Sustainable Cities and Society 13 (2014) 279–302

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Parametric analysis of environmentally responsive strategies for building envelopes specific for hot hyperarid regions

Alex Cicelsky[a], Isaac A. Meir[b,*]

[a] Center for Creative Ecology, Kibbutz Lotan, D.N. Hevel Eilot 88855, Israel
[b] The Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Desert Architecture & Urban Planning, Sede Boqer Campus, Israel

ARTICLE INFO

Keywords:
Desert architecture
Insulation
Thermal mass

ABSTRACT

The deep hot hyper-arid valley between Israel and Jordan presents unique design and construction challenges for energy conservation and thermal comfort. Winters are relatively mild, summers extremely hot during the day, with night air temperature remaining above 25 °C. Such conditions present real challenges in this sparsely populated yet rapidly developing region. Development depends on the ability to provide acceptable indoor environments at a low energy investment. Potential solutions were investigated through a parametric analysis including physical and operational elements aiming at establishing benchmarks for free running, low energy buildings under extreme conditions. First, building performance was simulated for a limited number of parameters. Additional operational and physical parameters were introduced and results compared. Data were analyzed to determine the best performing options for building assemblies.

Permutations investigated confirmed that conventional building systems did not allow for free running operation and that mechanical systems for heating and cooling were needed. This research concluded that it is imperative to extensively insulate building envelopes in order for them to be free running in winter. Extensive shading is needed in the transition seasons to allow for free running operation and avoid overheating. Completely shaded buildings, high efficiency window systems and levels of insulation above those currently employed when simulated with summer climate conditions had significantly lower energy consumption requirements than other building designs. The research showed that energy efficiency in this region depends on a combination of extensive insulation, full shade, high performance windows, air tightness and seasonal operation of window shutters utilized together.

1. Introduction

Settlement in hyper-arid regions has usually been scarce and sparse, yet the continuous processes of desertification and climate change on the one hand, alongside human expansion and search for new places to settle on the other hand, are bringing more people closer or inside deserts, and often bring the deserts to the doorsteps of people used to much more hospitable environments and temperate climates. Urbanization and population growth processes are also exacerbating housing related issues in such regions. The need to provide sustainable, low energy housing in deserts is thus becoming all the more pressing, as has been stressed in a number of recent publications (e.g., Beer, Tually, Krohen, & Law, 2012; Meir et al., 2012).

The case study dealt with in this paper is the Southern Arava Valley, part of the long Afro-Asian Rift, a natural border between Israel and Jordan. To the north lies the Dead Sea (over 420 m below Mean Sea Level – MSL), and to the south the port city of Eilat on the Red Sea coast, with a higher middle part rising to approximately 210 m above MSL. It is considered one of the climatically harshest parts of Israel. Its climate is unique in Israel and unusual when compared to deserts worldwide. Winters are relatively mild, frost is rare and no occurrences of snow have been recorded within the valley. Winter daily maxima range between 21 and 23 °C, and night minima between 9 and 11 °C. Rarely do temperatures go below 5 °C, and the absolute minimum registered ever was 1.2 °C. Summers are extremely hot during the day with temperatures often reaching 42 °C and above, and at night the air temperature remains above 25 °C, with katabatic winds from the cliffs to the west often keeping it higher. The absolute maximum registered was above 47 °C. Only one out of four nights reaches a minimum temperature below 24 °C. During the summer and transition seasons months relative humidity may go as low as 10% and below (Bitan & Rubin, 1991), though

* Corresponding author. Tel.: +972 86596880; fax: +972 86596881.
E-mail address: sakis@bgu.ac.il (I.A. Meir).

