Chapter one

INTRODUCTION

1.1 Background

Passive heating and cooling design is the process, which benefits from the local climate and site conditions to maximize human comfort and health within a building (structure) while minimizing energy use. The key elements of passive heating and cooling design include: building location and orientation, layout, window design, insulation (including windows), thermal mass, shading, and ventilation.

So Passive cooling has become one of the important factors affecting our daily lives, especially in a hot dry climate areas, but operating costs for hardware and maintenance have made it difficult to get access to devices that meet all the requirements of thermal comfort of the user's requirements, so we began to think in sustainability solutions for the rationalization of energy consumption and cost savings for the user with continuity of access to services at the lowest cost.

passive design might not help solve 100% of the problem, but it certainly will reduce the demand for energy consumption.

The reasons why this research topic chosen are:

i- Lack of thermal comfort in most of the residential buildings in all seasons of the year.

ii- Availability of renewable energies in Sudan (solar energy), without no benefit from them in operating of the buildings.

iii-The direction of architects and urban planners to modern design, without taking into account climate design in a way that leads to the continuity of keeping the same indoor air quality in all seasons of the year.

1.2 Problem statement

The research problem is, how to apply passive cooling techniques that help in continuous cooling throughout the year and applying it in a continues form in hot dry climate areas, because home is considered a safe place for humans and therefore should provide a total heat comfort for them, especially in a hot-dry climate, which is characterized by high temperature, therefore we need to think about passive cooling solutions for homes with the lowest cost possible.

1.3 Research objectives

i-To study ways that reduce consumption and take advantages of renewable sources of energies (wind energy - solar energy, etc.) in the operation of buildings.

ii-To study methods of incorporating thermal comfort in the design stages, in hot – dry climate areas through activation of passive cooling (through the building openings and the surrounding environment).

iii- Introducing a method to improve indoor air quality in all seasons of the year, through an appropriate environmental design.

1.4 Research Methods

Various research methods are used in this research, which are illustrated in table (1) below (Table 1: Research methods used in this research), these research methods are chosen accordingly to types of data to be collected.

Table 1.1 Fields of research and data types to be collected

Source : The author

Fields Of Research	Types Of Data
Hot dry climate preview.	Literature, Description
Passive cooling ,history and preview.	Literature, Description
Sustainability concepts and history preview	Literature, Description
How to apply passive cooling and sustainability concepts in hot- dry climate (case study :greater Khartoum).	Literature, Description, , field work, Analysis and Comparison.

1.5 Research boundaries

Spatial boundaries: Greater Khartoum - Architect Osman Elkheir.

Time boundaries: June 2016- February 2017.

1.6 Expected results and achievements

It is expected that the research will:

1- Find ways that enable maximum utilization of renewable energies in Sudan (for building purposes).

2- Identify some techniques that help in achieve thermal comfort for users of buildings as much as possible in a hot - dry climate zones.

3- Reach to a study that helps in effectively reducing energy consumption in the operation of buildings in Greater Khartoum, and similar climates.

4- Figure out how to provide appropriate means for equity in the indoor air quality in low cost buildings.

Chapter two

HOT DRY CLIMATE AND PASSIVE COOLING

2.1 Introduction

Modern societies are consuming earth's resources at an increasingly rapid pace to satisfy certain needs and desires. In the face of the present global climate change and related anthropogenic carbon emissions, the use of energy from fossil fuels becomes a main concern.

At least three pathways to reduce energy consumption are at hand: first is to simply lower the demand and use less energy; second is to be more energy-efficient in our energy-based technology and systems; and third is to substitute fossil fuels with renewable energy sources to meet the demand. The same approaches apply to buildings. This thesis takes the first pathway as a fundamental approach towards energy - saving in buildings. Its focus is on passive cooling in hot - dry climates and how to apply it in a sustainable manner.

2.2 Hot dry climate

Weather is the set of atmospheric conditions prevailing at a given place and time and climate be defined as the integration in time of weather conditions, characteristic of a certain geographical location. The climate of the sun is driven by the energy input from the sun. For designers there are two essential aspects to understand: The apparent movement of the sun (the solar geometry), and the energy flow from the sun and how to handle it(exclude it or use it). [Steven V.Szokolay, 2008, Page 22]

The earth moves around the sun on a slightly elliptical orbit. At the maximum (aphelion) the earth sun distance is 152 million km, and at its minimum (perihelion) is 147 million km. The earth axis is not normal to the plane of its orbit, but titled by 23.5. Consequently the angle between the earth's equatorial plane and the earth sun line (or the ecliptic , the plane or the earth orbit) varies during the year [Steven V.Szokolay, 2008, Page 23].

This angle is known as the declination (DEC) and varies as:

- + 23.45 on June 22(the northern solstice).

- 0 on March 21 and Sep. 22 (the equinox dates).

- -23 .45 on December (the southern solstice). See fig. 2.1.

While the heliocentric view is necessary to understand the real system, in building problems the loco centric view provides all the necessary answers. The view of the observer's location is at the center of the sky hemisphere, on which the sun's position can be determined by two angles:

- The Altitude (ALT): measured upwards from the horizon , 90◦. being the zenith.

- The Azimuth (AZI): measured in the horizontal plane from the north (0 ◦), through the east (90◦), south (180◦) and west (270◦) to north (360◦). See fig.2.2[Steven V.Szokolay, 2008, Page 21].

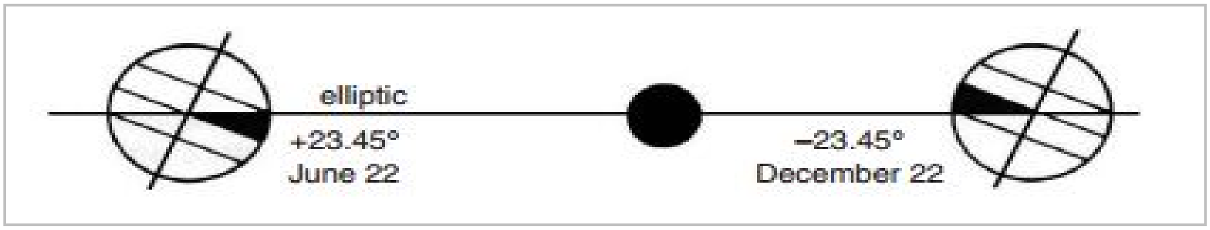

Fig. 2.1 The two-dimensional section of earth's orbit and DEC.

Source: Steven V.Szokolay, 2008, page 22.

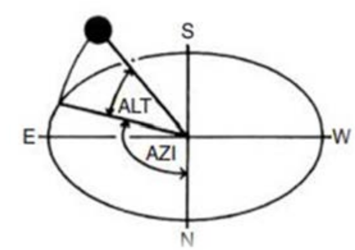

Fig.2.2 Altitude and azimuth angles.

Source: Steven V.Szokolay, 2008, page 23.

2.2.1 Elements of climate

The main climate elements regularly measured by meteorological organizations and published in summary form are:

i- Temperature (Dry Bulb Temperature) (DBT): measured in the shade, usually in a ventilated box, the Stevenson screen 1.2 – 1.8 m above ground level.

ii- Humidity: usually measured by an aspirated psychomotor which can be expressed as RH or AH or the WBT or dew point temperature.

iii- Air movement, i.e. wind, normally measured at 10 m above ground in an open country, but higher in built up areas, to avoid abstractions; both velocity and direction are recorded.

iv- Precipitation, i.e. the total amount of air, hail, snow or dew, measured in rain gauges and expressed in mm per unit time (day, month, year).

v- Cloud cover, based on visual observation, expressed on as fraction of the sky hemisphere

(octas = eighths, or more recently tenths) covered by clouds .

vi- Sunshine duration, I.e. the period of clear sunshine (when a sharp shadow on cast), measured by a sunshine recorder, in which a lens burns a trace on paper strip; shown by hours per day or month.

vii- Solar radiation, measured by *pyranometer* (solar meter), on an unobstructed horizontal surface and recorded either as the continuously varying irradiance (W/m2), or through an electronic integrator as irradiation over the hour or day. [Steven V. Szokolay, 2008. Page 28].

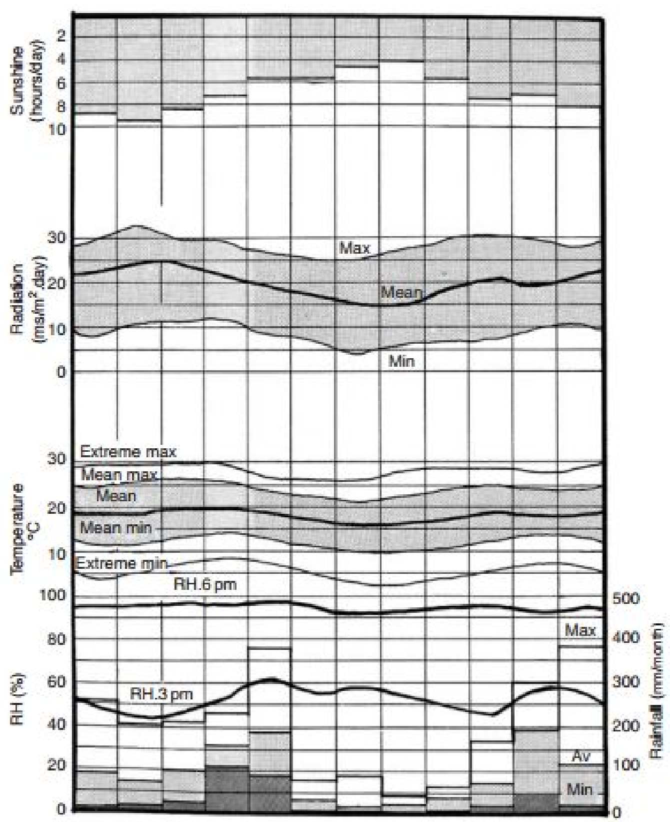

Fig.2.3 A composite climate graph (Nairobi)

Source: Steven V. Szokolay, 2008, page 30.

Table 2.1 The simplest climatic data..

Source: Introduction to ARCHITECTURAL SCIENCE the basis of sustainable design , page:30.

Climatic data for NAIROBI — Latitude: –1.2°

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
T.max	25.0	26.0	26.0	24.0	23.0	22.0	21.0	22.0	24.0	25.0	23.0	23.0	°C
SD.max	1.7	1.7	1.5	1.1	1.7	1.6	1.5	1.5	1.5	1.1	1.1	1.2	K
T.min	11.0	11.0	13.0	14.0	13.0	11.0	9.0	10.0	10.0	12.0	13.0	13.0	°C
SD.min	2.0	1.7	1.2	1.2	2.2	2.5	2.5	2.0	1.6	1.2	1.7	2.0	K
RH.am	95	94	96	95	97	95	92	93	95	95	93	95	%
RHpm	48	42	45	55	61	55	57	53	48	45	56	55	%
Rain	88	70	96	155	189	29	17	20	34	64	189	115	mm
Irrad	6490	6919	6513	5652	4826	4664	3838	4047	5245	5629	5489	6024	Wh/m^2

(standard deviations are estimated only)

2.2.2 Classification of climate

The most generally system used to classify the climate is the Koppen-Geiger classification which distinguishes between 25 climate types. This is shown in Fig 2.4. [StevenV. Szokolay, 2008. Page 32].

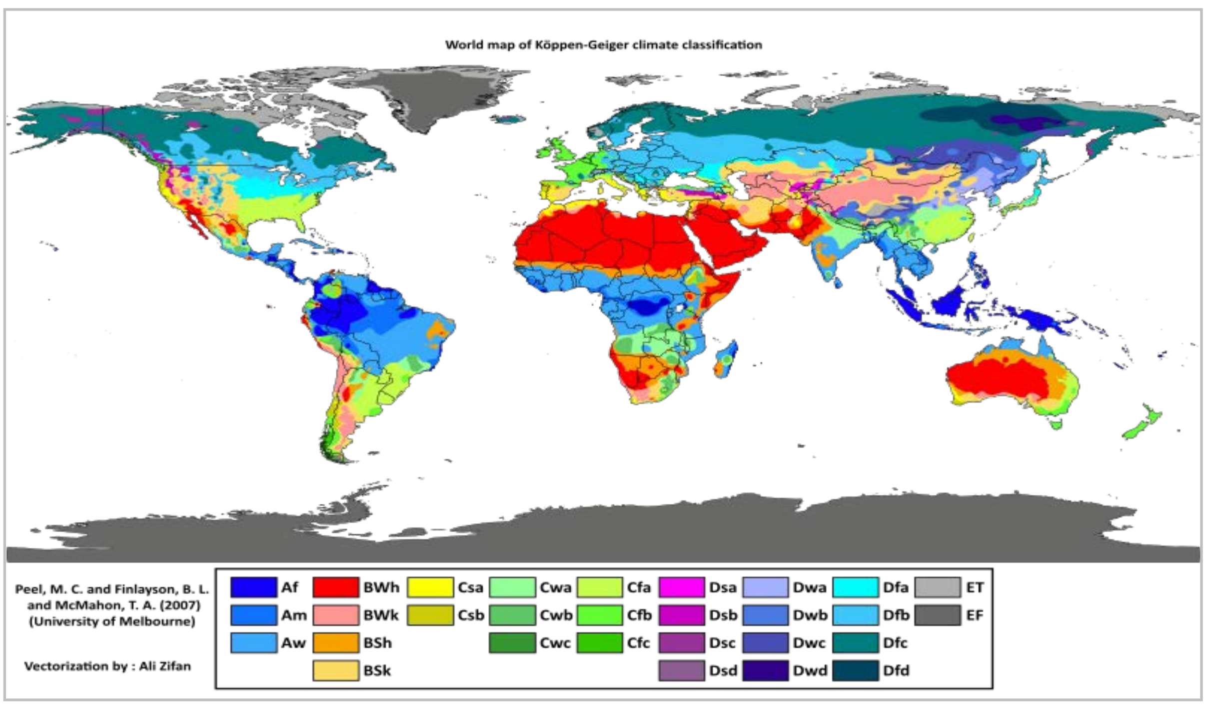

Fig.2.4 Koppen – Geiger classification of climate.

Source: https://en.wikipedia.org/wiki/File:World_Koppen_Classification, 2016.

For the purposes of building design a simple system (after Atkinson, 1954), distinguishing only four basic types, is adequate. This is based on the nature of the human thermal problem in the Particular location:

i- Cold climates: where the main problem is the lack of heat (under heating), or excessive heat dissipation for all or most of the year.

ii- Temperate(moderate) climates: where there is a seasonal variation between under heating and overheating, but neither is very severe.

iii-Hot-dry climates: where the main problem is overheating, but the air is dry, so the evaporative cooling mechanism of the body is not restricted. There is usually a large diurnal (day–night) temperature variation.

iv-Warm-humid climates: where the overheating is not as great as in hot - dry areas, but is aggravated by high humidity, restricting the evaporation potential. The diurnal temperature variation is small. Sometimes we also consider the following sub-types:

i- Island or trade-wind climate. ii- Maritime desert climate. iii- Tropical highland climate.

or indeed 'composite climates', with seasonally changing characteristics.[Steven V. Szokolay, 2008, Page 34].

2.2.3 Characteristics of hot dry climate

The daytime temperatures can be very high but the diurnal range is large, often more than 20K (Kelvin). Night temperatures may be too cold. Consequently, the single most important characteristic should be a large thermal mass: massive walls but also a roof with high thermal capacity. Building surfaces should be white, which would act as a selective surface. This is most important for roofs exposed to the night sky. The radiant cooling effect can help to dissipate the heat stored during the day. White paint has a high remittance, unlike a shiny metallic surface.

The outdoor environment is often hostile, hot and dusty, so the best solution may be an inward-looking, courtyard type building. The air mass enclosed by the building, by solid walls or fences is likely to be cooler than the environment, heavier, thus it would settle as if in a basin. This air can be evaporatively cooled by a pond or a water spray. The reservoir of cool air thus created can then be used for fresh air supply to habitable spaces. With adequate vegetation such a courtyard can become quite a pleasant outdoor living space, see fig. 2.5.

Much depends, however, on how the courtyard is treated. An un shaded courtyard, without water, can be a liability, warmer than the external environment, not only in 'winter' but also during the hottest periods. The traditional courtyards with shading, trees and some water element can be substantially cooler than the ambient at the height of summer.

Ventilation, beyond the small fresh air supply from the courtyard is undesirable as the outdoor air is hot and dusty.

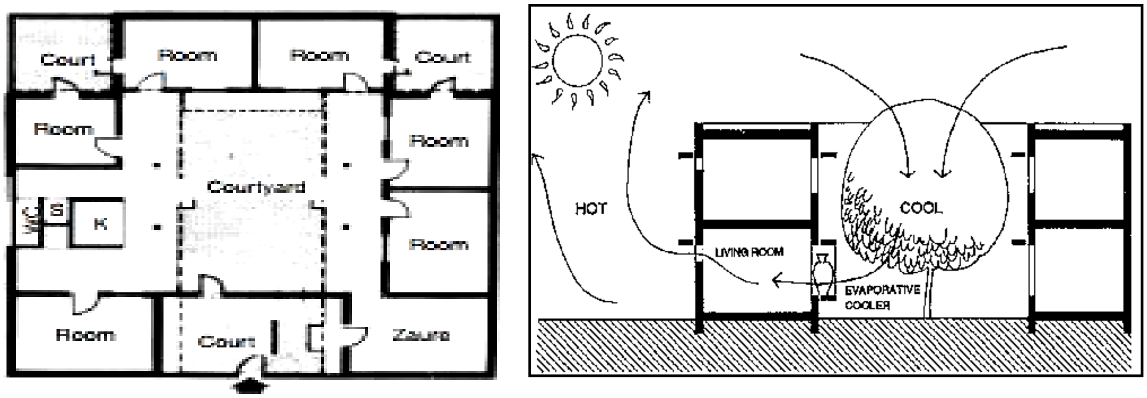

Fig. 2.5 modern courtyard: section and plan (by Max Lock; after Saini, 1973.

Source: Steven V. Szokolay, 2008, page 68

2.3 Passive cooling

2.3.1 Human comfort

Human comfort depends upon physiological and psychological conditions. Thus it is difficult to define the term (Human Comfort) There are many definitions given to this term by different bodies. The most accepted definition, however from the subject point of view, is given by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRI) which states: human comfort is that condition of mind, which expresses satisfaction whit the thermal environment. [Abass A.S.Al.Jebbri, 2014, Page 115].

The human body continuously produces heat by its metabolic processes. The heat output of an average body is often taken as 100 W, but it can vary from about 70 W (in sleep) to over 700 W in heavy work or vigorous activity (e.g. playing squash). This heat must be dissipated to the environment, or else the body temperature will increase. This deep-body temperature is normally about 37◦C, whilst the skin temperature can vary between 31◦ and 34◦ Heat exchange of the human body. The body’s thermal balance can be expressed as;

$M \pm Rd \pm Cv \pm Cd - Ev = S$

Where:

M=metabolic heat production. S=change in stored heat.

Rd=net radiation exchange.

Cv=convection (incl. respiration) Cd=conduction.

Ev=evaporation (incl. in respiration). See fig. 2.6.

[StevenV. Szokolay, 2004. Page 15].

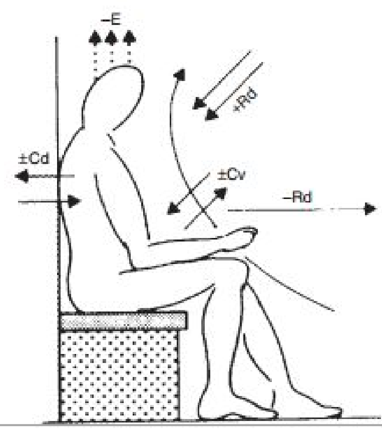

Fig. 2.6 Heat exchange of the human body

Source: Steven V. Szokolay, 2008, page 16.

In designing, the designer should be well conversant with a number of factors which physiologically affect human comfort. The important factors are as follows:

i- Effective temperature.

ii- Heat production and regulation in human body.

iii- Moisture content of air.

iv- Heat and moisture losses from the human body.

v- Quality and quantity of air.

vi- Hot and cold surfaces.

vii- Air stratification.

viii- Air motion.

2.3.2 Thermal Exchange of the body with the Environment

The human body works best at certain temperature (37◦C), but it can't tolerate wide range of variations in their environmental temperatures. The human body maintains its thermal equilibrium with the environment by means of three modes of heat transfer *i.e.* evaporation, radiation and convention. The way in which the individual body maintains itself in comfortable when the heat produced by metabolism of human body is equal to the sum of the heat dissipated to the surroundings and heat stores in human body by raising the temperature of body tissues. This phenomenon represented by the following equation:

Qm - W = QE + QR+Qc+Qs

Where:

Qm= Metabolic heat produced within the body.

W= Useful rate of working.

Qm – W = Heat to be dissipated to the atmosphere.

Qe = Heat lost by evaporation.

