RECOMPOSING THE CONTEXT

Sustainable housing in Hot-Arid regions, learning from Yazd.

THESIS DISSERTATION

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1 Introduction

Developing housing typologies able to meet standards of comfort and optimal efficient settlements, reducing fossil fuel consumption and therefore carbon emissions is one of the pressing challenges of contemporary architecture, especially when taking into account adverse settings and harsh weather conditions.

In a world where the scarcity of energy resources and the rising on the use of synthetic materials, the determination to make use of abundant local resources, and the pressing needs of habitat for the rapidly growing population, has risen the need to engage in a more serious and conscious discussion of the vernacular architecture and its lessons on sustainable ways to produce settlements.

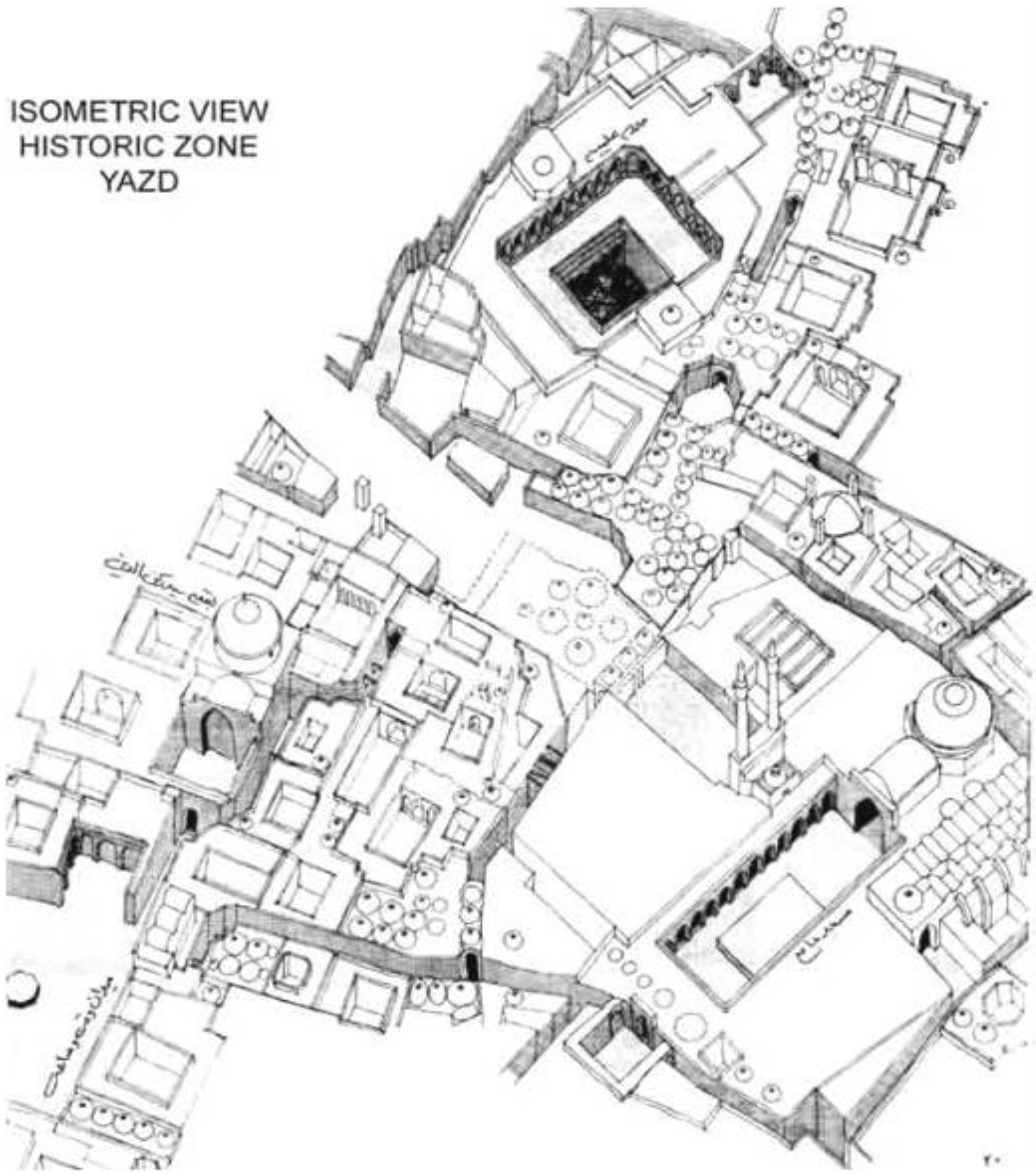

Figure 1.1. Sketch view of Yazd historic zone.

For the implementation of the research we have decided to choose as study case, the city of Yazd, at latitude 31.92 ° north and longitude 54.37 ° east. It is on the south of the Iranian central plateau, located on a desert oasis where the Dasht-e Kavir and Dasht-e Lut meet. Yazd is the driest city in Iran, with an average annual rainfall of only 60 millimeters (2.4 in), and also the hottest on the north of the Persian Gulf, with summer temperatures very frequently above 40 °C (104 °F) under a blazing sunshine with no humidity. Even at night the temperatures in summer are rather uncomfortable. In the winter, the days remain mild and sunny, but in the morning the thin air and low cloudiness cause very cold temperatures that can sometimes fall well below 0 °C (32 °F).

The choosing of Yazd as a case study not only offers a great challenge and the opportunity to test the outcomes of the research under very harsh conditions, but also the opportunity to learn from its particular architecture which has the renown of being one of the most conserved antic settlements in the world, hving a very interesting way of vernacular construction that has meet the needs of its population over centuries.

Implementing an urban housing development in a region with such strong characteristics of weather and of culture and tradition, demands a big challenge on reading and understanding the city's dense urban tissue and the reasons why it was developed in such a matter, but also getting the tools to transform and recompose the new urban tissues that had been implemented during the last decades as a result of opening and globalization to western acculturation.

1.2 Some basic considerations

Nowadays anyone involved in architecture and building design or even any other subject of study has face the term Sustainability, most of the times it is referred to green or ecological design. They are often interchangeably used in different terms to describe an architecture that is responsive towards the environment. But each of them in fact has a separate and identified definition, which cannot replace the other one.

"Green Architecture" is a term that is a combination of values of sustainability and ecological architecture that encompass social and political and environmental aspects.

The term "sustain," derived from the Latin word "Sustenere," means to keep in existence, to be capable of being maintained in a certain state or condition (Lawrence 2006). It is mostly referred to environmental or climatic concern; the interaction between nature and human developments.

However it was first introduced as a global socioeconomic concept during the 1970 and defined later in "Our Common Future" by Brundtland Commission as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (UN 1987). Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland et al. 1987).

As it can be seen, sustainability is not limited just towards architecture and designing, depending on the context there are different meanings and definitions towards sustainability. For example in the ecological point of view, sustainability is defined as the ability of an ecosystem to maintain ecological processes, functions, biodiversity, and productivity into the future (Naiman, Bilby and Kantor 1998; Waltner-Toews, Kay and Lister 2008).

In an architectural context, sustainability is defined as a term that describes economically affordable, environmentally healthy, and technologically efficient and/or high performance buildings (Edwards 2005; Steele 2005; Sassi 2006; Smith 2006; Steinfeld 2006; Williams 2007; Newman and Jennings 2008; Vallero and Brasier 2008).

A building will be sustainable if the entire component mentioned is obtained. Each of the components has certain targets to approach, for example in terms of technology and material used, durability and maintenance and recyclability even economic issues related to the construction, profitability and building stock value is also considered. Resource sustainability refers to site conditions and cost effectiveness of the operational and life cycle of the building, accessibility and favourable natural forces. And finally the environmental sustainability deals with creating healthy, habitable and safe environment with social and institutional capacity (Green Architecture 2010). The architect's challenge, therefore, is to find a balance among technological and materials considerations, resource availability, and environmental sustainability without neglecting the social aspects involved in the development of a project.

2 A holistic view on global warming

Climate change according to the "Intergovernmental Panel on Climate Change" IPCC, refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity.

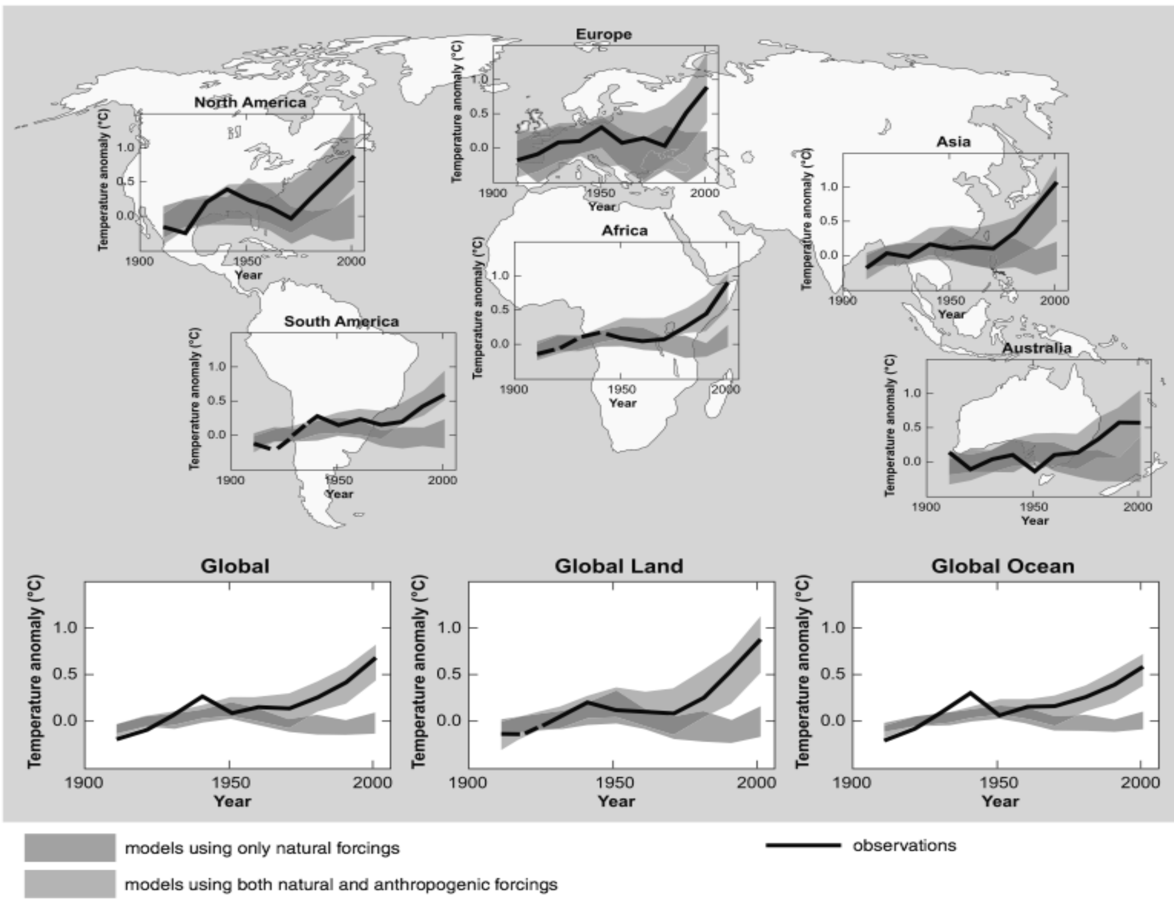

Figure 2.1. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. **Source:** from the Síntesis Report on Climate Change 2007.

