

The Unbearable Lightness of "The Paradigm"

On energy waste and discomfort in a hot arid climate

Isaac A. Meir¹ and Jennifer Y. Golding²

¹ Chair – Desert Architecture & Urban Planning, Dept. Man in the Desert, Blaustein Institutes for Desert Research (BIDR), Ben-Gurion University of the Negev (BGU), Israel, sakis@bgu.ac.il

² Albert Katz International School for Desert Studies (AKIS), Man in Drylands Specialization, BIDR, BGU, Israel

Abstract

This paper presents a number of case studies (surveyed and/or monitored) from a hot arid environment, covering a range of building types and sizes, among them government, university residential buildings, educational and tourist facilities. It hopefully demonstrates how preconceived ideas have prevented the designers of most of these to reach a healthy, responsive, comfortable indoor environment, whereas a basic understanding of the local conditions and the adaptive thermal model could have yielded much better results – easily achieved when appropriate design is coupled with informed users.

Keywords: sustainable desert architecture, energy conservation, IAQ, IEQ, POE

The unbearable lightness of the paradigm

Despite a continuously growing body of knowledge –scientific and technological – produced by the scientific community, this finds little actual application in everyday practices of architects. Most of those draw from "paradigms" – more-often-than-not misinterpreted architectonic phenomena, practices or principles. Two diametrically opposed trends characterize innovative design in recent years, the high-tech and the neo-vernacular. Both are informed by contemporary "paradigms" and are transplanted around the globe in a non-critical manner. Thus, office, institutional, educational and other "official" buildings are constructed on very similar lines across continents, climatic and cultural borders. At the other end of the scale are buildings that draw their design concepts from local vernacular traditions, materials and techniques – but not necessarily those of the locale they are situated in. In both cases, occupant discomfort seems to be the common denominator, often including Sick Building Syndrome (SBS) and Building Related Illness (BRI) resulting in unnecessary and counterproductive energy overuse. But worse than that, many of these buildings are branded by their designers "green". This last point may prove of detrimental implications as architects and clients look up to those pioneering paradigms for inspiration (Meir and Roaf 2003).

Can it be that this is a hard way of looking at a relatively new discipline - or philosophy? For one, the way architects have been confronting this and related issues has been "impressionistic" in many cases, i.e., consistent with the way many architects have been learning, in a visual rather than an analytical manner. In tandem, though, standards have often contributed to the ambiguity and the fog around what is sustainable and green, and what is not. This non-critical transfer of paradigms is not a new situation and has existed long before sustainable design became an issue, but the

vagueness of current standards exacerbates the problem. Following are some examples of current projects from the arid southern part of Israel, demonstrating how preconceived ideas affect building performance, occupant comfort and well-being, and energy consumption. Let there be no mistake: the following case studies are in no way typical of Israeli practices alone, but rather indicative of what is happening all over the world.

An unhealthy university building case study

A university building was surveyed as part of an educational exercise for graduate students. It houses offices, labs and assorted facilities. It is located in Beer-Sheva (31.15°N, 34.48°E, 270m above Mean Sea Level - MSL, 45km from the Mediterranean coast), on the lowlands of the Israeli desert. The area's climate is relatively mild with hot dry summers and moderately cold, but usually sunny winters. The yearly average rainfall is appr. 250mm. Although dust storms do occur, the more problematic ones are conveniently concentrated in the transition seasons. All of these make the use of free-running buildings an appropriate strategy for achieving thermal comfort and energy conservation at the same time. This, of course, implies the employment of passive strategies in the building, so that natural ventilation for comfort and cooling could be provided through openable windows, and solar heating could be achieved by appropriately positioned glazing.

The project's construction was completed in October 2000, making it one among the latest generation of university facilities aiming at upgrading not just working conditions, but also the university image. The specific building was chosen for the survey because of complaints made by its users, but can easily be considered indicative of many similar facilities in Israel and elsewhere. The survey included plan analysis, observational walk-through, questionnaires, interviews and spot measurements of temperature, relative humidity, light intensity and noise, all taken at the workstation of each one of the interviewees at the time of the interviews. These were conducted in laboratories, administrative and faculty offices on three typical storeys and the basement level. A total of 29 occupants (16 male and 13 female), approx. 50% of the daily average number of occupants, participated. The survey was conducted in December 2005 (Morhayim and Meir 2008).

Results showed that 28% of the interviewees complained about the ventilation; 42% were indifferent to it, but 40% of the interviewees found the odours condition to be "poor" and "very poor". 41% found the temperature "good", and lighting was considered "good" by 64%. The overall building Indoor Environment Quality (IEQ) was considered "good" and "excellent" by 48% of the interviewees. 37% of male interviewees considered temperature to be "good" or "excellent"; the same assessment increases to 60% with female interviewees. Lighting is also considered "good" to "excellent" by 56% of male interviewees and by 84% of female interviewees. The difference between genders is especially pronounced in the assessment of odours: 56% of male interviewees rate this parameter as indifferent or below, compared to 92% of female interviewees (Figure 1). In general, in private – faculty – offices, answers indicating good levels are higher than in non private –administrative staff – offices and in laboratories, with an exception in lighting levels, with "good" and "excellent" levels being lower in private offices (20% difference). The biggest discrepancy was identified in overall comfort levels: in private offices 69% rated

conditions as “good” and “excellent”, whereas in the rest of the spaces this assessment drops to 31%.

