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ENVIRONMENT DESIGN GUIDE

ENHANCED NATURAL VENTILATION IN HOT ARID LANDS

Emilis Prelgauskas

This note (DES 20), originally published in February 1998, was reviewed by Emilis Prelgauskas in January 2002. This summary page includes updates to the topic since publication

SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

The original paper outlines key environmental considerations for:

- passive and low energy cooling for improved summer building comfort with low energy demand
- internal space comfort modification resulting in minimum energy dependence and greenhouse emissions by utilising naturally occurring thermal convection, air pressure modification and humidification actions which generate airflows within the building
- associated enhanced interaction between building occupants and built environment infrastructure toward those comfort outcomes.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

The original paper looks at key actions and strategies to:

- provide a broader range of passive comfort design elements beyond 'passive solar' suited to hot arid locations where passive and low energy cooling contributes substantially to comfort
- consider intrinsic building comfort performance inherent in the building form, irrespective of energy and systems availability
- create passive heat extraction from building interiors, generated by thermal courtyard, clerestorey and greenhouse building design elements
- create passive cooling introduced into buildings by shaded courtyard, pergola and subsidence tower design elements integral to the building.

Cutting EDGe Strategies

Additional design connections include:

- the design elements are integral to the building form to create comfort outcomes rather than through attached mechanical solutions
- the achieved comfort contribution is through design elements integral to building superstructure cost centres which can offset both traditional services capital and recurrent operating cost allocations in project budgets
- these design elements have the potential to create a regional design form for buildings featuring sunside and shadeside design elements noted above in contrast to traditional symmetry derived building form
- the design elements can interact with related design elements; notably safari roof for increased solar insulation from the building interior, humidification and shading associated with understorey and canopy vegetation, wetting with sprays, fountains, drippers, flow forms for air infeed to the design elements discussed in the original paper.

Synergies and References

- Mobbs M, *Sustainable House* Chapter 10, Choice books 1998, Australian Consumers Association
- International building energy efficiency referrals: www.caddet-ee.org/infostore/details.php?id=2742
- completed projects updated: www.emilis.sa.on.net/projects/prj_fram.htm
- *BDP Environment Design Guide* TEC 2, TEC 7, TEC 12, DES 36, DES 38.

ENVIRONMENT DESIGN GUIDE

ENHANCED NATURAL VENTILATION IN HOT ARID LANDS

Emilis Prelgauskas

One of the goals in ecologically sustainable development (ESD) is to reduce energy demand in buildings. Occupant comfort then needs to be achieved with minimum assistance from mechanical systems. Such buildings depend on the effective performance of the building itself to maintain comfort. 'Passive solar' is the best known general design approach achieving these goals. This Note reports on 'climate responsive' design principles in hot arid locations. It considers the approach to, and elements of, low energy design of buildings for comfort where 'passive solar' alone is not the full answer.

1.0 INTRODUCTION

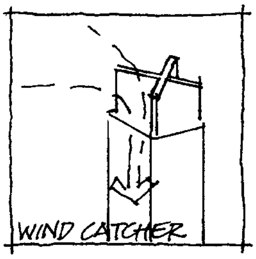
'Passive solar' design theory seeks to minimise heat gain into the building with passive design elements. Some 'passive solar' design elements (such as cooling by direct wind flow) can be inappropriate in a hot arid climate (with dust raised in the air). In conventional situations, residual excess heat load is then dealt with by mechanised air conditioning systems. Air handling system operation in a hot arid climate can be a significant part of total energy demand in buildings (up to 30%).

This Note does not cover any of the design elements that form an extension to traditional 'passive solar'. Rather, it emphasises the minimisation of energy demand for interior comfort conditioning in buildings in locations with a hot arid climate. Naturally occurring air movement forces are harnessed in the building design to achieve interior air crossflow, heat extraction, and some pre-cooling of air in-flow.

This is achieved by an integrated design of the building, its environs, and relevant building design elements. This design approach is characterised by six such building design elements described in this Note. Several draw air out of the building taking with it the accumulated heat from within—about nine air changes per hour can be achieved by these means. The other design elements pre-condition the air in-flow to create a sense of cooling to occupants and provide replacement air with lower heat content.

