CHAPTER FOUR

Energy Efficiency through Housing Design

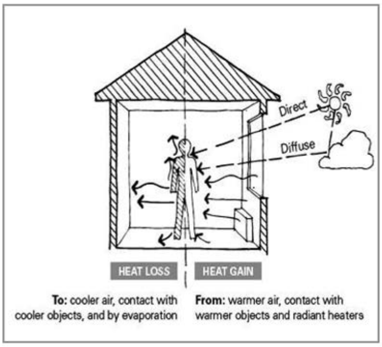


A passive design approach to energy efficiency and climate control is preferred when designing for lower-income populations needing affordable housing, as it generally entails fewer maintenance and replacement costs. The existing literature in planning, architectural design, materials and technology, and infrastructure reveals a variety of physical solutions that integrate design and planning decisions to achieve physical comfort using nonmechanical systems that have low energy consumption. In conceptualizing applications for settlements such as El Rincon in Tecate, passive approaches are useful as they offer a blend of choices to achieve sustainability yet meet the criteria of affordability, climatic responsiveness and social acceptance. The guidelines and approach to housing and community design described here can assist in making selections from a variety of possible technical options for efficiency. Choices need to be sensitive and to respond to the economic and cultural context of the U.S.-Mexico border. The criteria applied to assess sustainable housing solutions are:

- Capacity to generate affordable solutions.
- Capacity to meet minimum aesthetic characteristics which are in accordance with community preferences and social norms.
- Capacity to respond to Tecate's local climate.

The different stages in the design of a building and its neighborhood move from a general approach to settlement layout to the details of designing units. Passive energy conservation aspects are evaluated in terms of their energy savings, comfort capacities, feasibility of application, as well as their ability to be combined with other approaches. Aspects to be considered are:

- Community layout.
- House design.
- Construction materials.
- Waste and water management.



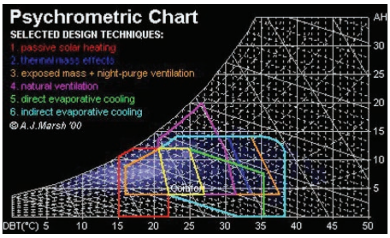


Figure 30: Schematic of Passive Heat Gain and Loss (Source: Australian Greenhouse Office 2004)
Figure 31: Psychrometric Chart for Passive Design Techniques
(Source: A.J. Marsh. Cardiff University, Welsh School of Architecture)

Human Thermal Comfort

Protection of the fragile human body from the natural surroundings is necessary for survival, and thus shelter is understood to be a basic human need. Access to adequate and secure housing is perceived as a fundamental requirement for physical and psychological health and comfort. Human beings are physically comfortable within a very narrow range of conditions. The human body temperature must remain at a constant 36.9º C. The body generates heat—even while at rest. It must lose heat at the same rate as it generates it. Factors which influence human comfort are: temperature, humidity, air movement (both positive breezes and negative drafts), exposure to radiant heat sources, and available cool surfaces to radiate heat to when cooling is desired.

Human settlement in climate zones that are outside human comfort zones rely heavily on energy-consuming systems of climate control within human shelter. In developed countries mechanical techniques of heating, cooling and air ventilation are applied to achieve comfort, an approach unaffordable in a less-developed context. The need for passive systems and smart design to attain those levels of comfort is an essential component of the vision for a sustainable future. To be effective, the design of the envelope of human shelter must be tailored to suit a particular climate, significantly improve comfort levels, and reduce heating and cooling expenses (Figure 30).

The specific environmental characteristics that influence construction patterns in Tecate include:

Climate:	Hot dry, warm winter.
Rainfall:	Distinct wet and dry seasons. Low rainfall and low humidity.
Temperature:	Hot summers are common and there is significant diurnal (day/night) range. In winter mitigating against cold is important.

