Social Housing in Costa Rica's Warm Humid Climate
Strategies & considerations for passive design

Msc. MICHAEL SMITH-MASIS

Architectural Association, Sustainable and Environmental Design Programme, London, U.K.

ABSTRACT: In the past ten years Costa Rica has experienced the impact from migration to urban areas followed by large increase in the demand for affordable housing in a country where 22% of the population still lives in poverty. This paper aims to set environmental guidelines for social housing projects in the warm-humid regions of Costa Rica. The research focuses on providing comfort by means of passive design strategies. Hence an improvement in Costa Rica's social housing scenario should consider design strategies that optimize effective use of spaces, natural ventilation and shading; where air permeability is related to spaces usage and the building's elements ability to provide comfort and low energy consumption.
Keywords: social housing, environmental guidelines, comfort, passive design strategies.

INTRODUCTION

In Costa Rica rapid urban developments are increasing, especially in rural areas where important tourism investments are taking place. Subsequently housing demand has augmented but affordability jeopardizes low-income families' aspirations for quality homes, in a country where 22% of the population still lives in poverty. Even though there have been significant efforts by local authorities to face housing demand, social housing projects do not consider climate adaptation, users necessities nor thermal comfort. This becomes quite evident in warm-humid regions where poor design applications are provided. This paper aims to set design recommendations for warm humid regions, where openness and shading becomes a main issue. Such concepts will be explored in regards of passive design strategies and thermal comfort.

SOCIAL HOUSING SCENARIO

Local authorities had established building regulations to ensure quality among social housing projects, however they do not consider climate adaptation, users necessities or thermal comfort. This becomes quite evident when comparing with basic design guidelines such as the Mahoney Tables (1971) for warm humid conditions. In typical practice, air movement is restricted by single sided ventilation, where internal obstructions do not allow cross flows. Additionally opening to façade ratios are 12% to 8%, whilst Mahoney recommends from 40% to 80%. Moreover, there is an obvious misconception of the openings where the effective area for each window is reduced up to 50%, by fixed glazing or wooden screens.

At the same time, dwellings envelopes are not well protected from the effects of solar radiation impinge, with short overhangs and poor thermal resistance. Perhaps attributed to a weak sense of cost, privacy and security reasons. Thus poor design applications are provided within hermetic households, low understanding of materiality and rigid spatial layouts (figure 1)

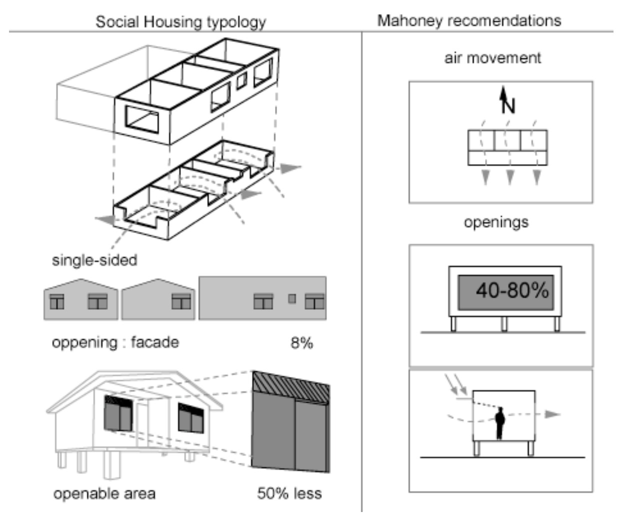


Figure 1: Typical problems in social housing practice in Costa Rica's warm humid regions.

COSTA RICA'S WARM HUMID REGIONS

Costa Rica is a tropical country located in Central America between latitudes 8° and 11° north. It has in a relative small territory (51100 Km2) with great biodiversity and climate variations. Within the country, its warm-humid climate is one of the most difficult to design for. High humidity levels and evaporation from the skin is restricted for heat dissipation when temperatures are over 34 ºC. Such regions can be found in Central & South Pacific and Caribbean side.