QR = Heat lost or gained by radiation.

Qc = Heat lost or gained by convection.

Qs = Heat stored in the body or lost from the body.

[Abass A.S.Al.Jebbri, 2014, Page 115].

2.3.3 Comfort indices, comfort zone

The range of acceptable comfort conditions is generally referred to as the comfort zone. The temperature limits of such a comfort zone (for 90% acceptability) can be taken relative to the above Tn (neutrality temperature) as from(Tn−2.5) ◦C to(Tn+2.5) ◦C.

As thermal comfort is influenced by three environmental variables, [Steven Szokolay, 2008, page 20] attempts have been made since the early 1900s to create a single figure comfort index, which would express the combined effect of all four (or at least several) of these variables. The first one was proposed by(Houghten and Yagloglou) in 1923, named 'effective temperature'. At least 30 different such indices have been produced over the years by various research workers, all based on different studies, all with different derivations and names.

Olgyay (1953) introduced the 'bioclimatic chart'(fig.2.7) which has the DBT on the horizontal and the RH on the vertical axis, and the aerofoil shape in the middle is the 'comfort zone'. Curves show how air movement can extend to the upper limits and lines below it show the extension by radiation. The latest comfort index now generally accepted, is the ET∗(ET star) or new effective temperature, and its standardized version.

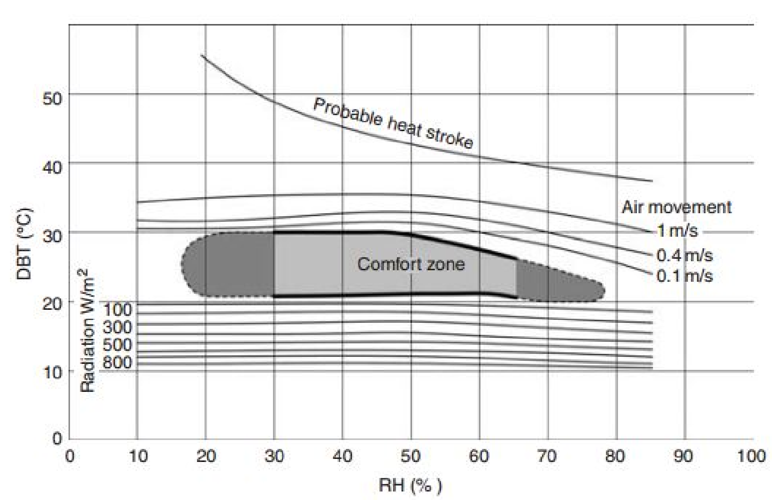

Fig.2.7 Olgyay's bioclimatic chart, converted to metric, modified for hot dry climates.

Source: Steven V. Szokolay, 2008, page 21.

The SET isotherms are drawn on the psychometric chart, see fig.(2.8), coincides with DBT at the 50% RH curve. The slope of the SET lines indicates that at higher humidities tolerance is reduced, whilst at lower humidities higher temperatures are acceptable. Up to 14◦C the SET lines coincide with the DBT. Above that the slope of these isotherm lines is progressively increasing, with the slope coefficient taken as X/Y or DBT/AH=0.023×(T−14) which gives the deviation from the corresponding vertical DBT line for each g/kg AH, positive below the 50% RH curve and negative above it. [StevenV. Szokolay, 2008, Page 20]

2.3.4 Effective temperature

The degree of warmth or cold felt by a human body depends mainly on the following three factors:

i- Dry bulb temperature . ii- Relative humidity. iii- Air velocity.

In order to evaluate the combined effect of these factors, the term effective temperature is employed. It is defined as that index which correlates the combined effects of air temperature relative humidity and air velocity on human body. The numerical value of effective temperature is made equal to the temperature of still (I.e. 5 to 8 m/min air velocity) saturated air, which produces the same sensation of warmth or coolness as produced under the given condition.

The practical application of the concept of effective temperature is presented by the comfort chart as shown in Fig.(2.7).This chart is the result of research made on different kinds of people subjected to wide range of environmental temperature, relative humidity and air movement by the (ASHRAE).It is applicable to reasonably still air (5 to 8 m/min air velocity) to situations where the occupants are seated at rest or doing light work and to spaces whose enclosing surfaces are at a mean temperature equal to the air dry bulb temperature.

In the comfort chart, as shown in (fig 2.7), the dry bulb temperature is taken as abscissa and the wet bulb temperature as ordinates. The relative humidity lines are repotted from the psychometric chart (fig 2.8**)** The statistically prepared graphs corresponding to summer and winter season are also superimposed. These graphs have effective temperature scales as abscissa and % of people feeling comfortable as ordinate. [Abass A.S.Al.Jebbri, 2014, Page 119].

2.3.5 Physiological Hazards resulting from heat

In summer, the temperature of the surroundings is always higher than the temperature of the body. Thus the body will gain heat from the surroundings by means of radiation and convection processes. The body can dissipate heat only through evaporation of sweat. When the heat loss by evaporation is unable to cope with the heat gain, there will be storage of heat in the body and the temperature of the body rises. Several physiological hazards exist, the severity of which depends upon the extent and time duration of body temperature rise. Following are some of the physiological hazards which may result due to the rise of body temperature.

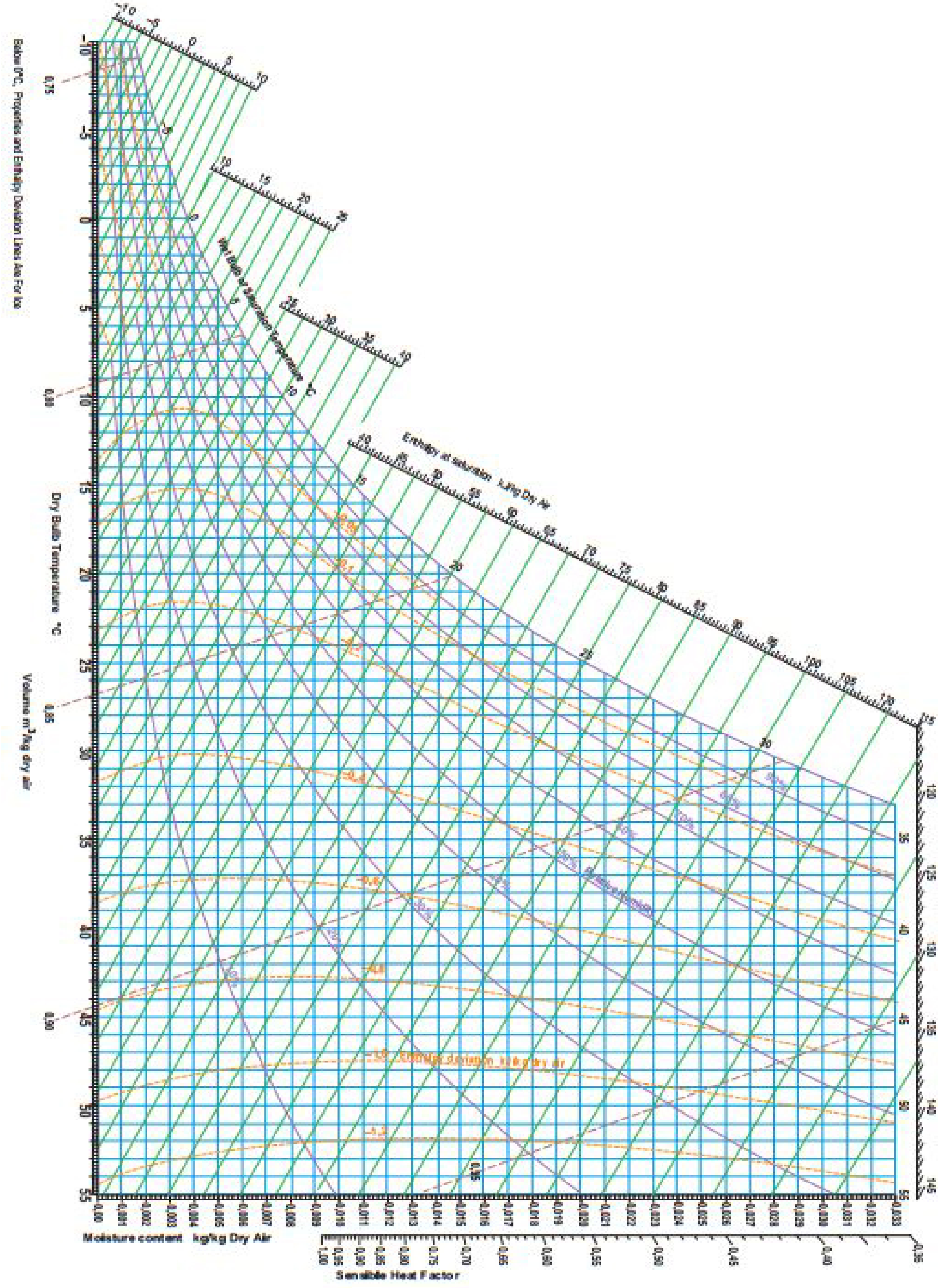

Fig 2.8 The psychometric chart, Carrier chart .

Source: https://google.com (Carrier psychometric chart), 2016.

i - Heat exhaustion

It occurs due to the failure of normal blood circulation . The symptoms of heat exhaustion include fatigues, headache, dizziness, vomiting and abnormal mental reactions such as irritability.

It also may cause fainting. The recovery is usually rapid when the person is removed to a cool place.

ii- Heat cramp

It results from loss of salt due to an excessive rate of body perspiration. It causes severe pain in the calf and thigh muscles. The heat cramp may largely to avoided by using salt tablets.

iii- Heat stroke

It is the most serious hazard. When a man is exposed to excessive heat and work, the body temperature may rise rapidly to 40.5C (105 F) or higher. At such elevated temperature, sweating ceases and the man may enter a coma, with death imminent. A man may have permanent damage to the brain. It may be avoided by taking sufficient water at frequent intervals. [Abass A.S.Al.Jebbri, 2014, Page 118].

2.3.6 Passive Cooling Definitions

The term ‘passive’ was adopted to describe space conditioning systems that are driven primarily by natural phenomena, i.e. without power driven mechanical devices, in the early 1970s by US researchers [Cook, 1989]. An oil embargo occurred at that time. International acceptance of the term since then can be seen for example in the organization called PLEA [PLEA, 2013]. A ‘passive’ building may include the use of a low-energy fan or a pump when its application might enhance the performance [Balaras, 1996; Givoni, 1994].

The above references are all in agreement that cooling strategies for buildings should be designed at three levels: (i) prevention of heat gains in the building; (ii) modulation of heat gains; and (iii) rejection of heat from the building to heat sinks by ventilation, evaporative cooling, radiative cooling or earth cooling [Dimoudi, 1996]. The natural heat sinks are the upper atmosphere (sky), the atmosphere (air) and the earth (ground and water).

Examples of heat prevention strategies are use of microclimate and proper site design, building form and layout, shading, use of light colors or reflective surfaces on the exterior, use of insulated envelopes and control of internal heat gains [Balaras, 1996; Cook, 1989; Dimoudi, 1996; Givoni, 1994]. Heat modulation is associated with high thermal mass materials, like brick and concrete, in building structures that act as a storage for heat during daytime and cold at night. It's considered to be useful for buildings in continuous occupation such as houses [Dimoudi, 1996]. Further, the role of heat rejection is to dissipate indoor heat to the heat sinks so that indoor temperature is possibly lower than the outdoors.

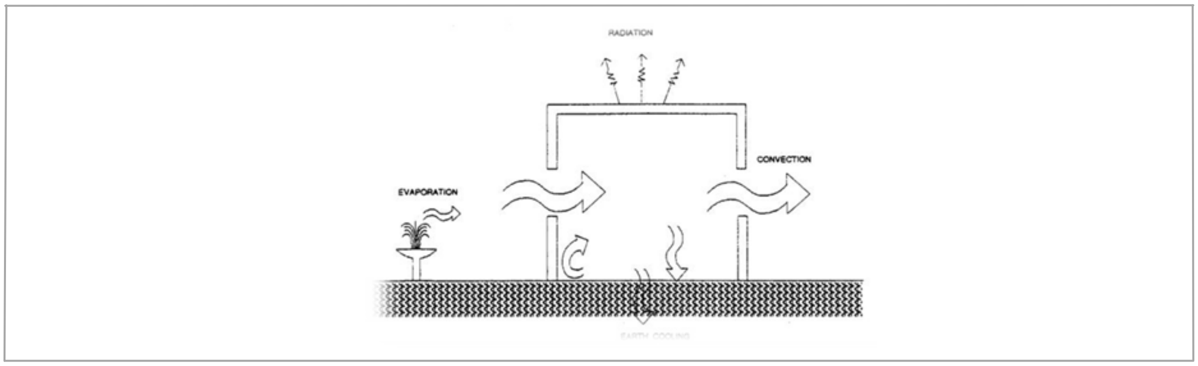

Fig. 2.9 Modes of heat transfer to heat sinks in buildings.

Source: Dimoudi, 1996.

2.3.7 fundamentals of passive cooling

i -Heat flows from high temperature area to low temperature area .

ii- Reverse flow can only be induced by feeding additional energy into the thermal system ,Fig. 2.10.

iii-Passive cooling seeks to use natural heat Flows whenever possible. See fig. 2.11

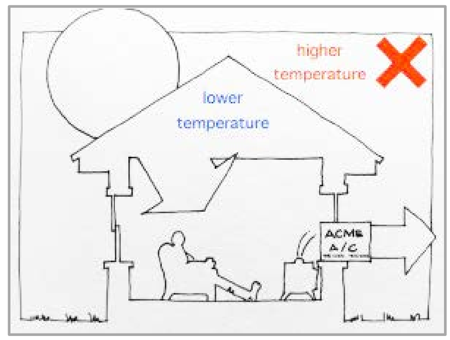

Fig 2.10 Cooling with a mechanical heat sink

Source: Dimoudi, 1996.

iv-Strategies:

- Reduce heat gains(internal and external) .

- open a high-to-low temperature heat flow path to divert the excess heat (heat removal into a suitable heat sink).Fig.2.12

v-Available natural heat sinks:

-Ambient air (ventilation). -Evaporative cooling(adiabatic). - Radioactive cooling (deep night sky).

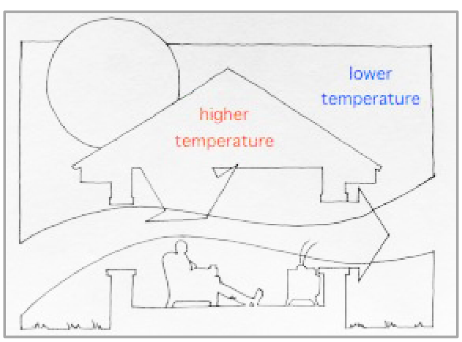

Fig.2.11 Cooling with the ambient as a heat sink .

Source : Dimoudi, 1996.

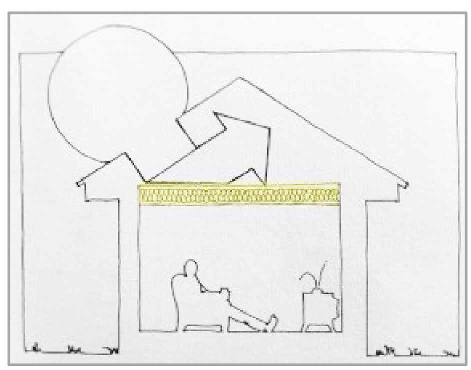

Fig. 2.12 Cooling by avoiding heat gain

Source : Dimoudi, 1996

2.3.8 Heat gain controls

Controlling the heat a building gains from it environment is what passive cooling is all about. It's also what passive heating is about, and the relation between those two functions is crucial. Keeping unwanted heat out in the summer and drawing it in during winter are issues that should -in fact- be addressed hand in hand, for the simple reason that in either case the design of the building itself is the climate-control mechanism.

There are designers, it should be noted, who define passive cooling techniques as strategies which literally introduce coolness into a building without mechanical assistance, a definition that excludes design strategies which stop heat before it can enter and become part of the cooling load. While it's a definition that has real meaning, especially in its opposition to active mechanical cooling strategies, even its proponents agree that controlling heat gain is the essential first step in any attempt to cool buildings naturally, passively, through design itself.

Passive cooling amounts to weighing those elements and coming up with the appropriate mix of techniques to keep users cool, naturally. [Michael J .Holtz, 1979, Page 6].Heat gain control are :

1-Site consideration(location, orientation, vegetation, land massing, microclimate modification).

2- Architectural factors(building exposure, surface or volume ratio, screens, shades, wing walls, overhangs.

3- Weather kin features(insulations, glazing, mass, material type, texture, finishes). See fig 2.13.

2.3.9 The microclimate

If the best offense is a good defense, the best passive cooling strategy pays as much attention to the microclimate surrounding a building as to the building itself. Landscaping and vegetation can have a tremendous impact on natural comfort inside a building, affecting both summer cooling and winter heating loads, both of which should be considered in the physical design of a site. Massed earth is particularly effective as a wind break. Earth baring can be used to deflect winter winds, to channel summer breezes in to interior space, and to shape the air circulation pattern around a building.

Vegetation is an asset of greater worth. Evergreens make excellent windbreaks, and deciduous plants, shedding their leaves to allow the penetration of solar radiation in winter, in summer become complex cooling mechanisms. Deciduous leaves reflect infrared, heat-bearing energy and filter cool, green light to the ground. Combined with air movement, the evaporation of water in to the air that occurs in plant transpiration has an evaporative cooling influence. The general effect in an area of massed vegetation is to keep temperatures in the shade a good 10-15°F lower than ambient a particularly valuable phenomenon if that cooler air can be sent in to the building. [Michael J .Holtz, 1979, Page 7].

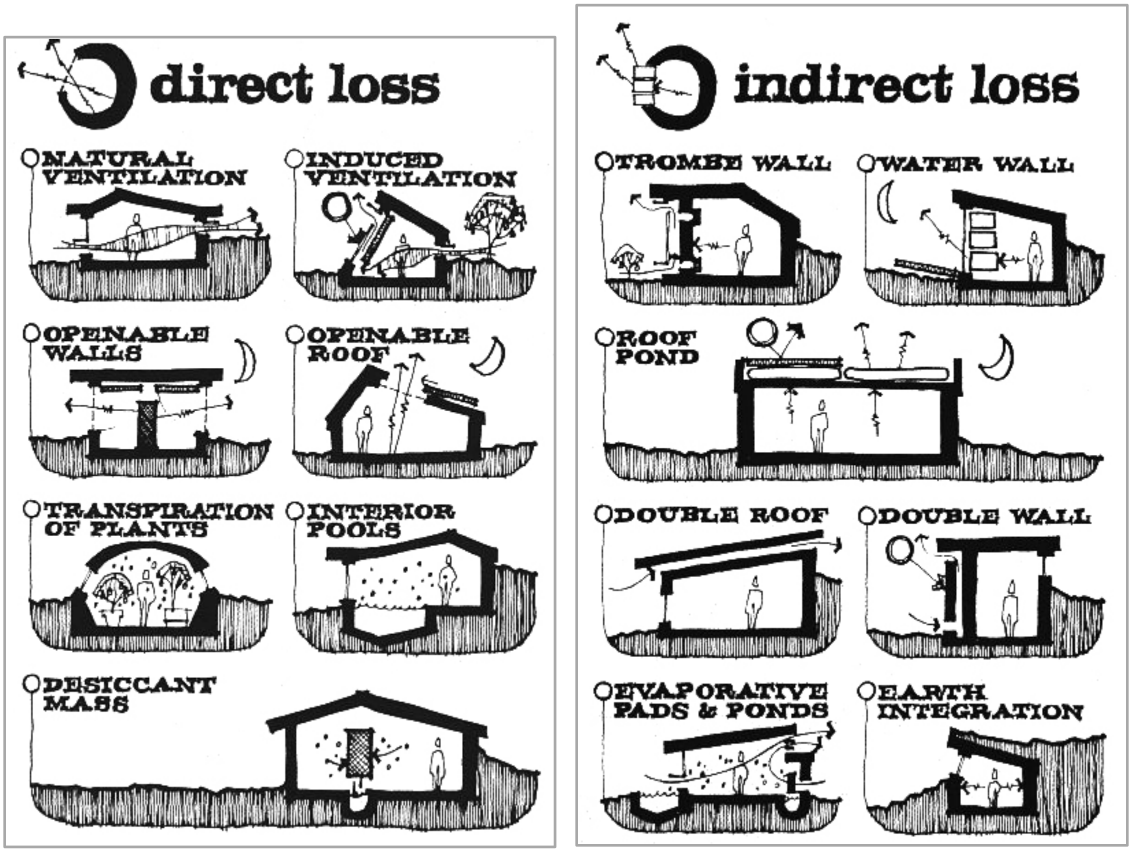

Fig. 2.13 Conceptual illustrations of passive cooling techniques. The direct ,indirect , and isolated loss breakdown mirrors the gain matrix of passive solar heating.