Passive Design

Homeowners pay considerably more in heating and/or cooling when they do not take advantage of inexpensive heating and cooling from passive design. Passive design systems are ones that that do not require mechanical systems for cooling and/or heating, but instead take advantage of natural energy flows to maintain thermal comfort. Using less power to perform needed functions is energy efficient. Passive design for energy efficiency aims to reduce energy consumption, maintenance and capital costs; produce less environmental impact; and enhance occupant comfort and health (US DOE 2004). Efficient use of energy helps to reduce fuel expenses and reduces atmospheric emissions of gases caused by the burning of fossil fuels. It thus helps to combat climate change and improves air quality (Energy Saving Trust 2003).

The systems that use passive design solutions are grounded in the basic understanding of heat flows through materials and air. Essentially there are three mechanisms by which temperature is transmitted: conduction, convection, and radiation. Conduction is the molecule-to-molecule transfer of kinetic energy where one molecule becomes energized and, in turn, energizes adjacent molecules. Convection is the transfer of heat where molecules physically move from one place to another. Radiation is the transfer of heat through space via electromagnetic waves. A passive design solution needs to turn to the most effective strategies suitable in any given climate. Attaining sustainability must be considered at the starting point of every design.

The Psychrometric Chart, Figure 31, (Marsh, 2005) assists in modeling, for a specific location, the range of temperatures for which passive design techniques using high energy-efficient materials and systems in the exterior envelope of buildings can offer significant benefits. Adoption of passive design principles helps reduce undesired gains or losses of temperature inside the building. The advantage is gained primarily by shifting peak load conditions or in actually reducing overall heat gain or loss. These benefits depend on where the building is located, how it is designed, and how it is operated. The regional significance of a material in terms of efficiency and the ways it meets desired performance standards guides the design process. Reducing heat gain can be achieved by reflecting heat (i.e., sunlight) away from the house, blocking the heat, removing built-up heat, and reducing or eliminating heat-generating sources in the home.

Community Layout

"A home designed to respond to site conditions can optimize lifestyle, improve energy efficiency and protect the quality of the natural environment." (Australian Greenhouse Office, 2004)

Identifying the design characteristics of a community which improve its ability to adapt to climatic conditions of a particular region is key in ensuring long-term vitality and moving to energy sustainability. Layout and design which improve the capacity of a community to achieve solar energy gain during the cold winter and protect it during the hot summer are key. These include orientation and placement of building, streets and vegetation. Several aspects of community layout planning follow.

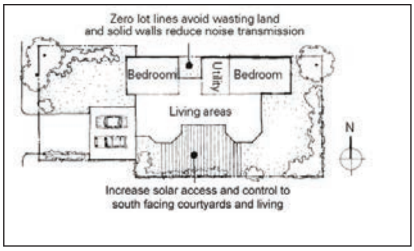
Efficient Land Use and Increased Density

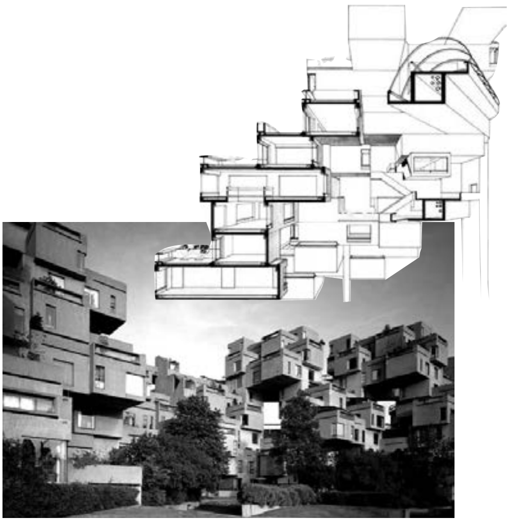
Efficient planning and land use reduces embodied and operational energy costs for individual units, families, and, the entire community. Good design of a building and its footprint can reduce negative impacts on the environment as well as increase energy efficiency of the building itself. Increasing density has several benefits for achieving sustainable housing including reducing distances, and, therefore a variety of costs of providing services. Density increase needs to be achieved so as to reduce the exposure of the surface of the building(s) to direct sun. Use of rectangular lots usually permits the most efficient land use, particularly when the lots are small and less than 300 square meters. Designing site coverage and building footprint to optimize the area available for landscaping allows more storm water to be absorbed on site and generally reduces site impact.