Climatic information of a Caribbean weather station[1] was analyzed to understand the climatic pathology. It revealed heavy and long periods of rain throughout the year, with two distinct dry seasonal breaks from March to April and September to October; differing from the two habitual seasons (dry and rainy) of tropical latitudes. Thus precipitation, relative humidity and overcast conditions prevail with a yearly average temperature of 25ºC and small diurnal variations (6Kº). Also 75% of prevailing wind speeds are above 2.7 m/s, as an available resource for passive cooling. Additionally the sun path due its proximity to the equator, is relative symmetrical, and protection from solar radiation must be considered in all facades.

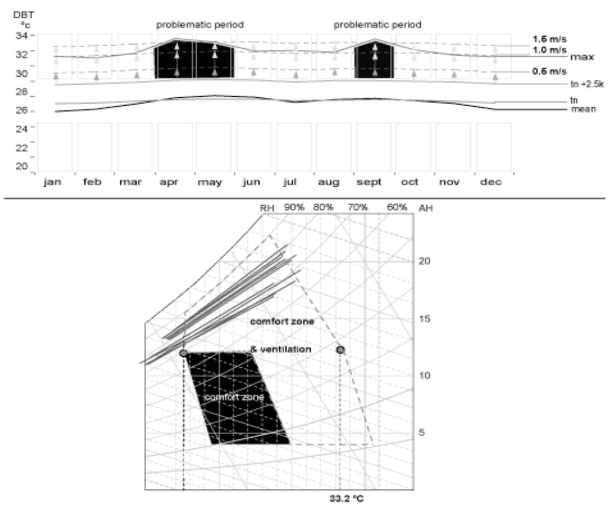


Figure 2: Average monthly temperatures, comfort margins and psychometric chart.

THERMAL COMFORT & AIR MOVEMENT

Research from various writers has proven that the ASHRAE summer recommendation of 26.1ºC is not applicable for tropical climates. Thus in developing countries due the limited available resources, constructions are simple and operate without any conventional cooling i.e. air conditioning, therefore people are more likely to tolerate higher temperatures and to adapt to external ambient conditions. Here thermal perception can be understood with a useful notion of Thermal neutrality[2] (Tn), which considers psycho-physiological factors of acclimatization when one feels neither cold nor hot. Hence the adaptability model can result on the expression for thermal neutrality:

$$Tn = 17.6 = 0.31 \text{ x } To_{av}$$

(Where Tn = neutrality temperature and Toav = monthly mean temperature)

Then adding or subtracting 2.5 Kº to Tn, as a function of monthly temperature variations, defined a comfort range of 90% of acceptability. Figure 2 shows specific problematic periods such as May, where mean maximum temperatures are outside the comfort range, or 87% of the days are equal or above the upper comfort limit[3]. Furthermore the Psychometric Chart illustrates the problematic pathology of the climate, where daily max and min means of temperature and humidity are outside the comfort zone.

High humidity restricts evaporative cooling from the skin (sweating), and wind speed at the skin surface becomes necessary to release heat from the body by increasing sweat rates. Hence ventilation as a passive cooling strategy can be used to expand the upper comfort limit. In spite of this, Szokolay & Tenorio (2002) after studying several sources about natural ventilation suggests that an apparent cooling effect can result from the expression:

$$dT = 6 \text{ x } V_e - 1.6 \text{ x } V_e\ 2$$

(Where Ve is the 'effective' velocity at the body surface)

Where the air velocity limit is 1.5 m/s, *for other than thermal reasons in an occupied space* (Szokolay & Tenorio, 2002). After applying the expression above, an apparent cooling effect will result of dT = 5Kº, where in a dwelling with minimal clothing (<0.3 clo) and low metabolic rates (<0.8 met), the upper limit of acceptable conditions can be taken as 33ºC. Hence social housing design should optimize natural ventilation and air movement to provide comfort and low energy consumption.