Source: Michael J .Holtz, 1979. Pages 6-7.

2.3.10 Passive Cooling Techniques

The design guidelines for passive cooling are much newer and less tested than those for passive heating. It's important that the designer first to check the match between the climate and the cooling strategies.[Steven V. Szokolay, 2008 , Page 240].

Passive cooling systems are least expensive means of cooling a home which maximizes the efficiency of the building envelope without any use of mechanical devices. It rely on natural heat-sinks to remove heat from the building. They derive cooling directly from evaporation, convection, and radiation without using any intermediate electrical devices.

All passive cooling strategies rely on daily changes in temperature and relative humidity.

The applicability of each system depends on the climatic conditions. These design strategies reduce heat gains to internal spaces.

A broad spectrum of techniques has been developed in different parts of the world reaching high maturity such as: dwellings cut in the rock (earth cooling), wind-captures(convective cooling),sprinkling water by fountains (evaporation cooling) and painting facades (protection from sun radiation). All these cooling techniques are based on solutions that:

-Reflect or minimize solar radiation penetration in dwelling premises.

-facilitate heat transfer from inside to outside without usage of any additional mechanical energy. [Sofia Energy Center ,Passive cooling and summer friendly design, Page2].

The above are completely passive cooling techniques that can be grouped in the following:

i) Architectural and building techniques;

a- Form and orientation; b- Building envelope, glazing;

c- Shading; d- Wind-catchers .

e- Infiltration f- Natural ventilation(stacked , cross , night ventilation).

g- Court yard effect .

ii) Natural techniques for cooling (passive cooling techniques)

a- Earth cooling; b- Evaporation cooling;

c- Radiation cooling. d- Cooling towers.

e- Roof Pond. f-Earth Tube.

i)Architectural and Building techniques

a. Form and orientation

Orientation and form of the building, as well as the structure, character and color of surrounding surfaces, influence on the values of absorbed solar radiation.

The reflection characteristics of one or another façade material or covering are directly connected with the color and texture of these surfaces, i.e. depends on their optical characteristics (coefficient of reflection, absorption and transmission).

The surface temperature of the wall can be reduced by about 10-15° C depending on the choice of appropriate color directing to the lighter ones.

The orientation towards the four cardinal points has high influence on surfaces of a given volume. At a given volume of the building its geometry also has an influence.

The right choice of orientation and geometry can protect the building from excessive heating.

A certain zone depending on its position on the building envelope and on its orientation towards the four points of the world, realizes different percentage of heat losses. Apparently mostly cooled are angle spaces in a building.

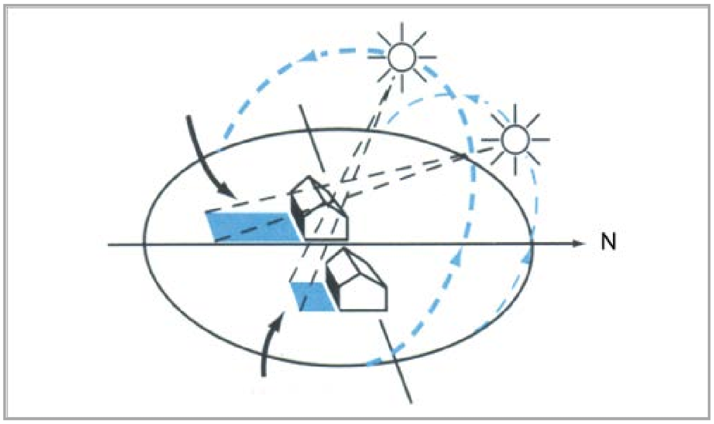

Fig.2.14 The effect of building orientation in cooling building.

Source:https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwig6bDM_OLSAhXDcRQKHZaUDMMQjRwIBw&url=http%3A%2F%2Fwww.vincent.wa.gov.au%2FServices%2FPlanning%2FSustainable_Design&psig=AFQjCNFjXHzGZkzYChJm8qhlTsChFc1ISw&ust=1490026714377077, 2016.

b. Building envelope, glazing

The cooling process can be increased with the application of a number of architectural and construction solutions. The building envelope is the barrier that controls the level of heat transfer.

A significant share of cooling is done through both transmission and infiltration processes.

Cooling due to natural infiltration can be quite significant if systems for its easy control are not applied.

When applying respective technical means it is necessary the architectural and building

Solution be also in compliance with:

- Topography of the terrain; orientation and location.

- Building forms, ratio between surrounding surface and built area.

- Direction, frequency and speed of wind.

- Coefficient of heat transmission of surrounding element (transparent and opaque).

- Type and characteristics of vegetation. - Zoning and planning.

- Infiltration and natural ventilation, convective heat exchange.

c . Shading

Traditional systems for solar radiation reflection are internal and external shading devices: curtains, blinds, sun canopies, etc. They reduce the brightness of the received sunlight, limit the ability of solar radiation penetration in the living space and improve its thermal and visual comfort.

The cumulative solar radiation is formed from direct solar radiation, diffuse radiation from the sky and reflected radiation from surrounding surfaces of buildings around.

The outside shading devices can stop direct radiation, reduce the impact of diffuse and reflected radiation, but also can influence the illumination, brightness, view and natural ventilation. Natural lighting, and overheating protection are the three factors which should be always be taken into account in order to avoid use of artificial lighting and forced ventilation or air-conditioning. See fig.2.15-2.16.

Thus in order to avoid overheating in summer month's it is necessary to use sun canopies but at the same time it is necessary to ensure three-hour sunshine on the day of the vernal equinox (on 21 March from 7 to 18 hours and sunrays to fall in the middle of window opening at a height 1 m from the floor at a horizontal angle not less than 20 deg.). Apparently the problem is complex and its solving requires multidisciplinary knowledge. When building environment with appropriate comfort it is necessary not only to guarantee maximum heat gains and illumination from solar radiation all year round but also to guarantee protection against overheat and over-lighting in the summer time and heat losses during winter time.

Often the architectural and building solutions necessary to keep thermal and lighting comfort are contradictory and the skill is to find the balance by compromising between them.

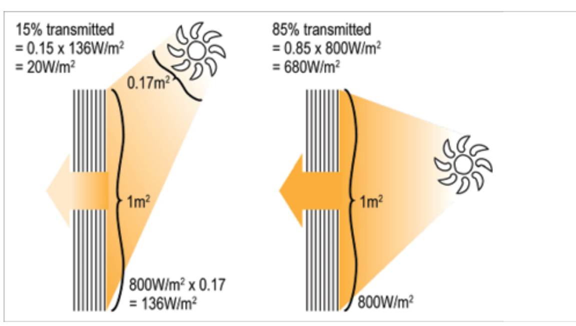

Fig.2.15 Relationship between sun angle and heat gain.

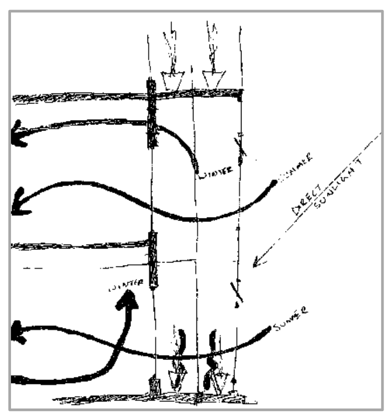

Fig.2.16 shades devices effect

Source:https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwj17oLc_eLSAhXIPhQKHTVVDKQQjRwIBw&url=http%3A%2F%2Fwww.yourhome.gov.au%2Fpassivedesign%2Fglazing&psig=AFQjCNEPWpG7_o0mm2cpcTHFBBD8_Mq8Dw&ust=1490027121181800,2016.

d: Wind Catchers

Wind catchers are traditional building element for passive cooling of buildings.

This device catches the wind from different directions. Cool air entering the openings falls down and cools the neighboring premises. If there is no wind, the air in wind catching tower will get warm and go up. In this way the cool air is taken from the garden and cools the house. See fig(2.17).

Wind catcher has been known in different countries, in Sudan it has been applied in the regions with hot and dry climate. wind catchers usually built with bricks and have had a height from 30 cm to 5 meters from the roof surface. They have been built on the roofs of dwelling buildings, caravanserais, mosques and water reservoirs.

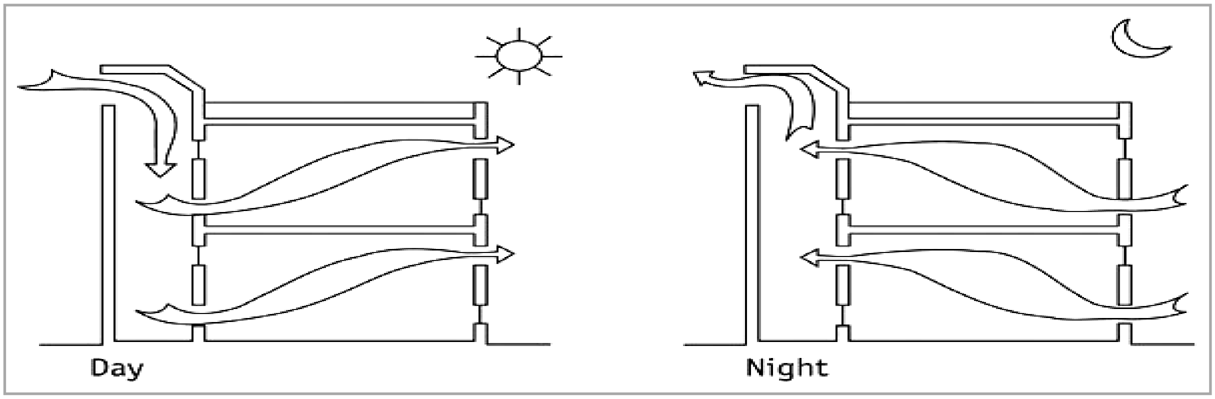

Fig. 2.17 Effect of wind catcher in day and night cooling.

Source: https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd, 2016

This system, a model for passive energy efficient ventilation, works only if there are great temperature differences. Based on the same working principle we have today a lot of varieties in the forms of this building element. It has been widely applied also in the modern traditional and contemporary architecture. See fig 2.18.

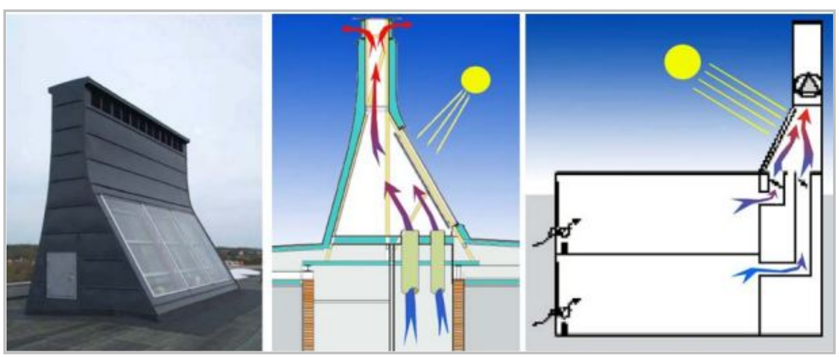

Fig.2.18 View and principle working scheme.

Source: https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=r,2016.

e. Infiltration

Infiltration (non-controlled transfer of air through surrounding walls of the building), can be a source of significant thermal losses (or gains) and thus it forms zones of thermal comfort in dwelling premises. In major parts of the buildings infiltration is inevitable. The process that is taking place influenced by infiltration can add to some design solutions for mixed and natural ventilation. Natural ventilation uses the natural wind power to supply fresh air to the building.

Fresh air refreshes the smell, supplies oxygen and increases thermal comfort. Natural ventilation system relies on the ability of air to move around the building in order to level the pressure.

f. Ventilation:

Building ventilation has two main goals - to control air quality and to keep thermal comfort during different seasons. The long known devices such as wind towers, solar chimneys, fountains, water pools, etc..

Today the interest towards ventilation is rising also from the point of view of energy efficiency strategy achieving the desired air quality in buildings and increase of thermal comfort. This has lead to giving new opportunities to use to a maximum extent of the principle of natural ventilation together with mechanical ventilation for solving these issues.

There are three types of ventilation:

i- Cross ventilation . ii- Stack ventilation . iii- Night ventilation of thermal mass.

i- Cross ventilation

One of the oldest methods known, this strategy provides plentiful fresh air but maintains a building at temperature slightly above the outdoors. The cross ventilation inlet (windows) areas expressed as a percentage of total floor area are related to wind speed and resulting heat removal. Any internal obstruction (such as partition) must have a total area of opening at least equal to this required inlet area .See fig(2.19). [StevenV. Szokolay, 2008. Page 240].

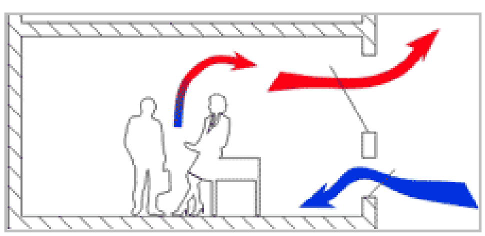

Fig. 2.19 Cross ventilation effect .

Source:hts://www.google.com/imgres?imgurl=http%3A%2F%2Fmoss-design.com%2Fwp-content%2Fuploads%2F2014%2F07%2Fcrossvent.jpg&imgrefurl=http%3A%2F%2Fmoss-design.com%2Fpassive-cooling%2F&docid=9Jqg5t8eOKWyxM&tbnid=RnDSQS-, 2016.

The principles of natural ventilation

The main driving force that causes natural ventilation through the building is the pressure differential a cross the building envelope.

The pressure difference can be generate by wind pressure, thermal buoyancy (stack or chimney effect) or by combination of both. These effects are operated in buildings of varying proportions, according to the strength of the prevailing wind and temperature conditions.

The effect of wind pressure is a very complex subject generally because it leads to erroneous architectural strategies. [Givoni B,1979,Page 355].

In principles, airflow occurs between areas of positive and negative pressure. See fig 2.20-2.22.

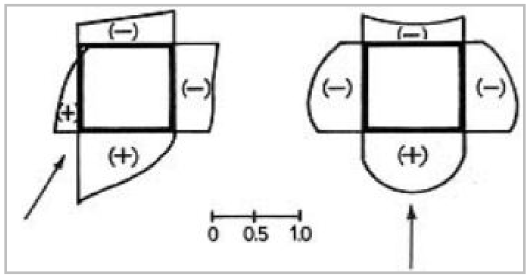

Fig.2.20 Schematic distribution of wind pressure around a building.

Source: givoni, 1976.

Natural ventilation and infiltration are driven by pressure and suction across the building envelope as indicated in the diagram below :[Baker N.,Streemers K.,1999, Page56].

b- Stacked ventilation

It's a historically useful strategy, like cross ventilation. It provides plentiful fresh air but maintains a building temperature slightly above outdoor temperature. The stack inlet area expressed as percentage of total floor area, are related to stack height and the resulting heat removal. The internal obstruction: partitions must have a total of openings at least equal to this required inlet area. See fig 2.21.

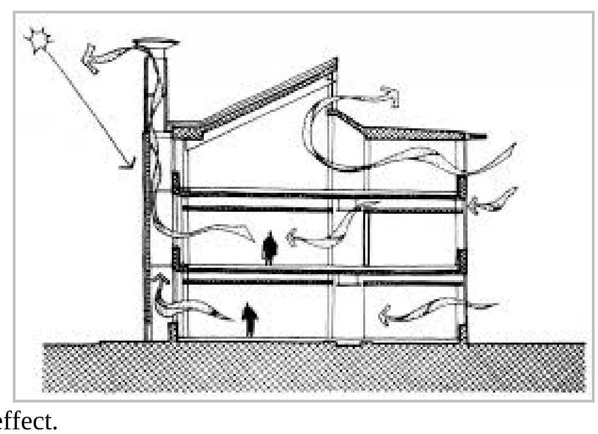

Fig. 2.21 Stack ventilation effect.

Source:https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwiQyJW7gePSAhVMbRQKHYSvBMUQjRwIBw&url=https%3A%2F%2Fsustainabilityworkshop.autodesk.com%2Fbuildings%2Fstack-ventilation-and-bernoullis-principle&psig=AFQjCNFdr0FxEfmTd-ZgMdQOWmEyGsm4fA&ust=1490028125751286, 2016.

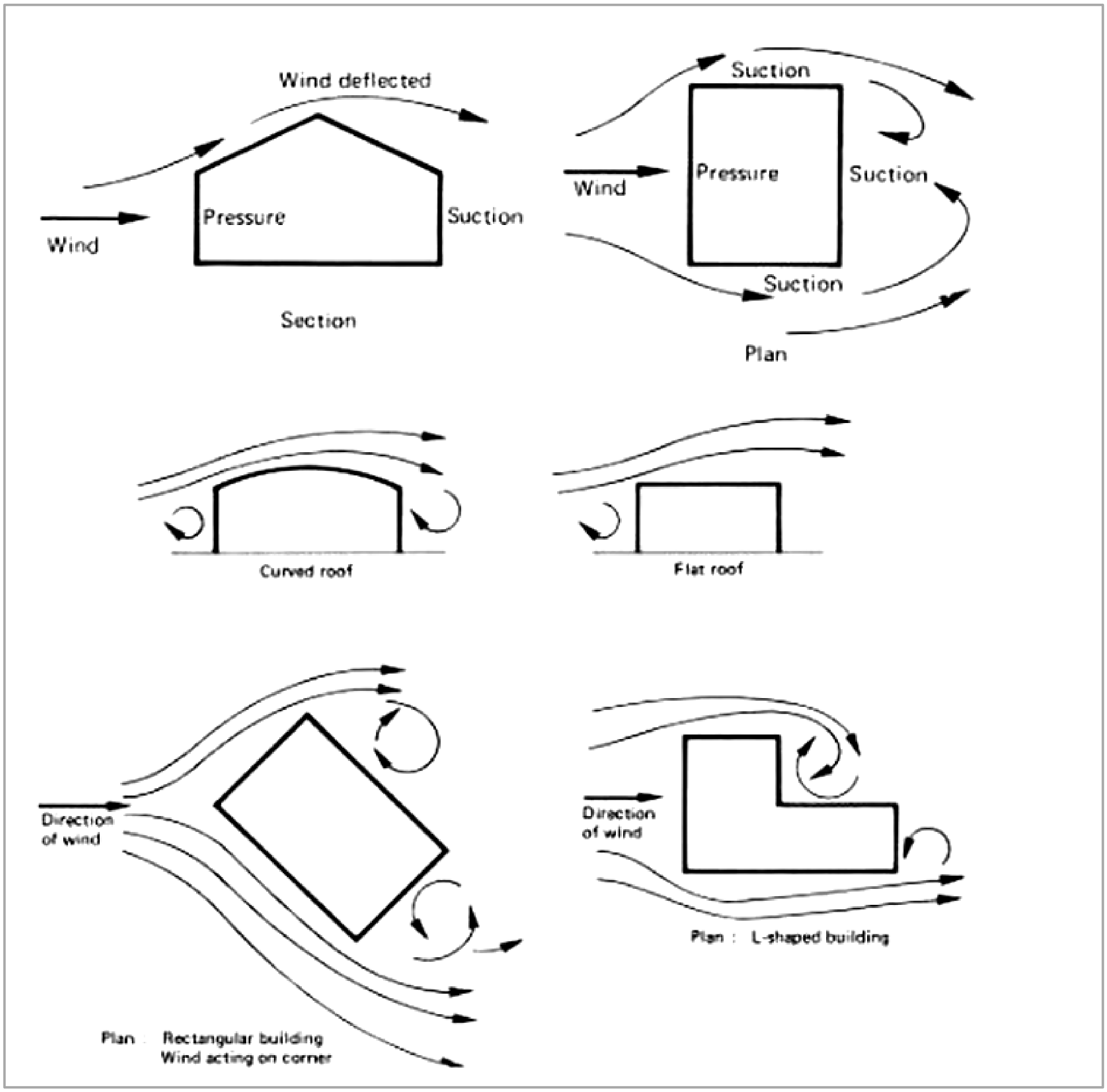

Fig. 2.22 Wind pressure, suction and wind flow around buildings.

Source: from markus and morries.1980.

c- Night ventilation of thermal mass:

This strategy maintain a building at temperature lower than those outside by day and flushes the building with plentiful fresh air by night. The average mass building is represented by a building with an exposed concrete floor(100 mm) thick (or an exposed ceiling of equivalent construction). There is one unit area of exposed mass for each unit floor area. The high mass building is similar to the typical passively solar heated. Direct gain building or to a multistory building with an exposed concrete structure, in which both sides of floor slab are valuable for thermal storage, or an equivalent exposed mass area in walls, and so on.

With the design of high ceilings throughout the breeze zone combined with clerestory windows at the 350mm ceiling height on three walls the rising hot air is allowed to escape which in turn does two things.

Firstly the rising air creates a low pressure zone on the cool mass floor, pulling air along the floor from other areas of the house as well as any open doors.

Secondly the rising and escaping air creates an interior low pressure that should pull in large volumes or exterior air from the patio doors.