According to the Synthesis report on climate change for 2007 [1] there is enough scientific proof and

[1] These findings are part of the Synthesis Report based on the assessment carried out by the three Working Groups of the Intergovernmental Panel on Climate Change (IPCC). It provides an integrated view of climate change as the final part of the IPCC's Fourth Assessment Report (AR4).

substantial evidence for the following statements:

- Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 (2.1 to 3.3)% per decade, with larger decreases in summer of 7.4 (5.0 to 9.8)% per decade.

- Precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia whereas precipitation declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia.

- Based on growing evidence, there is *high confidence* that the following effects on hydrological systems are occurring: increased runoff and earlier spring peak discharge in many glacier and snow-fed rivers, and warming of lakes and rivers in many regions, with effects on thermal structure and water quality.

- Based on more evidence from a wider range of species, there is confidence that recent warming is strongly affecting terrestrial biological systems, including changes as earlier timing of spring events, such as leaf unfolding, bird migration and egg-laying.

- Observed changes in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation. These include: shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans.

Through climate behavior observations and computer modeling on the effects of anthropogenic emissions and its effects on the global weather, it can be inferred that warming reduces terrestrial and ocean uptake of atmospheric CO_2, increasing the fraction of this emissions remaining in the atmosphere. This positive carbon cycle feedback leads to a larger atmospheric CO_2 increase and thus greater climate change.

2.1 The Greenhouse effect

When the sun's energy reaches the earth, most of the energy warms up the atmosphere and the earth's surface, which at the same time it radiates some of this energy by reflection and refraction back into the space as infrared rays. Anthropogenic emissions or Greenhouse gases in the atmosphere trap some of these infrared rays before they scape the atmosphere, resulting in additional warming of the earth's surface.

The burning of fossil fuels, CO_2 emissions and other human activities increased the levels of green house gases in the atmosphere, it is considered that construction industry and buildings use and maintenance take part in 35 to 40 % of the total energetic consumption and the emissions of CO_2 to the atmosphere, accentuating the Greenhouse effect and raising of global temperatures.

A Greehouse gas or GHG is a gas in the atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Greenhouse gases greatly affect the temperature of the Earth;

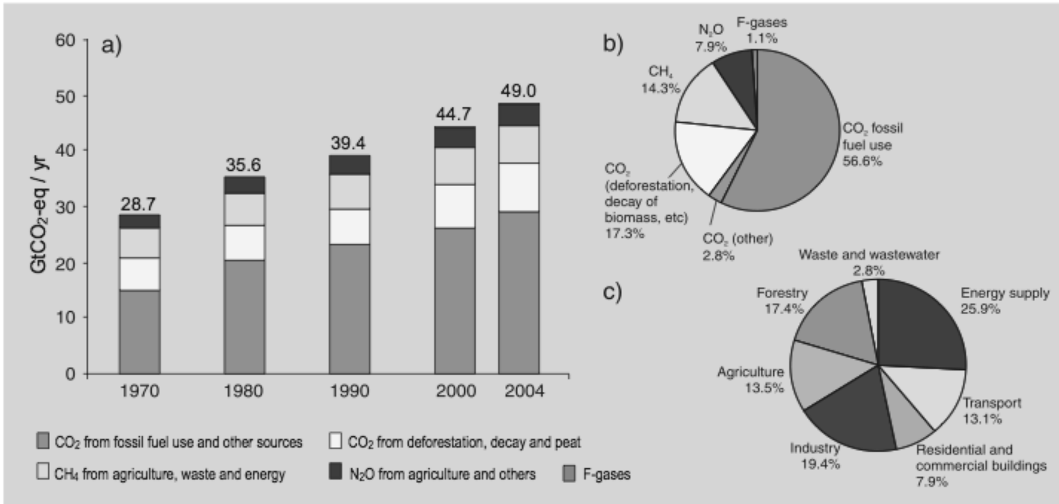

Figure 2.2. (a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.[5] (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO2-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO2-eq. (Forestry includes deforestation). **Source**: the Síntesis Report on Climate Change 2007.

2.2 Future scenario and its impacts

Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century.

Projected warming in the 21st century shows scenario-independent geographical patterns similar to those observed over the past several decades. Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean (near Antarctica) and northern North Atlantic.

It is *very likely* that hot extremes, heat waves and heavy precipitation events will become more frequent. Future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and heavier precipitation associated with ongoing increases of tropical sea-surface temperature.

For increases in global average temperature exceeding 1.5 to 2.5°C and atmospheric CO_2 concentrations, there are projected to be major changes in ecosystem structure and function, species' ecological interactions and shifts in species' geographical ranges, with predominantly negative consequences for biodiversity and ecosystem goods and services. It is estimated that approximately 20 to 30% of plant and animal species assessed so far are *likely* to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C.

The most vulnerable industries, settlements and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources and those in areas prone to extreme weather events, especially where rapid urbanization is occurring, poor communities can be especially vulnerable, in particular those concentrated in high-risk areas.

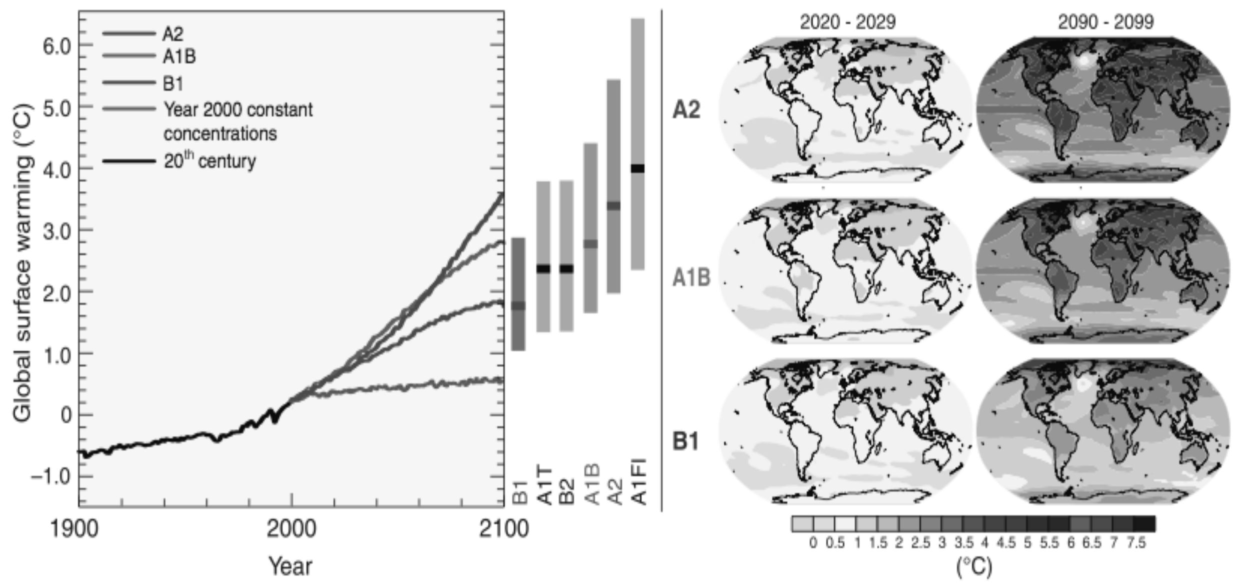

Figure 2.3. ***Left panel***: *Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The orange line is for the experiment where concentrations were held constant at year 2000 values. The bars in the middle of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six marker scenarios at 2090-2099 relative to 1980-1999. The assessment of the best estimate and likely ranges in the bars includes the Atmosphere-Ocean General Circulation Models in the left part of the figure.* ***Right panel***: *Projected surface temperature changes for the early and late 21st century relative to the period 1980-1999. The panels show the multi-AOGCM average projections for the A2 (top), A1B (middle) and B1 (bottom scenarios averaged over decades 2020-2029 (left) and 2090-2099.* **Source**: the Síntesis Report on Climate Change 2007.

2.3 Adaptation and mitigation for a sustainable development

Societies can respond to climate change by adapting to its impacts and by reducing GHG emissions (mitigation), thereby reducing the rate and magnitude of change. Measures should be implemented over the next two to three decades to assure a sustainable development.

The capacity to adapt and mitigate depends on socio-economic and environmental circumstances and the availability of information and applied technology. The capacity to adapt is dynamic and is influenced by a society's productive base, including natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance, national income, health and technology.

Energy efficiency and utilization of renewable energy offer synergies with sustainable development. In least developed countries, energy substitution can lower mortality and morbidity by reducing indoor air pollution, reduce the workload for women and children and decrease the unsustainable use of fuel wood and related deforestation.

Examples that can have positive impacts on mitigation should definitely involve interdisciplinary applications in the field of transportation, construction, goods production and services, as well as social and human changes in consumption patterns, education and training, changes in building occupant behavior, transport demand management and management tools in industry.

Without sustained investment flows and effective technology transfers, it may be difficult to achieve emission reduction at a significant scale. Implementing and researching on methods of low-carbon technologies is important in order to obtain a sustainable long-term development.

3 Strategies for ecologic hot-arid settlements

While saving energy has a high social benefit because it slows the depletion of finite reserves of fossil fuels, it is equally important in reducing the pollution caused by the extraction and burning of these fuels, and therefore in reducing acid rain and GHG emissions, the potential for global climate warmth, and the ecological impact on extinction of endangered species.

The design path and correct bioclimatic decisions can radically reduce energy consumption and end our dependency on fossil fuels for buildings. Using current knowledge and available technologies, American society of heating, refrigeration and air-conditioning engineers ASHRAE has produced a series of high-performance building design guides with targets of 30% and now 50% reduction from their own energy performance standards.[2]

They are necessary but not sufficient to reach a responsible net-zero energy building that does not depend on high levels of renewable energy, it correspond to each situation to adapt, try and prove different architectural passive strategies to reach the desirable levels of comfort with the less invasive, fossil energy and technical dependence to ensure a lasting and sustainable building archetypes.

3.1 Hierarchy of strategies for net-zero building design

The hierarchy suggests solving the energy design problem with the lowest level of technology possible and the least cost strategies, (Passive Design) while also substituting embodied intelligence in architectural form for hardware. The net-zero energy equations in a building can be solved in many different ways, however there are elegant and inelegant ways to reach net zero.

It is better to use site design to reduce the environmental stresses on buildings and to provide access to desired climatic resources to solve a portion of the energy problem before using building design to overcome what the building does not need to do. There is no point in designing a solar-heated or naturally ventilated building unless it is a low-load building to begin with. The hierarchy calls us to design effective passive systems for heating, cooling and lighting to radically reduce loads before designing and specifying a highly efficient HVAC system.