THE SOCIAL HOUSING TYPOLOGY

For a single detached social housing dwelling, low-income families have to struggle on how to shelter and optimize the minimum space available. At this juncture it is relevant to promote a flexible use of spaces that allows expanding and contracting the areas within a compact layout if necessary. Thus space usage; occupational patterns and spatial opportunities are relevant to be understood in regards of climatic responses.

In a typical dwelling of 42sqmts 61% of activities are performed under semiprivate or communal spaces or even outside, whilst 39% of the areas are constricted under a specific private use i.e. bedrooms only at night. In terms of diurnal space usage, critical periods occur in the early afternoon, when solar radiation reaches it peak

[1] Limon International Airport station, source: Meteonorm V.6
[2] Auliciems (1981)
[3] Hourly data from Limon International Airport station, source: Meteonorm V.6.

and communal areas are highly dense with additional heat gains from people activity and appliances (e.g. cooking). In this sense, activities and spaces can be extended outdoors gradually, by incorporating any misused space. For example during daytime, bedrooms can be integrated with semiprivate spaces by encouraging indoors to outdoors transitions. Here semi private spaces have an interface condition for coupling with the external environment, when it is desirable to achieve openness, thermal comfort & ventilation. Furthermore kitchen, living & dining room can be integrated gradually with a veranda, for the same reasons (figure 3).

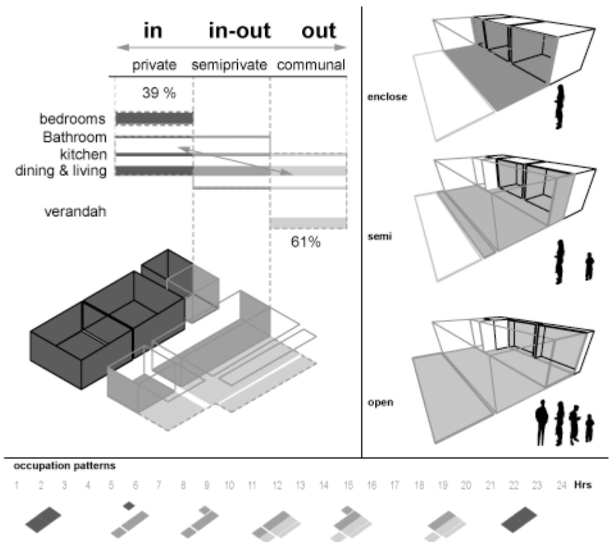


Figure 3: Occupational patterns & levels of enclosure

VENTILATION STRATEGIES

Due small diurnal temperature variations and high humidity levels, the only passive cooling design strategy beyond the prevention of heat gains is the physiological cooling effect of air movement. Therefore enhancing ventilation is essential to provide comfort when internal air temperatures are desirable to follow external air temperatures when are within the comfort zone, or to remove any heat input excess.

For single-family detached dwellings cross ventilation is the most efficient passive cooling design strategy. Such type of dwellings can be easily exposed to prevailing winds. Wind driven flows can stream efficiently indoors without obstructions, or when internal partitions do exist, they may allow independent ventilation of the rooms.

Also it is crucial to determine an appropriate design of the openings. They must be ample (40% to 80% of wall area) and well distributed around the envelope. Where inlets have the crucial role to control wind-driven flows. Its vertical location or if adjustable horizontal elements are placed within, wind can be controlled towards occupancy levels. Additionally when exposed to oblique winds, wind speed can be accelerated, and airflows well distributed. The later can be enhanced via balconies, porches or wing walls to catch or accentuate wind pressure and suction.

Generally speaking, it is essential to provide openness within the envelope with a wide variety of ample openings, however careful attention must be paid to aspects of exposure, privacy and security.