Zero Lot Line

Building to the boundary, to a "zero lot line", improves layout efficiency by maximizing the amount of useable outdoor space. Wasted space in the form of a narrow side passage is traded for space on the other sides of the house. If the house is built to the north boundary it will increase the amount of open space that has a south orientation. Zero lot line construction can also help increase density and provide shade for sidewalks (Figure 32).

This concept of zero lot line is particularly useful in the design of multifamily dwellings. The ongoing pressures for housing in the U.S.-Mexico border area make this an option to consider seriously. Resulting land use efficiency helps to preserve open space, reduce costs of services such as sewers and water and is more efficient in energy consumption. This technique





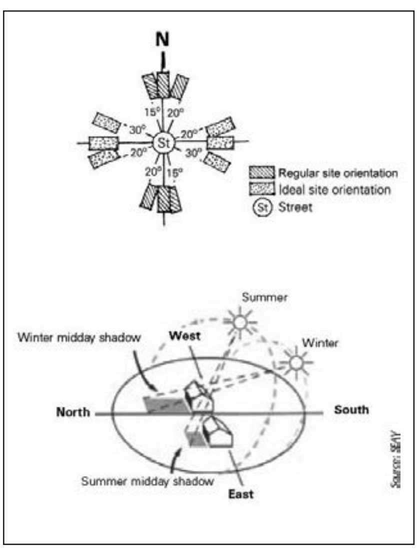


Figure 32: Illustrative Example of a Zero Lot Line House Layout (Source: Australian Green house Office 2004)
Figure 33: Habitat 67, Montreal
Figure 34: Orientation of Housing for Passive Climate Control

Source Figures 32, 33 & 34: Australian Greenhouse Office

allows for the creation of comfortable outdoor spaces which are useful in multifamily dwellings where common outdoor spaces are more likely to be used.

The financing challenges to this approach are many as it requires several families to agree to this type of layout. Families in Tecate have clearly indicated their preference for detached single-family units. As was noted earlier the percentage of people in Tecate living in apartments or attached housing in 2000 was only 7.8% of the total population of the municipality (INEGI 2004). Gaining community acceptance of a zero-lot line typology in the layout might require some effort. There is an example of lower income, accessible housing being developed in the surrounding areas of Tecate by private housing development corporations that use a terrace-house layout where individual housing units share side walls and have little or no front and side yards. The extent of such housing developments is quite significant. The economic efficiency of these units is proven by their viability in the market. However, the orientation and layout design of these "affordable housing units" take little or no account of factors which enhance energy and environmental sustainability.

SMART VOLUME AND SHAPE

Compact housing forms are more energy efficient because they reduce external surfaces which are exposed to maximum heat gain. They reflect an efficient energy design approach by reducing the amount of building surface exposed to direct sun and by self shading interior and exterior spaces. Two storey houses, where the upper storey overhangs and shades the lower, or generates shade over interior spaces could help in energy efficiency in Tecate. Moshi Safdie's Habitat 67 project in Montreal Canada, was an attempt to incorporate these principles of design (Figure 33).

ORIENTATION

Orientation for passive heating involves orienting building to maximize entry of winter sunlight into the buildings and keeping unwanted summer sun out. This can be done with relative ease on northern elevations by using shading devices to exclude high angle summer sun and admit low angle winter sun.

In hot humid climates and hot dry climates with no winter heating requirements, the orientation of a building should aim to exclude sun year round and maximize exposure to cooling breezes (Figure 34). The following orientation guidelines should be considered:

Sites running N-S are ideal because they receive good access to southern sun with minimum potential for being shaded by neighboring houses. In summer neighboring houses provide protection from low east and west sun.