Depending on the primary wind direction and which doors are opened relative to time of day and shade, we can create a breeze of cooler incoming air.

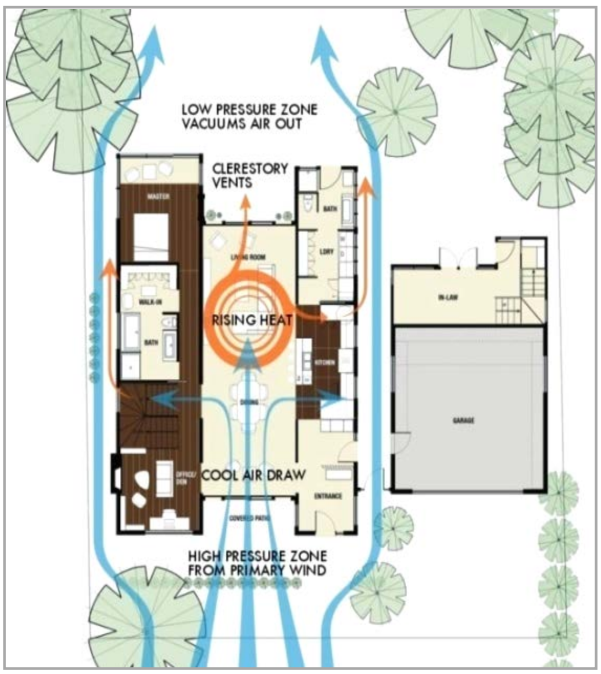

Fig.2.23. Low and high pressure zones plan

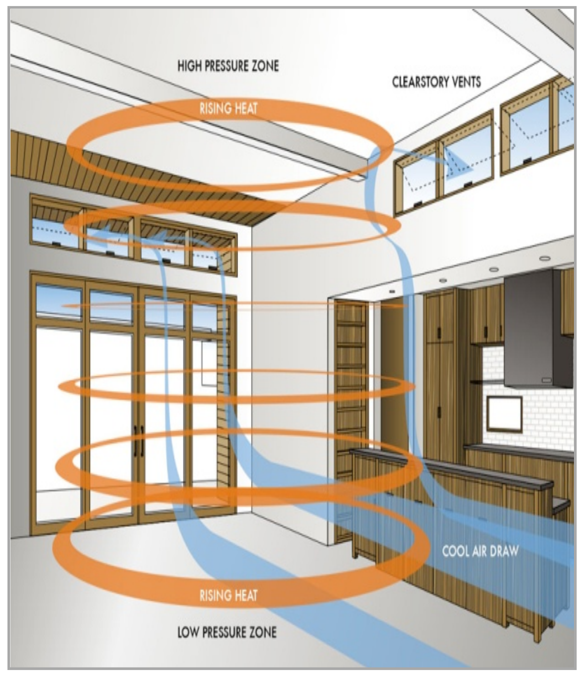

Fig.2.24 Low and high pressure zones view.

Source:https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwjj84jz_-LSAhXKORQKHV-OBgQQjRwIBw&url=https%3A%2F%2Fwww.slideshare.net%2Farchistudentportal%2Fpassive-coolingtechniques-59740412&psig=AFQjCNF8njX5lnpMNp48-xiOGDbiMOeCZw&ust=1490027706451317, 2016.

g-Courtyard effect :

Due to incident solar radiation in a courtyard, the air gets warmer and rises cool air from the ground level, flows through the louvered openings of rooms surrounding a courtyard, thus producing air flow.

At night, the warm roof surfaces get cooled by convection and radiation.

If this heat exchange reduces roof surface temperature to wet bulb temperature of air, condensation of atmospheric moisture occurs on the roof and the gain due to condensation limits further cooling. See fig 2.25 - 2.26- 2.27.

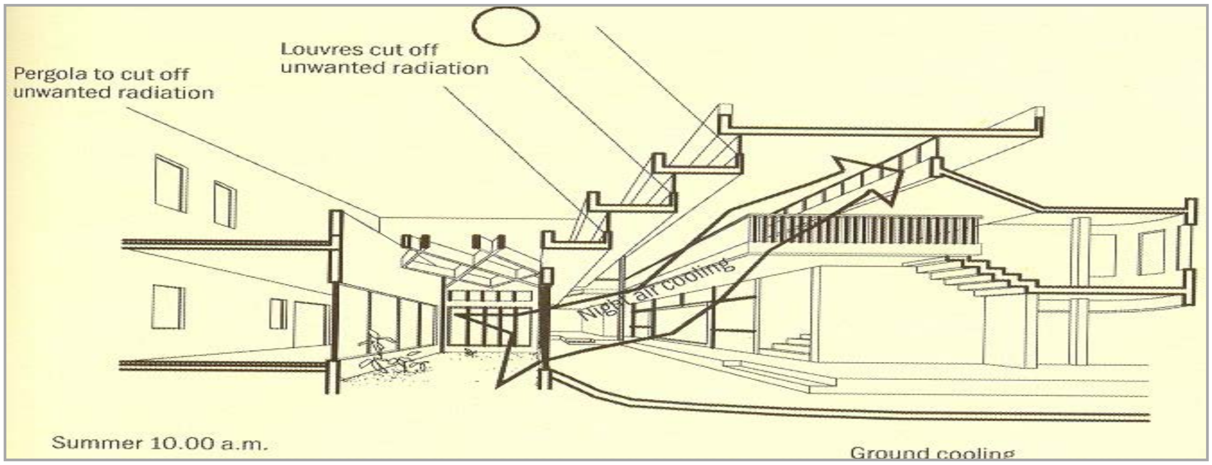

Fig. 2.25 Courtyard as a moderator of internal climat**e** (effect in summer) .

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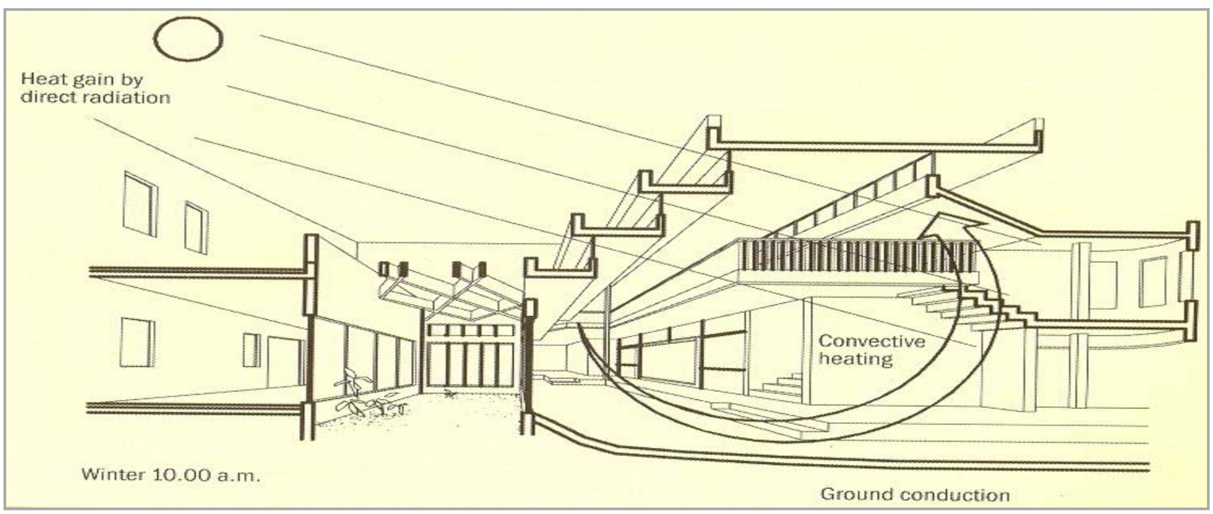

Fig. 2.26 Courtyard as a moderator of internal climat**e** (effect in winter).

Source:https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwjCpdLu_-LSAhWEWhQKHfUPCgwQjRwIBw&url=https%3A%2F%2Fwww.slideshare.net%2Fswapnika15%2Fpassive-coolingtechniques&psig=AFQjCNF4dF-3OOh2_Zf_Wm5QiXe2VmRcqA&ust=1490027696620313, 2016.

If the roof surfaces are sloped towards the internal courtyard, the cooled air sinks into the court and enters the living space through low-level openings, gets warmed up, and leaves the room through higher-level openings.

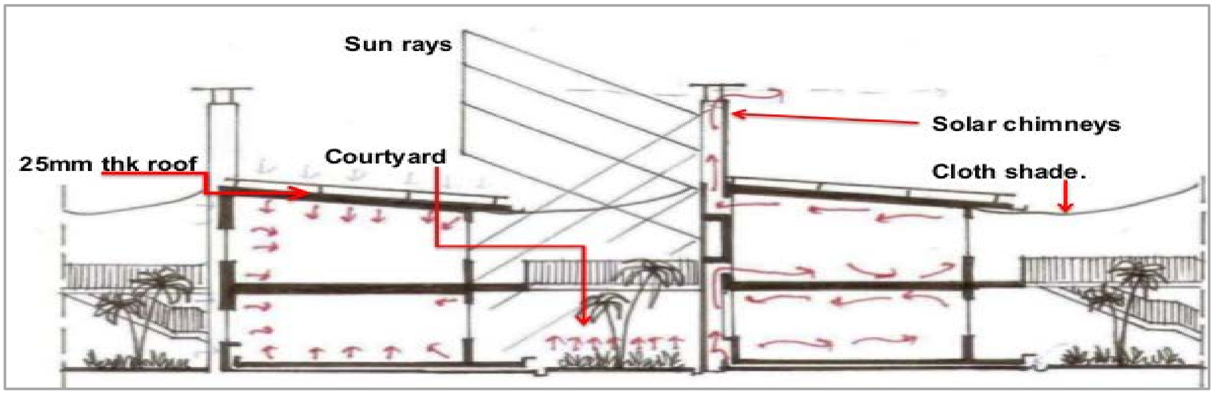

Fig.2.27 Courtyard effect in winter.

Source: https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=r, 2016.

ii) Natural techniques for cooling (passive cooling techniques)

Passive cooling techniques include using some well known phenomena based on basic physics laws leading to removing bodies heat. These phenomena can be grouped as follows:

a- Evaporation cooling; b- Radiation cooling. c- Cooling towers . d- Roof Pond. e-Earth Tube .

a. Evaporation cooling

The most common evaporative cooler is not strictly passive cooling , as it depends on a fan to force large quantities of outdoor air through a wet filter , thereby lowering the airs temperature and rising RH before delivering the air to the space to be cooled .In hot climates , the energy used by the fan in evaporative systems is less than the energy needed to achieve conventional cooling based on the compressive refrigeration cycle.

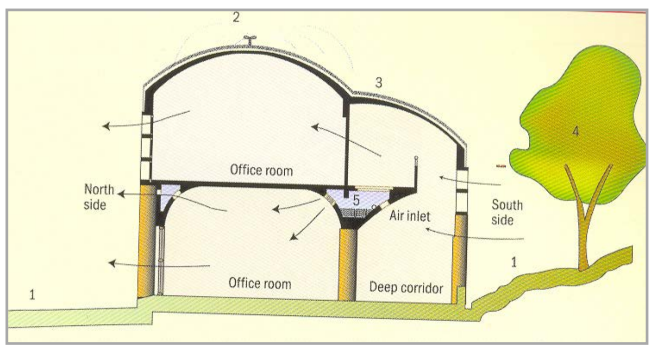

Fig.2.28 A Typical section showing passive solar Feature of WALMI BUILDING ,BHOPAL

Source:https://www.google.com/imgres?imgurl=https%3A%2F%2Fimage.slidesharecdn.com%2Fpassive-cooling-techniques2-150 2016.

Although his process requires quantities of water, it doesn’t use refrigerants than, may pose a threat to the earth's environment. [Steven V. Szokolay, 2008, Page 247].

Evaporative cooling lowers indoor air temperature by evaporating water. It is effective in hot and dry climate where the atmospheric humidity is low.In evaporative cooling, the sensible heat of air is used to evaporate water, thereby cooling the air, which, in turn, cools the living space of the building increase in contact between water and air increases the rate of evaporation. The presence of a water body such as a pond lake, and sea near the building or a fountain in a courtyard can provide a cooling effect. See fig. 2.28

b- Radiation cooling :

Radiation cooling is based on heat losses of long-wave radiation of one object to another. with lower temperature. There are two types:

i- Passive radiation cooling. ii- Hybrid radiation cooling.

The structure of the two types is of three parts:

i- Radiator, radiating heat energy; ii-Building (site).

iii-Medium, that accumulates heat energy of the building and transfers it to the radiator (transfers heat energy from certain parts of the building to the radiator).

While in passive radiation cooling the building envelope is the one to perform the three functions, in hybrid radiation cooling there are specially designed elements with specific characteristics performing separately or in combination these functions. In spite of the fact that these passive cooling techniques include using some known natural phenomena, their application requires involvement of additional equipment and energy sources providing higher efficiency of these systems. The necessity to use additional energy source makes these systems active and therefore not of interest from the point of view of passive cooling techniques.

Architectural applications:

- Sleeping on terraces. - Roof pond cooling.

-Water surface radiates heat to the night sky open water ponds or large bags of water.
- movable insulation panels during daytime.

For example; closing of the umbrellas in the courtyard of the Mosque in Madinah in the evening in order to benefit from the nightly radiation to the cool deep .See Fig.2.29.

Fig.2.29 Umbrellas of court yard in Madinah Mosque.

Source: https://www.google.com, 2016.

c- Cooling towers :

A more passive approach to evaporative cooling appears as a tower on the residential buildings. It depends on a cool tower with a wetted pads on all faces of the building at the top. Hot dry air is cooled as it passes through the pads . Dropping to the base of the tower and then into a house. Analysis by [Givoni 1994] indicates that such a towers delivery of wetter, cooler air is almost independent on the second tower at the opposite end of the building.

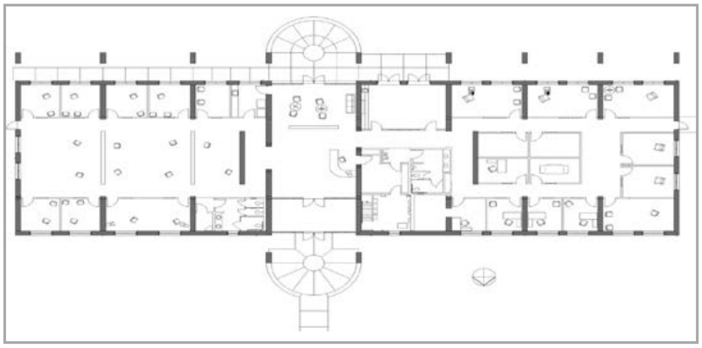

Fig.2.30 Plan shows the relation of a work station to north and south daylight.

Source : https://www.google.com,2016.

Fig.2.31 Fetzer winey administration building entrance.

Source : https://www.google.com,2016.

d- Roof Ponds

This promising strategy has rarely been implemented, possibly due to water phobia among architects and client alike. Yet it demonstrates the most stable interior temperature of any of these techniques, needing electricity only to open and close the sliding insulation panels of the roof .Roof ponds sized for cooling will likely be nearly equal in area to the floors of the building they cool. Average pond depth is between 3 and 6 in (75 to 150 mm).

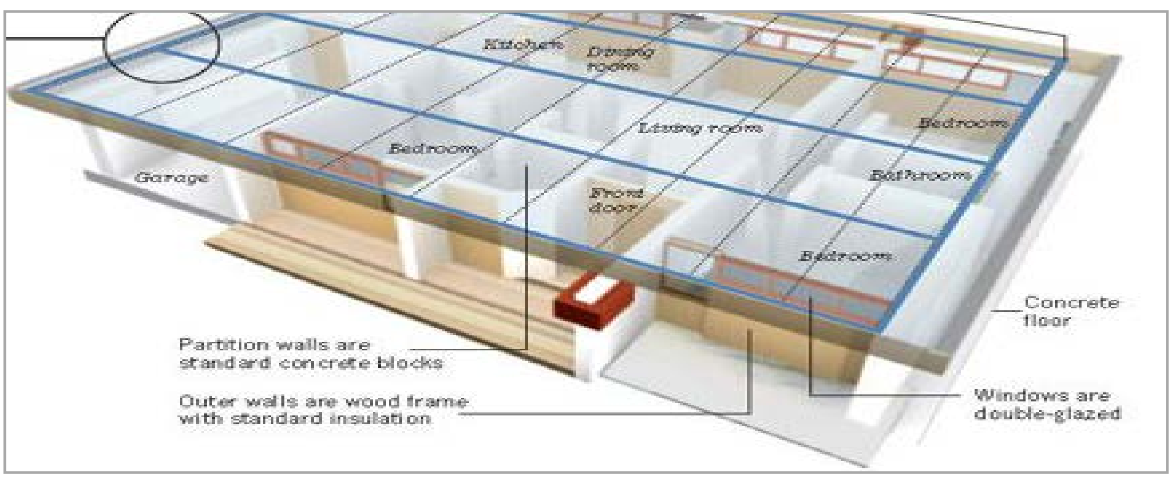

Fig.2.32 Roof pond.

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Steel roof duck holds four long water - filled bags and insulation panels that work together to maintain constant indoor temperature.

How it works

Summer: In day time the cover roof keeps heat out and the indoor space cool at night exposing the water bags radiates the heat into the air.

Winter: The uncovered roof draws heat in the day time and the covered roof maintain it at night.

SUN + H2O = COMFORT

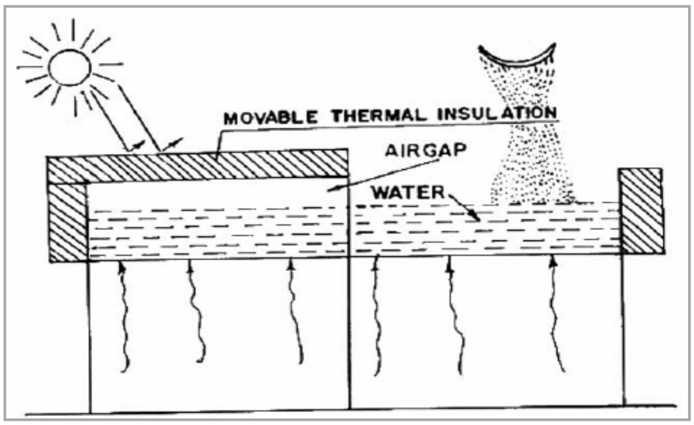


Fig. 2.33 Roof ponds cycle in summer.

Source:https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwjClLfagePSAhVBNI8KHW27AkoQjRwIBw&url=https%3A%2F%2Fwww.researchgate.net%2Ffigure%2F230523942_fig3_Fig-3-Roof-pond-Summer-cooling-and-winter-heating&psig=AFQjCNFXQIzaiAqy_46qFgIz1U9HxGn4UQ&ust=1490028190524628.

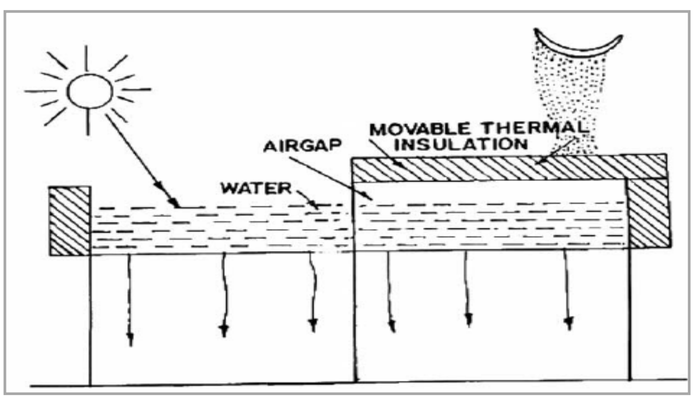


Fig. 2.34 Roof ponds cycle in winter.

Source:https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwjClLfagePSAhVBNI8KHW27AkoQjRwIBw&url=https%3A%2F%2Fwww.researchgate.net%2Ffigure%2F230523942_fig3_Fig-3-Roof-pond-Summer-cooling-and-winter-heating&psig=AFQjCNFXQIzaiAqy_46qFgIz1U9HxGn4UQ&ust=1490028190524628

e-Earth Tube

These provide a way to cool outdoor air before it enters the building. A fan is used to force sufficient quantities of air through these long tubes. Because Earth tubes need to be well undergrounded as well as rather long in order to cool outdoor air. Its rarely economical to install enough earth tube to completely meet building needs for cooling. If long trenches are needed for another purpose(underground water lines, for example), an earth tube is more feasible. Where earth tubes are considered , the component of building heat gain that is represented by cooling fresh air. See fig(2.35, 2.36, 2.37).

Daily and annual temperature fluctuations decrease with the increase in depth below the ground surface.

At a depth of about 4 m below ground, the temperature inside the earth remains nearly constant round the year and is nearly equal to the annual average temperature of the place.