THE ROOF HIERARCHICAL ROLE

"In the tropics, it is the shade that refreshes and unifies, […] and it is everywhere. In the tropical latitude the local experience of family cohesion becomes relative and dilutes through the open spaces – some members of the family lie on a hammock under the shade of a tree, others in the corridor seated on a bench under the shade of the eaves.",(Bruno Stagno,1999)

The quote above describes the 'way of living' in Costa Rica's warm humid regions, where outdoors spaces are traditionally conceived for family spatial delight, and the roof has a hierarchical role to provide shade and protection from heavy rains and solar radiation.

Since openness in the building is required, **the roof** has a hierarchical role among other elements, which practically remains it as the only considerable element that protects interior spaces or any external surfaces from solar irradiation impinge. Well designed, a roof can prevent any indoor temperature raise above external air temperatures, by keeping surface temperatures under the roof (ceiling) around the same level as other surfaces in the interior space.

In terms of walls or any other element underneath the roof, it is important to ensure appropriate ventilation and shading all year long, wherever *the indoor air then practically follows closely the average surface (the radiant) temperature* (Givoni, 1998).

The roof in Costa Rica's social housing practice is externally covered with corrugated galvanized steel sheeting, and indoor ceilings if 'provided', has poor insulation where unventilated cavities find no escape for any heat surplus. Thus heat is conducted through the underside of the roofing sheets and re-radiated to the interior spaces producing thermal stress and occupants discomfort.

For diminishing such adverse conditions, careful attention has to be paid to at least three distinctive layers of the roofing system (Figure 4):

-The **outside layer** or roofing sheet needs to be highly reflective; light colours or shine are recommended to optimize solar radiation reflection. However, Givoni (1998) suggests assuming an absorbance value of 0.6, unless the building is periodically painted because it is impractical to assume a perfect white colour (0.9) in warm humid climates, due abundant fungi growth or even corrosion over roof and walls.

-The **middle layer** separates the roofing sheet from the ceiling, containing an attic space or air cavity and linings of a reflective foil. In warm humid climates the roof surface is warmer than the interior surface of the ceiling, thus an air gap can help to reduce heat gains by convection. Heat excess in the cavity, can be prevented with ventilation when the external air temperature is below internal air temperatures.

-The **Inside layer** is composed of insulation materials and ceiling boards. It is determine by additional thermal resistance, which is required to prevent that the interior surface temperature of the ceiling do not rise above a desirable performance standard, hence it depends on the inside and outside surfaces emittance.

Among layers, the greater contribution for thermal resistances comes from the air cavity and insulation material, however the latter unfortunately is still rather expensive to achieve for most low cost housing.

It could be said that for any surface temperature rise above the 30 ºK, U-values could vary on a range from 1 to 1.5 W/m2ºC, with approximate ceiling temperature excess of 2.5 to 3.5 ºK.

SURFACE TILT & SHADING ANGLES

Solar radiation approaching an exposed surface can reduce as function of the tilted plane (Figure 4). For example by tilting the surface with a 30 degrees gradient the north slope have experience a reduction of 15% of the average incident global radiation, whilst the south have 5% less radiation with the same angle. Additionally higher angles or close to vertical surfaces received less solar radiation, which can be strategically accounted for narrower shaded east-west facades.[4]

For this type of climates protection from diffuse radiation (overcast skies) is more difficult than protection from the direct sunbeam because solar radiation comes from the whole sky hemisphere (Givoni, 1998). The roof has to be extended to provide sufficient shading beyond walls, i.e. eaves with a greater coverage of the sky hemisphere. This approach can be encouraged ideally in the form of balconies or shaded verandas. But careful attention has to be paid by increasing construction cost or diminishing daylight availability.

For a straight north orientation, the roof vertical shading angles can significantly cover all critical periods. For example for a 2.40 meters wall height, VSA 53º (75% wall height) and VSA 69º (38% wall height) south can provide sufficient shading and allow semi outdoors spatial opportunities. At the same time a fully yearly coverage may happen by adding horizontal shading angles. Conversely shading east and west facades is more difficult. In this case VSA of 45º can cover periods from 8:00 to 16:00 hours, and with the addition of horizontal elements underneath the overhang, this can be furthered enhanced e.g. louvers.