N-S sites on the south side of the street allow north-facing living areas and gardens to be located at the rear of the house for privacy. They should be wide enough to accommodate an entry at the front as well as private north-facing living areas.

Sites running E-W should be wide enough to accommodate north-facing outdoor space. Overshadowing by neighboring houses is more likely to occur on these sites.

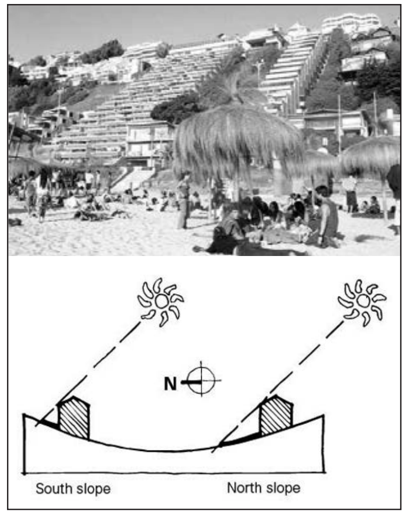
Sites located on slopes should take advantage of the diverse heights to capture sun as illustrated in Figure 35.

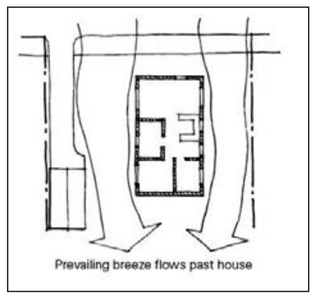
NATURAL VENTILATION

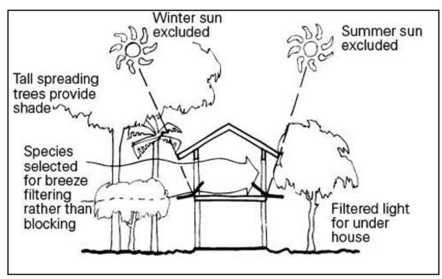
The smart use of wind flow allows cooling of spaces between buildings, and reduces the reflected heat from the ground and from vertical parapets. The location of the main body of buildings should be in line with wind movements (Figure 36). Streets needing more ventilation should run east–west. The use of trees with high canopy and little understory growth facilitates a flow of breezes at the level of the house (Figure 37). Trees planted in a line north to south help screen morning and afternoon sun and provide shade. A well-designed landscape also helps control noise and air pollution.

DESIGNING LANDSCAPES FOR SHADE AND HEAT REDUCTION

Shade from vegetation can improve the fit of housing to environment. Shading is the most cost-effective way to reduce solar heat gain (Figure 38). It can also reduce the need for, or, cost of running air conditioning units. In







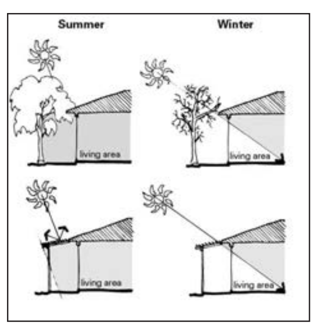
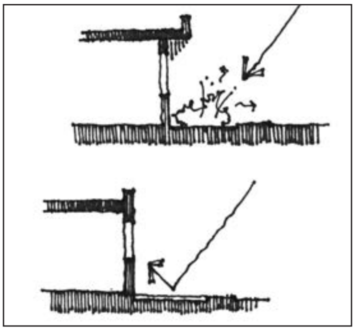
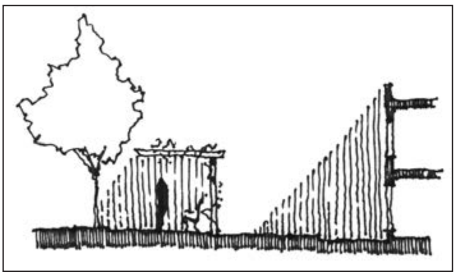
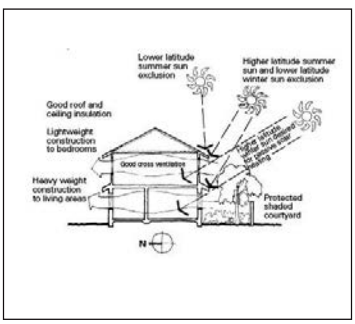