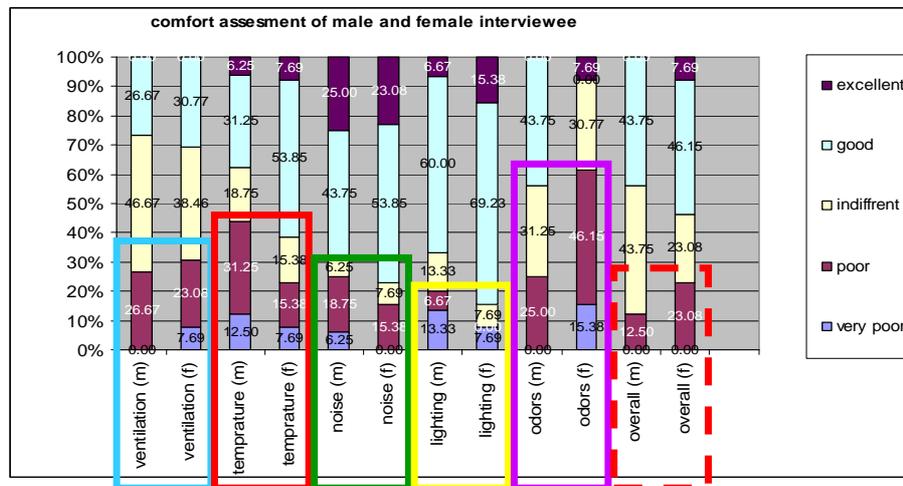


Figure 1 Comfort assessment of male and female interviewees in a university building (after Morhayim and Meir 2008).

Despite the relatively small number of interviewees, the results may be considered indicative and representative of the general relation of occupants toward their working environment. The interviewees included senior and junior academic, as well as technical and administrative staff, and research students (master’s and doctoral), thus spanning ages between late 20s and late 50s. A walk-through that preceded the measurements and surveys indicated air quality problems, not least due to visible mould concentration on HVAC outlets and return air openings, moisture-caused patches on acoustic ceilings, and condensation-induced mould on aluminium window frames, indicating lack of thermal brakes. These were referred to in the interviews held with the building occupants. A general discontent was indicated by the Indoor Air Quality (IAQ), and anecdotal evidence was mentioned, including the fact that since the building was occupied two senior staff members died of cancer (we are not aware of any evidence suggesting any relation between the two, and the time frame seems to make such a connection impossible, but the fact that building occupants make this connection indicates there is certain discontent with the building, creating psychological problems, to say the least).

To this general perception contribute additional parameters. For one, the central HVAC system leaves little room for individual control. The air temperature measured in most spaces during the survey ranged between 22-25°C. Considering the fact the survey was undertaken in December, and the ambient temperature at the time of the survey was less than 13°C, it seems that the building is overheated, causing unnecessary energy use and expenditures, while causing relative discomfort in most spaces. Using the adaptive model algorithm presented by Nicol and Humphreys (2002) for free-running buildings (as opposed to ASHRAE standards):

$$T_c = 13.5 + 0.54T_o$$

where T_c is the calculated comfort temperature and T_o is the monthly ambient average, the comfort temperatures for the months of December (the month of the survey) ($T_{oDec}=13.8$), January ($T_{oJan}=11.2$) and February ($T_{oFeb}=12.6$), usually the coldest months of the year, would be 20.9, 19.55 and 20.30 respectively. These are 3-5°C lower than the measured indoor temperatures. This means that unnecessary energy is invested to heat indoor spaces to uncomfortably high temperatures, as reported by the people present during monitoring. This may also explain the discrepancy between male and female occupants, the latter usually preferring higher air temperatures.

Similarly, relative humidity measured indoors was in the range of 20%, which may be considered low for indoor spaces, and seems to be in accordance with complaints of eye, nose, throat and skin irritation, as well as persistent headaches. A significant amount of the windows in the labs, all of them south facing, were covered with paper sheets, cardboard and other makeshift shading devices. Subsequent visits have shown the situation has not changed. These windows are mostly narrow and tall. The external fixed shading devices provide very little shading, esp. in winter when the sun is low and in the southern part of the sky dome, entering the lab space from appr. 09:00 to 15:00. Offices, esp. those of the secretarial staff, are located in the eastern wing of the building, and have large east-facing windows, with no external shading. Glare is one of the major problems in these spaces, and the repeated attempts to treat them (Venetian and rolling blinds) indicate the need for solutions integral to the design process, explicitly lacking here.

The overall fenestration issue is also of interest. Certain working and office spaces have been located on lower levels, some of them being partly underground in relation to the building access way, but having high windows exposing them to the passers-by. Users of such spaces were observed to show signs of uneasiness, often peeking towards the windows. Several offices have fully glazed facades, floor to ceiling, thus resembling a terrarium, jeopardizing privacy. In all such spaces female employees adopted a sideways sitting posture visible from outside the building, with the lower part of the body rotated in relation to the torso. Such posture was almost dictated by the furniture arrangement in the room when one wears a skirt, and seemed to be more than uneasy or uncomfortable.