High-performance, high technology buildings that ignore the fundamental levels of the net-zero energy design hierarchy are expensive, even when the technology used is "green." Architects and designers should focus on a set of different levels to ensure a good low energy building performance:

- THE LEVEL OF ARCHETYPES is the level of basic architectural design where issues of siting, orientation, location, shape, proportion and surface to volume ratio are considered, along with the neighborhood or urban fabric such as shared shade, solar envelopes, breezy or calm streets, migration, east–west plan, deep sun and rooms facing the sun and wind, daylight zones, cooling zones, heating zones, borrowed daylight, buffer zones, and so on.

- THE LEVEL OF EFFICIENT TECHNOLOGY is a prerequisite to the design of passive systems. For example, the European passive house standard is essentially a heating season envelope performance standard driven by efficient envelope technology. Such as equipment heat gain, electric lighting heat gain, ventilation or infiltration gain and loss, skin thickness, window and glass types, exterior surface color and exterior shades.

- THE LEVEL OF PASSIVE DESIGN, in which the building is configured to consciously heat itself

[2] The following chapter correspond to a basic summary and extraction taken from the book "Sun, Wind and Light" architectural strategies, third edition by Mark Dekay and G.Z. Brown, adapted to the corresponding situation of this research and project.

with the sun, light itself with the sky and cool itself with the wind and other natural forces. Given neighborhood, site and building massing solutions, such as direct gain rooms, sunspaces, thermal storage walls and so on, along with the details of these systems, such as thermal mass, solar apertures and mass surface absorbance. Scale bundles including passive solar building, passively cooled building, daylight building and outdoors microclimate, daylight room geometry, sidelight room depth, daylight apertures and daylight reflecting surfaces. Similarly, passive-cooling systems can be selected and designed at this level. Examples include cross-ventilation rooms, stack-ventilation rooms, night-cooled mass, evaporative cooling towers, ventilation apertures and double skin materials.

- THE LEVEL OF HIGH-PERFORMANCE engages both sophisticated and efficient HVAC systems and their integration with architectural design and with passive systems. Strategies include electric lighting zones, mixed mode buildings, heat pumps, manual or automated controls, mechanical space ventilation and so on.

- THE LEVEL OF GREEN POWER in strategies for photovoltaic walls and roofs and for solar hot water, along with their associated analysis techniques. Both of these upper levels and the whole hierarchy of strategies for net-zero buildings are supported by a set of high performance buildings assessment techniques designed to help users design and evaluate net-zero and carbon-neutral buildings. These include energy targets, annual energy use, net-zero energy balance, energy use intensity, emissions targets and carbon-neutral buildings.

3.2 Climate as a resource

The physical location of a given building site defines a set of climatic conditions that will influence the energy use of the building. Key climate variables include temperature and relative humidity, the position and intensity of the sun, the speed and direction of the wind and the dominant sky conditions, or cloudiness, which influences the quality and quantity of light.

A climate with optimal sun, wind and light resources coupled with a building program that introduces relatively few additional loads allows the designer latitude in implementing passive strategies. At the opposite end of the spectrum, an extreme climate coupled with high internal loads requires more careful consideration of each design decision.

Assuming that the building loads have been reduced as much as possible, peaks can occur when climate and occupancy factors align. The cooling peak occurs when the outdoor temperature is highest and often the greatest number of occupants is present. By contrast, the heating peak occurs when it is coldest, generally at night and when in nonresidential buildings, fewer people tend to be present.

3.3 Building occupant’s behaviors

It is important to recognize the different roles played by people and by climate in driving peak building loads. While climate conditions can contribute to either a heating or cooling peak, human occupants are always heat sources (and often turn on additional heat sources) and thus may increase the climate-driven cooling peak or may decrease the climate-driven heating peak.

Occupants are spatially flexible if they can migrate to areas that they find most comfortable at different times of the day and year, for example, to sunny east-facing spaces on cold winter mornings. Temporal flexibility means that occupants can shift their schedules, either as a group or individually, according to seasonal conditions.

3.4 Passive design strategies

Orientation and organization set the stage for patterns of sun, wind and light interaction that vary with changing climatic conditions over the course of days and seasons. The building design modulates sunlight and wind resources by controlling their access and distribution throughout the building. Building form determines which internal spaces have direct access to sun, wind and light.

Orientation influences the quantity and quality of the resources that enter the building, as well as the degree to which admission can be controlled, as observed in south-facing glazing, which permits the best access to solar radiation during winter months while also being the easiest to shade during summer months (rooms facing the sun and wind, locating outdoor rooms).

Integrating thermal mass into the building design helps modulate temperature swings, resulting in greater thermal comfort and less energy use. To realize these potential benefits, designers can consider not only the gross area and thickness but also other details that affect mass performance, such as the provision of insulation outside the thermal mass and the different pathways and sources for heat loss and gain.

Consider the following general principles for a mixed climate with heating and cooling needs:

- During overheated periods, when the indoor temperature is above the outdoor temperature, ventilation apertures may be opened to allow natural ventilation for cooling.

- If the outdoor temperature is warmer than the upper limit of the comfort range, close apertures retard excess heat gain.

- If night-cooled mass is employed, open apertures at night once the outdoor temperature has dropped below the indoor temperature.

- Organizing occupancy patterns in load-responsive schedules so that occupant-associated heat gains do not exceed the rate at which the thermal mass can absorb heat will increase the ability of the mass to provide cooling throughout the day.

- During the cooling season, shade all glazing from direct radiation. Employ movable insulation as a barrier against heat gain during the daytime, so long as sufficient glazing area for daylight is maintained, or in the case of unoccupied rooms.

- During under heated periods, open internal shades and operable external shades to admit sun.

- Organize occupancy patterns using migration so that the parts of the building that warm up first, such as those with east-facing glazing and those on upper levels, are occupied early in the day. As spaces become unoccupied and lose access to direct solar radiation, employ movable insulation over the glazing to reduce heat loss.

- All glazing can use movable insulation at night when windows are the main source of heat loss.

3.4.1 Situational strategies variations based on hot-arid climate

Hot-arid cooling neighborhood as in hot-humid climates, shading is important in hot-arid climates, but as the skies are clearer and the sun often more intense. Similarly, wind access is important, but the air can be very hot at times and dust- laden. These factors combine to shift the strategies more toward shade and less toward ventilation. Evaporative cooling strategies also become available in arid climates:

- INTERWOVEN BUILDINGS AND WATER can reduce air temperatures if the water is either very large, such as a large lake or ocean with winds blowing over it, or if it is located within semi-enclosed spaces, such as **Courtyards**.

- SHARED SHADE helps designers configure buildings to shade each other, particularly on north-south streets.

- SHADING UMBRELLA works similarly to shared shade, but on a smaller scale by providing shade to particular open spaces or courts by shaping surrounding buildings and edges to cast shadows.

- GREEN EDGES of vegetation can cool incoming breezes if relatively large and especially if irrigated and/or shaded. When located leeward of the built neighborhood, the green edges can also help to remove dust.

Iranian example

The German-Iranian research project, young cities, developed a master plan for a 35 ha. Area, applying Climate-sensitive urban form and culturally adapted building typologies for reduced heating and cooling in the Hashtgerd new town in the Tehran province of Iran (young cities, 2011; Selig, 2011). Like traditional towns in the region, the quarter takes on a compact dense urban pattern, as shown in the neighborhood cluster drawing, where 29 compact neighborhood clusters are organized along north-south primary roads with each cluster defined by a central shady courtyard of 15 m x 30 m. and surrounded by four building groups.

See also the site plan, Hashtgerd new town on the next spread. Narrow 6 m. wide streets, running N-S connect the courts, giving shared shade. The arrangement of buildings blocks the prevailing western/northwestern winds and the hot, dusty southeast summer winds while admitting cooler north-south winds from the Alborz Mountains. Solar exposure is minimized by longer south facades (east-west elongated building groups), giving each unit winter solar access. Interwoven buildings and planting is achieved by a variety of green spaces and tree planting, including constructed wetlands for wastewater recycling.

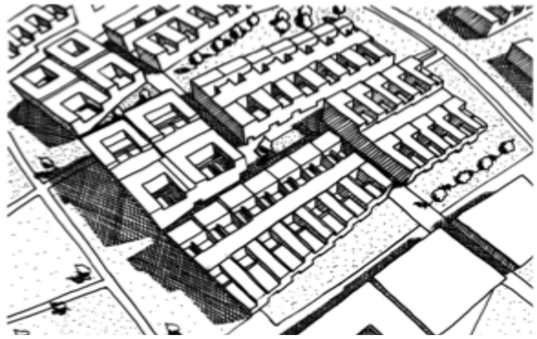

Figure 3.3. *Neighborhood cluster, Hashtgerd New Town.*

Figure 3.4. *Site plan, Hashtgerd New Town, Iran, Young cities project , 2011.* **Source:** Sun, Wind and Light, architectural design strategies.

3.4.2 The passively cooled building

A passively cooled building is set to cool itself by using different strategies that start from a good orientation and the seize of the sky, wind and earth, using a family of strategies fit to place to serve a purpose, cooling.

There are five strategies that are considered invariants in all passively cooled buildings. While one of these strategies might be left out or its function carried out by an alternate strategy, all passively cooled buildings will benefit from each of these five strategies, whether the climate is arid or humid:

1. **LOCATING OUTDOOR ROOMS:** Outdoor rooms expand the living space and allow places for MIGRATION. They may support associated occupied floor areas inside the envelope, this str ategy directs the designer to consider the combination of wind and sun directions when locating outdoor rooms. For example, in a hot climate, when the summer sun and wind come from the same direction, admitting the breeze rules, and the designer must admit wind first and provide structured or landscaped shade to minimize harsh sun.

2. **BUFFER ZONES**: Some rooms can tolerate temperature swings and can be located between the more protected rooms and undesired heat sources, often the eastern or western sun, or the roof. These spaces can be used as thermal buffer zones between the more extreme outside conditions and spaces that need somewhat more careful temperature control.

3. **COOLING ZONES:** If parts of the building can be cooled during only a portion of the day, with a passive strategy or with a low-energy cooling system such as evaporative cooling, then the overall energy for cooling will be significantly reduced. This strategy directs the designer to consider arranging spaces that have similar cooling needs and occupant schedules together in zones of the plan or section. Its consideration begins with ENERGY PROGRAMMING. If these spaces are in the same zone they can employ the same energy efficient design strategies to maintain the space's comfort. In ENERGY PROGRAMMING, spaces are categorized by allowable temperature range, internal rate of gain and occupant density.

4. **STACK-VENTILATION ROOMS:** In almost all climates natural ventilation will provide some or all of the cooling for some portion of the cooling season or for some portion of the day. It is like throwing money away not to employ it. In a significant number of climates, the wind is calm for portions of the day, so CROSS-VENTILATION, while effective when the wind blows, does not always work. In most cooling climates, temperatures during the summer afternoon will be too hot for the outside air to provide much cooling. In such cases, NIGHT-COOLED MASS strategies will often work well, but winds tend to be most calm at night. For all these reasons, we recommend stack-ventilation for almost all passively cooled buildings. This strategy directs the designer to consider the sectional quality of the building to enhance this gravity-driven ventilation system. In a room cooled by stack-ventilation, warm air rises, exits through openings at the top of the room, and is replaced by cooler air entering low in the room.