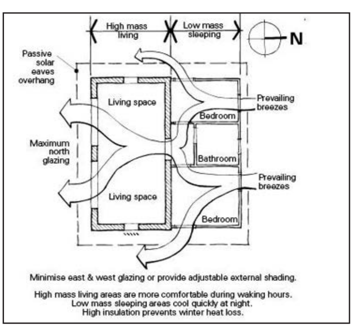
Figure 35: Sloping Site and Diagram of Shade on South and North Facing Slopes
Figure 36: Site Design to Facilitate Air Flow Around Buildings (Source: Australian Greenhouse Office 2004)
Figure 37: Landscaping for Shade and Sun
Figure 38: Designing and Landscaping for Heat Reduction in Summer and Heat Gain in Winter

Source Figures 35, 36, 37 & 38: Australian Greenhouse Office









Figures 39: Landscaping Ground Surfaces to Reduce Heat Gain
Figures 40: Landscaping for Shade
Figure 41: Design Guidelines for Passive Cooling in Building
Figure 42: High Mass and Low Mass Enclosure for Passive Cooling
Source Figures 39, 40, 41 & 42: Australian Greenhouse Office

colonias the use of old, recycled unit air conditioning equipment can be observed. Older units are far less efficient then newer models. Proper shading of a house can increase the efficiency of mechanical systems such as Air Conditioning units or coolers by 10% to 25% with a return of costs in less than 8 years. The returns in savings may be even higher in colonias where recycled, reused, less efficient units are in use.

The use of landscape materials on ground surfaces surrounding a house is a key design element to reduce heat gain. A grass-covered lawn is usually 10° F (6° C) cooler than bare ground in the summer. Concrete pavements are considerably higher in terms of heat gain. In arid climates the use of native ground cover that requires little water is recommended (Figure 39). In lower density *colonia*s residents do plant fruit trees and vegetables when they have some security of tenure. Placing these and other types of flowering vines and shrubs for shading can help reduce heat gain (Figure 40).

Incorporating the design guidelines for achieving a sustainable community layout described above must occur in the early stages of planning a community. A thoughtful layout can deliver several energy benefits and increase the quality of life of residents. Constructing communities consisting of a mix of housing types so as to yield higher density may face resistance in terms of community acceptance. A multifamily dwelling typology is not found in the Tecate region. But new private sector developments which are in high demand are developing more dense layouts for housing. In designing sustainable community layouts the community must be studied in its context and the design solution must be sensitive to how the community is inserted in the existing urban fabric. The settlement should strive to both maximize the benefits it can derive from its surroundings and what it can offer and contributes to its surroundings (Figure 41). Design suggestions for this include:

- Optimize land use to reduce distances for obtaining services and utilities through compact site plans and increasing the amount of useful open areas.

- Increase cross ventilation to reduce heat gain from the ground and reduce heat gain in the building.
- Increase the amount of shade by reducing areas of building and ground surface exposed to direct sun by increased density and compact design.
- Design the landscape and locate vegetation so as to block heat and noise.

House Design

A house should operate independently of any inputs except those of its immediate environment. (Vale and Vale 2000)

PASSIVE COOLING

Designing the functional arrangement of a house in relation to use of spaces in the daily cycle of day- and night-time occupancy can serve to enhance comfort levels within the home (Figure 42). The main elements of house design for passive cooling are:

- Orientation to maximize exposure to cooling breezes.
- Increasing natural ventilation by reducing barriers to air paths through the building.
- Effective shading of the external surfaces including use of plantings to reduce heat gain.
- Providing fans to increase ventilation and air movement in the absence of breezes.
- Providing adequate levels of appropriate insulation.
- Choosing construction materials with high thermal mass in regions which experience a significant diurnal range.