The design elements inform the overall building design and operate by the forces described in this Note. The extent of cooling is determined by detail design and occupant decision making. Examples of completed, detached, residential projects embodying these design elements are operating at less than 2 kWhr/day total energy demand. Only those design elements involving water movement require any energy input (0.5 to 3 amps) to operate.

2.0 BACKGROUND



2.1 Historical precedents

Settled indigenous societies in hot arid lands have developed a range of passive, interior comfort, conditioning elements. Hot arid climate buildings can feature wind catchers or solar up-draught towers, single room depth buildings surrounding courtyards, courtyard construction with paving and fountain elements as air conditioners.

Traditional buildings in Middle and Far East arid lands have incorporated a number of evaporative air conditioning elements consistent with the technology of the day. Evaporative air conditioning systems have included linen drapes wetted and unfurled across openings, and water filled porous clay pots placed in high locations in rooms or in down draught towers.

Consistent with limited energy options available at the time, these comfort control systems operated by natural means.

2.2 Climate systems

The atmosphere surrounding the planet contains a vertical temperature structure. This is characterised by a dry adiabatic lapse rate of about 1½°C reduction for every 100 m altitude increase. Air density also reduces with height. The result is that the gaseous layer remains attached to the planetary surface. This atmospheric structure however also tends toward stasis which is a state of equilibrium or inactivity.

If these were the only factors acting in the climate, over time the lower atmosphere stratum would become filled with low weight items in continuous suspension (pollen, dust, microbes and pollution). The result would be that the planetary surface would become untenable for life.

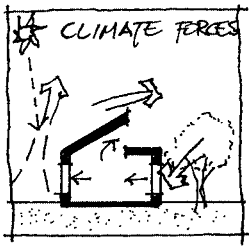
However, naturally occurring macro- and micro-climatic forces can keep the planetary atmosphere healthy. They introduce regional and local chaotic air movement within this overall stasis system.

As identified in the next section, several of the micro-climatic forces can be harnessed in the design elements of buildings utilising climate responsive design.

3.0 CLIMATE RESPONSIVE DESIGN APPROACH

Knowledge about climate systems and historical precedents can be applied to building design. Thoughts have developed about the potential to enhance ventilation for cooling of buildings in hot arid locations by using naturally occurring forces. Natural ventilation and cooling can achieve comfort sufficient to obviate mechanical air conditioning and thereby avoid the associated recurrent energy use.

(As this Note is being written based on Australian conditions, the magnetic directions of north and south mean sunward and downsun respectively. Readers in the northern hemisphere need to make appropriate adjustments).



Three prominent, naturally occurring, micro-level atmospheric forces can be applied to building ventilation:

- solar heating and the consequent ground level air flow through vertical thermal convection;
- changes in atmospheric pressure arising from wind flow over objects creating secondary air flows; and
- changes in the flow and latent heat capacity of air through introducing moisture to the air.

Solar heating is considered the enemy of comfort in hot arid locations. Solar heat will generally penetrate the building structure on days of long and high level radiation. As well, human occupation and appliance operation adds to interior heat load. The overall result is that the building becomes too hot later in the day.

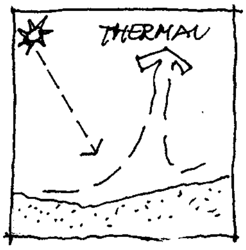
The strategy of overnight cooling of the building interior is sometimes insufficient to maintain comfort throughout the following day. The natural ventilation schemes outlined in this Note provide possible follow up strategies to maintaining interior comfort once the stored coolth has been exhausted.

In arid locations, the normally very low ambient humidity enables the design elements in this Note to work. Thus an elevation of the water content to 35-40% will enhance cooling while avoiding interference with body cooling efficiency through evaporation of perspiration.

From the approaches discussed below have evolved a number of building design elements whereby naturally occurring, enhanced cross ventilation forces can be designed into buildings. As these systems generally use no or little energy input, the result of designing in these building elements is enhanced comfort while avoiding energy demand for mechanical comfort conditioning systems.