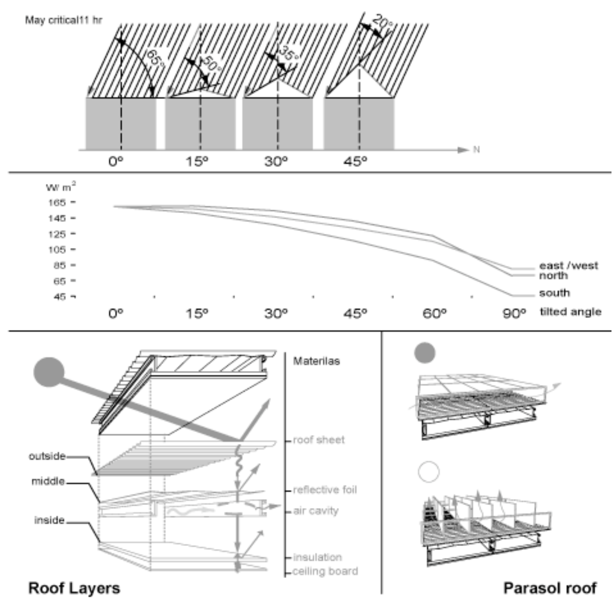


Figure 4: The roof: tilt angles vs. solar radiation, layers and parasol.

ROOF SHADING EXPLORATIONS

Galvanized-steel roofs are highly conductive, and cause severe thermal stress and discomfort during daytime hours. However according to Givoni (1998), '*such roof cool down very fast during night hours, often below the ambient air temperature, owing to long-wave radiation to the sky.*' The roof daily behaviour can be optimized with a passive design strategy that accounts shading and immediate heat dissipation to the environment. This can be easily achieved in rural areas by means of adjacent trees, trunks or wide natural canopies, however in some cases due urban developments this is unlikely to happen.

A '*Parasol roof*' (Szokolay, 2004), can be used over the roof itself to provide solar radiation protection. Figure 4 illustrates a lightweight textile-shading element that can be set on top of a roof. Such element can provide

[4] Source: Meteonorm V.6 - Tilted plane solar radiation calculations based on Limon International Airport station.

enough shading and allow ventilation underneath. By exploring this, solar radiation impinges or expensive insulation can be avoided.

CASE STUDY

In 1940's rural agro industrial villages were emerging on Costa Rica's warm humid regions. Their architecture can be taken as 'vernacular' or adapted Victorian style, which mutated from the Victorian fascination for ventilation, industrialization processes or climate adaptation.

Thus the housing typologies came along with generous overhangs, multiple pitched roofs with accentuated slopes, generous openings on the facades, elevated floors and less ornamental elements. Following function as the main environmental requirement to provide sufficient natural ventilation to catch breezes for its cooling effect.

For example the **Victorian house type "F" was** a 72-sqmt 2-bedroom housing unit is a lightweight wooden structure lifted approximately 2 meters above ground. The roof is metal sheeting, with 35^{o} quadruple pitch roofs ensuring free falling rainwater evacuation. The functional aspects were predominant over an internal rectangular layout. The first floor comprises a kitchen, 2 rooms and bathroom with open spaces facing galleries or verandas within an access porch connected to external stairs. The open plan on the ground floor allow storage facilities, plus under extreme conditions a few hammocks served to chill out peak temperatures, by using the first floor as a thermal buffer.

Its Facades fenestrations are generous, containing fully open-able windows with wooded louvers or lattices to control airflows and light. Some of these vertical elements where located between the walls to floor or roof joints, to allow easily the flow of cross breezes within the plan.