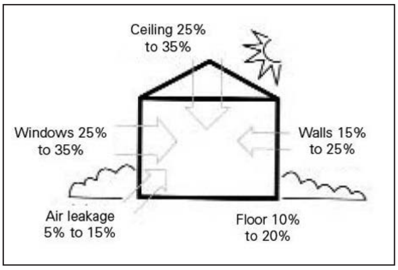
EVAPORATIVE COOLING

Evaporative cooling units are generally lower in initial and running costs. They have several energy and sustainability advantages. The principle of evaporative cooling is relatively simple. Air moving past water will cause the water to evaporate. The heat necessary to cause evaporation is drawn out of the passing air stream and cools the air. Modern evaporative coolers draw outside air through wet filter pads. Impurities in the air are screened by the air filters, moisture content is increased and air temperature lowered by the evaporation of water in the pads. Cooled air is distributed through the building (See The Evaporative Cooling Site.). Evaporative cooling works better in dry climates and has the following advantages over a refrigerated system

- Generally lower (up to 50% less) initial purchase costs than refrigerated systems.
- Lower peak energy usage (up to 90% less), which means lower wiring costs, poten tially useable with solar energy and fewer requirements for additional power stations.
- Lower (typically 80% less) running costs than refrigerated systems.
- Lower energy usage (typically 80% less).
- Less greenhouse gas production (typically 80% less).
- No CFC's or HFC's hence no contribution to ozone depletion.
- In dry areas higher humidity is better for human comfort levels. Refrigerated systems dehydrate the air more.
- Allows flow-through ventilation with plenty of fresh air.
- Wet filter pads filter the air and improve air quality.

HOUSE LAYOUT

A thoughtful configuration of rooms in a house is a simple way to avoid spaces becoming overheated during the times they are in use. Reducing exposure of any surfaces of the room—walls, flooring and roof—to direct sun and managing thermal mass capacity in balance with climate and needs is necessary in the design of sustainable houses. Design of the vertical configuration of the house for passive climate control involves locating some rooms at ground level to protect them from heat gain. In the case of hot and arid zones spaces which are used daily such as living rooms should remain on the first floor and their direct exposure to sun reduced, by projection of upper stories, to cast a shade on lower ones. An intrinsic insulating air layer is also provided. Courtyards provide design opportunities to allow or block solar penetration, and also create protected outdoor areas. Public spaces located on lower floors should have high thermal mass, so heat gain can be delayed and heat released at nighttime when those spaces are not



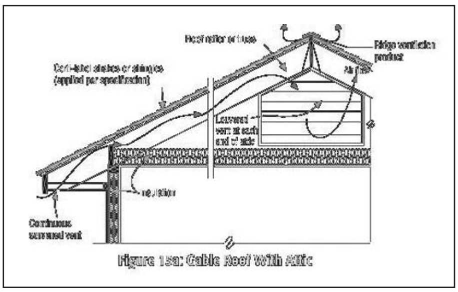


Figure 43: Building Envelope
Figure 44: Roof Treatment

Source Figures 43 & 44: Australian Greenhouse Office

occupied. In the case of horizontal zoning, optimum design decisions include maximizing indoor/outdoor relationships and providing appropriate, screened, shaded, rain protected outdoor living spaces, adjacent to long term uses to the south. Short-term uses can be placed to the west.

Tecate is in a climate zone of hot summers and cold winters. Therefore rooms facing south are protected from the heat in the summer since the sun is higher, and benefit from solar warming in winter when the sun is lower. Living rooms should have a southern orientation. A north orientation has no sun exposure and is suitable for secondary uses such as kitchen, bathrooms, and storage (Roaf et al., 2003). However, in arid climates bedrooms may be located to the north to maintain coolness and avoid heat gain during the night. The east has morning sun which can also be good for bedrooms. The west is the least desired orientation because of strong afternoon sun. Bathrooms and other short-term uses can be located there.