Though no direct complaints were registered, it is assumed that such working conditions have a negative influence on the overall time spent by the occupants in such spaces. High levels of odours were observed in the laboratory spaces despite the existence and use of chemical hoods, but no measurements of VOCs were made during the survey. However, a senior faculty member working in the building had monitored VOCs in it during the first occupation stages, and stated in a private communiqué (March 22, 2005) that “odour problems in the building are common, well-known to everyone in the university, ...” His comments refer to the ventilation system of the building drawing air for the chemical hoods through the building corridors, office spaces and eventually other lab spaces in which the hood ventilation is not operated at the same time. Additionally, exhaust chimneys on the roof (inc. those of the lab hoods) seem to be positioned upwind from the outdoor air intake openings, thus reintroducing air exhausted from the labs back to the building’s ventilation system.

It is obvious that certain design features of the building were based on basic lack of understanding of the environmental parameters vis-à-vis the specific building's functional needs. Such are the windows in both lab and office spaces, obviously designed for aesthetic reasons, but causing glare and overheating, as well as lack of privacy. It is also obvious that various design decisions were not made on the basis of full consideration of all the parameters. Such is the location of outdoor air intake on the roof - high above traffic pollution level, but close to indoor air outlets. It is the claim of this paper that unless Post-Occupancy Evaluation (POE) is established as a standard procedure following the commissioning of buildings, the change of design practices so much needed to adapt buildings for energy conservation at a time of climatic uncertainty cannot be achieved. In climatic regions such as the one described here, where free-running buildings can operate with little or no conventional energy input for significant parts of the year, this may be regarded as a major design flaw.

Poor IEQ in a government office complex

In 1992 the Israeli government decided to initiate the design and construction of six large government complexes, to house the central and regional representations of the ministries, till then located in various buildings, not necessarily custom-designed. Later on, four regional courthouses were added to the project. Coordinated by the Directorate for the Construction of Centres and Court Houses, reporting to the Accountant General of the Ministry of Finance, the project included some 225,000m² of office space and 90,000m² of courthouses, excluding parking and assorted spaces and functions. The overall estimated cost for the period 1993-2002 was US\$ 670 million. Most new buildings incorporate technologies and design techniques, methods and styles that follow the current trends and practices in industrialized countries (e.g., enlargement of average space per employee and open office space design for flexibility and adjustability), which the web site of the Accountant General presents in detail under the heading "The Modern Office" (State of Israel 1999). In addition to higher efficiency, lower operation costs and better services to the public, the site states the improvement of government image as one of the project's goals.

Shortly after occupancy, anecdotal information spilled out, hinting at problems stemming from the very practices employed and expressed in SBS related complaints. Reluctance of ministries and departments to move into the new complexes was followed by complaints about the design, among them lack of openable windows, and open space working area located in the core of the building with little or no access to the façade, as well as building-specific issues. As many of these buildings are representative of the current practices in office building design (paradigms?), a POE project could yield guidelines relevant to over 45% of the Israeli work force employed in office buildings. It was thus decided to indicatively survey one of these projects, the Beer-Sheva Government Campus.

Its kick-off was a design competition held in 1995. The complex is made up of a series of interconnected buildings with office space (26,000m² of government and 7,000m² of private office space) located over a two storey, partly underground commercial mall (10,000m²), which in turn sits on top of a two layer underground parking and services area (30,000m²). The overall area is 73,000m² and is usually occupied by some 1,200 employees. The project won a prestigious national design award.

However, the actual design of the campus raised certain questions. These included a relatively high percentage of glazing in the southwestern and northwestern wings, few openable windows, relatively deep plan creating interior open space offices and various other issues. During survey visits to the building, coordinated with and accompanied by the complex's manager, employees complained about eye and nose irritation, dry coughing, fatigue and inability to concentrate, recurring illness, inability to reach comfort conditions with or without the air conditioning system. Some expressed their frustration at the absence of openable windows in many of the workstations, while others stressed the lack of personal control over one's working conditions. Still others complained about the inability to get fresh air, especially in conference and meeting rooms, where one could get either heating or cooling but no ventilation. Issues of noise were raised with regards to open office space.

During indicative winter measurements in one meeting room, indoor temperatures proved to be high and relative humidity low considering the ambient (Figure 2), this on the basis of the adaptive model. Using again the Nicol and Humphreys (2002) algorithm for free-running buildings, indoor comfort temperatures (T_c) for the time of the survey should be 19.55°C and 20.30°C for January and February, respectively. These are between 2-3°C lower than the measured indoor temperatures. This means that unnecessary energy is invested to heat indoor spaces to uncomfortably high temperatures, as reported by the people present during monitoring. Furthermore, the low relative humidity measured seems to be in accordance with complaints of eye, nose, throat and skin irritation, as well as headaches.

Light intensity was not uniform and was considerably lower (by appr. 50%) than the 500-600 lux standards for offices, desktop etc. as defined by CIBSE (1994) and other European and US standards used in Israel. CO₂ concentration measurements were 815-850 ppm, which seems to be below the ASHRAE (1992) standards (Figure 2), that define a concentration of up to 700 ppm above the outdoor as reasonable.