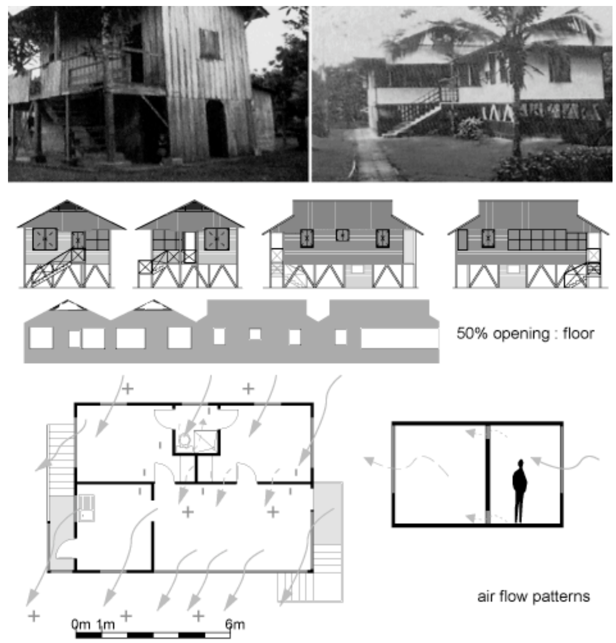
The Costa Rican 'Tropical Victorian' typology has a sensible climate adaptation. It promotes quality within spaces, and it has a legacy of local tradition and accessible technology that can be emulated or improved by the actual practice. (Figure 5)

DESIGN RECOMMENDATIONS

The design recommendations are based on relevant literature review, analysis and parametric studies[5], which helped to narrow down key design aspects throughout this paper (Figure 6).

[5] Simulations with TAS 9.0 (dynamic thermal simulation software)

Layout, spacing & orientation: to ensure adequate exposure of the dwelling to prevailing winds. Space organization: to facilitate a wide range of spatial options for a very compact internal layout. Ideally with multifunctional spaces, where the plan responds to users demands for living, working, growing or producing in the same place. Here private spaces or single banked bedrooms can be reduced gradually through its internal partitions, thus semiprivate and communal activities can take over a greater area to incorporate balconies or verandas to the open 'interior' communal plan.



source: photos, House 'F', Stagno, Ugarte (1998) Rural Architecture in the Tropics
diagrams based on (1998) Rural Architecture in the Tropics

Figure 5: 'F' house ventilation strategies.

Air movement: to ensure ample cross ventilation by reducing internal-external obstructions to prevailing breezes. Here oblique wind incidence angles are desirable to increases speed indoors, hence openings should capture prevailing breezes. External 'adjustable wing walls' located at the veranda external ridge can re-direct winds with beneficial angles for the interior spaces.

Composite construction: Considering applying composite structural elements is relevant for cultural, economical and structural reasons. For this region's climate, heavy and lightweight structures can achieve similar thermal comfortable conditions with adequate shading and ventilation. In fact depending on the user necessities and available resources both systems can coexist under the same scheme.

The openings: multiple openings on the walls should be encouraged to make available a wide range of opportunities for natural ventilation. Where large openings increases the chance of coupling indoors to outdoors conditions and its design must attain airflow patterns and velocities to be well diffused and distributed at the body height, with almost a 100% of effective open area at the opening.

The envelope: the roof has a hierarchical role to provide shading over walls and large openings all year long. The extension of the roof beyond the walls in form of eaves or overhangs should be encouraged as much as possible to ensure shading, as however without diminishing daylight availability. Furthermore occupants may be able to manipulate and control the envelope whenever it is necessary to promote a closer relationship with the environment

CONCLUSION

The design recommendations aim to have an intrinsic relationship within bioclimatic design, comfort assessments and sustainable architecture, where social housing dwellings have to enhance and promote quality and dignity for the occupants. This asset can be achieved within a sensible creative act, in which design comes from a legacy of local tradition, social awareness and sustainable resources. Living in the tropics becomes an open experience of climate responsive-responsible design, which does not generate negative impacts for the occupants.