BUILDING ENVELOPE

Once the general plan for a community has been laid out and the building volumes have been designed, the next step is the definition of the building envelope, which is the layer of the building in direct contact with the exterior environment. The envelope consists of the roof, the walls and the floor. Through these heat is gained or lost. Therefore energy can be managed by controlling the way the envelope is designed to reflect, insulate, or absorb heat (Figure 43).

Roof

Insulation and reflection of heat are the main thermal properties provided by a roof. Insulation can be provided by specific materials or air layers. An efficient way to avoid heat absorption from the roof is to use air gaps to ventilate the structure. This technique can be applied in many ways including using aerated thin spaces with roof vents (Figure 44) to the provision of entire detached roofs. Higher reflectivity of the roof also helps minimize the absorption of heat into the roof. Light colors and non-absorbent materials also increase reflectivity. In *colonia* housing, placing a sheet metal roof on poles where a second storey might later be built serves to provide shade, reduce heat gain, and provide covered space for various activities.

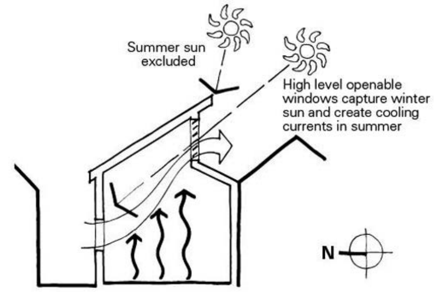
Facade

The appropriate design of building elevations can control and optimize the amount of sunlight which is captured in various rooms. Facade elements can adapt to different conditions throughout the day through control of openings and the creation of shade in facades. Moderating the size of openings is the simplest way of controlling exposure to direct sunlight—the smaller the opening to a house the less the direct exposure. Avoiding the exposure of big surfaces of glass to the sun will also reduce the reflection of light and heat to the outdoors ground surfaces and/or adjacent buildings. Figure 45 illustrates the ways in which the design of the building envelope provides good opportunities to manage the entrance of light and the flow of air currents through the house.

The design suggestions include the following directives: reduce heating of principal rooms by location and layout; reduce heat exposure through control of openings, elevation design, and air layers; avoid reflecting materials that will return heat towards outdoors or on to adjacent buildings; and increase thermal mass capacity of the building envelope.

An Illustrative Case Study: Iquique, Chile

Housing construction in the city of Iquique, located in the north of Chile provides an illustration of housing design which reflects responses to opportunities in its immediate region. Adoption of materials, layout and design in Iquique optimized and utilized opportunities and made for appropriate and sustainable design. The city of Iquique is surrounded by the Pacific Ocean and the Atacama Desert, which is the world's driest desert with less than 0.1 inches of annual rainfall. The city has a rich history which influenced and shaped its particular architecture and its climatic adaptation. Iquique developed in the late 19th and early 20th Centuries as an exporting seaport for saltpeter to Europe and North America. Most of its housing and public buildings were constructed with Oregon pine brought in the ships as ballast. The houses were built with a balloon frame structures and expressed a blend between immigrant architectural ideas, drawn especially from San Francisco, and the local climate, which required shade from sun. The result was a housing typology that used balconies and detached aerial roofs (Figure 46). This design solution provided good ventilation for buildings as well as a covered extension on top for homes. This served to relieve space needs given the small and tight lots. Currently these buildings have been designated a historic patrimony and developed as an attraction for tourism.



ORIENTATION	SUGGESTED SHADING TYPE
SOUTH	fixed or adjustable shading placed horizontally above window
EAST & WEST	adjustable vertical screens outside window
SE & SW	adjustable shading
NE & NW	planting

Figure 45: Designing Façade Elements for Passive Climate Control
Figure 46: Building type in Iquique, Chile

Source Figures 45 & 46: Australian Greenhouse Office