

## **THERMAL COMFORT - THERMAL MASS: HOUSING IN HOT DRY CLIMATES**

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### **ABSTRACT**

The concept of thermal mass as a means of ameliorating diurnal temperature swings seems to be ideally suited for hot dry regions, which are characterized by wide daily temperature fluctuation in summer, and a considerable number of sunny days in winter. Furthermore, recent years in Israel (and the Middle East in general) have been following a worrying pattern of climate changes and “freak” weather events. Under such conditions, within an energy market where demand grows faster than supply, and with an ever increasing awareness of the environmental consequences of uncontrolled energy consumption patterns, thermal mass and its storage potential seem to be one of the most appropriate strategies to deal with energy conservation and thermal comfort issues within the broader framework of indoor air quality (Givoni, 1976).

### **INDEX TERMS**

Arid climate, Energy conservation, Free running buildings, Thermal mass, Thermal comfort

### **A SHORT NOTE ON HOT DRY REGIONS AND CLIMATE CHANGE**

One of the most profound characteristics of hot dry climates is that of wide fluctuation of temperatures, daily and seasonal. In many arid regions, summer days may be very hot and dry (especially in continental areas and on the mountains), while nights may be cool and even cold. Diurnal swings of 15-20deg.C or more are common with minima often reaching below 15deg.C. Winter days are generally sunny with clear skies, whereas nights are cold, with temperatures close to, and even below zero, frost being a common occurrence. Rainfall is usually limited and concentrated in a small number of downpours during the winter months, resulting in violent floods. Dust and sand storms are common, especially during the transition seasons. Such conditions may vary from year to year, drought being an endemic phenomenon in arid regions.

However, in recent years, the Israeli arid south has experienced a strange change in climatic conditions, expressed in an ever increasing occurrence of adverse conditions and “freak” events, both in winter and summer. Hot spells common in summer and the transition seasons, but not unknown in winter, too, may cause a sharp rise in temperature, reaching within a few hours 10deg.C or more above the previous days’ maxima. Such conditions may be considered characteristic of a large part of the deserts in the Middle East, although each region’s altitude and distance from the sea do play a major role in defining the “continentality factor”, and thus the final formation of local meso and microclimate.

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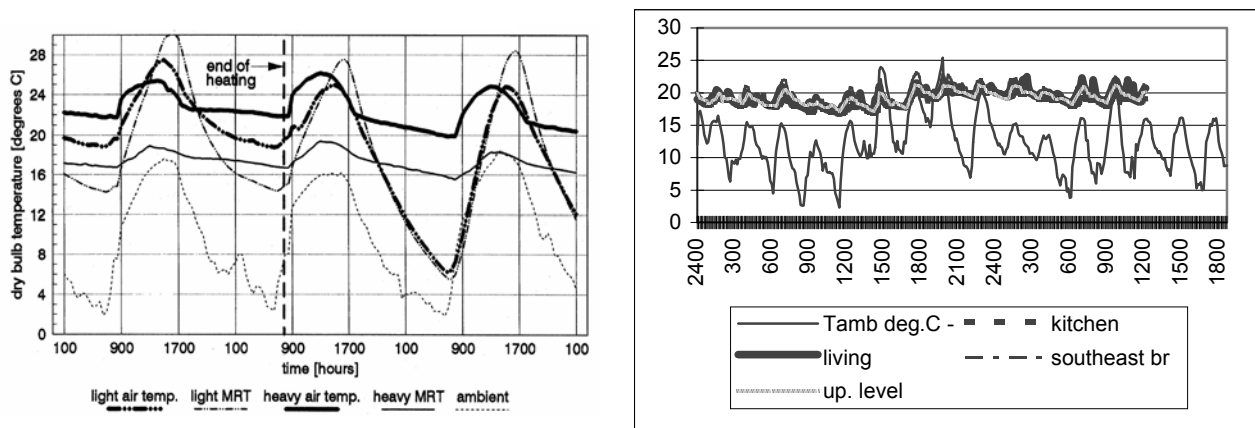
Due to these conditions and the subsequent lack of wood, with soil or stone as the only building materials available, vernacular architecture has been traditionally heavy, of high thermal capacity. The various materials limitations dictated thick walls (reaching 50-100 cm), small windows, and roofs made of similar materials to the walls, often in the form of vaults and domes.