http://dx.doi.org/10.1016/j.scs.2014.02.003
2210-6707/

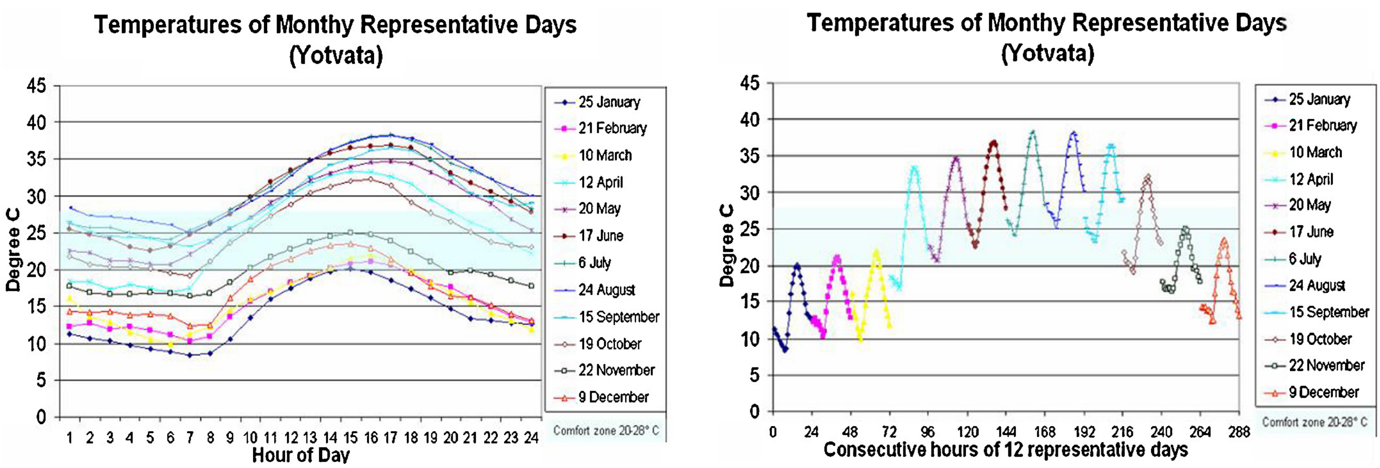

Fig. 1. Left: external temperatures of representative days from Typical Meteorological Year (TMY). Right: temperature measurements of representative days for each month selected from the Yotvata TMY. The consecutive hours in the graph are multiples of 24 times the numerical month of the year (– after Faiman et al., 2004).

in recent years there have been anecdotal reports of high relative humidity, which renders climatic conditions nearly unbearable without mechanical cooling (see Fig. 1).

The region of Eilot Regional Council, stretching 102 km northwards from the port city of Eilat on the Red Sea, has been traditionally sparsely populated. Within the valley nine modern communities have been established in the past 50 years along with limited industrial, commercial and municipal facilities. The regional authority has announced its commitment to become energy independent in the next decade, using solar technologies and other alternative and renewable sources electricity production. The master plan for the region calls for tripling the population of around 3000 residents in the same period. Both of these goals depend on building housing units in each of the existing communities. The existing models of housing are recognized as energy inefficient and inappropriate for the region. This is because they are copies of units built in (but not necessarily planned to be adapted to) other regions of the country and either transported to the Arava or built in situ according to plans that only marginally relate to the particular extreme climate. Common building types and technologies include concrete, flat roofed non-insulated houses which were marginally improved post construction by the addition of "thermal" external plaster (a mix of cement with polystyrene beads, applied to exterior concrete walls); aerated autoclaved concrete (AAC) blocks; introduction of the most basic model of double glazed windows (in aluminum frames with no thermal breaks); and roof shading. Recently, lightweight housing units have been introduced. In all cases, the level of satisfaction has not increased and heating ventilation and air conditioning (HVAC) use is high. The development of architectural strategies that are particular to this region with an emphasis on energy efficiency should be recognized as a component in the renewable energy plan and the physical development master plan of the regional council and the communities.

Residents of the southern Arava are quite aware that heating and cooling systems and their associated costs are inseparable with living in this region. Winter days, normally sunny and often moderate are pleasant outdoor, but marginally tolerable indoor, while nights are cold and internal walls and windows feel very cold. Temperatures in the spring and fall are moderate during day and night, allowing daily ventilation, with windows open or closed at night. Summer daytime mechanical cooling can begin as early as late April and even March during sandstorms with hot wind events blowing up from Africa. By late May air conditioners are running during the day and night until cool nighttime breezes begin again in September.

During the peak summer heat many of the predominantly agricultural settlements (moshavim – cooperative villages) in the area practically go dormant, with significant parts of their population leaving for up to two months. This is both because of the discomfort conditions and the fact there is little or no agricultural activity during such times (not including animal husbandry, which is more typical of the kibbutzim – communal settlements – or tourism oriented activities). In agricultural settlements of the region outdoors physical work is usually done either very early in the morning or in the early evening when ambient temperature is not at its peak. This in itself comprises a very specific form of adaptive behavior as assumed by the adaptive thermal model, based on the principle that "people have a natural tendency to adapt to changing conditions in their environment" (Nicol & Humphreys, 2002). However, the ability to function appropriately at such times depends on the individual's ability to rest appropriately between work sessions which, in the specific environment and climate constraints, depends on the ability to provide thermally comfortable indoor environments. The fact that most of the adult population of the region comes from the less extreme climatic parts of the country, as well as the fact that in recent years climatic extremes have been experienced at a growing rate, create an urgency for appropriate solutions (O'Neill et al., 2009).

Quite often it is claimed that local, vernacular and historic precedents should be considered as sources of inspiration for sustainable solutions (albeit after appropriately adapted for modern living and needs – see, e.g., Meir & Roaf, 2003, 2005). Yet in the specific region the only permanent settlements established in the past were located in the few areas rich in sweet water springs, such as Jericho. There the microclimate tended to be more favorable due to the abundance of water and vegetation, providing ample shading and evaporative cooling. Local building technology included soil bricks, thick walls and vaults, buildings were constructed around courtyards and intra-mural migration was one of the main strategies of climatic adaptation. However, construction (and primarily land) costs in today's Israel prohibit the construction of buildings whose size can allow intramural migration. The excess thermal mass provided by soil brick construction technology has been shown to be counterproductive (see, e.g., Meir & Roaf, 2002) and their air tightness necessary for efficiently air conditioned buildings is arguable. Whereas internal courtyards may have been a necessity in the past serving for summer night sleeping, their functionality today is not self-evident, and they enlarge the building envelope where compactness is an imperative. Thus, it may be concluded that in the specific region and constraints, for the specific population, upgrade