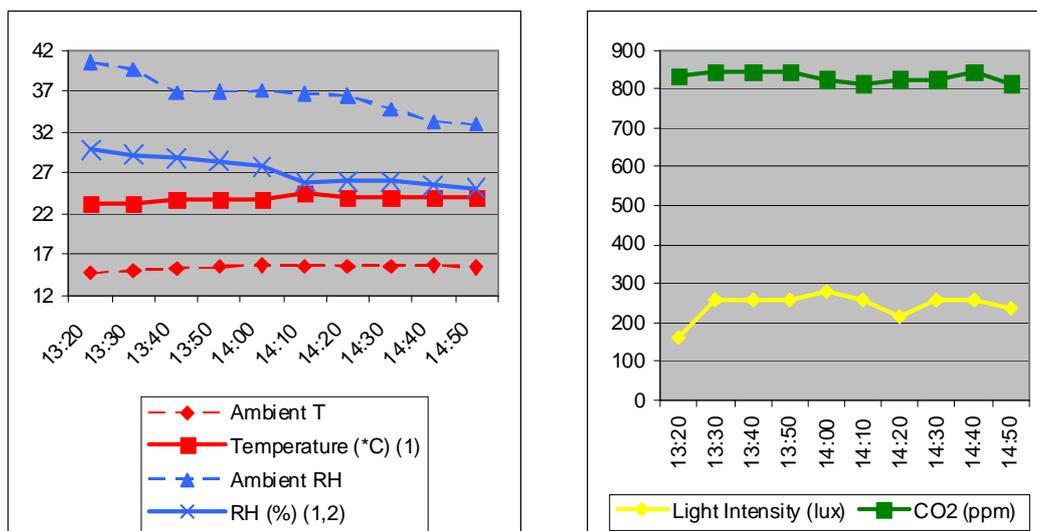


Figure 2 Left: winter indoor and outdoor air temperature and relative humidity in a meeting room. Indoor temperatures are too high and relative humidity too low relative to the outdoor. Right: winter light intensity and CO₂ concentration in a meeting room.

Assuming a modest outdoor concentration of 350 ppm, that would mean that anything up to 950-1000 ppm is reasonable. Nevertheless, it should be kept in mind that such concentrations, though defined as *acceptable air quality*, do not necessarily constitute *good air quality*. To stress this point even more it should be noted that during monitoring the specific meeting room was usually at half its potential occupancy capacity at most. It should also be noted that the measured CO₂ concentrations with the assumed 350 ppm ambient indicate a ventilation rate of appr. 10 l/sec/person. Recent studies indicate that an increase of the ventilation rate up to 15-17 l/sec/person will bring a statistically significant increase in performance. Considering the type of activity within the monitored room (which may be considered representative of many others in the specific building and other similar buildings around the government campuses), one could say with a great degree of confidence that the design of the building and its systems and their operation may actually be costing the taxpayer more than they should, and may be reducing the efficiency of civil servants and employees unnecessarily. All these are contrary to the original goals of the government, as these have been stated on the Ministry of Finance Accountant General's web site (State of Israel 2002).

POE of a university dormitory complex

The third case study presented here is a "Scientists' Village", a complex including different teaching, administration and accommodation facilities for a graduate school located on a remote research facility (Meir et al 2007). The project is located in the heart of the Negev Desert Highlands in Israel (NL 30.8°, EL 34.7°, altitude 456m above MSL). The region is arid, and its climate is characterized by cold and mostly sunny winters (with occasional frost and below-zero night temperatures) and hot and dry summers with cool-cold nights. Diurnal temperature fluctuation is wide throughout the year, except during heat spells that bring a rapid temperature rise well above the average maximum for the season. Average annual rainfall is 85 mm. Such conditions provide numerous possibilities for the design of free-running buildings, based on solar heating in winter and cross ventilation, evaporation and radiation for cooling in summer (Meir et al 1998).

The complex's main bulk comprises 84 single units (floor area 28m² each), 10 couples units (34m²) and 13 family units (55m²), housing the school's research students. The design was informed by contemporary research in building adaptation to desert conditions. Wall sections are made of an internal layer of poured concrete, a layer of rigid insulation and external dressed stone rendering. Floors and balconies are made of poured concrete with external rigid insulation and terrazzo tile flooring. Roofs are poured concrete with external rigid insulation and waterproofing membrane. Windows are double glazed and fitted with external rolling shutters. So are south facing glazed French windows. (This is a major difference from the two previous case studies, where glazing is left exposed.) North facades are kept practically opaque except for minimal fenestration needed for ventilation and light. Although small in overall size, most of the units spread over two levels to allow better stack and cross ventilation. The two-storey units are fitted with a wind chimney intended to facilitate forced night ventilation in summer.

The project was commissioned at the beginning of the winter semester of 2004-5. As ambient winter temperatures dropped, the new tenants complained about low indoor temperatures. This seemed strange as most of them had been housed up to that moment in mobile homes, with negligible thermal mass, single glazed windows and

negligible possibilities to passively condition them. It was thus decided to undertake a POE study in an attempt to understand the source of such discrepancies between a doubtless high standard of design and construction and the complaints.