It is of relevance to remember that most of the world's arid regions are sparsely populated and therefore underdeveloped, lacking infrastructure. It is also important to remember that in the last 25-odd years the world's deserts have expanded from a considerable 22% of the world's potentially arable lands (Saini, 1980) to over 30% (Middleton and Thomas, 1997). This process, known as "desertification", is bringing the desert and its adverse extremes to the doorsteps of temperate and composite climatic regions. Although theoretically possible for man to adjust to new climatic conditions, such climate and environmental changes may cause – and indeed have caused in the past – uncontrollable migration movements, with consequent humanitarian, economic and political problems.

### THERMAL MASS AND ITS RELEVANCE TO DESERTS

Under climatic conditions such as those described above, the ability to store energy is a vital strategy in controlling and ameliorating the building microclimate and lowering energy demand heavily weighing on the infrastructure. Rising living standards on the one hand, and the environmental implications of increased fossil fuel exploitation on the other hand, indicate the need for alternative solutions, and a more sane use of energy in buildings. High thermal capacity in a shaded and insulated building can help lower indoor maxima by 35-45% of the outdoor ones when the building is unventilated (Givoni, 1994). Similarly, indoor minima will be higher than the ambient ones by a similar percentage. Day ventilation (comfort ventilation) will raise indoor temperatures, while night ventilation will lower them. There are, of course, differences between the theoretical and the real effects of thermal mass in such indoor climate modification.

Research carried on the Negev Highlands in Israel demonstrated that properly designed and constructed heavy buildings will perform better than lightweight ones almost under all climatic conditions of the Highlands and under different operation modes (Pearlmutter and Meir, 1995). The ameliorating effect mass has on the indoor climate is especially interesting over a period of time such as after switching off the backup heating, or during hot spells. This is of special relevance to both arid climates and to climate change.



**Figure 1.** Left: comparison of interior air temperatures and MRT before and after cessation of backup heating in light and heavy buildings, Negev Highlands (Pearlmutter & Meir, 1995). Right: indoor temperatures in four rooms of an insulated free running building with evenly distributed internal mass, during a winter hot spell (Meir, 2000).

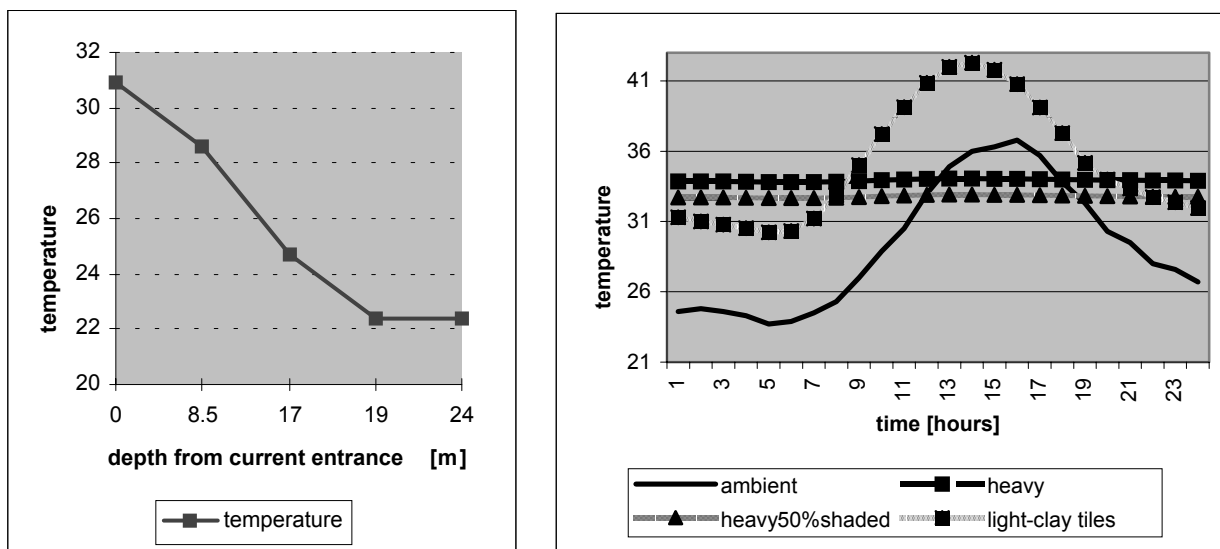
One of the common occurrences of large parts of the Middle Eastern deserts are the hot spells. During summer these outdoor conditions may become unbearable in a matter of hours. This, in turn, may create indoor conditions that are even worse. Combined with dust storms, such hot spells may even prevent the use of outdoor spaces and the opening of windows to allow for comfort ventilation. Thermal mass provides probably the best – sometimes the only – solution, especially considering the possibility of power failures due to the storms or excess peak energy demand. Alternately, when such spells occur during the winter, thermal mass is able to take advantage of the high air temperatures and store heat (Meir, 2000).