A tunnel in the form of a pipe or otherwise embedded at a depth of about 4 m below the ground will acquire the same temperature as the surrounding earth at its surface.

Therefore, the ambient air ventilated through this tunnel will get cooled in summer and warmed in winter and this air can be used for cooling in summer and heating in winter.

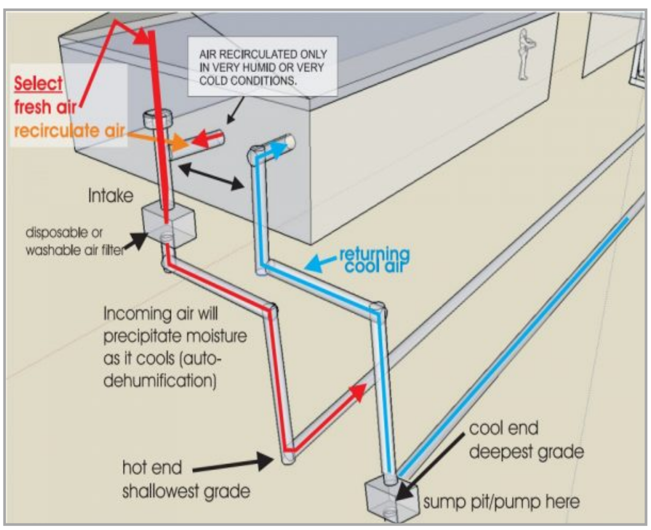


Fig. 2.35 Earth tube details for houses.

Source:https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwighNHRguPSAhXFu48KHRacAZoQjRwIBw&url=https%3A%2F%2Fwww.pinterest.com%2Ftruenscott%2Fearth-tubes%2F&psig=AFQjCNEEd6hhqmPfwwFw6zUfN4q891viVg&ust=1490028440515326.

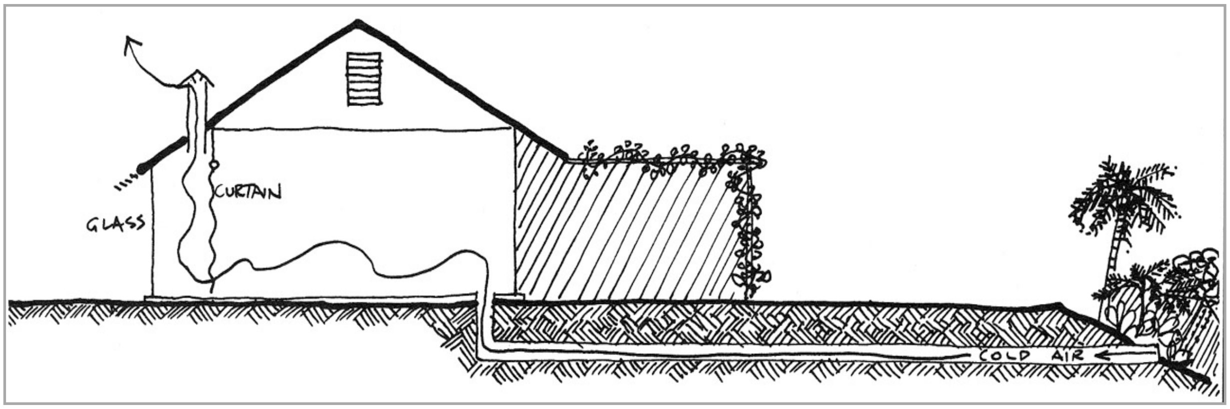


Fig. 2.36 Earth tube for single story building work plan.

Source:https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwighNHRguP,2016.

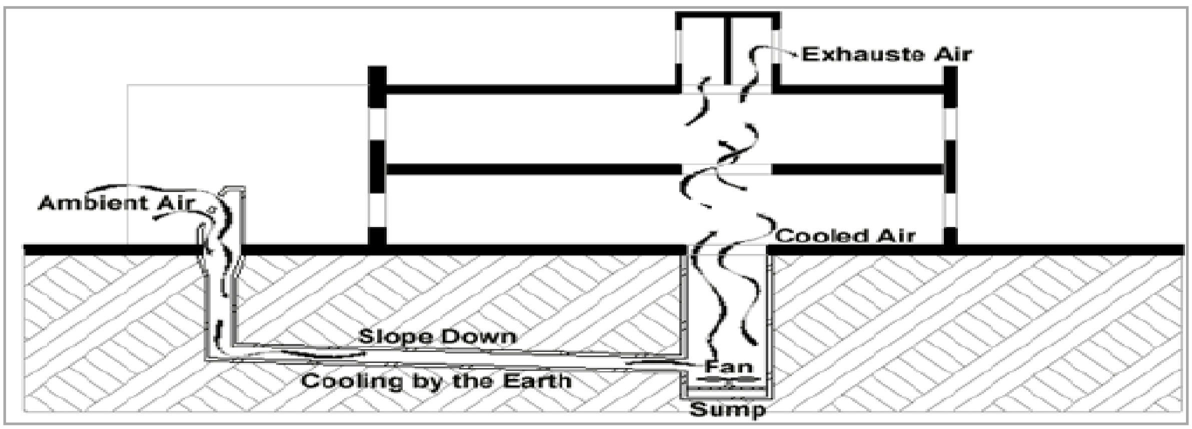


Fig. 2.37 Earth tube for multi story building.

Source: https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=r,2016.

2.4 Conclusion

- The area of study is located in a hot - dry climate zone, therefore this factor must be considered as well as in the design process, because the type of climate has a very strong influence on the design of the building.
- There are some solutions that can be used to reduce heat gain in a hot dry climate like: roof insulation and the use of white color in the outer finishing of the buildings (in the external environment), courtyards and water bodies can be used in the interior.
- Ventilation must be provided and good orientation of buildings must be considered in the design process.
- Thermal comfort for a human depends on the psychological and physical conditions, according to the activity that is practiced by human (sleeping - hard work).
- The human body generates heat and exchanges it with the surrounding environment through three ways: radiation, conduction and absorption.
- There is a certain extent where humans can withstand the thermal conditions, that's called thermal comfort zone.

- There some factors that must be taken into account for the sense of a heat (dry bulb temperature, air speed and relative humidity) therefore, make a balance between them in the design process.
- The effect of temperature on the human, can cause some diseases that can lead to death, therefore, providing appropriate, should be considered,eg. use of microclimate.
- Passive cooling strategies for buildings should be considered at three levels:
  (i) prevention of heat gains in the building; (ii)modulation of heat gains; and(iii) rejection of heat from the building to heat sinks by ventilation, evaporative cooling, radiative cooling or earth cooling.
- Heat gain controls advantage must be utilized in the design process which consists of three factors (site consideration (location, orientation..etc)
  architectural factor (shades, screens, building exposure..etc)
  weather kin feature (mass, glazing, insulation..etc).
  Also heat gain controls can be applied locally.
- Microclimate can be used in buildings by planting and vegetation to decrease the heat entering the building.
- Passive design might not solve 100% of the problem, but it certainly will reduce the demand for energy consumption.
- All passive cooling strategies rely on daily changes in temperature and relative humidity.
- Some architectural and building techniques, can easily be applied locally(ventilation of all it types (cross, stack, night ventilation). (courtyard effect, wind tower, shading, orientation and massing formation of the building).
- Some natural techniques for cooling can't be applied locally, because of the high potentials and it has rarely been implemented (roof ponds, earth tube), others can be applied such like (cooling tower, evaporative cooling).

Chapter Three

SUSTAINABILITY

3.1 Introduction

Sustainability building design has become very popular in recent years .The most prominent organization promoting sustainability has been the United States Green Building Council(USGBC) ; which sponsors the LEED (Leadership in Energy Environmental Design) accredited professional program and the LEED certified building program

In the past few years other professional organizations, such as American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) have joined the sustainability design community .

Sustainable design is a term used to help bring awareness to the built environments impact on our natural resource , the health and comfort of building occupants , and Earth's climate.

Through the use of Earth-Friendly products, recycled products, rapidly renewable materials (bamboo, cotton, linseed oil, lumber, and recycled products), and renewable energy sources (solar, geothermal, and wind), the impact of new renovated buildings on earths nonrenewable resources(oil, metal) is reduced, along with the impact on the environment of producing and using nonrenewable resources.

Sustainable design also includes designing buildings that promote a healthy environment for the building occupants. This accomplished in different ways, including indoor air quality, using products with low levels of volatile organic compounds(VOCs), proper lighting levels including natural lighting, and individual controls of personal thermal environment.

3.2 Definitions

Sustainability encompasses environmental social and economic dimensions. A widely accepted definition of sustainability is "Meeting the needs of the present without compromising the ability of future generations to meet their own needs.” [Brundtland Report, 1987] Griffith’s Strategic Plan refers to the principles of sustainability to inform our corporate, operational and workforce policies and practices and the management of our financial security. Economic efficiency and environmental sustainability are equally reflected in building design, as well as in energy and water use and waste management. This includes constraining per capita costs and resource use while maintaining high quality services.

Sustainability at Griffith involves incorporating our values into our way of thinking, our decision-making processes and our actions. Sustainability includes prudent financial management.

“Sustainability” refers to the continuation of a project’s goals, principles, and efforts to achieve desired outcomes. Although many grantees think that guaranteeing the sustainability of a project means finding the resources to continue it “as is” beyond the grant period, ensuring sustainability really means making sure that the goals of the project continue to be met through activities that are consistent with the current conditions and workforce development needs of the region, including the needs of both workers and industry. Thus, sustainability does not mean simply maintaining the status quo in terms of funding, staffing, and activities.

Sustainability can be quite a malleable term. While most people understand its intention intuitively, it's difficult to actually pin down since it can cover so many domains. The World Commission on Environment and Development, known more popularly as the Brundtland Commission, created the above mentioned definitions, which one of the best-known and often used definitions:

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The natural step, in another widely-adopted framework, goes on to lay out four system conditions, derived from the laws of thermodynamics, through which such a state can be achieved:

In a sustainable society, nature is not subject to systematically increasing.

i. Concentrations of substances extracted from the Earth's crust.

ii. Concentrations of substances produced by society.

iii. Degradation by physical means and, in that society.

iv. People are not subject to conditions that systemically undermine their capacity to meet their needs.

[http://www.solidworks.com/sustainability/images/content/sustainability/Guide_to_Sustainable_Design.pdf]

3.3 Scope of sustainability

As it can be seen in the definitions, sustainability represents a balanced interaction between the human-built and natural worlds. This interaction is often expressed as having three components: environment, social equity, and economy. The relationship between each of these elements is often represented as either a Venn diagram, with sustainability at the intersection, or as concentric circles, reflecting a layering of domains. This second case reflects the more realistic perspective that a healthy economy depends on a healthy society, both of which rely on a healthy environment. Sustainability occurs when all three are thriving. See fig (3.1).

In the extensive discussion and use of the concept since then, there has generally been a recognition of three aspects of sustainable development:

- **Economic**

An economically sustainable system must be able to produce goods and services on a continuing basis, to maintain manageable levels of government and external debt, and to avoid extreme sectored imbalances which damage agricultural or industrial production.

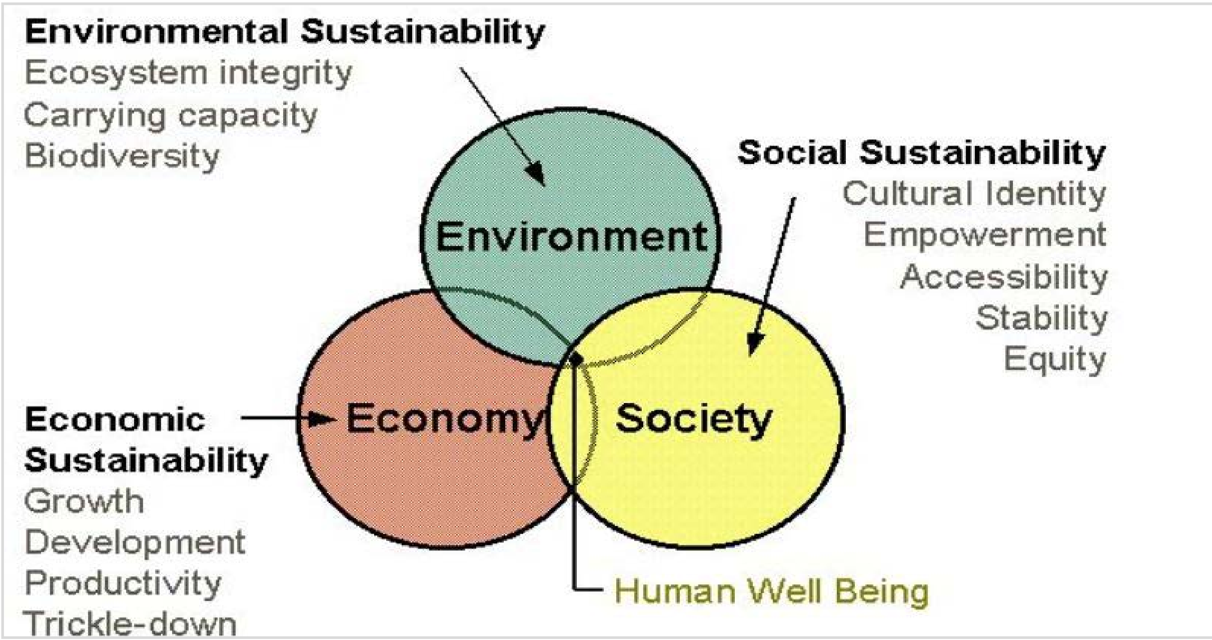


Fig.3.1 Scope of sustainability.

Source: Sustainable architecture and building design, page 4.

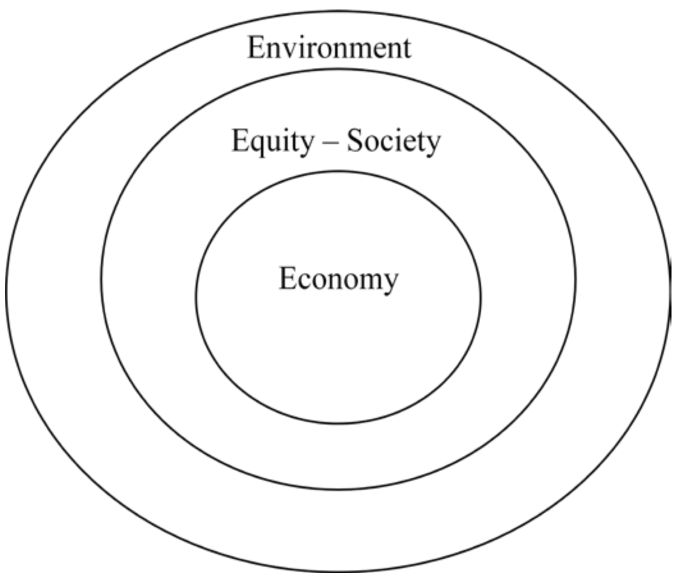


Fig. 3.2 Concept integration.

Source: Guide to Sustainable Design, page 9.

▪ **Environmental**

An environmentally sustainable system must maintain a stable resource base, avoiding over-exploitation of renewable resource systems or environmental functions, and depleting non-renewable resources only to the extent that investment is made in adequate substitutes. This includes maintenance of biodiversity, atmospheric stability, and other ecosystem functions not ordinarily classed as economic resources.

▪ **Social**

A socially sustainable system must achieve distributional equity, adequate provision of social services including health and education, gender equity, and political accountability and participation.
[http://www.solidworks.com/sustainability/images/content/sustainability/Guide_to_Sustainable_Design.pdf].

3.4 LEED green building rating (Leadership in Energy and Environmental Design)

LEED, or Leadership in Energy and Environmental Design, is changing the way we think about how buildings and communities are planned, constructed, maintained and operated. Leaders around the world have made LEED the most widely used third-party verification for green buildings, with around 1.85 million square feet being certified daily. It divided as follow, See figs 3.3- 3.4- 3.5- 3.4- 3.5-3.6 and 3.7.

i-Sustainable Sites
- Construction Activity Pollution Prevention.
- Site Selection.
-Development Density & Community Connectivity.
- Brownfield Redevelopment.
- Alternative Transportation.
- Site Development.
- Storm water Design.
- Heat Island Effect
-Light Pollution Reduction.

Fig. 3.3 Sustainable sites.

Source : https://www.google.com/url?sa=i&rct=j&q=&esrc,2016.

ii. **Water efficiency**
- Water Efficient Landscaping.
- Innovative Wastewater Technologies.
-Water Use Reduction.

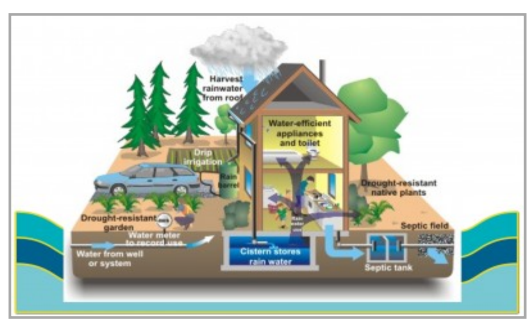


Fig. 3.4 Water efficiency.

Source: https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=, 2016.

iii- **Energy and atmosphere**
- Refrigerant management.
- On-Site Renewable Energy.

- Commissioning of the Building
  Energy system.
- Energy performance.
- Measurement & Verification.

iv- Materials and Resources

- Storage and Collection of Recyclables.
- Building Reuse.
-Construction Waste Management

Fig. 3.6 Material and resources.
Source: https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source, 2016

- Materials Reuse.
- Recycled Content.
- Regional Materials.
- Rapidly Renewable Materials.
- Certified Wood.

Fig. 3.5 Energy and atmosphere.
Source: https://www.google.com/url?sa=i&rc&esrc=s&soimgres&cd,2016.

v- Indoor environmental quality

-IAQ Performance.
- Environmental Tobacco Smoke (ETS) Control.
- Outdoor Air Delivery Monitoring.
- Increased Ventilation.
- Construction IAQ Management Plan.
- Low-Emitting Materials.
Controllability of Systems.
- Thermal Comfort.
- Day lighting and Views.

Fig.3.7 Indoor air quality.
Source: https://www.google.com/url ource=imgres&reewdssgjcd,2016

vi- Innovation & Design Process

Architectural Design has a major affect on buildings' sustainability and environmental efficiency. If a building is well-designed and takes into consideration all environmental aspects from the very beginning, it will positively affect the electro-mechanical work afterwards. See fig.3.8 -3.9.

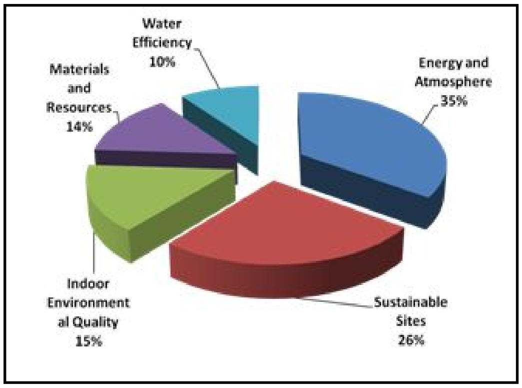


Fig 3.8 LEED for New Construction (LEED NC)

Source: https://www.google.com/url?sa=i&rct=j&q=&esrc=s &source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwjT8f

Fig. 3.9 Innovation & Design Process

Source: https://www.google.com/url?sa=i&rct=j&q &uact=8&ved=0ah, 2016.

3.5 Main principles of sustainability in design

Access to sustainable design has to be full integration between the architecture and all the complementary disciplines (civil engineering - Electrical - etc.) in addition to aesthetic values, proportionality and the composition of the future cost of respects (Environmental - Economics - Human).

Basics of sustainable design

- Reliance on the sun and daylight and natural cooling natural sources of supply and to create the right atmosphere for the user light.
- Dependence on the philosophy of constructivism and not on a particular form resorting to the familiar shapes.
- Assumed that the cost of sustainable buildings be very high, in contrast to operation, it helps to save cost.
- Consideration in the rationalization of energy consumption and improve the health of the user of the key elements in the design.

[https://ar.wikipedia.org/wiki/%D8%B9%D9%85%D8%A7%D8%B1%D8%A9_%D9%85%D8%B3%D8%AA%D8%AF%D8%A7%D9%85%D8%A9].

3.6 Main principles of sustainability in planning

Sustainable planning is an application of the theories of sustainability and flexibility in the design and management of operation of urban communities.

Sustainable urban design elements

- **Stacking**

Or stacking density, plays an important role in sustainable planning because it supports reducing the use of resources and benefits from the services of public transport.

- **Biophilia**

This term was introduced by Wilson, which refers to the relationship of man to live its systems, linking the presence of open spaces such as parks, gathering places, and sustainable food production and the use of agricultural land to the concerns of rights and its relationship with nature.