A series of studies was planned with the cooperation of the owner (BIDR), the user (students and faculty) and the architects, in an attempt to study the project, its use and operation; to identify possible discrepancies between intended and actual operation modes and the reasons for these; and to suggest possible adaptations and fine tuning. POE included a series of monitoring periods in different parts of the complex, including air and surface temperatures, relative humidity, light intensity, energy consumption and qualitative observations of air infiltration. These were considered alongside data obtained through user surveys, observations and questionnaires, focusing on operation issues, as well as potential discrepancies between the need to ensure thermal comfort by passive means and privacy issues. The project was undertaken as part of an education exercise within the graduate studies program module of the school, and the results were discussed with BIDR representatives and the architects. An extensive and detailed description of the various monitoring periods, operation modes and surveys can be found in Meir et al (2007). The data presented here are those of the long term monitoring period in one of the bigger units (family, two-storey).

In this study, the adaptive approach was used for establishing ideal operative temperatures in the apartment, assuming that *“if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort”* (Nicol & Humphreys 2002: 364). Brager and de Dear (2001) showed that the adaptive comfort standard (ACS), proposed to ASHRAE Standard 55 has a great energy-saving potential. For naturally ventilated (free-running) buildings, ASHRAE Standard 55 suggests an alternative for the PMV-based method for establishing a comfort zone. Optimum comfort temperature T_c is therefore calculated based on the monthly mean ambient temperature T_o (de Dear & Brager 2002):

$$T_c = 0.31 * T_o + 17.8$$

The comfort range for 90% acceptability is of 5°C and for 80% acceptability is of 7°C. For the period when temperature monitoring took place, the comfort ranges for the location of Sede Boqer are presented in Table 1.

Using the adaptive approach for thermal comfort (ASHRAE 55 Standard-2004), the resultant comfort level for the family apartment could be assessed for the entire monitoring period. Ambient temperatures collected at the local meteorological station were used as reference for the calculation of the monthly outdoor temperature, which in its turn was used for the assessment of the comfort temperature and its range. An acceptability of 90% was adopted. Figure 3 shows indoor and outdoor temperatures over the background of the comfort range.

The percentage of hours below and above the comfort lines can give an indication of the overall thermal stress of the apartment. About 10% of the total monitoring hours corresponded to a “cold condition” inside the apartment and only about half of that to a “hot condition”. Ambient temperature data for the same period resulted in 56% cold and 21% hot hours. Except for the rather cold months of January and February, indoor temperatures were either quite close to comfort limits or within the adaptive comfort zone, while outdoor fluctuations were far from such standards.

Although the project has followed the guidelines and concepts of environment informed, energy conserving design, there are several issues that have not been addressed or solved. Firstly, the southern façade articulation and the relation of wall thickness and glazing position have created a lower-than-optimal solar access and admittance, thus lowering the buildings' ability to heat up sufficiently in winter. Secondly, the thermal mass provided by the concrete envelope and internal partitions seems to be too high to allow adaptation of indoor temperature to needed levels, even with the use of auxiliary backup in winter. Surface temperatures in both summer and winter indicate these patterns. Infiltration, esp. through the wind chimney on the roof, causes heat losses, which only worsen indoor conditions.

Having said that, it is important to clarify a number of issues and stress the advantages of the project. The units were commissioned shortly before the lateral monitoring period. Preceding days tended to be unusually warm, thus units were operated under summer mode, even as days were getting shorter and nights colder. Thus, the beginning of the original lateral monitoring undertaken in different types of units, coinciding with a sudden drop of temperatures, found the units' thermal mass significantly colder than should be under regular conditions. Considering the overall temperature uniformity as indicated by the negligible differences between air and surface temperatures, one may say with a high degree of confidence that such units can provide indoor thermal comfort if properly operated on a continuous base over seasons, as indicated by the in-depth measurements of the family unit. However, such operation proved to be less than self-evident in the case of single research students.

Surveys did not establish a significant correlation between privacy and proper operation of the units (Baker & Steemers 2000). Questionnaires showed that privacy and thermal comfort are equally important to tenants. However, the observations did not match the questionnaire results and cannot reflect the inverse relationship between the perception of privacy to the way tenants operate their units and shutters. Most tenants stated they operate their units as should, yet observations show great variability. The observations did show a clear trend in lack of shutter operation (50%) which may stem from a compromise between contradicting needs - privacy and thermal comfort. Lack of fences between private porches and public walkways may have also affected perceptions of privacy and thus operation of shutters, adversely affecting solar gains and thermal comfort within units. Further research is needed in order to better understand behaviour patterns.

Table 1: Adaptive comfort ambient temperature range for Sede-Boqer, 2006

Month	T _o	T _c	Lower Limit (90% acceptability)	Upper Limit (90% acceptability)
January	10.1	20.9	18.4	23.4
February	12.0	21.5	19.0	24.0
March	14.5	22.3	19.8	24.8
April	17.5	23.2	20.7	25.7
May	20.4	24.1	21.6	26.6
June	23.9	25.2	22.7	27.7
July	24.58	25.4	22.9	27.9
August	26.0	25.9	23.4	28.4
September	24.7	25.5	23.0	28.0

The "Scientists' Village" units are of a quality and standard much higher than those common in student accommodation. These create high expectations, which in turn cause tenants to be more critical than usual. The design was that of a passively heated and cooled complex, assuming the tenants' full cooperation in appropriately using and operating the units. The surveys though showed that not all students living in the complex units feel committed to the idea of passive heating or cooling, which have been shown to be efficient techniques in the case of the in-depth monitored family unit occupied by a post-doc researcher specializing in environment and building physics. Doubtless, instructions (provided to each new tenant) are not sufficient for the tenants to commit themselves to the idea. Whereas the "carrot" of a more comfortable living unit is not enough, the "stick" of electricity bills higher than what one might pay in a properly operated unit does not seem to provide a significant incentive, either. It might be necessary to present the rationale behind and potential of the project to each new wave of tenants. Energy efficient building is hardly just a technology – it truly is a way of life and a tool to achieve a bigger goal, thus this kind of building should be nurtured by education and not left to self-explanatory tools.