The end product is energy efficient buildings in hot arid locations.

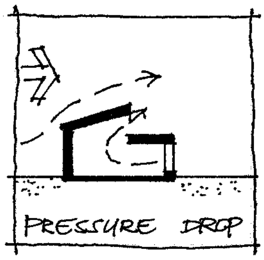
3.1 Thermal convection



Air in external spaces solar heated to temperatures higher than ambient results in an expanding air volume, which is lower in air density than the surrounding ambient air. This imbalance is solved by thermal convection. The lighter air streams upward either as a bubble or a funnel shaped column, being replaced by ground level horizontal air inflow which in turn is heated and the process repeats.

This naturally occurring action can be designed into a project site as either an external courtyard or an internal greenhouse space linked to the occupant spaces. Air drawn away is then in part replaced from those occupant spaces, resulting in enhanced cross ventilation in the occupied building spaces at flow rates greater than natural infiltration could achieve.

3.2 Air pressure modification

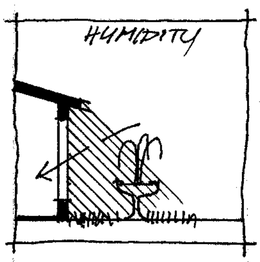


Air flowing over an obstacle, including buildings, will modify in flow speed and air pressure relative to various parts of the obstacle's surface. Broadly, air pressure at upwind surfaces will be higher than ambient pressure while sheltered or leeward places will be at lower pressure.

Similar effects can be incorporated into single building form. Air flow in the lee of roof ridges is at lower than ambient air pressure. Vents there will draw air from inside the building. In arid lands where summer winds are northerly (hot), these openings could be in a south facing clerestory where an additional benefit is natural lighting to the centre of the building without direct solar heat gain.

This approach is the reciprocal of the 'passive solar' clerestory in cool climates seeking to attract additional direct interior solar heat gain.

3.3 Humidification



Adding moisture to ambient air in arid locations both increases its mass and its latent heat capacity. This is the basis of all evaporative air conditioning. However, systems using natural means take advantage of the tendency of humidified air to sink to ground level, to 'lean' against ambient air and press it aside.

Such air volumes are suitable for replacement inflow air to occupied building spaces where stale air is being exhausted by thermal convection or air pressure modification.

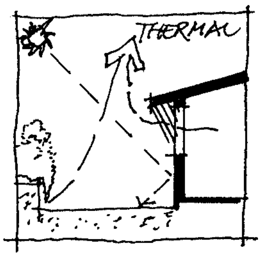
Heated air on the sunward side of the building exerts an outward suction, and humidified air from the shade side of the building will roll in to replace the hotter, drier air sucked out. Together this mix of actions creates air change within the building. The cooling sensation of the flow of the replacement air results in occupant sense of comfort in the building spaces, while the sunward 'generating' spaces adjacent, such as a greenhouse, will be outside comfort range.

4.0 DESIGN ELEMENTS

Climate responsive design is a complete system extending on from passive solar. Best performance is achieved where each element is consistent with an overall design incorporating correct orientation, insulation, thermal mass, and congruent warm and cool climatic spaces.

The design elements considered here fall into one of two general categories—heat extraction and cooling inflow—determined by the fundamental principles of their action.

4.1 Thermal courtyard (heat extraction)



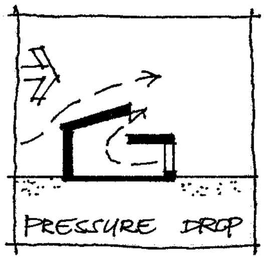
Ground adjacent to a northerly face of a building is subject to solar heat load both from direct sunlight, and reflected heat from adjacent surfaces, notably the building exterior itself. The air in this location reaches temperatures higher than ambient, and vents vertically by thermal convection. From this pressure reduction at ground level, suction draws ground level air in from all around, including through abutting openings in the adjacent building itself.

Through this mechanism, cross ventilation is enhanced within the building, with replacement air inside the building coming from the shaded spaces around the building as described in Section 4.4 onward.