This property is becoming of ever-increasing importance as the climate is becoming less predictable and more adverse, with extreme hot spells throughout the year and extreme cold spells in winter. Providing conditioning demands for lightweight buildings under such changing conditions is difficult to achieve and sustain. This can be easily illustrated by noting the different energy demands for heating the structures mentioned previously: 3.4 kWh/day for the heavy and 9.7 kWh/day for the light. There also exist significant differences for these two buildings even when located on the warmer coastal plain.

### SIZING THERMAL MASS

On the one extreme of the thermal mass scale are the lightweight structures, be they mobile or stationary, made of wood, corrugated metal, sandwich panels, or other materials. As already mentioned, such structures will have a relatively quick reaction to outdoor changes (a short Thermal Time Constant – TTC), will retain little or none of the energy invested in their conditioning, and will have indoor extremes close to the outdoor ones. Such properties make them poor envelopes in climates of extreme variations, as well as for energy conservation.

One of the most extreme examples of massive structures occupying the other end of the scale is that of underground and earth-sheltered buildings. With soil temperatures stabilizing around the daily average at a depth of about 1.5-2m, and around the seasonal average in greater depths, there seems to be an obvious advantage to such types of construction, as well as additional advantages, such as minimizing visual and landscape impact.



**Figure 2.** Left: temperature drop in relation to distance from subterranean dwelling entrance, August, Avdat, Negev Highlands. Right: indoor summer temperature profiles for different roofing options of a Byzantine stone house with 80cm thick walls), Shivta, Negev Highlands (both graphs after Meir, 2001).

One of the main drawbacks of traditional architecture has been the lack of insulating materials. However, it has been considered “common knowledge” that excess thermal mass can compensate for lack of insulation. Obviously, this is not the case for traditional architecture and construction, characterized by high infiltration rates, small windows, often unglazed, and doors that are often mere pieces of fabric. Such buildings are of inferior microclimatic conditions compared to the ambient for a large part of the year. One indication of that is the behavioral adaptation common in deserts during the summer, when people prefer to sleep on roofs, balconies and verandas or in the patio, under the open sky, thus escaping at night from the hot indoors of stone and mud buildings (Imamoglu, 1980). A research project including over 450 simulation runs for four traditional Middle Eastern prototypes, on three different locations (coastal/Bet Dagan, mountain/Amman, continental/Baghdad) and for two different building materials (stone and mud), showed that for most of the traditional cases, walls of 50-100 cm thick encouraged the creation of indoor temperatures that were extremely low in winter, and well above the ambient for most hours of the day in summer (Meir, Bennett Mackenzie and Roaf, 2001).

The thermal capacity appropriate for a building should, of course, be considered vis-à-vis the specific building type, plan, details, location and climatic conditions, and use patterns for each and every project. Calculations, simulation and monitoring have shown that the equivalent mass of 10cm of concrete in the envelope of an insulated building is enough to moderate diurnal temperature extremes, and provide a long TTC under most of Israel’s conditions. But is that enough for “freak” events and, even if so, where should that mass be positioned in the building?

**Table 1.** TTC as a function of wall mass and insulation thickness, and their relative position (Meir, Etzion and Faiman, 1998).