This study stressed the vital nature of the privacy issue in such projects, where a big portion of the building is transparent. Dealing with privacy solutions is essential to prevent a key obstacle in the operation of the energy efficient building and eliminating this parameter from dictating the indoor climate.

Lastly, it is important to stress that unlike most other POE cases, this project enjoyed the full cooperation of all stakeholders: the architects regarded POE as an important feedback tool to allow them to evaluate the actual performance of the project and correct possible flaws; the BIDR authorities saw POE as a tool allowing the study of the reasons for student tenants' complaints, aiming at possible upgrade and retrofit that could save energy and money in the long run and limit complaints; the tenants considered the project as a possible way of solving everyday problems, and the base for a constructive dialogue with the architect and the owner.

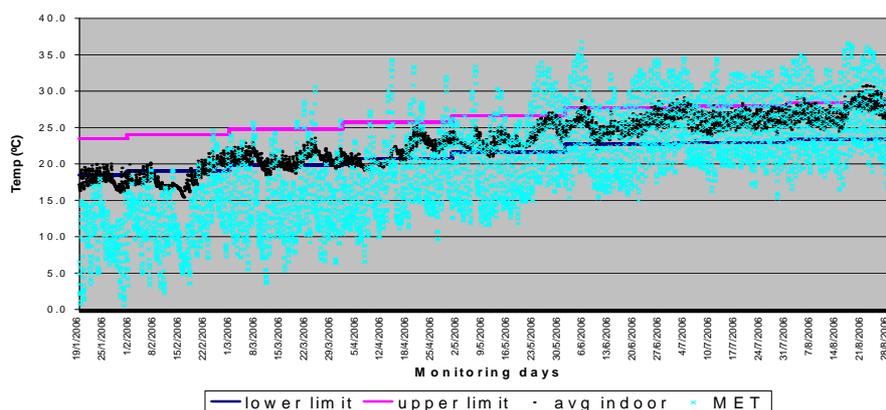


Figure 3 Adaptive comfort range - indoor and outdoor temperatures for the entire monitoring period (Jan.19-Aug.30,2006).

A neo-vernacular tourist facility

The last case study is diametrically opposed to the three previous ones. It is an attempt to introduce neo-vernacular technologies, materials and forms as part of a tourist facility in one of the harshest climatic regions of Israel. Despite its apparent uniqueness, this case study may be considered typical of the general attempt to

reintroduce traditional materials into a modern market, among them adobe, cob and rammed earth, straw-bale and other similar ones.

Kibbutz Lotan is located in the southern Arava Valley, part of the Afro-Asian Rift Valley dividing Israel and Jordan, and one of the harshest climatic regions of the country. A deep hyper-arid valley mostly below sea level, located on the northern part of the desert belt and far from the Mediterranean Sea, along with the southern Dead Sea area this is the hottest and driest part of Israel. Heat stress in summer is exceptionally high with temperatures reaching over 40°C, not uncommonly over 42°C while highs of 47.4°C have been recorded in June. Lowest night temperatures in summer reach at least 24°C however can remain close to 28°C for the majority of the evening. Relative humidity may reach as low as 10% in summer and transition-season days and may be expected to reach 15% on any day of the year, while summer evenings are around 40-45%. In contrast to these conditions are the winter ones, with average night minima below 10-8°C, absolute ones near 1°C, and strong winds which enhance the wind chill factor. Despite the hot hyper-arid image of the region, Heating Degree Days (HDD) are near 400 (Bitan and Rubin 1991).

Most of the construction in this area has been either prefabricated uninsulated concrete panel units, or lightweight ones (caravans). A few years ago, Kibbutz Lotan decided to launch a research project aimed at sustainable planning and renewable energy. This includes a series of geodesic domes in an 'off-the-grid' eco-neighbourhood (KLCCE). The initial structure is a geodesic steel-pipe skeleton, the inner wall an agricultural by-product: insulating-straw bale which is coated with 5cm of local mud plaster inside and out.

Being nearly spherical (later versions of the dome are a slightly heightened semi-sphere allowing more head-space at the perimeter), they provide the lowest possible ratio of surface area compared to volume and enclosed floor area – between 40% and 60% less surface area than a rectilinear form covering the same floor space (depending on the type of geodesic structure). This minimizes heat-gain through the envelope in summer and loss in winter. A simulation study comparing walled round, square and rectangular plans in a hot arid climate, found that the rounded walls had a significantly reduced net absorbed solar flow compared with the rectilinear forms of the same height and volume; 81 Wh/m² compared to 114 Wh/m² (Masmoudi and Mazouz 2004).