ACKNOWLEDGEMENTS. I will like to acknowledge my tutor Raul Moura and our course director Simos Yannas for all their support at the Architectural Association Sustainable and Environmental Design Programme. Also, this research was supported by the Programme Alban, the European Union Programme of High Level Scholarships for Latin America, scholarship No. E07M400970CR.

REFERENCES

1. Auliciems, A. & S. Szokolay (1997) PLEA Notes: Design Tools and Techniques 3 - Thermal Comfort. PLEA, Brisbane.
2. Bittencourt, L.S. (1993). Ventilation as a Cooling Resource for Warm Humid Climates. Ph.D. Dissertation Environment and Energy Studies Programme. Architectural Association, London.
3. Corbella, O.D. and Magalhães, M.A. (2002). *Reflections about Bioclimatic Architecture in the Tropics*, pp693-696, PLEA 2002, Touluse.
4. Givoni, B. (1998) Climate Considerations in Building and Urban Design. John Wiley & Sons, Inc., New York
5. Givoni, B. (1994) Passive and Low Energy Cooling of Buildings. Van Nostrand Reinhold.
6. Koenigsberger, O., T. Ingersoll, A Mayhew and S. Szokolay (1973) Manual of Tropical Housing and Building, Part 1: Climatic Design. Longman Group Ltd., London.
7. Hyde, R.(2000). Climate Responsive Design. E & FN Son, London.
8. Stagno,B. Ugarte, J.(1998). Rural Architecture in the Tropics. Institute of Tropical Architecture, San Jose.
9. Szokolay, S.(2004) Introduction to Architectural Science: the basis of sustainable design. Architectural Press, London

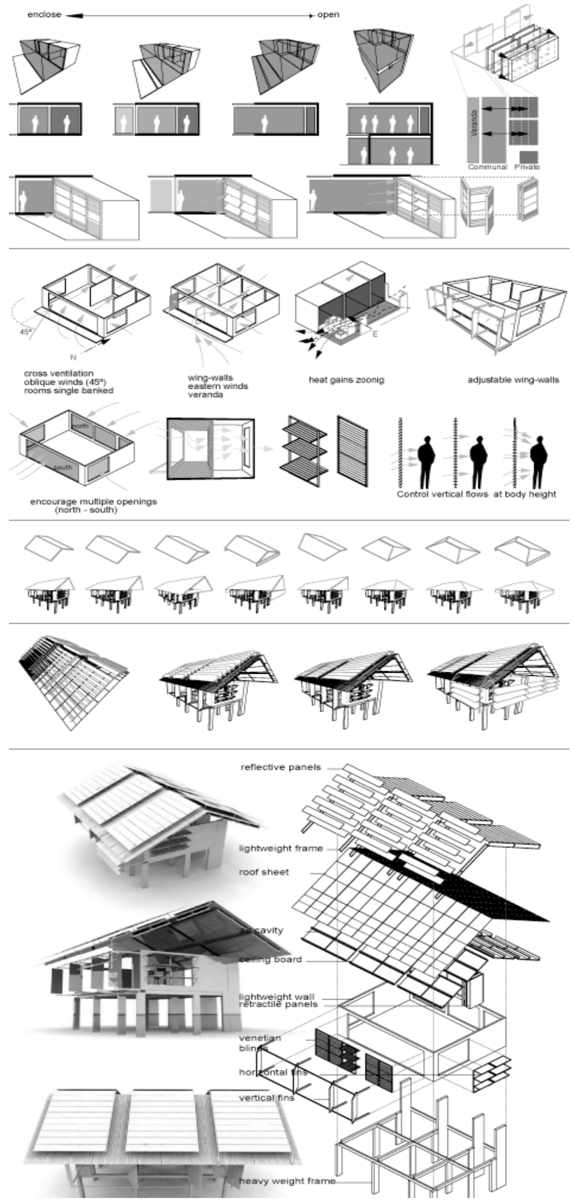


Figure 6: Compilation of various design recommendations.