5. **LAYER OF SHADES:** One of the greatest design opportunities in hot climates is to expand the idea of the envelope from a thin construction to a broader spatial zone of elements. Solar heat gain on the roof is greatest in the middle of the day, when the sun is overhead in summer. In most hot climates, the sun is high enough in the sky for much of the day that a horizontal structure of overhead elements is effective at shading outdoor spaces, roofs, or entire buildings. This strategy gives recommendations for the size and location of overhead shades. On east and west walls in very hot climates, consider the related DOUBLE SKIN MATERIALS strategy.

In addition to the five core strategies applicable to all buildings, these strategies will apply to most buildings in hot-arid climates:

- SHADY COURTYARDS offer a relief from intense sun. Their proportions are influenced toward shade rather than wind, as in hot-humid climates.

- EVAPORATIVE COOLING TOWERS, not a viable option in an already humid climate, work well in arid conditions by using gravity to drive airflow without wind or fans and to cool and humidify air. They can cool when the air is much too hot for natural ventilation cooling alone.

- NIGHT-COOLED MASS ROOMS are a great fit in arid climates where temperature ranges tend to be high and connect the comfort zone. This is a good combination with evaporative cooling, which can be used to supplement mass cooling or can be used during the day, depending on conditions.

- MASS ARRANGEMENT assures that thermal mass for cooling is located where it can absorb the most heat during the day and give that heat up to ventilation air during the night. The location of massive and non-massive elements can be a major driver of building order.

Italian example

Mario Cucinella architects designed a prototype design for an experimental office building in Catania, Sicily, as part of the EU's passive downdraft evaporative cooling research project (ford et al, 2010). The building is organized into cooling zones with spaces clustered around a series of central cylindrical, glazed downdraft evaporative cooling towers that function when the air is too hot outside for natural ventilation. The cooling towers can also operate as updraft shafts for stack-ventilation rooms during the day when outside air is cooler than inside or at night while employing night-cooled mass.

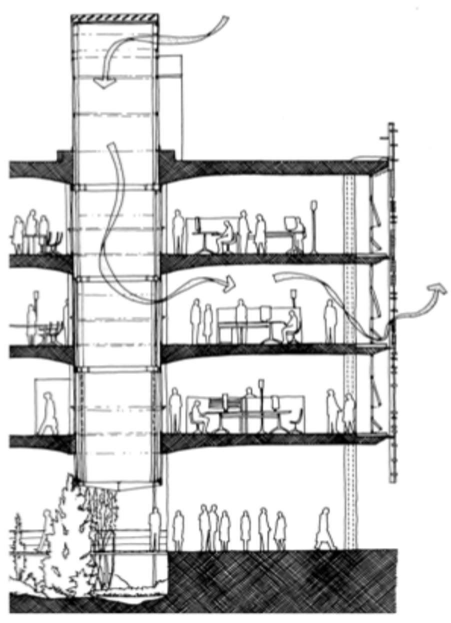

Figure 3.6. Evaporative cooling towers, Experimental Office building, Catania, Sicily, mario Cucinella Architects, 1998. **Source:** from Sun, Wind and Light, architectural design strategies.

The building's mass arrangement is in the form of concrete floors and ceilings. The ventilation openings arrangement was carefully studied with predictive models to provide the proper and controllable amount of cooling to each floor and zone. A layer of shades over the entire building reduces solar gain to the roof and provides a shady/breezy roof terrace (locating outdoor rooms), while the raised building provides a shady cooled garden below (shady courtyards). The building is predicted to use only 15% of the cooling energy of a conventional office building (Cucinella et al, 2004; Cucinella, 1998).

3.4.2.1 Hot-Arid Situational Strategies

In addition to the five core strategies applicable to all RESPONSIVE ENVELOPES, these situational strategies will apply to most buildings in hot-arid climates:

- MASS ARRANGEMENT: To support NIGHT-COOLED MASS requires large surface areas of thermal mass located where it can absorb heat and be cooled by night ventilation. For cooling, mass is best placed in the ceiling or walls.

- THERMAL MASS: Mass surface must be sized to store adequate cold. Since its area is often twice that of the floor area, some or all of the mass will be in the envelope.

- EXTERNAL SHADING: To reduce high solar load and make passive cooling possible, external shading is required. Fixed external shades can be combined with movable external shades for the swing seasons, or combined with movable INTERNAL OR IN-BETWEEN SHADES.

- VENTILATION APERTURES: Natural ventilation alone can often handle the cooling load for many months. Many hot arid climates are moderate for all but a few weeks. During more extreme periods, CROSS-VENTILATION ROOMS and STACK-VENTILATION ROOMS can support NIGHT-COOLED MASS. In buildings with EVAPORATIVE COOLING TOWERS, ventilation apertures will be used for outlets only.

- EXTERIOR SURFACE COLOR: More than in any other climate, the color and materials of the outside skin in hot- arid climates can contribute to comfort, in this case by reducing solar gains and quickly releasing absorbed heat.

3.4.2.2 Hot-Arid Refined Strategies

- REFLECTED SUNLIGHT: Hot-arid climates tend to have bright clear skies in which daylight from the direct sun or bright sky can come with a heat gain liability. Using reflected lighting strategies can provide a cooler light and works better here than in a more diffuse overcast sky.

- DOUBLE SKIN MATERIALS: Hot-arid climates have intense east, west and overhead sun in the summer (or all year in the tropics). A ventilated double skin strategy works particularly well here and can eliminate the solar load on opaque envelope surfaces.

- DAYLIGHT-ENHANCING SHADES: Because a good passively cooled building will have extensive external shading and because the outside sky is bright, glare can be an issue. This strategy resolves the tensions between shade and daylight.

South African Example

In the sunny, semi-arid climate Johannesburg, South Africa, Jo Noero's **Nxumalo House** organizes the sunny north side with deep attics protecting the upper floor glazing, and on the lower floor, louvered vents (VENTILATION APERTURES) and an external trellis (LAYER OF SHADES) (Noero Wolff, 2012), The majority of openings are on the easily shaded north and south exposures, while east and west windows are kept small (WELL-PLACED WINDOWS). Small awning windows on the top floor and high louvers on the lower floor provide VENTILATION APERTURES. When more airflow is needed, larger awning windows on the top floor and glazed doors below the trellis can be employed. Daylight is provided by fully shaded clear glazing on the upper floor, the louvered apertures above the trellis, and the larger glazing beneath the trellis (DAYLIGHT APER- TURES). Unshaded portions of the wall are insulated and opaque (SKIN THICKNESS). Winters are sunny but mild, so partial sun is admitted when the sun's altitude is lower [(APERTURES).

In contrast to the Murcutt building, each opening serves more than one purpose (SEPARATED OR COMBINED OPENINGS). The EXTERIOR SURFACE COLOR is white stucco on the lower floor and natural wood below the windows of the second floor. Because windows are well-shaded, they can be made of clear glass to admit more cool daylight (WINDOW AND GLASS TYPES). The deep shading means that most of the interior light comes from REFLECTED SUNLIGHT. THERMAL MASS is located not in the north envelope, but in the massive floor and EARTH EDGES on other orientations.

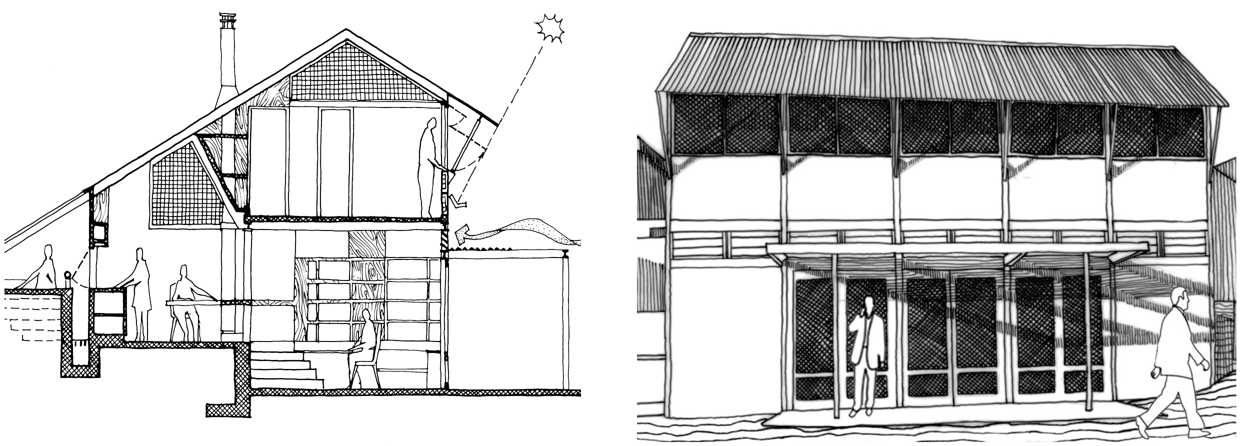

Figure 3.7. *Nuxmalo house, Johannesburg, South Africa, 1998, Joe Noero architect,* ***Source****: Sun, Wind and Light, architectural design strategies.*

4 The context, tradition and modernity in Iran

A new age in Iranian architecture began with the rise of the Islamic Revolution. The political and social events of 1979 created a rupture between architecture before and after the Revolution. The special and unique characteristics of the Islamic revolution of Iran and the historic background of this country culminated in the comprehensive tendency to the revival of Iranian and especially Islamic patterns at so many fields, particularly the art and architecture.

Many studies attempting to create the architecture with an Islamic-Iranian identity is perceivable in today's architects comments and thoughts; but they have not been so much successful in connecting their theory to the practice.

Contemporary Iranian Architecture is one of the most controversial issues in the recent decades in this country. Most architects or architecture critics in accordance with their definite approaches have categorized the existing trends. Certain pluralism and variety of point of views are the special features of architecture after the Revolution.

On one hand, creating the architecture to correspond with the values and ideals of Islamic society was an essential element in this period; On the other hand, western-influenced trends like Post- Modernism and Deconstructivism also played a role in today's trends and categories, ranging from:

1. Revitalization/Rejuvenation of traditional patterns.
2. Eclecticism related to western post-modern architecture.
3. The permanence of Modern architecture.
4. Creation of a dialogue between Iranian architecture and world architecture.
5. Scientific-functional trends (abstracted from the environment)

The last category seems to be the less known but yet influenced on worlds trends, that taken in to consideration carefully in most cases, it was one of the major issues on developing ancient settlements, vernacular architecture on the other hand have been tested through time and acknowledged by many to meet human comfort and coop with environment in a passive an reciprocal dialogue, nevertheless using renewable sources of energy has been widely neglected. As an example we can consider the case of a great researcher André Godard, who was employed by Shah to develop the basic plans of University of Tehran's complex in the first Pahlavi period, ignoring Tehran's climatic condition and intense sun radiation from west direction.

Iranian Islamic traditional houses have changed fast in recent decades. These changes have had influence on social lifestyle and relationship behavior of people. The traditional architecture of Iranian housing for instance used to include a courtyard surrounded by rooms which in addition to climatic well-being and joy of internal green, controlled privacy, movement and separated people in different situations. In contemporary housing however, this cultural behavior has been lost.