- **Sustainable corridors**

Similar to the corridors of the big neighborhoods that are linking regions and other areas in easily ways. People can move from their area to other areas without relying on cars. It also depends on the provision of public transport in an effective manner so that they become the best option for the population to move from one area to another. Sustainable corridors include passages that allow diversity to move around cities and communities.

- **High-performance buildings**

The high-performance design of buildings to increase energy savings and to reduce the impact of construction. That process consumes the construction of buildings and running cost enormous amount of resources and energy and increases pollution. High performance buildings are working to make the buildings less harmful. It's determined by the amount of energy used by the building's two types of loads heating / cooling or in other words the amount of heating or cooling needed to maintain the home in a reasonable temperature (loads of Interior: Lighting, people, equipment, ventilation system used inside the building, and the external loads: building walls, ceilings, windows, and how that affects the flow of energy).

One of the best examples of sustainable cites is Masdar city, is a planned city project in Abu Dhabi, in the United Arab Emirates. Its core is being built by Masdar, a subsidiary of Mubadala Development Company, with the majority of seed capital provided by the Government of Abu Dhabi. Designed by the British architectural firm Foster and Partners, the city relies on solar energy and other renewable energy sources. Masdar City is being constructed 17 kilometers (11 mi) east-south-east of the city of Abu Dhabi, beside Abu Dhabi International Airport. See fig.3.10.

Masdar City hosts the headquarters of the International Renewable Energy Agency (IRENA). The city is designed to be a hub for clean tech companies. Its first tenant was the Masdar Institute of Science and Technology, which has been operating in the city since it moved into its campus in September 2010.

[https://en.wikipedia.org/wiki/Masdar_City, 2016].

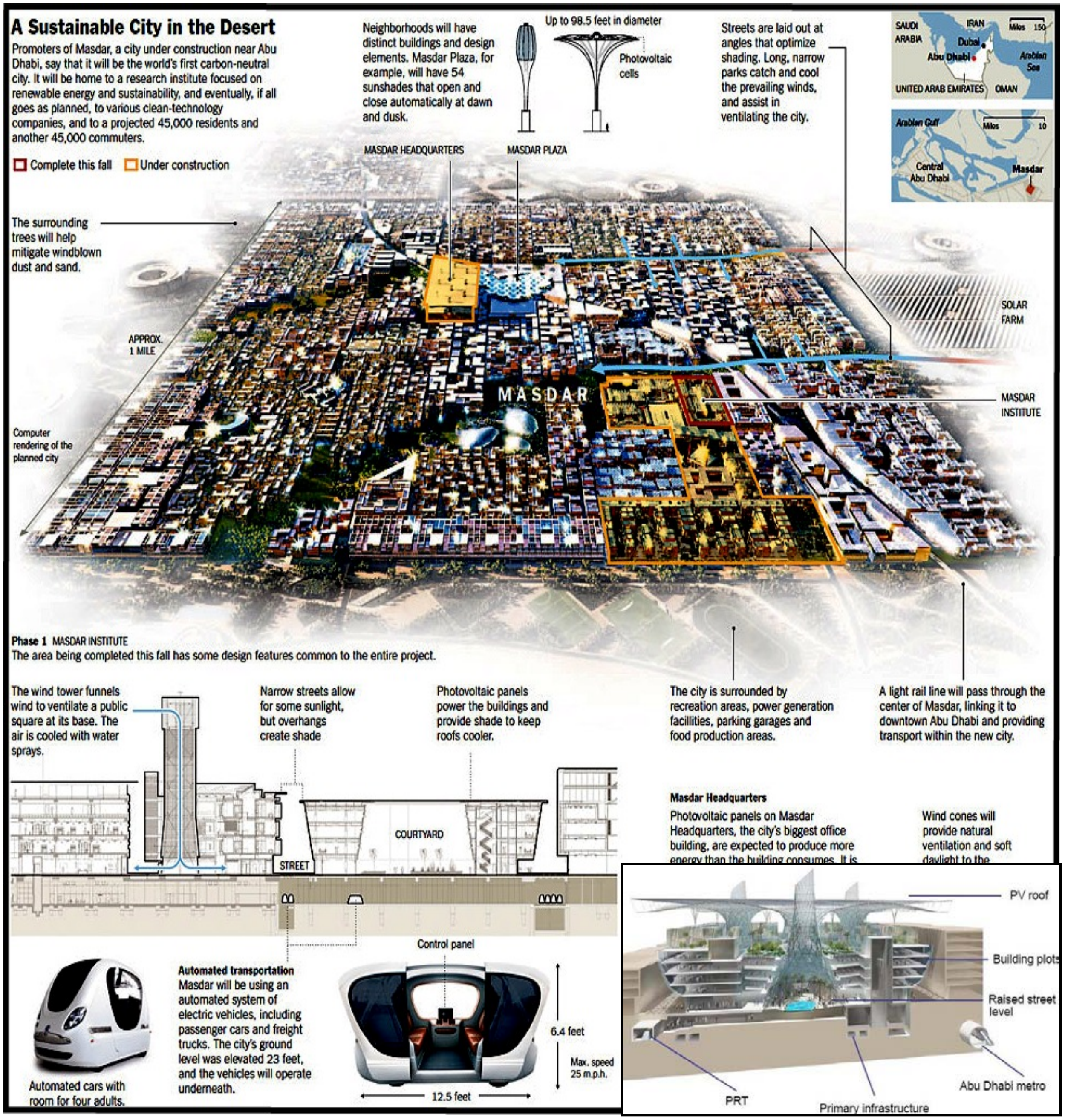


Fig.3.10 High-performance building(Masdar city) .

Source: https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwjf5O-mh-PSAhXEtRQKHQCnCTMQjRwIBw&url=http%3A%2F%2Fwww.2daydubai.com%2Fpages%2Fmasdarcity.php&psig=AFQjCNE7uGfxOjOiyfgUfh9L9hMhWzaXCg&ust=1490029693496680,2016.

3.7 Examples of passive cooling projects

3.7.1 General Introduction

In this section the author will give some international projects for passive cooling to have an overview for its techniques and its benefits in saving energy. The author presents two kind of examples, international and regional examples.

3.7.2 Example (1) A house in An ocean (Florida).

Table 3.1 Example (1) House in An ocean (Florida)

Source: The author, William S. Hoffman, 2004.

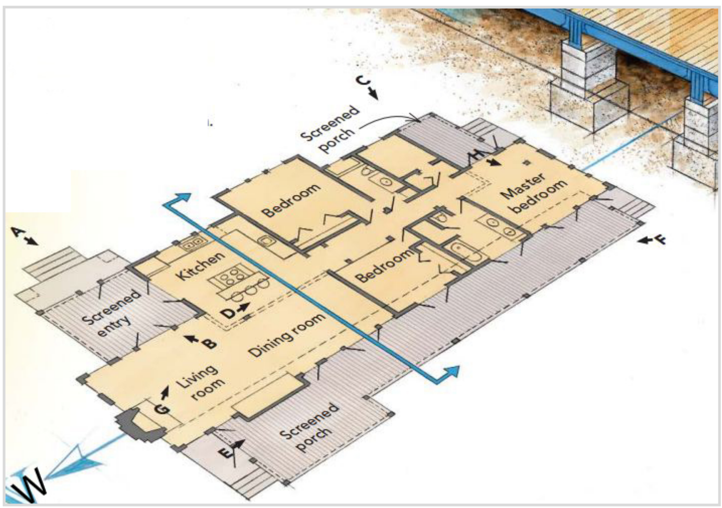
<table>
<tr><td colspan="2">Example (1) House in An ocean (Florida)</td></tr>
<tr><td colspan="2">

Fig.3.11 The house ground floor plan.
Source: William S. Hoffman, 2004, page 96.</td></tr>
<tr><td>a) General Information:
Location: South Melbourne Beach, Fla.
Total Area: 1800m sq+ 780m sq of screened porches.
Bedrooms: 3
Bathrooms: 2
Completed: 1996.
Architect: William S. Hoffman</td><td>
Fig.3.12 Passive cooled house .
Source: William S. Hoffman, 2004, page 96.</td></tr>
<tr><td colspan="2">b) The goal of the project:
The goal for this project was to:
i-Design a home that keeps the owners cool without relying heavily on air-conditioning (keep out the sun, and stay comfortable when things heat up outside).
ii- Lowering the temperature and increasing airflow around a house. Designing a passively cooled house starts with the site and includes every aspect of the house right down to the color of the paint.</td></tr>
</table>

c) Techniques Used in the building

i- Wind and shade

Wind comes from the south. So it was important to have one of the long sides of the house, with plenty of doors and windows, facing south, because the best remedy for hot weather is positive airflow.

ii- Open plan

Open floor plans complement, make small spaces feel larger, and keep fresh air flowing through the house. The open kitchen, dining room, and living room connect to outdoor areas through French doors and allow the breeze to cool the interior of the house. Photo taken at B on floor plan. See fig 3.13.

iii- Reflective material reduce heat gain:

The metal roof and light gray cypress siding reflect the sun's radiant heat, while vegetation shades the east and west-facing walls from early- and late-day sun.

Combined with the cupola and various styles of windows and doors, the exterior finishes make an attractive house for any climate. Photo taken at C on floor plan . See fig3.14- 3.15.

[William S. Hoffman.2004 , Page101], said " This is a perfect example of passive cooling. An ocean breeze, a wooded site, and a willing homeowner allowed me to incorporate all the principles into one home."

To remain cool without air-conditioning, this house is designed to promote the circulation of cool air and to keep the sun from turning the interior into an oven. Setting the house to take advantage of the prevailing breeze is the first step toward better airflow. Shade, light colors, and reflective materials keep the sun's radiant heat where it belongs to outside. See fig 3.16.

iv- Hot air exits the Cupola :

1- In the center of the house where bedroom walls inhibit cross ventilation, warm air that rises to the ceiling escapes through the cupola's windows. When the forces of thermal dynamics aren't enough, reversible-blade ceiling fans give the warm air a push. Louvered vents above the doors also help to keep air flowing. Photo taken at D on floor plan. See fig3.17

Fig. 3.13 Internal view of the building.
Source: William S. Hoffman, 2004 ,page 97.

Fig 3.14 Metal roof.
Source: William S. Hoffman, 2004,page 98.

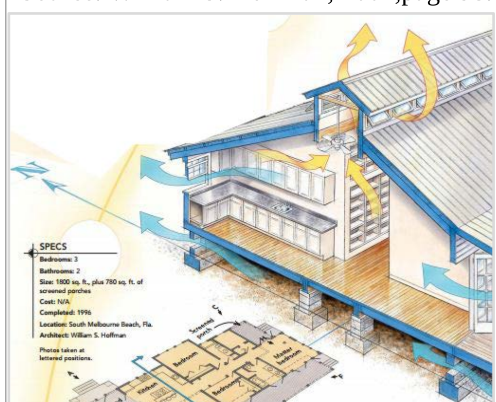


Fig.3.15 Plan and 3d for the house.
Source: William S. Hoffman, 2004, page98.

Fig. 3.16 Cupola windows.
Source: William S. Hoffman, 2004 ,page 99.

v- House orientation:

The house slightly to the east, just enough to:

a- Capture the breeze without exposing too much of the house's long wall to the strong, low sun early and late in the day.

b-To consider the sun's orientation throughout the day because solar-heat gain along the house's walls and roof raises the temperature inside. Here, the midday sun is so high in the sky that a small overhang is enough to keep the south wall shaded.

c-Vegetation: the site is dense with sable palms, water oaks, and gumbo limbos.

d-Use trees to maximize the amount of shade.

e-A full-length screened porch on the southern side offers an outdoor space accessible from every room on that side of house. French doors allow the ocean breeze to enter the house, and a vented block foundation wall allows the breeze to flow beneath the floors Photo taken at E and on floor plan. See fig 3.18.

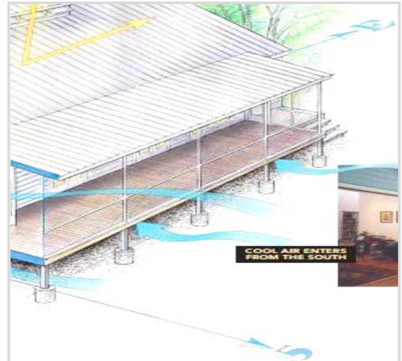


Fig .3.17 House orientation.
Source: William S. Hoffman, 2004 ,page 99.

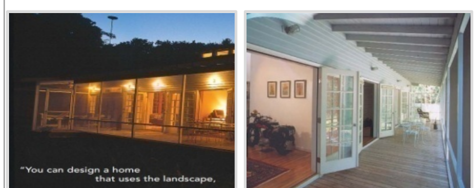


Fig.3.18 French doors and screened porch+ using landscape and plants effect.
Source: William S. Hoffman, 2004,page 99-100.

vi- Use plant effect:

more than just a porch. During the day, the long screened porch shades the south-facing wall. At night, it offers a great place to relax. More than one-third of the house's total square footage is made up of outdoor spaces. Photo right taken at F on floor plan. See fig3.19.

vii- Natural ventilation: (windows and doors plays the role of stacked ventilation).

viii- Use special kind of ceiling: valume roof*(valume roof: is a type of roof. For more details visit(www.steelroofing.com,2016), for two reasons:

a-Metal valume roof reflect radiant heat, and metal outperforms other roofing material in strong storms and wind-driven rains.

b-Rigid-foam insulation prevents radiant heat from transferring to the tongue-and-groove cypress ceiling inside.

Fig 3.19 Valume ceiling.
Source: William S. Hoffman, 2004 ,page 101.

3.7.3 Example (2) A house in Bowen Island in British Columbia.

Table 3. 2 Example (2) A house in Bowen Island in British Columbia.

Source: The author, http /www.archdaily.com,2016.

Example (2) A house in Bowen Island in British Columbia.

b) General Information

Location: western coast of Bowen Island in British Columbia.
Bedrooms: 2.
Bathrooms: 2.
Clients: professor of East Asian archaeology and a researcher from Kyoto, Japan.

Fig3.20 Modern and low-impact.
Source: http /www.archdaily.com,2016.

b) The goal of the project

The goals for this project was:
i- The home must fit the site. ii- It should have minimal impact on the landscape.
iii- Use natural systems to reduce its environmental impact and lower its operating cost.
iv- Improve the house integration to the exterior environment.

The designer said “the passive systems that I integrated into this house were based both on the general needs of the homeowners and on the specific demands of a challenging site.”

Design challenges

i- The building site faces west.
ii- The building was surrounded by forested hills and granite rock outcroppings to the south, east, and west that captured the warmth of the sun throughout the afternoon.

The designer integrated design details that would handle heating and cooling demands passively, the need for water conservation and rainwater harvesting, solar-shading, and natural day lighting. See fig. 3.21 - 3.22.

c) Techniques Used in the building

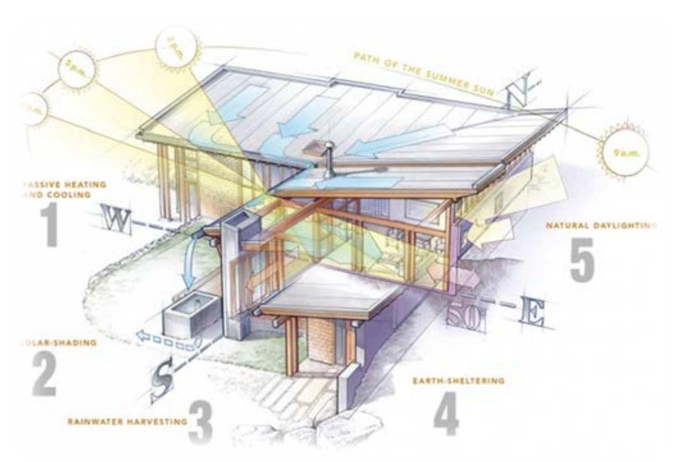


Fig 3.21 Passive cooling and sustainability techniques used in the house.
Source: https://www.archdaily.com/, 2016.

Fig.3.22 Ground floor plan for the house
Source: http /www.archdaily.com, 2016.

i-Passive cooling and heating

By using sunlight, shade, and ventilation to regulate the house's interior temperature. See Fig.3.23.

ii-Solar shading

Solar-shading keeps a house cool by blocking solar-heat gain and minimizes the damaging effects of solar rays.

Sunlight can be controlled through several structural details. Deep overhangs, small or well-positioned windows, and solar shades are all ways of controlling the influences of the sun.

The designer uses deep, covered deck to block the afternoon sun. See fig.3.23.

iii-Rainwater harvesting

Rainwater runs off the roof into barrels or cisterns.This can virtually eliminate the use of well water for irrigation. Photo taken at B on floor plan. See fig 3.24.

iv- Earth – sheltering

Earth-sheltering uses the insulating properties of soil to decrease the strain on mechanical heating and cooling systems by keeping interior temperatures stable.

The earth's ambient temperature is roughly 50°F year-round, which helps to cool the house in summer and makes it easier to control interior temperatures in winter. Earth-sheltering works best on east and north elevations. See fig3.24.

v- Natural daylight

The high windows in the east wall bring ambient light into this house's main living space.Carefully positioned spotlights illuminate the concrete wall, which serves as one of the homeowners 'art galleries. Photo taken at D on plan. See fig3.25.

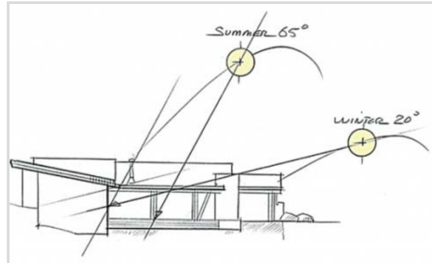


Fig. 3.23 In winter, the sun's trajectory is lower in the sky, so more light penetrates the west-facing windows of the house and warms the concrete floors and the east wall.

Source: http /www.archdaily.com, 2016.
Fig 3.24 Rainwater harvesting
Source: http /www.archdaily.com, 2016.

Fig.3.25 A lighting scheme that works.
Source: http /www.archdaily.com,2016.

3.7.4 Example (3) A house in Singapore.

Table 3.3 Example (3) A house in Singapore.

Source: The author, https://www.archdaily.com.

Example (3) A house in Singapore.

a) General Information:

Location : Singapore .
Total Area : 448.0m sq.
Bedrooms : 3.
Bathrooms: 3.
Completed: 2016.
Architect: Aamer Architect.

Fig.3.26 Main elevation of the house.
Source: https://www.archdaily.com/789395, 2016.

b) The goal of the project:

i- Have a special view for the building. ii- Have a good indoor and outdoor air quality.
iii- Save energy.
iv- The house is located in front of a bus-stop at a junction of a minor road and a busy main road, so the client wants a strong protection from noise, and wants natural light and ventilation.

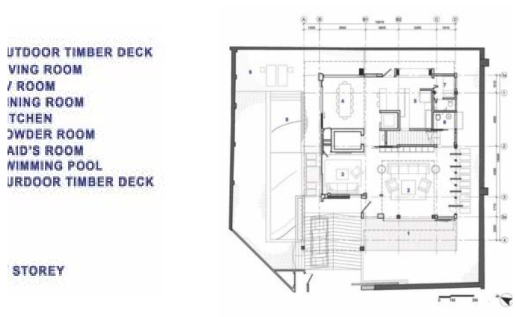


Fig 3.27 Second floor plan of the building
Source: https: //www.archdaily.com/789395,2016.

Fig.3.28 First floor plan of the building
Source: https://www.archdaily.com/789395,2016.

c) Techniques Used in the building

i- Use plant effect

At ground level, the internal spaces of the house blend easily with the outdoor decks, gardens and swimming pool, which also provides passive cooling to the house. See fig.3.29.

ii- Use natural ventilation

The master bedroom located in the attic enjoys the comfort of deep overhangs, plenty of natural light and long distant views, not typical of such a dense urban site. See fig 3.30.

ii- Colors and materials

At first floor plan solid boundary walls and landscaping mitigate the traffic noise from the main road while providing an intriguing visual delight to bus drivers, passengers and passersby. see fig 3.32.

iv- Use the effect of the high hall

The grand double volume living room, surrounded by a mezzanine study library and corridors improves connection between occupants and gives the living space a dynamic interactive quality, see fig4.31.

Fig.3.29 Usage of plants effect.
Source:
https://www.archdaily.com/789395

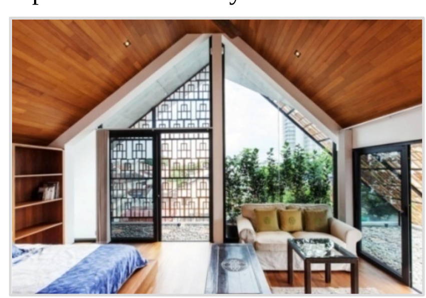


Fig.3.30.Usage of natural ventilation.
Sourcehttps://www.archdaily.com/789395

Fig 3.31 High hall.
Source: https://www.archdaily.com/789395,2016.

Fig.3.32 Colors and materials.
Source https://www.archdaily.com/789395

3.7.5 Example (4) A house in Dahshur, Egypt.

Table 3.4 Example (4) Akil Sami house in Dahshur, Egypt.