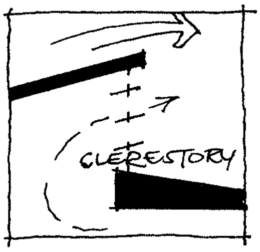
The suction effect can be maximised by the thermal courtyard layout featuring heat reflection surfaces on the courtyard paving and adjacent building walling, whilst light matt colours minimise glare to other places and heat gain to the building structure.

Constructing the thermal courtyard in a sunken profile, or surrounding it with garden wall or low growing vegetation minimises the intrusion of general wind effects to distort the thermal convection effects being deliberately sought.

4.2 Clerestory (heat extraction)



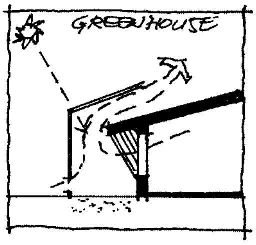
'Passive solar' often features a north facing clerestory to increase heat gain along with direct natural light into the building. In hot arid locations, indirect natural light into the centre of the building is attractive as a means to balance room light levels and avoid eye strain when facing the external glare from building perimeter windows. In these circumstances, a south facing clerestory secures the natural lighting objectives without glare or direct heat gain.



Such building form also provides opportunities for openings at the low pressure portion of the building roof shape in relation to summer winds. Thereby air from the occupied spaces can be drawn outward as a deliberate secondary airstream using the roof top suction from northerly winds which are otherwise unusable, being hot, dry and embedded with dust.

Replacement air is drawn from the south protected spaces adjacent to the building as described below.

4.3 Greenhouse (heat extraction)



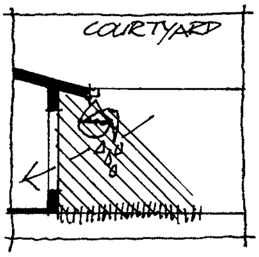
The traditional greenhouse is a solar heated space either for comfort in cool climates, or for enhanced propagation of vegetation, notably that not native to the location.

The climate responsive approach in hot arid lands continues to use the greenhouse as a food production location. In addition, it uses the high air temperatures generated within to vent air out of the greenhouse, forming a natural suction pump whereby air can be drawn across from the adjacent habitable building spaces. The greenhouse itself is not a habitable space.

Such a greenhouse mechanism requires appropriate orientation to the north, a sloping roof to high level vents, large connecting openings from adjacent habitable spaces, and low level air intake vents from outside.

In contrast to a cool climate greenhouse, there is little heat transfer from an arid land's greenhouse to the adjacent habitable spaces. The airflow from habitable space to greenhouse to outdoors draws air and heat from the habitable space and opposes infiltration of hot air from the greenhouse toward the habitable space. Adequate insulation of directly separating walls is required. To further reduce any possible heat load on these walls, the low level external vents can be used in conjunction with the high level ones to vent hot air from the greenhouse. This mechanism is useful when the interior space is relatively cool and air is not being drawn from the interior into the greenhouse.

4.4 Cooling courtyard (cooling inflow)



The traditional Mediterranean courtyard layout is sometimes viewed as a lifestyle design element suited to temperate climates. In hot arid climates, the Mediterranean style of single room depth building surrounding an inner courtyard can also be a pragmatic air conditioning solution.

The cooling courtyard abutts the shade side of the building. In an appropriately sized layout, the building volume on the north side of the courtyard shades the immediately abutting portion of the courtyard to the south while leaving the far southerly portion of the courtyard in direct sun. This creates a cooling zone in the shaded part of the courtyard and a thermal convection exhaust zone in the other part within the one courtyard.

The portion of the courtyard in shade adjacent to the building holds air at less than ambient temperature. This air 'leans' against the building, venting in as replacement to that venting out the northern side of the building. The cooling effect of this air movement is enhanced by vegetation within the shaded portion of the courtyard. Such vegetation might include grasses, hanging baskets and deciduous pergola vines (see also Section 4.5). Active humidifying systems there include waterfalls, form flows, fountain, and the dripper or sprays noted in Section 4.5.