4.1 Iran's geographic and climatic conditions

The geographic conditions of each region are the factors that affect the climate elements of that region. Latitude, altitude, and distance from sea or ocean are geographic conditions, considered as climatic factors that affect the climatic elements. These elements are the amount of solar radiation, temperature, humidity, precipitation and also wind intensities and directions.

The Iranian plateau is situated in a dry geographic region. The dry climates of Northern Africa and the Middle East continue into Iran and the central Asia, with the result that average precipitation in Iran is less than the global average.

Even though Iran is generally classified as a dry country, in fact it is climatically diverse and can be divided into four main climatic regions:

1. The northern coastal region-temperate climate
2. The central plateau region-hot and dry climate
3. The mountainous and high plateau region- cold climate
4. The southern coastal region-hot and humid climate

The first region stretches along the southern coasts of the Caspian Sea, has the highest level of precipitation in the country, very dense forests in its highlands, and its lowlands have been used intensively for agriculture. It is cold in the winter and hot and humid in the summer. Average annual precipitation is between one to two meters, and relative humidity is above 70% percent throughout the year [3]. Average temperature is between 14.5° to 18° C and the temperature fluctuations are between 25° to 35° C [4].

The central plateau is the biggest climatic region in terms of surface area, it is cold in the winter and hot and dry in the summer. Average annual precipitation is between fifteen to thirty centimeters, and relative humidity is about 20% in the summer and 60% in the winter. The two large central deserts of Dasht-e Kavir and Dasht-e Lut, which comprise one seventh of the total area of the country, are in this region. Average temperature is between 19° to 23° C and the temperature fluctuations are between 35° to 42° C.

The high mountain ranges of Alborz and Zagros are situated to the north and the west of the country. This region is cold in the winter and mild and dry in the summer. Some of its mountain peaks such as Damavand and Sabalan are snowcapped all year round. Average annual precipitation is about thirty centimeters. Average temperature is less than 11° C and the temperature fluctuations are between 35° to 42° C.

Relative humidity is 35% in summer and minimum of 50% in winter. The hottest region of Iran stretches along the coasts of the Persian Gulf and the Sea of Oman. It is mild in winter and hot and humid during its long summer months. Its average annual rainfall is less than twenty centimeters, and the relative humidity is above 50% throughout the year. Average temperature is between 24° to 27° C and the temperature fluctuations are between 19° to 31° C.

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[3] Some of the information in this chapter has been taken from Ghobadian, Vahid, 2009.

[4] Other source of climatic information was found in Tahbaz, Mansoureh and Djalalian, Shahrbanoo, Architectural Design Principal Compatible with Climatic Conditions of Iran, 2009.

Average annual precipitation is less than twenty centimeters, but sometimes the amount of one-month rainfall will happen in one day so precautions should be taken to prevent floods. A very important aspect of almost all traditional buildings in Iran is the adaption of their physical form to their natural environment and climatic conditions.

4.1.1 The central plateau region- hot and dry climate

The central plateau covers a large section and eastern parts of the country, the two great barren deserts of "*Dast-e-Kavir*" and "*Dast-e-Lut*" are located in this region, which receive very low precipitations throughout the year, very little vegetation is found. Around this desert areas there is also low population density; only some small villages in or around them.

There is relatively higher temperature with higher rainfall density on the perimeters of the two deserts and their surrounding hills. This region is a very difficult place to live, however traditional builders and architects had come up with successful solutions for human comfort and building shelters. One of the most outstanding examples is undoubtly the solution for obtaining water; In the early part of the first millennium B.C., Persians started constructing elaborate tunnel systems called "*Qanats*" which were a series of well-like vertical shafts, connected by gently sloping tunnels, coming from the upper parts of the mountains down to the human settlements, creating a reliable supply of water.

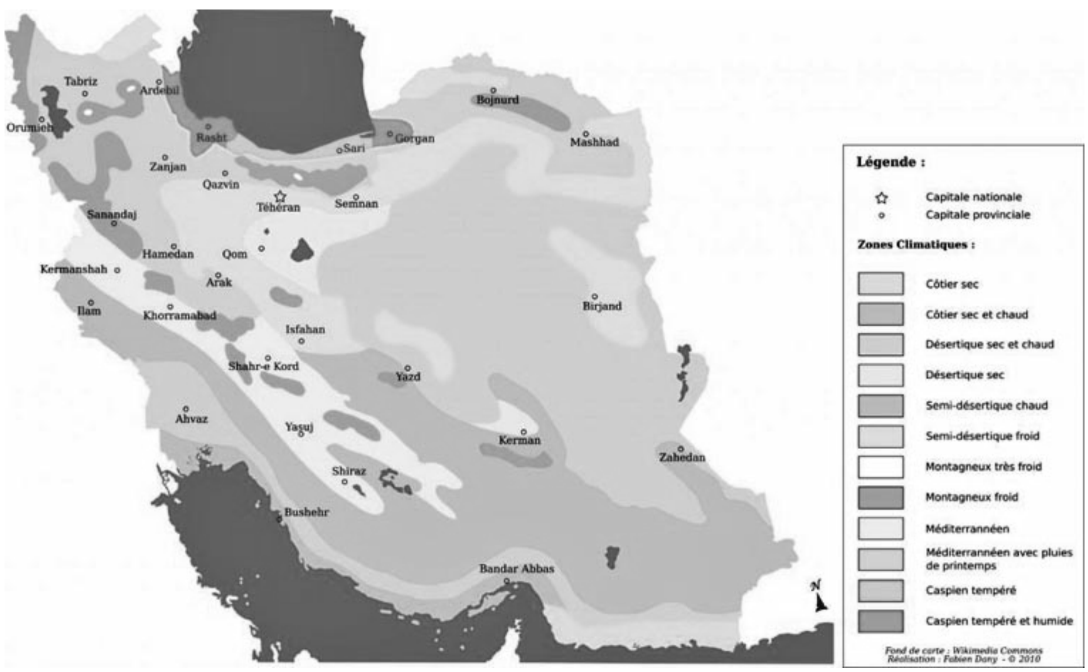

Figure 4.1. *Iran's climatological situation by regions, notice the location of the city of Yazd in the central plateau, in a dessert hot-dry weather.* ***Source:*** *carte des zones climatiques en Iran, Wikimedia.*

5 Iran's Cities morphology and the physical environment

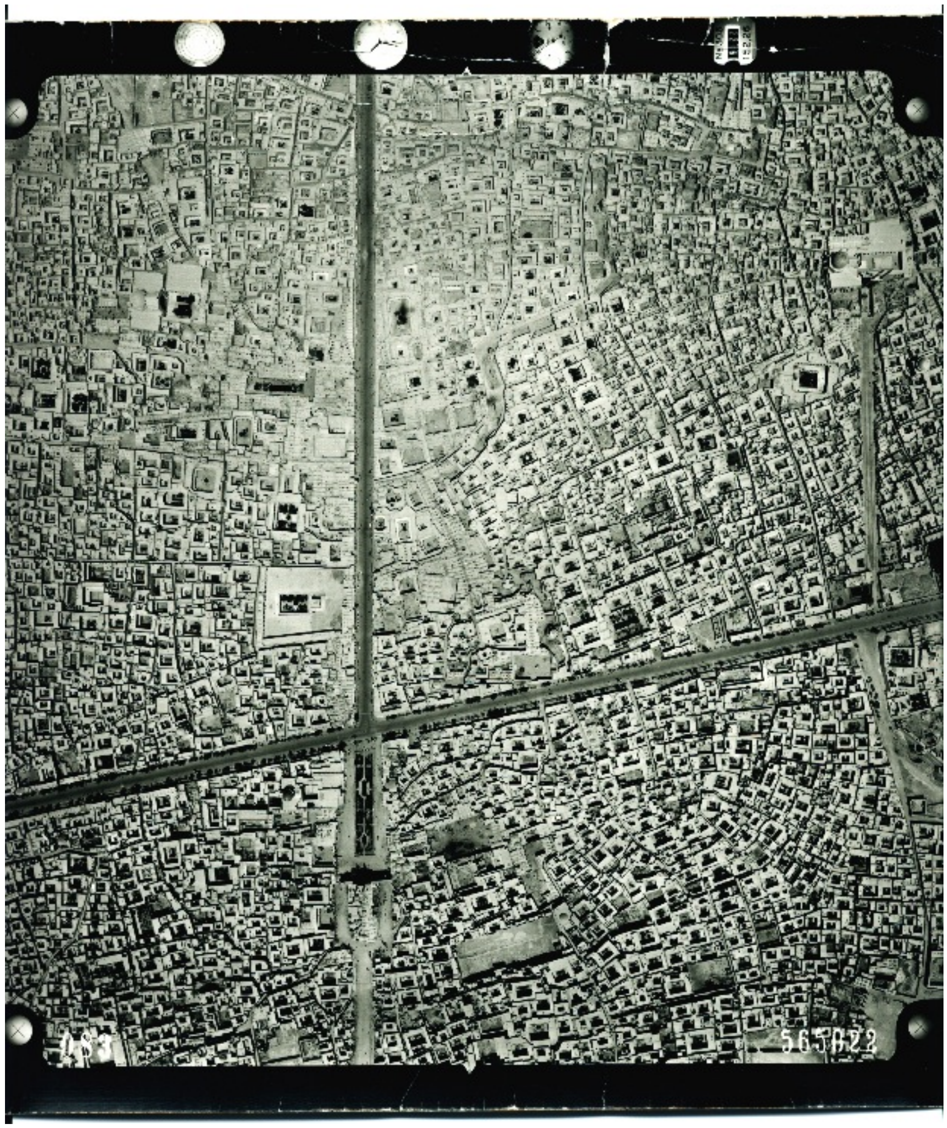

Figure 5.1. *Aerial view of Yazd Old town city structure, notice the dense and complex city tissue.* ***Source:*** *taken in 1922.*

The physical morphology of the traditional Iranian cities are in great extend due to a cultural-historical response to the natural environmental conditions, especially when concern to the Central Plateau, with the exception of two narrow regions, one along the Caspian sea and the other along the western slopes of the Zagros mountains, Iran is an arid country.

Its extreme climatic conditions are characterized by a shortage of water, higher evaporation than precipitation by this resulting in a low humidity, intense solar radiation specially during summer days, high diurnal and seasonal temperature ranges, torrential but sporadic precipitation and damaging desert dust and sand storms.

Though the millennia, the urban form of Iranian cities developed to cope with such climatic conditions, to adjust and deal with to the hostile climate, traditional Urban planners learned to minimize the direct impact of solar radiation, soften the blow of harmful and unpleasant winds and to optimize the use of shade, breeze and water. This main objective on the Urban strategies for planners and builders were achieved by adopting a compact urban form, developing special streets and alley patterns and enclosing the living spaces into a courtyard house typology[5].

In contrast to modern Iranian cities morphology, which are simply copies of the diffused European and American contemporary cities, the traditional Iranian city is a concentrated homogeneous built up, combining diverse land uses in a tight relationship with each other.