Source: The author, Hassan Fathy / editor, Ismail Serageldin, 2007).

Example (4) Akil Sami house in Dahshur, Egypt.

a) General Information:

Location: Dahshur, Egypt.
Completed:1978.
Architect: Hassan Fathi.

This house was built in local limestone because of a governmental ban on the use of mud - brick flowing the construction of the high dam, as well as unsatisfactory test result for the structural strength of the soil in this area. The tukhtabouh and the courtyard area of the house with wooden pergolas, recall the latticework notably used in Moastrili residence.

Fig.3.33 Main perspective of the house
Source: Hassan Fathy / editor, Ismail Serageldin, 2007).

b) Techniques Used in the building

i- Use plants effect

Usage of plant effect helps in cooling the house passively, have shaded areas in the building, create good interface for the building. See fig3.34.

Author observation is that there is an integration between inside and outside environment, by using local building materials (wooded pergolas), made this effect.

ii-Using tukhtaboush

Wooded tukhtaboush as a strong effect in the house, it filter the air and make an easy way for it to pass through the building. See fig 3.35 - 3.36.

Fig.3.34 plants effect.
Source: Hassan Fathy/editor,Ismail Serageldin, 2007).

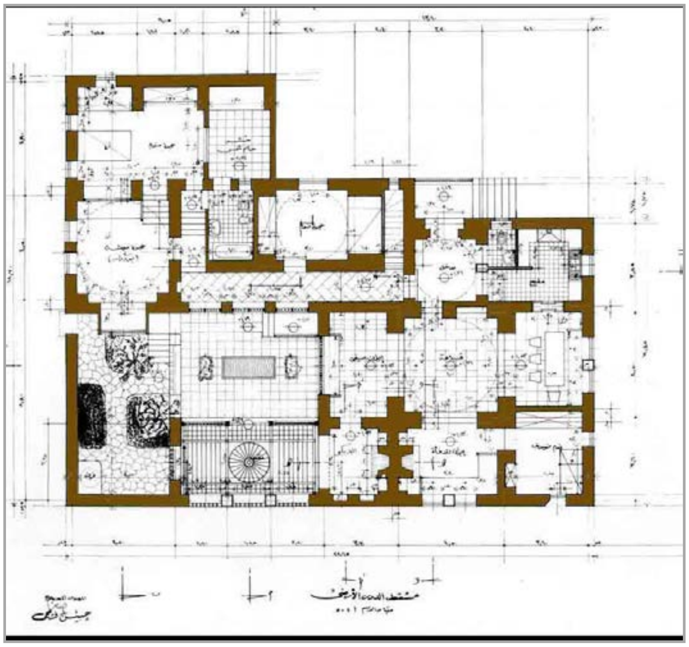


Fig 3.38 Architectural drawings for the house.
Source: Hassan Fathy/editor,Ismail Serageldin, 2007).

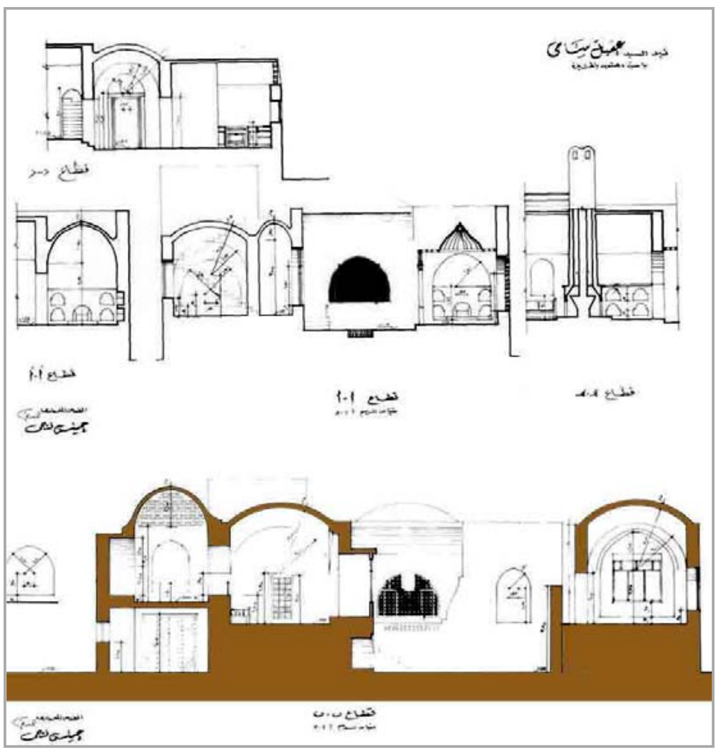


Fig 3.39 section A-A for the house
Source: Hassan Fathy/editor,Ismail Serageldin, 2007).

Fig.4.35 Using of tukhtaboush in the building.
Source: Hassan Fathy/editor,Ismail Serageldin, 2007).

Fig 3.36 In and out view of the wooded window
Source: Hassan Fathy/editor,Ismail Serageldin, 2007).

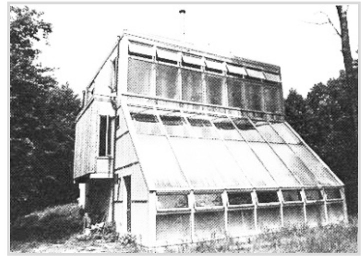
Fig. 3.37 Internal view for the house .
Sourc: Hassan Fathy/editor,Ismail Serageldin, 2007).

3.7.6 Example (5) A house in California.1.

Table 3.5 Example (5) A house in California.1.

Source: The author, Michael J .Holtz, 1979.

<table>
<tr><td colspan="2">Example (5) A house in California.1</td></tr>
<tr><td>a) General Information:
Location : California.

Architect: Headed by architects/authors David Wright and Dennis Andrejko, California's SEA group .</td><td>
Fig 3.40 General view of the house
Source: Michael J .Holtz, 1979. Page 11.</td></tr>
<tr><td>b) Techniques Used in the building
i-Earth tube.
ii-stack ventilation.
iii- roof pond.
iv-plants effect.

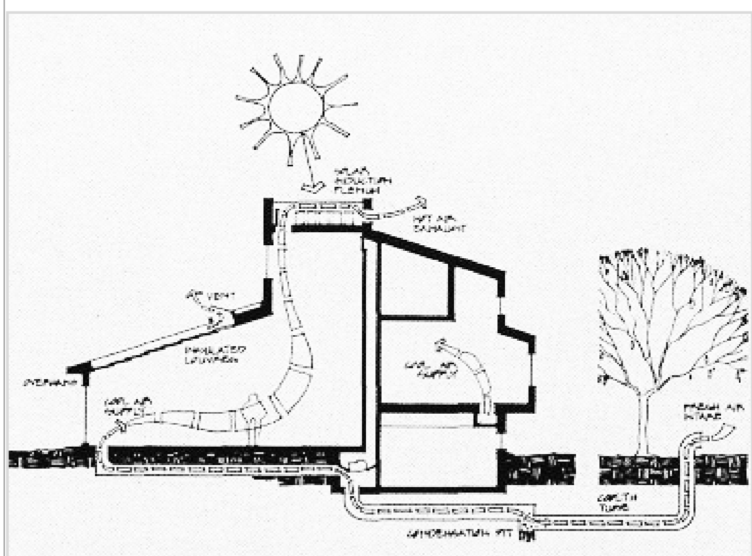
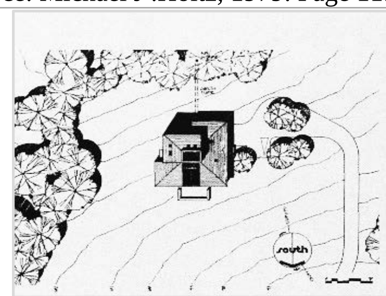



Fig 3.43 Passive technique that used in the building .
Source: Michael J .Holtz, 1979. Page12.</td><td>
Fig 3.41 Site plan.
Source: Michael J .Holtz, 1979.Page12.

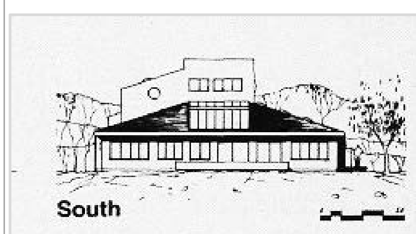


Fig 3.42 South elevation
Source: Michael J .Holtz, 1979.Page12.</td></tr>
</table>

3.7.6 Example (5) A house in California.2.

Table 3.6 Example (6) A house in California.2.

Source: The author, Michael J .Holtz, 1979.

Example (6) A house in California.2.

a) General Information:

Location: California.

Architect: Headed by architects/authors David. Wright and Dennis Andrejko, California's SEA group.

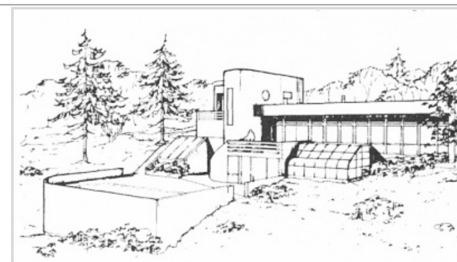


Fig 3.44 General view of the house
Source: Michael J .Holtz, 1979. Page12.

California's SEA group (for Solar Environmental Architec4ture) has been designing passive buildings around the country for several years. The J Davis residence for Hutchinson, Kansas helps meet its cooling load by drawing cool, shaded exterior air through a lengthy " cool tube" and in to the house. The air circulation is solar - induced at the massive roof plenum.

b) Techniques Used in the building

1-Earth tube.
2-cross ventilation.
3- plants effect.
4- Shading. See fig 3.46.

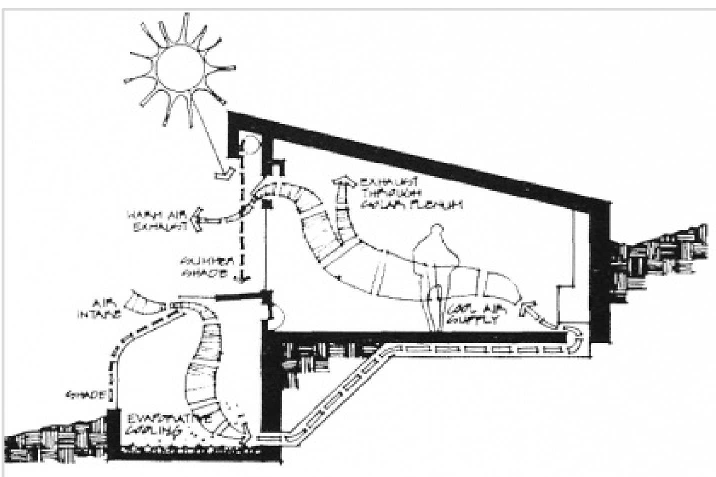


Fig 3.46 Passive technique that used in the building .
Source : Michael J .Holtz, 1979. Page12.

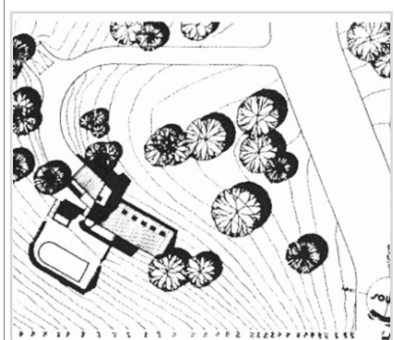


Fig 3.45 Site plan.
Source: Michael J .Holtz, 1979. Page12.

4.8 Conclusion

- Sustainability Concepts have been widely used during the last years. This could save energy, because it's an integration of the components (environment, social equality and economy).

- There are some principles of sustainability in planning which can be locally applied (stacking Biophilia and sustainable corridor), some can't be applied (high performance building) because of the high potential costs.

- The principles of sustainable design can be applied locally.
- For LEED green building rating it can be applied in the design process (sustainable sites, water efficiency, indoor air quality, energy and atmosphere, local building materials and innovation in building design).

For the global models;

- Studying the first model; it's noticed that the designer used several methods of passive cooling in the home and relied on natural ventilation, as well as reducing costs and saving energy. He also used the outdoor spaces in the hydration process of the building by creating a microclimate around the site.

- In the second model, it's obvious that the house is a good example for sustainable passive cooling, the designer saved energy in the house by using natural ventilation and selected a well oriented site, using local building materials and simple drainage system.

- While for the third model; it's noticed that using a double height hall helps in cooling the house naturally, also using local building materials and plants effect passively cooled the house.

- In the fourth model, it's noticed that Hassan Fathy building techniques very affordable and uses available building material. This is also applicable to conditions in Sudan.

- Finally, in the fifth and sixth models it's noticed that using one or two passive cooling techniques in the building can also add to thermal comfort.

Chapter Four

PRESENTATION AND ANALYSIS OF THE CASESTUDY

4.1 Introduction

4.1.1 Sudan

For many people mentioning Sudan brings up images of famine, war, child soldiers in the south and slavery and ethnic eradication in the Nuba Mountains.

For those who know more about the country maybe what is remembered are the ruins of hundreds of small pyramids scattered on the desert plains of Nubia, the uniqueness of its art and architecture, and the sophistication of its building methods. Or maybe the more recent art of house decoration in Old Halfa, drowned by the waters of the Nile after the construction of the Aswan Dam, or the ruins of the Turkish town of Sawakin on the Red Sea. In Western Sudan what is fascinating for foreigners is the nomad way of life that has remained largely unchanged. [Omer S. Osman; Ibrahim Z. Bahreldin; Amira O. S. Osman, 2015].

The Sudan is called ‘the land of a million square miles’ by its people. There are 596 tribes speaking 115 languages and the country has a population of approximately 34,400, 000 people (1999 census). It gained independence in 1956 from British/Egyptian rule. It has one of the longest running civil wars in Africa, on and off since 1955.

The country, like many others, inherited extreme poverty and social upheaval from the colonialists. The author think that can be very effected to the Sudanese culture.

The country consists of the tropical south and the arid north. The Nile is the country’s greatest asset and life exists along its banks, populations thinning out as one moves to the arid areas to the west. [Omer S. Osman; Ibrahim Z. Bahreldin; Amira O. S. Osman, 2015].

4.1.2 Greater Khartoum

It was founded in 1821 as an Egyptian military post for captured territory in the Sudan. It is the chief administrative city and the center of transportation. It is divided by the great life-giving Nile River into three towns, Khartoum city, Omdurman city and Khartoum North city, where three different worlds meet. Khartoum-the colonial wide street city, the labyrinthine world of Arabic Omdurman and the world of a present day industrial city, Khartoum North.

Geographically, Khartoum is in the center of the Sudan, it is flat and surrounded by infinite expanses of scarcely populated deserts savannah. The only prominent structure is the Nile which cuts through the country from the South to the North.

In Khartoum the pure abstract absolution of Islam meets the magic world of Africa, so it is located at the center of several worlds, the eternal order of the Nile valley to the North, the world of black Africa to the South, the infinite desert to the West, and the harsh mountains of Ethiopia to the East.

The colonial town is characterized by its horizontal development which is the existential dimension of the desert.

Arabs in fact, have always preferred low, horizontally extended buildings, and the only vertical element was the minarets of the mosques.

[https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwiGm-fh3ePSAhXCWxQKHRr8ByoQFggZMAA&url=https%3A%2F%2Ftheses.lib.vt.edu%2Ftheses%2Favailable%2Fetd-050599-103655%2Funrestricted%2Fch7.pdf&usg=AFQjCNGoqyZSbYbU4jkmbAdrqVcry7x3mQ&sig2=lpbutI9Jvgv-dP4qpDWpfQ&bvm=bv.149760088,d.d24, 2016].

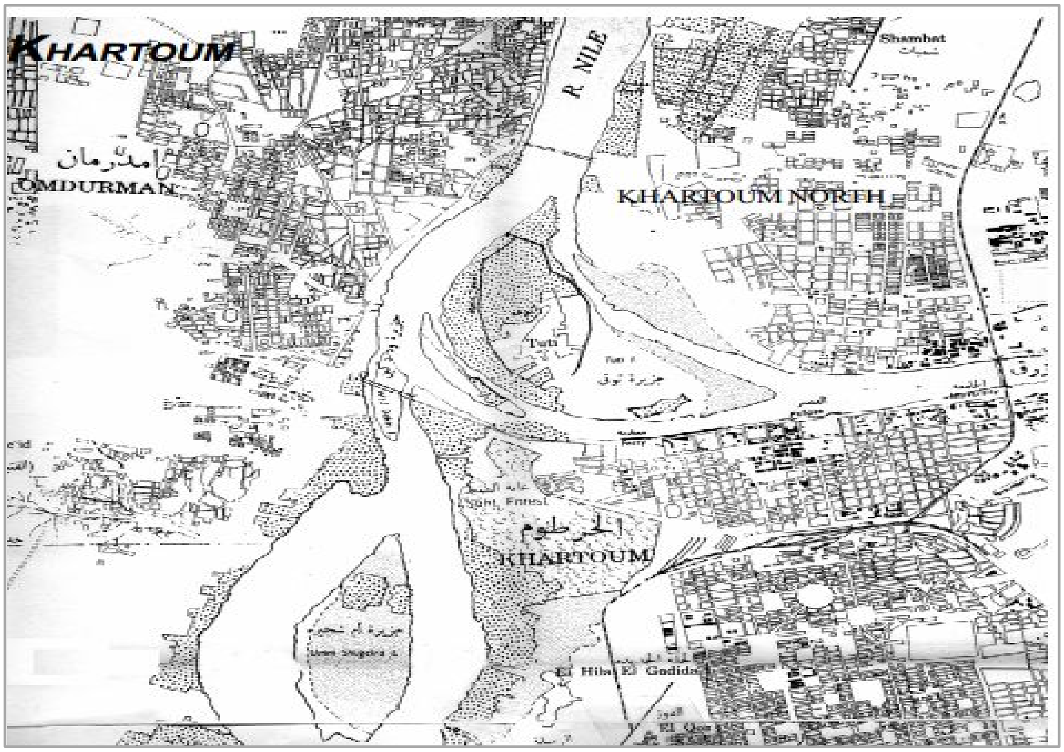


Fig.4.1 Khartoum map
Sourcehttps://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwiGm-, 2016.

Basic types of urban structure:

Two basic types of urban structures are found in Khartoum city, the labyrinthine world of the desert settlement, which represents the original vernacular solution (Tuti Island), and the geometric pattern of " Baroque", which symbolize a general ideological system.

Geometrically, Khartoum is a geometrical network, with which land marks and nodes are distributed according to their functional and symbolic role. Khartoum North is less distinct. The three towns are united by the bl

ue-green belt of the Nile.

Fig.4.2 The parliament building.

Source: http://www.sudantribune.com/, 2016.

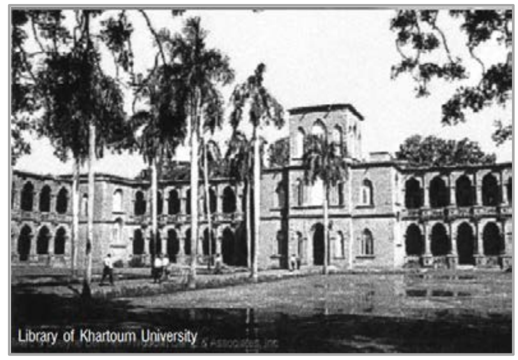


Fig.4.3 library of Khartoum university

Source:https://www.google.com/imgres?imgurl=https%3A%2F%2Fupload.wikimedia.org%2Fwikipedia%2Fcommons%2F5%2F54%2FSudan_Khartoum_Gordon_College_1936,2016.

4.1.3 The techniques used in Khartoum to To reduce hot climate

i- Colors and materials

The character of Khartoum is determined by the appearance of concrete, and sand which is the most prominent element that represents the desert that surrounds the city. Sand is presented not only as material, but as color and texture.

Christian Norborg-Schultz, in Genius Loci, describes Khartoum "as a city with a strong quality of space, burning sun and immense sky, all these elements helped to create a powerful environment."

The architecture of Khartoum represents an interesting combination of Arabic and African character, where the enclosure of the private domain is in accordance with the social structure of the Arabs.

However the plastic modeling and the soft details that are found in the use of small windows that could have a circular shape, the use of mud or sun-dried brick, and also the burned brick is African more that Arabic. As Norborg-Schultz mentioned in his Genius Loci, that " the Arabic architecture of North Africa in fact gives more emphasis to the regularity and geometrization".

The architecture is more to do with obeying "the law" of the natural environment, which is expressed by color and materials.

The vernacular architecture in the three towns depends mainly on the usage of local materials as mud, or sun-dried brick and burned bricks. The houses consist mainly, as any Muslim house, of the perimeter wall, which is usually built before the dwelling, it is continuous and an enclosing element.

ii- Courtyards

The wall encloses a courtyard that is surrounded by "several or one room" which is free standing, or attached to the perimeter internally; the wall prevents the entering of the desert feeling.