<i>Envelope Wall Concrete Thickness [cm]</i>	<i>Thickness of Polystyrene Insulation – EXTERNAL [cm]</i>					
	0	1	2	3	4	5
10	4.3	18.7	33.1	47.6	62.0	76.5
20	11.2	40.1	68.9	97.7	126.6	155.5
<i>Envelope Wall Concrete Thickness [cm]</i>	<i>Thickness of Polystyrene Insulation – INTERNAL [cm]</i>					
	0	1	2	3	4	5
10	4.2	4.3	4.3	4.4	4.4	4.5
20	11.2	11.3	11.3	11.4	11.4	11.5

**ON THE RELATIVE POSITION OF THERMAL MASS**

In insulated structures the relative position of the thermal mass should be considered carefully. Positioning it within the insulated envelope will grant the structure a better and longer TTC as shown in Table 1. It has been argued that this mass can be located in different parts of the structure with the same overall effect. The most vulnerable part of the envelope is the roof, which, under the Negev Desert conditions, is exposed to over 7.5kWh/sq.m/day and to mostly clear sky during winter nights, thus functioning as an outgoing longwave radiator. Thus, insulating the roof of any building is crucial. Furthermore, both simulation and monitoring have shown that in hot dry climates a massive roof changes drastically indoor conditions, and especially diurnal swings. A massive floor will absorb heat in winter days and release it gradually at night thus creating a more thermally uniform environment. In many countries exterior walls are load-bearing and provide an easy storage mass. Various publications argue the appropriateness of internal thermal mass - horizontal and vertical partitions (Holm, 1983) – and in many cases the use of heat storing walls is advocated.

A number of considerations should be kept in mind while deciding the position of the thermal mass. Mean radiant temperature (MRT) is a significant factor in the overall thermal comfort considerations, and thus a uniform distribution of thermal mass within the building should be considered as appropriate. In such cases, it is possible to achieve a minimal temperature gradient among all surface and air temperatures within a building. A uniform allocation of thermal mass in floor, ceilings and roof, external and internal walls has been shown to create a maximal temperature gradient of no more than 1.5deg.C under summer and winter conditions, and “freak” weather events, including all surface and air temperatures of a two storey, 200 sq.m. house (Meir, 2000). Limiting the thermal mass of a structure to its internal partitions may have certain advantages, such as in buildings a priori designed with lightweight envelope, but it can only function properly under very specific conditions. In the case of free running buildings this means that all internal mass should be equally exposed to summer night ventilation and winter direct solar access. This dictates open space design, which may have certain noise and smell transfer implications, and cause lack of privacy.

Trombe wall type storage mass should be neutralized in summer by fully shading it, and even by isolating it from the rest of the internal spaces, to avoid its overheating and affecting indoor temperatures. In free running buildings with little or no auxiliary heating or cooling back up, a prolonged “freak” event may render such a high thermal mass concentration a heavy liability. Due to such considerations it is desirable to spread evenly the thermal mass within the building envelope and internal partitions, thus creating a more thermally uniform and stable indoor climate.

#### **DRAWBACKS**

It has been argued that for non-continuous, intermittent use of buildings, lack of internal mass may enable easier and faster conditioning (Hassid, 1994). It is also assumed that heavy cooling and heating peak loads are more easily treated in light interiors, where indoor air can easily be conditioned. This may be true under certain conditions and specific building types. Nevertheless, it should be kept in mind that even under such conditions it is possible to take advantage of internal thermal mass by preconditioning it (night ventilation, HVAC operation using off-peak energy etc), thus minimizing loads during building use.

Another potential drawback is that of improper operation of the building, which may cause thermal mass not to cool down or heat up sufficiently. In such cases thermal mass may become a thermal liability, which may be hard to bring to acceptable levels after having been misused over a long period of time. It is, therefore, assumed that the thermal mass of any building should be treated as an integral part of its conditioning systems and strategies and should be properly managed.

#### **CONCLUSIONS**

Thermal mass is an essential strategy for indoor climate control in hot dry climates. It has the potential to ameliorate indoor extremes and provide a considerable TTC in free running as well as energy conserving conditioned buildings. It can also provide a proper solution to protection from “freak” weather events, such as those which are typical of deserts and are becoming more common in adjacent regions.

Thermal mass should be evenly spread within the building, to enable the creation of a more balanced indoor microclimate. Extreme solutions, such as excess thermal mass and Trombe walls, should be considered with skepticism, and when used they should be designed so that they may be isolated when need be.

The case of high thermal mass as a passive strategy has been undergoing a continuous revision and “canonization”. Having been traditionally considered as appropriate for housing in hot dry climates, its advantages are being reassessed for free running buildings as well as for lowering energy consumption in conditioned ones, in a wide variety of climates and building types (Szockolay, 1996).

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