While the primary reasons for the development of the early compact cities may have been the need to defense, social cohesiveness land conservation for agricultural use, and optimal size the compact system as the dominant urban form in arid regions of Iran, probably has been maintained as a result of its climatic advantages.

The advantages of a compact urban tissue can be resume as:

1. Reduction of direct solar radiation and evaporation.
2. Minimizing of heat gain during the day and heat loss at night.
3. Shade provision and cooler air flow gain.
4. Eases human movement and socialization.
5. Controls undesirable winds and harmful effects of dusty storms.

In addition to responding to the climatic stress, a compact urban system offers other advantages to the city dwellers like a noticeable reduction of the infrastructure network and transportation, minimizing energy consumption and air pollution. The heat island effect is minimized by the fact of reduction of large empty spaces unless shades by trees or contains a body of water.

The height of buildings in the city is mostly uniform (with exception of mosques and minarets) throughout the city, allowing free movement of air above the city reducing turbulence and unpleasant dust storms. Streets and alleys within the city also function as channels for air movement and heat exchange, narrow streets and alleys, surrounded by tall walls oriented toward pleasant winds are well shaded during hot summer afternoons.

Covered bazars and enclosed passageways protect people from hot sun, turbulent winds and torrential downpours, linear bazars are usually covered by a series of mud domes and its floor level is lower than neighborhooding areas creating a flow of cool air into the bazar (cool air is denser than warm, so it descents), resulting in a more comfortable environment.

The water supply made through "*Qanats*" made the life and formation of cities possible throughout most of the Iranian Plateau. At the city scale water often defined the order of main access networks. Also used as a cooling element, often appearing in form of "jubs"(open ditches) running along the streets and center line of alleys, giving also appeal to the city, wherever possible streets where lined with trees, receiving water through this jubs, water appear as forms of pools at the center of court yards, for evaporative cooling as well as recreational purposes.

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[5] Masoud Kheirabadi makes a series of researches on the matter of Iran's cities development in 1951 and post it on the book "Iranian Cities formation and development".

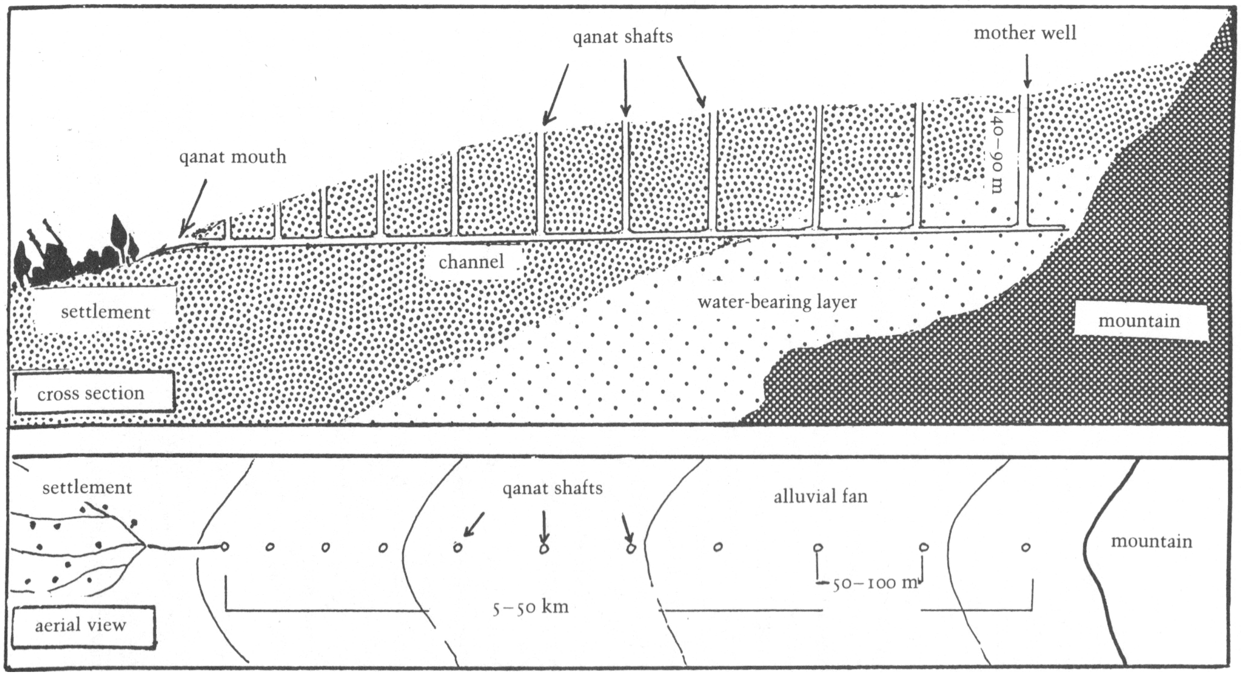

Figure 5.2. *Diagram section and plan of a typical Qanat.* ***Source:*** *Iranian Cities, formation and development.*

6 Learning from the vernacular

Vernacular and indigenous traditions are often assumed to be grounded in the type of practices that produce sustainable built environments. They describe how the theoretical tradition that connects climate and the vernacular has often held that architecture originated as a product of necessity and not as a product of aesthetic requirements.

Nezar AlSayyad and Gabriel Arboleda

Since the primetimes of society when human kind change the methods of meeting their needs for food provision passing from being collectors to become farmers, from nomadism to sedentary, the urgent need to provide shelter in every condition forced people to use their surrounding environment and available materials as construction method to build their own settlements. Vernacular building and skills in general terms usually has been referred to as "indigenous knowledge", this know-how passed from generation to generation by practice and tradition, adapting the building object with the surrounding ecosystem and urban tissue, generating identity and social acceptance.

Vernacular architecture consists of the dwellings and other buildings, related to their environmental context and available resources; they are usually self or community built, using traditional technologies. All forms of vernacular architecture are built to meet specific needs, accommodating the values, economies and ways of living of the cultures that produce them.

Vernacular identifies buildings as social representations and links them to coherent cultural systems of values and beliefs. Taking a look into traditional technics may help us to identify how vernacular architecture may play an important role in current and future attempts to create appropriate and sustainable built environments, to do so we shall see these indigenous knowledge as processes that dynamically and interdependently relate, evolving and transforming over time while remaining distinctive to a specific place. Understanding the vernacular as part of the traditions of certain community, thus as something not fixed but by the contrary, a social construction that can evolve and be renegotiated in every generation and every single community.

There is an interplay still to be done in contemporary architecture and development, thus as how the experience, knowledge and skills of the vernacular builders all around the world, can still have an important contribution to make to the creation of the sustainable settlements and buildings needed in the future, as well they may also have a lot to learn from the technologies, skills and knowledge common to contemporary, modern architectural and building practices.

There's been an arising awareness on the importance of the conservation of architectural heritage in the last fifteen years or so, many decision makers have come to realize that the cultural identity they are so proud of, is clearly related to the architectural heritage and vernacular settlements we have been losing. Unfortunately, in most cases, what have been selected for conservation are the physical shells of the traditions, rather than the cultural values and practices underlying them.

Architectural heritage is considered a fundamental issue in the life of modern societies [6]. In addition to their historical interest, cultural heritage buildings are valuable because they contribute significantly to the economy by providing key attractions at a time when tourism and leisure are major industries.

[6] Isfahan`s dovecotes: remarkable edifices of Iranian vernacular architecture Aryan Amirkhani, Parham Baghaie, Ali Akbar Taghvaee, Mohammad Reza Pourjafar, Mojtaba Ansari, 2009.

The need for preserving historical constructions is thus not only a cultural requirement, but also an economical and developmental demand.

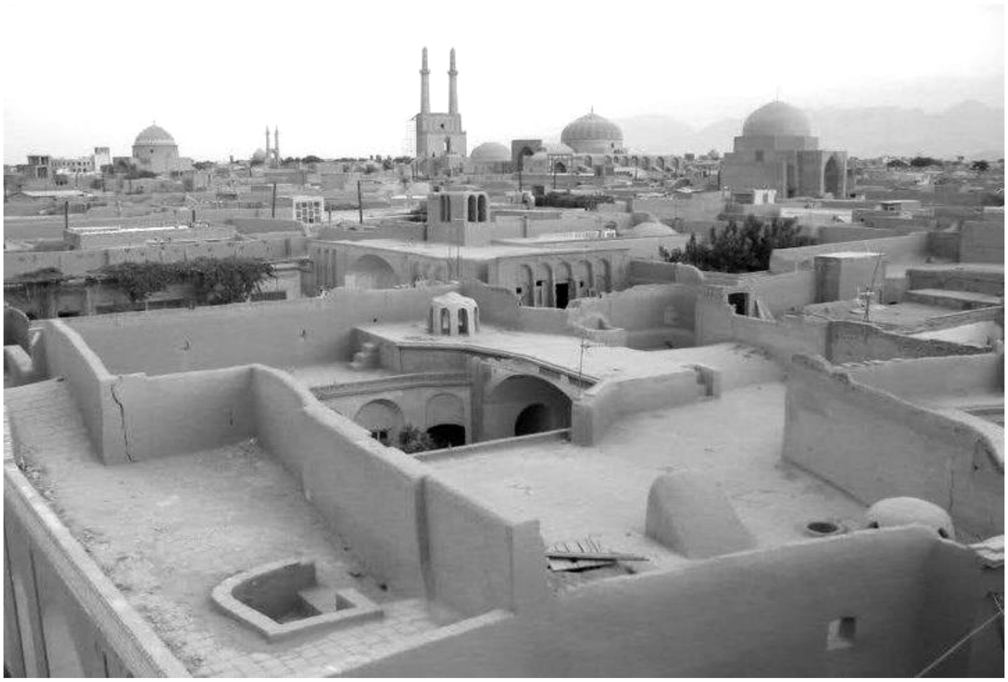

Figure 5.1. *Aerial view of Yazd and its traditional architecture.* ***Source:*** *Iran daily online publication.*

6.1 Urban and Neighborhood Macro-strategies

Choosing an adequate urban site after a conscious analysis of transportation systems, functions and services around it, with the possibility to be reached from the major business district thus well inserted into the urban tissue, will also guarantee the social and local acceptation in a sustainable and prolonged term.

It's crucial in order to obtain the desire comfort on the building to implement some basic passive strategies based on the study of the weather, wind and sun behavior directly on the site. A good east – west orientation of the building will minimize percentage and incidence of solar radiation, as well as a correct analysis of openings, sizing and location and the study of some other elements like window louvers will help achieve the best performance from ventilation while shadowing the glassed elements of the building. Good distribution of the interior living spaces, naturally ventilated and illuminated according to the activity developed on it, is overriding for improving comfortable healthy living environments.

Non single element can be neglected or left to chance in a location with such strong characteristics of weather, climate and social values, thus having a holistic approach of the urban blocks and its organization in the site will help obtain the best achievements and seize of the natural elements to produce the desired comfort and reduce the heat island effect thus improving the social life and urban value. According to different studies and recent research papers [7] having a discontinuous urban texture with difference on height, improves the airflow and wind exchange, decreasing the turbulence and harsh air speed, while creating a good visual effect avoiding the monotony of an equal profile.