Occupants perceive cooling from the achieved continuous, low-speed flow of this somewhat humidified air, even when the temperature of the incoming air is lowered only a little below ambient.

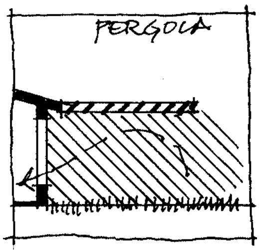
Layout of features in courtyards for comfort conditioning therefore is not symmetrical, with fountains offset into the shaded portion, and paving in the sunlit portion. Relative positioning of these features is determined by the sun angles specific to any particular location. A good example of such a climatic response design is the 'Treasury' buildings courtyard surrounded by a two storey building at 142 King William Street, Adelaide begun in 1858 by architects Hamilton & Owen Smyth.

Thermal ventilation continues to function in the sunlit portion of the courtyard as described in Section 4.1. In a multi-building complex then, it is possible to establish a succession of thermal and cooling courtyards to maximise natural cross ventilation. The Halifax EcoCity scheme by Paul F Downton has such a layout (refer to website http://www.eastend.com.au/~ecology/ for details). The result is to re-introduce natural climatic actions into city built form, the outcomes are improved air quality and human health contrary to the stasis outlined in Section 2.2.

The cooling courtyard can be extended by incorporating additional shading cover such as a pergola structure as discussed in Section 4.5. Such an extension provides additional benefit around the summer solstice, when the sun is highest in the sky, by increasing the volume of air shaded from solar heat. It is also possible to add air in-flow to the courtyard by addition of a subsidence tower as described in Section 4.6 opening into the courtyard—in effect an outdoors air conditioner.

In contrast courtyards laid out to symmetrical visual parameters alone do not accrue any of this comfort conditioning potential. Centrally placed fountains balance the ambient temperature and humidity across the courtyard, reflective surfaces add radiant heat into the shade portion of the courtyard. The atmospheric structure there then tends toward stasis. The courtyard gains its own 'inversion', trapping air within the courtyard, which itself then is not a habitable space in hot arid locations.

4.5 Pergola (cooling inflow)

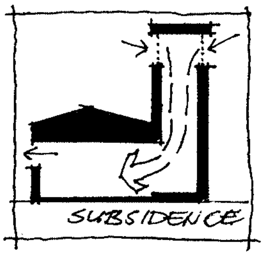


Passive solar design advocates the pergola as a shading device on the northern building side to reduce heat load on the building. The climate responsive approach uses the pergola as a design element on the southern, shade side of the building to enhance the cool characteristics of the air volume there. This cooler air is then available to be drawn into the building during the day.

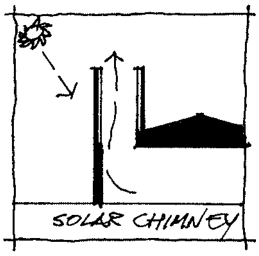
The air volume under a south-side pergola is humidified by water vapour expiration from the vines and vegetation on and under the pergola, and by water delivered by the vegetation watering system. Air humidification is assisted also by any excess water dripping from hanging basket watering points, or fine spray water delivery to the underside of the vine cover on the pergola roof.

Pergola battens can be aligned to winter sun angles to permit continued winter daylight infiltration, but form full shading in summer. For this to work effectively, any vine coverage must be deciduous.

4.6 Subsidence tower (cooling inflow)



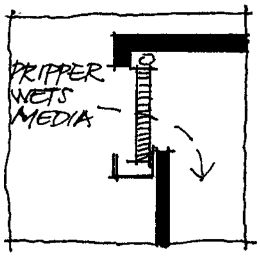
As noted in Section 2.1, in arid lands of the Middle East and Far East, some traditional indigenous architecture embodies evaporative air conditioning systems characterised by low energy demand. The principles applied are to achieve both increased latent heat capacity of air for cooling, and air movement from humidification increasing the ambient air mass at the top of a tower. The increased latent heat capacity provides the sense of cooling. The increased air mass creates airflow downwash down in the tower and into the building while drawing in replacement ambient air at the tower top.



