house, from April to November. During 3-4 summer months it reaches temperatures so high that the collector has to be shaded by a 50% shading mesh, to protect young children from hot water burns and protect the water piping from extreme expansion. However, the concealing walls around the collector affect its efficiency during about four winter months, creating need for auxiliary heating backup.

The adjacent open spaces of different orientations are very successful and enable outdoors activities throughout the whole year.

One of the major drawbacks in the case of passive bioclimatic buildings is the user factor. Even in the specific case, keeping a correct operation lifestyle is not self-evident, and sometimes undesired operation (such as early start of ventilation in summer) may cause undesired side effects (such as heating the mass). Thus, buildings cannot be total, absolute solutions to fluid problems. The Corbusian axiom labelling the house "a machine to live in" is incorrect in perception, since a house - unlike a machine - does not perform the same task day after day. The theorem "a passive house needs an active user" is more accurate, since it implies that a house is a non-fixed combination of variations.

Finally, it may be stated that appropriate design and construction in climatic environments such as the one discussed here, may enable single family houses (and other buildings!) be fully or largely energy independent regarding their heating and cooling requirements.

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