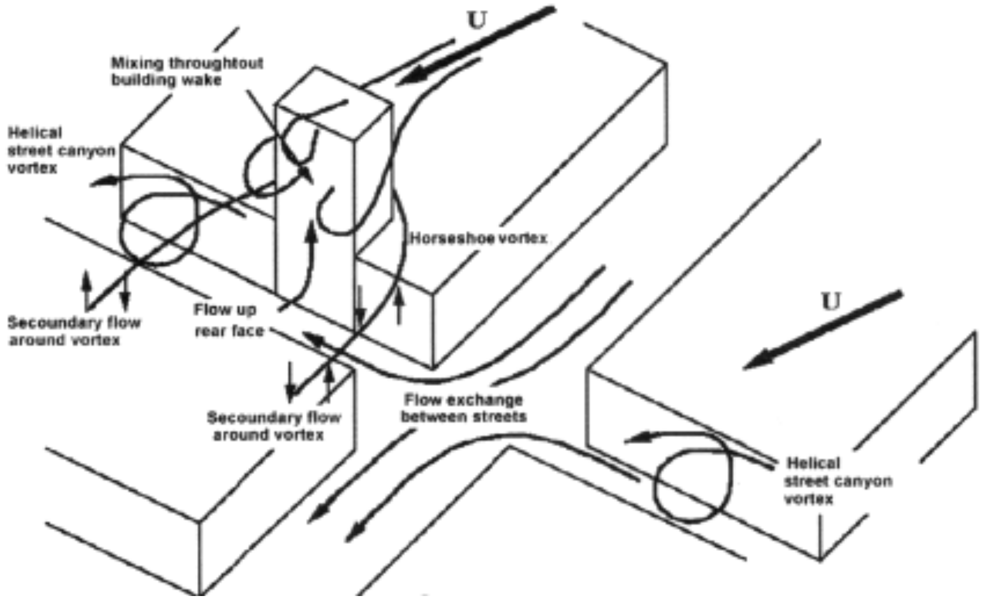

Figure 5.2. *Ahmad Okeil concludes that Tall buildings would cause additional vertical flow down from the urban boundary layer into the urban canopy layer…air exchange between streets and courts is enhanced by providing adequate apertures between these spaces.* ***Source:*** *Research paper "A holistic approach to energy efficient building forms".*

A careful analysis on different archetypical building forms demonstrate that for a hot arid weather the best fitting shape for its environmental performance is the courtyard [8], given that its interior generates a microclimate with higher natural ventilation that improves the qualities of the living spaces if well used and oriented, besides offering a better land use, because it only requires the 30% of height to fulfill the area if compared to a compact block or pavilion; no wonder why locals have used this archetype for centuries on its vernacular way to produce settlements in the region.

6.2 Typological Housing a matter of identity

Producing contemporary architecture in a context where the lacking of space and the high cost of the few empty ones, gives another challenge that has to be analyzed without neglecting the importance of

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[7] In "A holistic approach to energy efficient building forms", a research paper by Ahmad Okeil concludes that "Tall buildings would cause additional vertical flow down from the urban boundary layer into the urban canopy layer…air exchange between streets and courts is enhanced by providing adequate apertures between these spaces

[8] The article "Building form and environmental performance: archetypes, analysis and an arid climate" compares and analyses two different archetypical building shapes and its behavior on hot weather conditions, the courtyard and the pavilion, concluding the courtyard as a optimal archetype for hot- arid conditions.

the social and urban traditions of a city with very strong roots on its history and the vernacular relevance of its architecture.

In every traditional society heritage plays a significant role in achieving sustainable development, Iran is a vast country with different climatic zones, and each one of them has developed a different type of vernacular approach to meet the logical solutions in order to enhance human comfort. Yazd masons and builders set different techniques and passive strategies to coop with the harsh conditions of the existing climate.

The greater challenges for Yazd inhabitants are: the burning sun, excessive heat, high temperatures during the day even over 40º C and low temperatures at night (specially during summer), very hot summers and cold winters, high dehydration or arid weather due to very little rain fall precipitation throughout the year and eventually sand storms; all of this features describe the scenario the people and builders of the city faced since foundation in addition to the necessity to defend against enemy attacks.

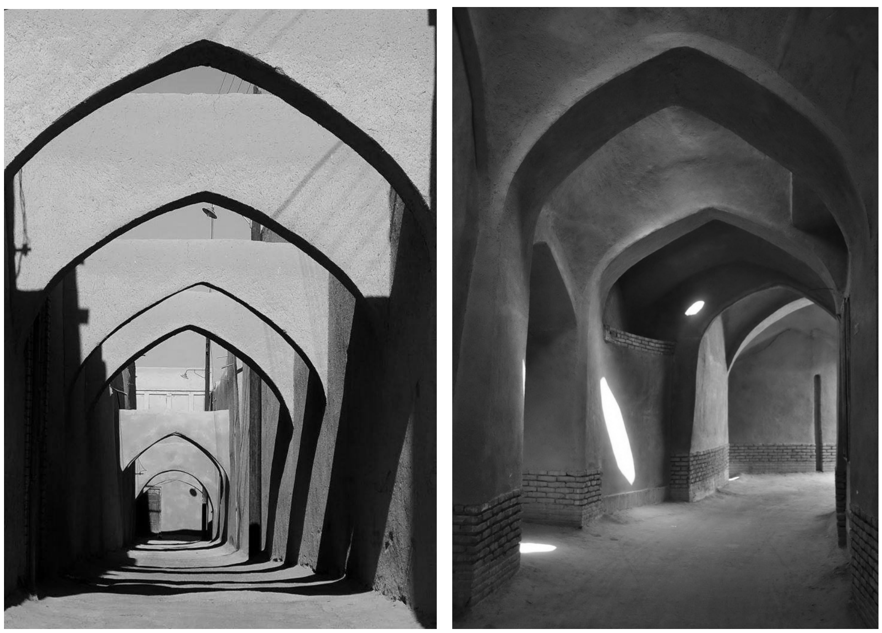

Figure 5.3. *Yazd alleys are built to keep the most comfort to the pedestrians by casting shadows and most of times oriented to conduct the wind flows.* ***Source****: Panoramio, google maps, taken by Parastooo.*

All of this different conditions made of Yazd urban tissue to develop on a dense and complex matter, with narrow alleys and high closed walls often partially covered *Sabat* to cast the most shadows, pedestrian sidewalks were mainly constructed east-to-west direction covered from the sun and expose to wind flows, providing favorable conditions even on the hot summer days.

This type of close dense settlement permit not only having outdoor protection against solar radiation but also some fresher sides of the housing interior due to a lesser exposure of the facades to the sun and therefore less heat transmission by conductivity. In order to prevent sand dust and excessive radiation from exposed openings as well as creating more private interiors by cultural reasons, windows and openings to the exterior of the buildings are usually placed in the ceiling or high up on the walls, most of the house openings face the protected central courtyard area, which generally enjoy better conditions and a more favorable environment by the microclimate generated in them.

Yazd as many historical cities around the world was raised up from what the ecosystem had to offer, and what a better material than the earth, mud construction is by far one of the most practical building techniques, not only for its availability, but also for its thermal capacity and low conductivity, for it takes longer periods of time for the heat to pass through the walls to the indoor spaces.

Almost any type of mud can be used as construction material, it only takes to be stabilized with little compounds and in most cases there is no need for any treatment. Adobe and rammed earth construction provides good conditions on dry hot weather not only for its conditions but due to technical aspects of the building process, the wall thickness (40 to 60 cm) generates an excellent thermal mass. As finishing of the building envelope, the surfaces are cover by plaster, raw clay and hay to give a smooth and glossy effect with light colors that help reflect sunlight.

6.2.1 Yazd house typology -The Courtyard House

Based on the question, what building forms make better use of land? Researchers on the 60s addressed the analysis of the subject and their findings led to a number of influential papers on urban planers and subsequently on architectonical designs, this findings not only prove the courtyard as a best fitting typology in land use, but later demonstrated its value on the matter of environmental and energy terms when examined and compared the impact of the geometry on the energy behavior of this archetypal by testing it on modern computer techniques.

The Archetype buildings of this area were all inward orientated, by this meaning that all opening except the main entrance, would face the central courtyard. The main reason was to protect the building against sand storms or prevailing winds. Abundant literature claims that courtyards are environmentally responsive building forms on hot arid climates, due to its introversion of functions enhanced by ingenuous natural cooling strategies, bringing protection against wind blown dust and mitigation on the effects of solar radiation caused by the higher shadow casting alone.

Figure 5.4. *A traditional Yazd house, where every space in the house radiates into a central courtyard.* ***Source:*** *out there somewhere, taken by Chris.*

6.3 Traditional housing analysis

Most of the traditional houses in Iran, especially luxurious ones, have an element called "*Sar-Dar*", actually in order to access the house one should go through this *Sar-Da*r which in most cases has Islamic and traditional decoration. After passing Sar-Dar there is a space called "*Hashti*", this space used to be designed in different shapes, like octagon, hexagon, square, and rectangle. *Hashti* is a waiting and division space where people who want to visit the landlord of the home should wait in.

"Rahrois" is a roofed and narrow space, which connects *Hashti* to courtyards in "*Andaruni" and "Biruni"*. *Andaruni* is a space of the House in which the private quarters are established. In this part of the home women are free and they can stay without observing dressing codes. In other words *Andaruni* is a private part of the house, *Biruni* is a public part.

After main entrance door there is a small lobby that would lead to the central courtyard. This lobby is called "*Hashti*". All the spaces of the house are arranged around an open rectangular courtyard that links the different areas of the house. The arrangement follows certain geometrical rules. According to Haji-Qassemi, this geometry not only defines the general body of ensemble and gives shape to its every single detail, but also imposes a hierarchy to its different areas, which determine their locations and relationships in accordance with their character and importance. While harmoniously connected to each other in the design, the areas of the house enjoy of complete independence and are always separated from others by intermediary areas[9].

In order to increase ventilation and fresher the air during summer some wind towers were implemented, which brought air from the outside into the buildings and courtyards. Basements were used in summer because of their relative coolness compared to upper floors because of the thermal mass of the earth around them.

The ground floor of the building is usually lower than the street level; this was because the water channel was build in a way to transfer the water using the gravity force. Masonry usually adobe or brick vaults or domes were the best way of roofing in buildings in accordance of the lacking of vegetation. Thick walls with high thermal mass were built in order to protect the buildings from the harsh weather and minimize the temperature fluctuations, also to carry the heavy load of the domes or vaults and the wind towers.

A commonly used term in Iranian architecture is "Four seasons houses". In traditional building in general and in traditional houses in particular it was very important to adapt everyday living habits to climatic conditions in order to bring comfortable conditions for inhabitants. During the winter, the northern part of the house which receives direct sunlight and heat through the central courtyard was used as the family living quarter. The southern side of the house which was always shaded was used during the hot months of the year.