The domes have an opening at the apex and air inlets at the bottom of the wall. The combination of the dome and materials is unique in this region.

The aim of this research is to quantitatively assess the performance of this building type in this climatic region and gauge the comfort of people inside. The interest is to ascertain the role it takes, if at all, with all its features, in lightening cooling and heating loads.

According to the results, including temperatures of irrigated soils to the immediate north (prevailing wind direction) of these domes, indicators should be provided of other possible ways, if there are any, to condition these interiors in the warmest and coldest months with little or no electrical energy.

Preliminary monitoring yielded results that may at best be defined as ambivalent. During summer conditions and steady state (fully closed) mode, a heavyweight uninsulated but shaded structure showed an almost constant indoor temperature lower by 2°C than that of the straw-bale domes, and by almost 9°C compared to a lightweight structure. Its maximum and minimum indoor temperatures were apprx. 13°C lower and 12°C higher than the ambient maximum and minimum, respectively, the indoor heavyweight building extremes being 32.9°C and 31.7°C respectively. Additional monitoring during summer, winter and transition seasons has shown that the original assumption that straw-bale would prove a climatically appropriate material for this region was not easily proven. When the different buildings were operated appropriately (openable windows, movable external shutters), the results of the straw-bale domes and heavyweight buildings were only marginally different.

Whereas straw-bale would easily be considered a more sound material in terms of sustainability and embodied energy, two issues need to be taken into account. Firstly, straw-bale construction evolved in areas with excessive straw as an agricultural waste product. This is not the case in Israel where straw/hay is sought after as fodder for animals. Secondly, the actual site of the project is extremely seismic, with a major earthquake occurring every 80-odd years. This demands that buildings be built according to the strictest standards. Thus, straw-bale domes are built over a steel-pipe geodesic frame. The energy embodied in this frame offsets by far the low energy advantage of the straw-bale itself. The original intention of the architects to use date palms was not endorsed by the structural engineer due to lack of standards and the strict building codes. It is therefore still to be proved that the specific material has any advantages in the specific region. (Monitoring results of a two year period are currently being processed and will be published shortly.)

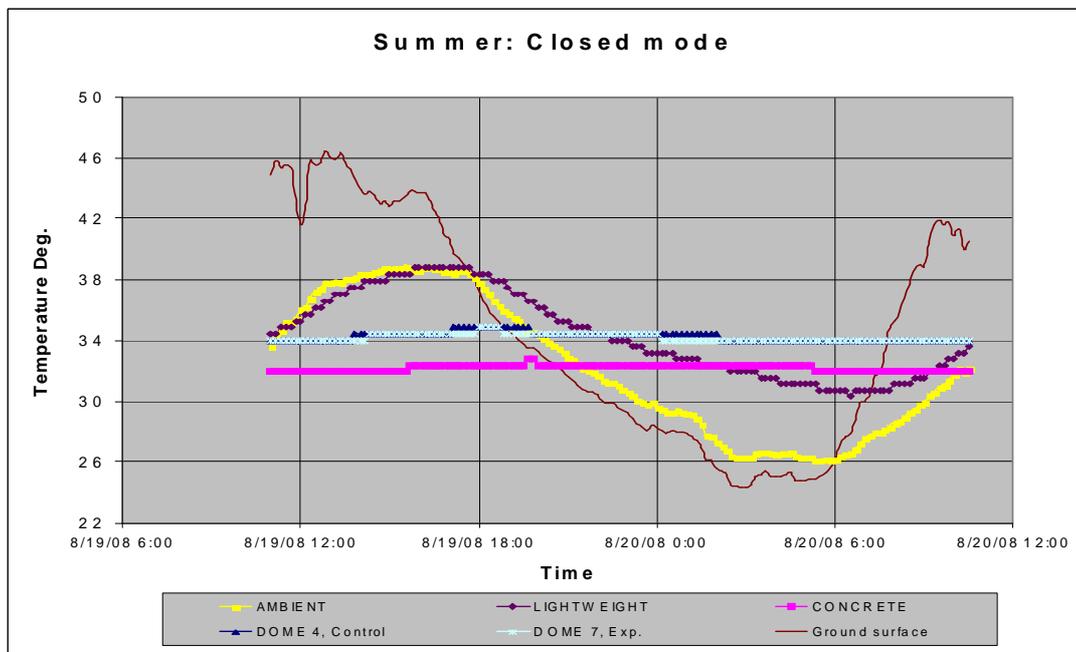


Figure 4 Thermal performance of four buildings (three building systems) in closed mode under summer conditions in the Arava Valley. Note: the concrete building is shaded on the west and north facades and as well as the roof.

Conclusions

The four case studies presented above show a consistent "intuitive" approach to design, as opposed to one based on actual facts and their analysis. Monitoring showed that in the first two cases excessive energy is used to create discomfort. In the third case study it was shown that under the specific climatic conditions of the desert highlands less thermal mass might allow a higher flexibility in compensating indoor conditions for prolonged outdoor extremes. In the last case, it is claimed that the use of a non-standard system and material are not necessarily better adaptable to the extreme conditions of the location, and their influence on indoor temperatures is not necessarily self-evident.