This approach was revived in a modern context by the Environmental Research Laboratories at the University of Arizona in Tucson between the mid 1970s through to the mid 1980s including an 'outdoor' demonstration tower in a civic plaza in Phoenix in 1987. From this, a prototype house was built and tested and subsequently correlated with mathematical modelling by Givoni (1994). Temperature drops of up to 11½°C and airflows about $0.3m^3$/sec are recorded.

The system in the US is called a 'cool tower'. The Thompson and Cunningham trial in Phoenix also included windcatcher elements at the top of the tower, and a solar heat chimney exhaust at the other end of the building. Givoni (1994) considered the tower airflow both in its role in occupant space ventilation, and ventilation within the building fabric to extract heat from the building structure.

4.6.1 Local experience



The term 'subsidence tower' is used here to avoid confusion with commercially available air conditioning systems using a heat exchange bath 'cooling tower', and their connotation with health effects including Legionnaires Disease.

The first Australian subsidence towers proposal was in 1990 by Paul F Downton as part of the Halifax EcoCity Project in Adelaide. The author trialed locally available filter media in a workshop rig in 1994 for a subsidence tower in AP Lands indigenous housing in north-west South Australia. The architects Phillips Pilkington incorporated tower elements in the 1997 Monarto Zoological Park Visitor Centre project.

In the US, material used for the filter pad is cardboard egg-crate matrix 'CELdek', whereas local installations to date have used 'Woodwool' media. Both are standard evaporative air conditioner materials. 'Woodwool' consists of aspen shavings which fully wet up. This permits low flow, low pressure water application to achieve full evaporation. In contrast CELdek presents surface area aligned with the air stream over which larger water flows are recirculated.

Water delivery currently used locally is low pressure irrigation dripper with rate adjustable outlets.

Rain water is used to avoid suspended solids deposits to pad media. In a minimum water overflow installation, a typical 0.78m^2 pad is supplied with a 2 litre/hr water supply. Such low pressure/low flow water delivery is achievable by a DC power diaphragm pump with an integral pressure switch.

Specific construction issues to be observed include perimeter gaps around the pad or unwetted parts of the pad allowing ambient air to bypass the pad.

Subsidence tower energy demand is limited to raising water to the filter pad at the tower head. This is about 15% of the energy required by package evaporative air conditioners, which in turn operate at a fraction of the energy use of reverse cycle systems.

Givoni (1994) cites achieved airflows related to tower height and filter pad face area. Tower effectiveness can also be expected to be affected by the individual building interior layout and tower position in relation to the other climatic influences described in this Note.

SUMMARY

In hot arid lands, ambient temperatures, solar heat gain and internal heat loads raise habitable space temperatures beyond human comfort levels.

Climate responsive design principles add to those of passive solar design to maximise natural ventilation to achieve comfort. In addition to the general building orientation, form, and warm and cool space disposition principles, a number of design elements are defined which maximise the warm or cool sides of the climate responsive approach.

The approach also tends toward a non symmetrical disposition for buildings in hot arid lands.

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Downton, PF, Prelgauskas, E & Hancy, M, 1991, *Climate Responsive Building Design in the South Australian Context*, SA Energy Forum.

Givoni, B, 1994, *Passive and Low Energy Cooling of Buildings*, Van Nostrand Reinhold, New York.

Kessler, HJ, Yoklic, MR & Medlin, RL, 1994, Community concepts for living in arid regions—a solar oasis’ in *Proceedings of International Passive and Low Energy Architecture Conference*, Mexico City.

FURTHER READING

Mobbs, M, 1998, *How to build an ecological house*, Choice Books (a forthcoming book by the instigator of the Chippendale ESD townhouse which includes details on subsidence tower infrastructure trials).

BIOGRAPHY

Emilis Prelgauskas, B.Arch, RAIA is in private practice in South Australia emphasising ESD projects, including his own solar powered and climate responsive home/office built in 1985. Most of the design elements described in this Note were trialed in that building, and have been applied in about 30 subsequent projects. As a glider pilot of long standing, Emilis has 3500 hours of personal experience with the air flow forces available in the atmosphere. The work of the practice is accessible at http://www.emilis.sa.on.net