There was often a basement below the summer side and the shaft of the wind towers was connected to the basement. The activities in summer would move to the courtyard from dusk to dawn. The plants in the courtyard would be watered in the dusk to cool the courtyard and provide humidity for the

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[9] Haji-Qassemi, 2003.

inhabitants to stay there. After dawn the occupants would return inside again, at this time the building fabric loses much of its heat from the day sunlight.

Since all the buildings in this area were inward orientated the need for cross ventilation and fresh air was provided with the use of wind channels and wind towers. The cool summer breeze would enter the building from the wind tower and directed to the building. Sometimes a small water pond was placed under the shaft of the tower triggering the cooling and humidifying of the incoming air.

It is common the use of clay as it was the most plentiful, cheap and available material on the region, three common building materials: mud, adobe and brick are made of clay. Almost every part of the buildings was built with these three materials. Some of the main advantages were the high thermal capacity, which minimize the temperature fluctuations inside the building, High structural capacity to carry the loads to the foundation which were made of stone and lime mortar. Only the frames for the building opening were built with timber.

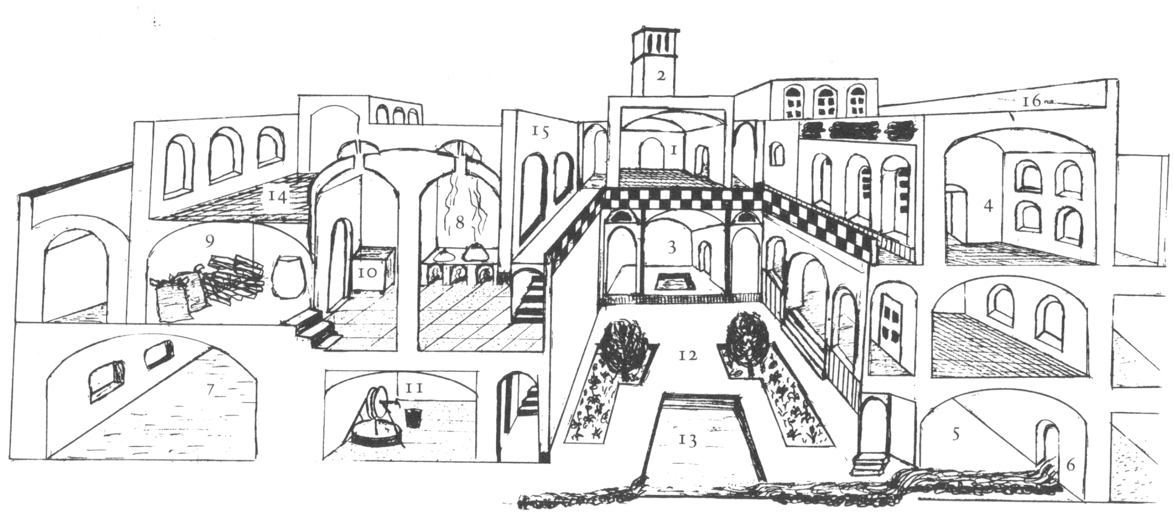

Figure 5.5. *Diagram section of a typical wealthy family's courtyard house and its elements.* ***Source:*** *Iranian Cities, formation and development.*

6.4 Architectonical bioclimatic elements

Building orientation, method of communication with ground, introversion and closure, wall thickness, height of rooms and applied materials, play an important role on sustainable bioclimatic construction on traditional Yazd. The most important architectural provision elements found in buildings of the area that play an important role in the provision of resident's comfort conditions are:

6.4.1 Ivan (lobby or porch)

In contemporary buildings, closed spaces are located immediately after the outdoor or entrance, however in traditional Iranian buildings there is always an interface called "Ivan", a semi-open space which links the closed spaces to the outdoor environment, light and climate. The least kind of such a space is an Ivanche or arcade, which is generally situated in lower parts of the building or formed between the rooms and the courtyard and in combination with door and windows or around the courtyard.

The best-known semi open space is Ivan, which has one open side overlooking the courtyard, two semi open sides and one closed side. The close side is linked to "*Shahneshin*", which can be integrated into this main room by openings, doors and windows. The two other sides are mainly connected with transition areas.

Regarding spatial organization, *Ivan* is along the open and closed spaces, which preserves the spatial hierarchy of the building. Moreover it helps creating thermal comfort conditions to adjacent indoor spaces. Facing south and east, Ivan would be more efficient in winter; while more proficiency could be resulted in spring and summer when facing north and the latter is way more used in most parts of Iran.

As previously mentioned, converting an open space into a semi open one, results in a significant modification of indoor air temperature of rooms. *Ivan* was mostly located in summer spaces of the building, facing north and back to the afternoon sun and always shaded. Consequently, the temperature of one side of building is lower than other sides and also the courtyard; this difference of temperature between semi open and open space leads to a gentle airflow from the courtyard, making *Ivan* a usable space in summer and providing indoors with favorable thermal comfort.

Ivans used to function as a place for living and resting during the day, sleeping at night, having dinner and breakfast, guest gathering, pass ways, linking the rooms and also the seize of the view of sky and courtyard.

6.4.2 *Godalbaghche* (deep pit yard)

Its no secret that courts become microclimates that improves the interior behavior when is well used, bringing natural comfortable ventilation to the interior spaces, but also limits the extreme temperature stress or high differences on temperature changes from day to night time, experimented on hot arid regions like the one in Yazd.

In traditional Yazd housing is common to find very deep courtyards with the interior spaces of the building and openings surrounding it, this typology is called *Godalbaghche*, Increasing the height of the walls on the interior yard, increases the shadow casting and helps to keep for longer daytime hours the cool air that settles down at night, becoming an excellent thermal regulator by the existence of a water pool and vegetation that increment the air humidity which makes the indoor spaces more comfortable during the summer days.

It also facilitates access to the subterranean canals that are used to water the plants and gardens in the yard as well as bringing comfort to the whole house.

6.4.3 *Badgir* (Wind catchers or wind towers)

As many literature suggest wind catchers are build purely by bioclimatic reasons, some go deep into history placing its use as an architectonical element of social distinction born when the trade for silk between China and occident placed Yazd in the mayor trading route and boost the silk industry thus the economy; hence rich merchants started to build high towers in their houses as a symbol of social and financial status.

Wind catchers are often located behind the summer space of the house or "*Cellar*" on the southern zone of the building, facing the favorable Winds called "*Isfahani*", that move towards the north-west to direct them into the interior of the building, some openings or sucking holes permit the entrance of the wind conducting it downwards trough channels in the stalk and chest of the tower into the main room, basement and the water storage of the house. It functions due to the positive and suction pressures wield by both sides of the tower, cooling the interior by convection and sometimes by evaporation of water placed on pools under the channels and forcing the warm air to exit by the suction channel on the opposite side of the tower.

6.4.4 *Sardab* (the cellar)

Sardab is a room entirely underground whose roof is a few meters below surrounding ground level. The temperature of *Sardab*'s walls, floor and roof is far less than outdoor air temperature, thus by heat radiation of occupants to these surfaces their thermal comfort would be greatly met.

In general, the release of heat into the soil and temperature changes of layers of earth follows two basic rules: First the range of circadian variations of temperature decreases versus the earth's depth. Additionally, at a definite depth into the soil, the temperature remains constant and the variation range is nearly zero. This rule is highly regarded in cellar placements underground.

In some traditional houses of Yazd there used to be a water underground channel or *Qanat* below the building. In such cases the *Sardab* provided access to this *Qanat*, where the water could enter into a small pond in a space called *Hoze-khane*, it was a covered area with a central pool, usually elevated and lit through the ceiling. The pond along with the air conducted through ducts on the wind catcher increases the humidity and cools the space.

6.4.5 Basement

Unlike the *Sardab*, ceiling of basement is above courtyard ground level, adjacent to the basement so that the windows will allow natural light into the space. At first hours of the day during warm months, courtyard becomes a place to live in, while the basement is occupied around midday. Indeed, there is a sequential movement or occupant's migration along the day, looking for comfort around the different spaces of the house.

In order to enhance the basement efficiency, the floor of *Ivan* used to be some steps above the courtyard, providing a surface suitable for ventilation openings below the summer space of the building.

In many different research projects[10] the average temperatures in basements were continuously and substantially below the mean outdoor temperature, suggesting that basements could be a permanent source of cooling and a place to seek comfortable shelter during hot summer days. Nevertheless in almost all the ground-floor spaces in which measurements were taken the mean indoor temperature was below the mean outdoor temperature. This shows that the selected buildings did reduce the temperature in the ground-floor rooms by means of vernacular passive cooling systems, but not enough to bring it down within the comfort zone.

6.4.6 Vault and dome

Rainfall lacking and wood scarcity in the deserted regions of Yazd, might be the reasons that roofs are made into arched or domed shapes using adobe and mud.

As the angle of incidence is more on curved surfaces, vault roofs are less affected by radiation heat gain, they have less heat absorption compared with flat roofs, on the other hand, as a result of its shape domes are more exposed to the wind, helping the heat loss during cool night breezes Additionally, as the intensity of solar radiation is non-uniform over the entire surface of the roof, some parts of the dome are always shaded, reducing the temperature transfer underneath the dome. The spherical or cylindrical shape of the dome causes an increase in height of the cceiling for the room below, providing more space more space for the hot interior air to raise and exit through the roof by holes placed in the top.

6.4.7 Khishkhan

Another important element of Iranian architecture in the hot and dry areas is *Khish* or *Khishkhan*, which works as a cooling instrument like a wind catcher. In order to build a *khishkhan*, a hole is first made in the roof and then covered with a small dome, with numerous holes all around, letting the air and light come into the space. Khishkhan is generally located on *Hoze-khaneh* and *Tanbi*, which function as building lobbies and have the access to other rooms. It was occasionally built on the vestibule, especially in the absence of windows. As vestibule used to function like a temporary gathering room in the past, *Khishkhans* provide air and light to it.

Khishkhans are mostly located in the southern part of the building and function through suction in order to yield better ventilation. Therefore, the space below is usually more in height, making the warm air rise and being replaced by cooler air downside the room.

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[10] From the paper “Traditional solutions in low energy buildings of hot-arid regions of Iran” by Mitra Khalili, Sanaz Amindeldar published in the journal Sustainable Cities and Society that focuses on a wide range of original high quality papers covering fundamental and applied research, critical reviews and case studies.

6.4.8 Tabeshbands (Shutters)

Different ways have been employed to control solar radiation in traditional houses of hot and dry areas of Iran. In this regard, shutters have been important elements of climatic architecture.

According to Pirnia: "*Tabeshbands* are rather thin blades applied over a window or doorway in order to shade it. A shutter mounted above the window or doorway is a horizontal one, called *Sarsaye*. Vertical shutters are brick or plaster blades between two doorways, which are sixty to seventy centimeters wide and ten to fifteen centimeters thick in order to shade windows and doorways.

Above doorways its found the *Kharakpoosh*, which is a slot decorated by plasterwork. Apart from shutter and *Kharakpoosh*, other alternatives used to be considered. It is important to notice that large pieces of glass were never used in doors or windows, instead windows used stained glass works the glass was colored in order to prevent the sunshine to some extent. At a point the method of vertical shutters shading the doorway was later change by piers with beveled edges, which would let the sunshine penetrate the room.