IEQ, however, is much more than just energy consumption and temperature control. It involves additional issues of IAQ, as well as the overall design of the building and its details. These seem to have been sacrificed – at least in the first two cases – in the name of "design". Thus, windows were turned into non-openable unprotected glazed surfaces, jeopardizing indoor temperatures, as well as privacy. Architectural design has a major significance and role in creating a feeling of occupant perceived control. A major design tool in achieving privacy is hierarchy of spaces ranging from public to intimate space. A succession of spaces on different hierarchical levels is one of the tools used to distinguish between public and private and to control social interaction and visual exposure (Evans & McCoy 1998). One's sense of privacy in and control over the inner space is also affected by windows. It has been found that window sill height under normal, which is between 0.8-1m, will severely harm privacy (BRE 2003). Blinds are considered to be a solution to the problem of privacy in passive solar buildings. External operable shutters are an even better solution.

It is the claim of this paper – hopefully substantiated through the above case studies - that unless architectural design moves into a process of informed analysis based on a number of different domains (among them climate, materials and systems, energy consumption and conservation, Life Cycle Analysis of material and buildings, behavioural and physiological issues), the end product of the architectural synthesis will remain shallow, will cause discomfort (thermal, visual, acoustic, psychological) and this in turn may well cause a much higher consumption of energy, mistakenly assumed to be able to compensate for the architect's mistakes. At a time of climatic uncertainty, rising energy prices and uninformed adherence to "paradigms", this may prove unsustainable at best. The targets and tools are known: free-running buildings, adaptive thermal comfort standards, energy conservation, operable windows, flexible space design allowing each person to find their appropriate location within a given space. Not too much to ask, is it?

References

- ASHRAE (1992), Standard 62-1989: Ventilation for Acceptable Indoor Air Quality. American Society of Heating refrigerating, and Air Conditioning Engineers, Atlanta, GA.
- Baker, N. & Steemers, K. (2000) Energy and Environment in Architecture. London: E & FN Spon, p.89.
- Bitan, A and S Subin (1991) Climatic Atlas of Israel for Physical and Environmental Planning and Design, Tel Aviv University, Ramot, Tel Aviv.
- Brager, G.S. & De DÉAR, R.J. (2001). Climate, comfort & natural ventilation: A new adaptive comfort standard for ASHRAE Standard 55. Proc.Int.Conf. Moving Thermal Comfort Standards into the 21st Century, Windsor.
- BRE (2003) Good Practice Guide 192: Designing Energy Efficient Multi-residential Buildings.

- CIBSE (1994), Code for Interior Lighting. The Chartered Institution of Building Services Engineers, London.
- Davara, Y, IA Meir and M Schwartz (2006), Architectural design and IEQ in an office complex. In E. de Oliveira Fernandes, M. Gameiro da Silva, J. Rosado Pinto (eds) Healthy Buildings: Creating a Healthy Environment for People, Proc. HB2006 Int.Conf. Lisboa, III:77-81.
- de Dear, R. & Brager, G.S. (2002). Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. *Energy and Buildings* 34(6): 549-563.
- Evans, W.G. & McCoy, J.M. (1998) When buildings don't work: The role of architecture in human health, *J. Envir. Psych.* 18: 95-94.
- KLCCE (2008) Kibbutz Lotan Centre for Creative Ecology. 2002-2005 [cited July 2008] <http://www.kibbutzlotan.com/creativeEcology/altBuilding/index.htm>
- Masmoudi, S, S Mazouz (2004), Relation of geometry, vegetation and thermal comfort around buildings in urban settings, the case of hot arid regions. *Energy and Buildings* 36(7): 710-719.
- Meir, I, Y Etzion and D Faiman (1998), Energy Aspects of Design in Arid Zones. Jerusalem: Israel Ministry of National Infrastructures – Division of R&D.
- Meir, IA and SC Roaf (2003), Between Scylla and Charibdis – In search of the sustainable design paradigm between vernacular and high-tech. In W. Bustamante G., E. Collados B. (eds.) Rethinking Development, Proc. 20th PLEA Int. Conf. Santiago de Chile, I:281-286.
- Meir IA, W Motzafi-Haller, EL Krüger, L Morhayim, S Fundaminsky, L Oshry-Frenkel, L (2007), Towards a comprehensive methodology for Post Occupancy Evaluation (POE): A hot dry climate case study. In M. Santamouris, P. Wouters (eds) Building Low Energy Cooling and Advanced Ventilation in the 21st Century. Proc. 2nd PALENC & 28th AIVC Conf., Crete, II: 644-653 (Keynote Presentation).
- Morhayim, L and I Meir (2008), Survey of an office and laboratory university building – An unhealthy building case study. Proc. Indoor Air 2008 Conf., Copenhagen, Paper ID: 933 (electronic proc. version only).
- Nicol, JF and MA Humphreys (2002), Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings* 34, 563-572.
- Seppanen, O, WJ Fisk and QH Lei (2006), Ventilation and performance in office work. *Indoor Air* 16(2006)28-35.
- State of Israel (1999), Government Centers & Court Houses. Ministry of Finance, Accountant General. <http://www.mof.gov.il/hashkal/krayot/mainpage.htm>
- State of Israel (2002), Official Annual Apparatus of State Comptroller no.53A. <http://www.mevaker.gov.il/>