The courtyard will create a pleasant environment by having green areas and the shadows of the rooms which will replace the burning sun and the sand color of the exterior world. This arrangement is commonly used in Omdurman .

iii- Use of the effect of plants and gardens

In the colonial Khartoum, houses are more open to the environment and the enclosing walls substituted by a transparent fence. Therefore it's not only the environmental factor.

iv- Use of arches in buildings as verandas

The density in Khartoum is less and the streets are more defined and wider, at the level of buildings and houses, columns, arches and architraves substitute the wall. The columns take different shapes, for example, Ionic prefabricated of concrete.

Currently Khartoum city is expressed by the interaction of the Arabic, African and European styles and colors, but maintain the same Arabic social structure in more developed sequence.

Khartoum city, in the beginning did not follow the Islamic city porticoes as much, because it was planned by the British Lord Kitchener in the shape of the Union Jack.

[https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwiGm-fh3ePSAhXCWxQKHRr8ByoQFggZMAA&url=https%3A%2F%2Ftheses.lib.vt.edu%2Ftheses%2Favailable%2Fetd-050599-103655%2Funrestricted%2Fch7.pdf&usg=AFQjCNGoqyZSbYbU4jkmbAdrqVcry7x3mQ&sig2=lpbutI9Jvgv-dP4qpDWpfQ&bvm=bv.149760088,d.d24, 2016].

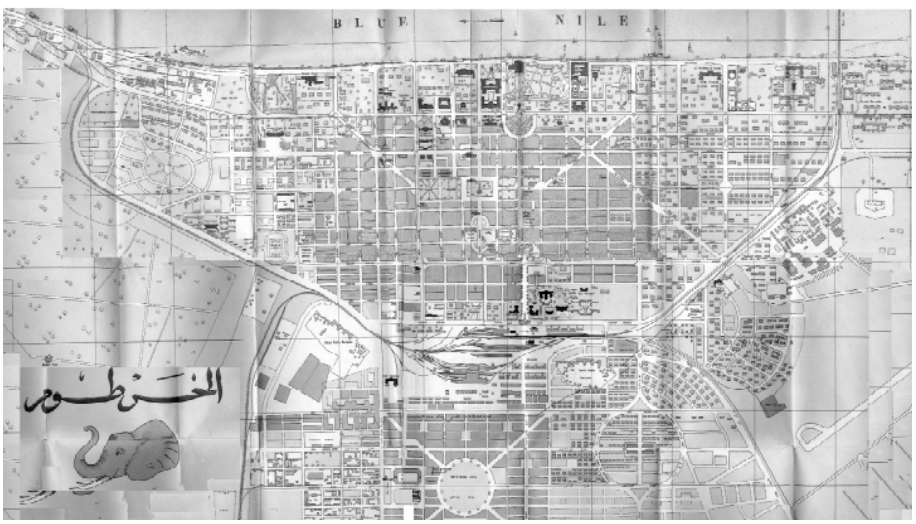


Fig.4.4 Khartoum map during the 50s and 60s of the 20th century.

Source:https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwiGm-

4.1.4 Colonial architecture in Sudan

a) Early colonial architecture (1900–1920)

Since the last decade of the 19th century, there is strong evidence that the invading British architectural practice was under the influence of the modernist movement initiated by the construction of the Crystal Palace in 1851. [Omer S. Osman; Ibrahim Z. Bahreldin; Amira O. S. Osman, 2015].

Herbert Kitchener (the first Governor-General of Sudan) did not believe that indigenous construction techniques were suitable for the necessary civic edifices and housing facilities for the new rulers, who needed facilities comparable to the standards they were accustomed to be it in Britain or in Egypt. Despite the fact that Sudan was under Anglo-Egyptian Condominium Rule, British culture was the dominating element in that period. The British had the upper hand both in town planning and in architecture; they supplied the engineers, whilst builders were mostly recruited from Egypt. This process led to a transformation of the construction industry in the twentieth century, a transformation that was extremely significant, yet very slow in pace, due to the recession caused by World War One. [Omer S. Osman, 2016].

In regards to town planning, Kitchener employed a renowned town planner of the period, W. H. Mclean, to prepare the first master plan for the capital, Khartoum. Mclean was much influenced by Ebenezer Howard, the creator of the garden-city concept.

Concurrently with the renovation task of his Governal Palace, Kitchener called for funds to build an educational institute in commemoration of his predecessor, the late General Charles George Gordon. The job of designing the main building was assigned to Fabricious Pasha, the architect for the Khedive of Egypt, who completed the building in April 1899.

Lieutenant George Frederick Gorringe, a self-educated architect, was then assigned the job of producing the architectural details and supervising construction of the Gordon Memorial College which was inaugurated in February 1902 by Lord Kitchener, a year in advance of the completion of the construction.

The cathedral, designed by Robert Weir Schultz, still stands as one of the finest buildings of the early colonial period.

In addition to administrative, educational and public service facilities, the colonialists were obliged to consider the wishes of the predominantly Muslim population. In that respect, the Khartoum Central Mosque was erected at the same time as the first batch of colonial buildings. The mosque is situated in the middle of Abbas Square, which occupies a central plot in Kitchener’s plan of the town. [Omer S. Osman, 2016].

b) Late Colonial Architecture (1921–1956)

By the 1950s, the colonial authorities had started training local recruits to assist the foreign experts and learn from them. This helped fill the gap in skills in the construction domain, which had, until that moment been lacking. The architectural heritage of the closing years of condominium rule could be said to be represented by two buildings that have very little in common: the Farouq Mosque in Khartoum(1951) and the Omdurman Municipality (1954). The two buildings, though both built by the bi-partite authority, depict very different architectural approaches and conflicting cultural attitudes. This could be attributed to the very different functions they were meant to serve.

The Egyptian government financed, prepared the design, and built the mosque that carries the name of the Egyptian king of the day, King Farouq. Although only half the size of the solemn and prestigious mosque in Abbas Square, the Farouq Mosque is nevertheless an aesthetically-pleasing building.

Omdurman Municipality was designed by D. H. Mathews. Ariba and British influence is shown in the details of the building. It is a composite structure with massive exposed brick walls as well as large spans indoors where reinforced concrete columns are used. [Omer S. Osman; Ibrahim Z. Bahreldin; Amira O. S. Osman, 2015].

Fig.4.5 King Faroug mosque.

Source:https://www.google.com/imgres?imgurl=http%3A%2F%2Fi1.trekearth.com%2Fphotos%2F4688%2Ffarouksmosque12.jpg&imgrefurl=http%3A%2,2016.

Fig.4.6 Omdurman Municipality.

Source: https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwivy6Dvi-,2016.

c) The Post-Independence Era (1956–2000)

After independence in 1956, Sudan faced an era of unrest and uncertainty that had a negative impact on almost every aspect of life.

When American aid programs commenced in 1958, Khartoum's first architectural private consultancy was opened.

The Department of Architecture, University of Khartoum was established in 1957. In the ensueing years; this Department became a main center of architectural education in the region. During his time as the first head of this department, Professor Alick Potter designed various minor buildings for the University, mainly residential villas and apartment blocks. Nevertheless, his Examination Hall remain an outstanding architectural benchmark for generations to come.

Before the 1960s, architecture by Sudanese architects was scarce as most architects working in the country were foreign, for example Peter Muller, George Stefanidis, Alick Potter and Miles Danbi. However, in 1962 onward, there was a great construction boom initiated by massive demand for housing in the new Khartoum extensions, and this created increased need for the services of architects. Four architects who were educated at Leciester in Britain were lucky to come back at the apex of that demand; they had the opportunity to explore the relevancy of the knowledge they acquired in Britain, in their home land. Two of these Brtish-educated architects, AbdelMonim Mustafa and Hamid ElKhawad, were able to distinguish themselves through their authentic design approaches.

AbdelMonim Mustafa, is now considered the father of modern architecture in Sudan. Examples of significant buildings designed by Mustafa include the Headquarters for the Arab Bank for Economic Development in Africa, El-Ikhwa Commercial Building, El-Turabi Primary School and Nifidi and Malik Mixed-Use offices and apartment building in Khartoum Central Bussiness District.

d) Architecture from 2000 onwards

During this period, architectural practice in Sudan seems to have regressed. With the discovery of oil, and aspirations for images of Dubai, glass towers and aluminum cladding came to dominate the architecture style. By then, as Rowan Moore puts it “form started to follow budget” [Omer S. Osman; Ibrahim Z. Bahreldin; Amira O. S. Osman, 2015].

4.1.5 Examples of some colonial buildings

i- Colonial building

a) The Sudan club

It was like a focal point of the British colonial elites social life, it was designed by G.F.Gorringe. After the military coup of 1969 it become – with compounded irony – the headquarters of Sudan socialist union .

Fig.4.7 The Sudan club, Khartoum.

Source: Collection: G.B Bridgman, 2016.

It's noticed that old British buildings were designed to face the hot climate in Sudan. They uses the veranda. Thickness of the wall was very big to avoid the heat. So they thought since that time about the techniques that can keep heat away because they didn’t have air conditioners. They think about passive cooling techniques to have the same thermal comfort in their country.

b) The colonial governmental building

They used of large verandas in front of buildings, they also used thick walls to delay the arrival of the heat into the building. In addition, the buildings were properly oriented .

It's noticed that old colonial buildings were all characterized by high height, thick walls. In addition to that use of large verandas in front of buildings is a very big evidence of their interest in climatic aspects and thermal comfort of building occupants. See fig.4.8, 4.9.

It's also noticed that old colonial buildings have special characters in designing (large arches – big walls and well orientation).

Fig.4.8 Colonial building , Khartoum**.1.**

Source:https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwiTtuy8iOPSAhXMuRQKHczzB7w0CVoQjRwIBw&url=, 2016.

Fig.4.9 Colonial building , Khartoum. 2

Source: https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&cad=rja&uact=8&ved=0ahUKEwiBidT5iOPSAhXCaRQKHV-QjRwIBw&url=http%3A%2F%2Fwww, 2016.

ii- Colonial housing

They use of large veranda in front of buildings, also they used the thick walls to delay the arrival of the heat into the building . See fig(4.10, 4.11, 4.12).also garden are used to cooling purposes.

Fig.4.10 Khartoum Hosing Scheme, a house for the accommodation of senior British officials.

Source :*(The author find this picture in the internet and didn't know it photographer or reference).

Fig.4.11 Khartoum Hosing Scheme, a house for the accommodation of senior British officials 2.

Source :*

Fig.4.12 Colonial House plan and section and exterior view.

Source: plan * - photo: Osman Ekheir, 2016.

4.2 An architects who were concerned with passive cooling

1- Jack Ashkhanis; Architect

His Architectural career began in the sixties. His principles of design and create a modern style of buildings. In spite of this, the architecture is more than what has been affected by Islamic architecture

Fig.4.13 Integration between building and its environment.

Source: Osman Elkheir, 2016.

Fig.4.14 Effect of plant in court yard.

Source: Osman Elkheir , 2016.

Fig.4.15 Usage of court yard effect.

Source: Osman Elkheir, 2016.

Fig.4.16 Jacks elevation style.

Source: Osman Elkheir,2016

Fig.4.17 Usage of mashrabiyya.

Source: Osman Elkheir,2016.

It's noticed that Jack Ashkhanis architecture is affected by Hassan Fathi architecture (using arches – Mashrabiyya– plants- court yards).

Fig.4.18 Bay windows.

Source: *

Fig.4.19 Uses of Mashrabiyya.

Source: *

2- Alkhawad ;Architect

It's noticed, in the photos(figs 4.20 ,4.21,4.22) Alkhawad used the idea of the inner courtyard and good orientation of the buildings, which helped in natural ventilation, and to moisturize the building.

It's also noticed Alkhawad was interest in interior design of the building and the use of local building material (finishing) inside or outside. See fig.4.20.

Fig.4.20 Courtyard (inside building).

Source: Osman Elkheir ,2016.

Main ideas of his work appears in three aspects:

i- Uses of courtyard techniques.

ii-Baying Attention to the external environment (landscape and trees). See fig. 4.21.

3-Uses of local building materials in the interior design. See fig.4.22.

Fig.4.22 Use of local building material.

Source: Osman Elkheir, 2016.

Fig.4.21 Outside building environment.

Source: Osman Elkheir, 2016.

4.3:Case study: Osman Elkheir House

The case study is about Architect Osman Elkheir own house. It's located in Khartoum state at Gereif West.

4.3.1 Why the house is selected

- The study area falls within the hot - dry climate area of Khartoum state.
- The application of some of the passive cooling techniques (use of external Garden plus the use of wind catcher, the effect of indoor plants in the building and water elements).
- The uses of sustainable solutions in the building since the nineties. That means the designer took into account the reducing energy consumption rather early.

4.3.2 The criteria that used in analysis

Describing the building chosen as a case study and the building site, then views it's basic parameters.

Building components have been reviewed including all levels and void space. After that, the passive cooling techniques have been presented and some problems which faced the building since its inception have been overviewed.

Lastly a comparison between local and global models has been done in terms of passive cooling techniques that have been used.

4.3.3 General information:

Location : Khartoum–Gereif West–Cinema bus stop.

Bedrooms : 3.

Bathrooms: 3.

Completed:1996.
Architect: Osman Elkheir.

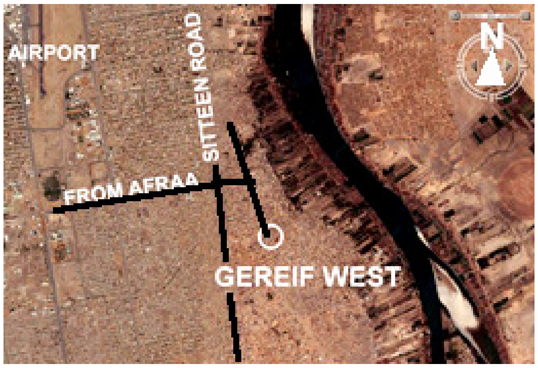


Fig.4.23 location plan of the house .

Source: Osman Elkheir, 2016.

Fig.4.24 South elevation.

Source: Osman Elkheir ,2016.

4.3.4 Building components:

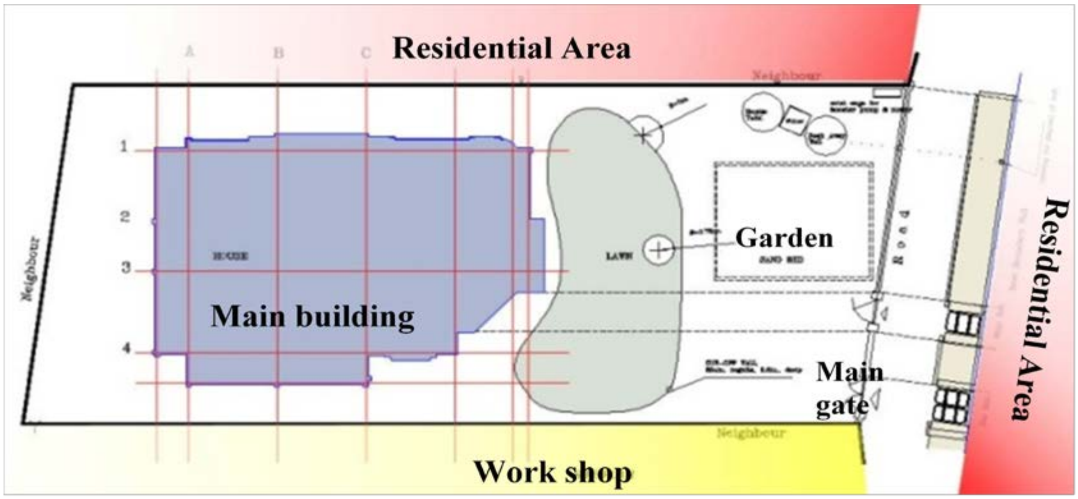


Fig.4.25 Site plan.

Source: Osman Elkheir, 2016.

The house consists of 3 stories (actually 2 stories with a mezzanine floor): See fig.4.25.

1- Garden+ Main entrance gate.

2- Indoor plant and water sprinklers.

3- open plan kitchen.

4- Tripple height hall.

5- 3 Bed rooms(Master-guest–daughter).

6- 3 Bath rooms.

7- Library.

8- Mezzanine floor and Stores.

1- House main entrance gate + Garden

A) Main Entrance Gate

The main concept of the main entrance gate meant to be different (simple walls, organic flow lines, water and flowers).

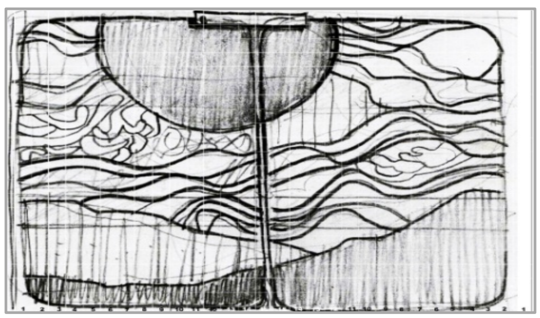


Fig.4.26 Main gate sketch drawn by Osman Elkheir.

Source: Osman Elkheir, 2016.

Fig.4.27 Main entrance gate and panels.

Source: Osman Elkheir,2016.

it's though that the gate introduces the sustainability concept was adopted in the house of Osman elkheir. Simple curvilinear panels intersect with colorful plants creating harmony between walls and the two adjacent elements (trees + gate panels) .See fig.4.27.

Fig.4.28 Main entrance gate.

Source: The Author.

b) The Garden

There is landscape in the building (hardscape, trees, shrubs, water surfaces, semi shaded area and stones along the access path), this makes the garden look so integrated with the inside of the building. See fig.4.29, 4.30,4.31.

it's noticed that the vault roof appears within the

landscape design in a strong manner.

Fig.4.29 Main entrance with landscape.

Source: The Author.

Fig 4.30 Main entrance gate with landscape.

Source: The Author.

Fig.4.31 Garden view.

Source: The Author.

2- Indoor plant and water sprinklers (The thermal LUNG of the house) :

It’s a tripple height hall with climber plants and trees, Osman Elkheir, named this area “THE LUNG OF THE HOUSE”; because it cools the house in three ways:

i- The plant effect .

ii- Water sprinklers. in one side wall.

iii-Natural ventilation.

It's noticed that there is integration between the buildings inside and outside environment.

Fig.4.32 Thermal LUNG OF THE HOUSE.

Source: The Author.

Fig4.33 Entrance of the thermal LUNG from inside.

Source: The Author.

Fig.4.34 The thermal LUNG form above.

Source: The Author.

Fig.4.35 Integration between the thermal LUNG of the house with the internal spaces.

Source: The Author.

Water sprinklers let the air be so cool before entering the house and give the house an effective interface .See fig4.32,4.33,4.34,4.35. It's thought that, these sprinklers serve another function, the esthetic and psychological impact on the building occupants as well as helping in moisturizing the building. See fig4.36.

Fig 4.36Water sprinklers with plant and entrance.

Source: The Author.

3- Open plan kitchen

Open plan and modern kitchen. See fig4.37.

Fig.4.37 Open plan Kitchen.

Source: The author.

4- Tripple height hall

This is a hall with an extra high ceiling, with a vault roof and high level windows, that provide natural ventilation and this helps in cooling the house by expelling hot air and replacing it with cold air.

At first floor there is a climber plant and plants suspended down to the first floor. See fig 4.38.

It's noticed that the house look like a single space, no separation with wall or slabs between the kitchen and halls, the library at the first floor,(separation between spaces only by one step), that means there is a problem in sound distribution. See fig 4.39, 4.40.

Fig.4.38 Tripple high hall.

Source: The Author.

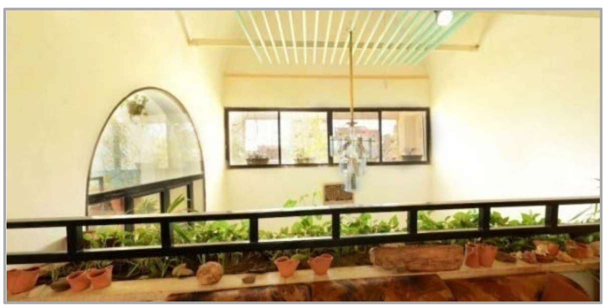


Fig.4.39 First floor plants.

Source: The Author.

Fig.4.40 Separation between halls.

Source: The Author.

5-Bed rooms (Master-gust–daughter)

These rooms have extra high ceiling created by the effect of the vault roof.

6- Bath rooms :

The bathrooms ceiling is at a lower level than the bedrooms high ceiling.

7- library :

A library with natural light at first floor with the master bedroom. See fig 4.41.

Fig.4.41Vault roof

Source: The Author.

8-Mezzanine floor and Stores

This floor contain water tanks, stores and air conditioning units, thus helps to protect the mechanical devices from exposure to direct sunlight and thereby reducing the damage and therefore maintenance. See fig.4.43.

Fig.4.42 View of stair case with Library(first floor).

Source: The Author.

Fig.4.43 mezzanine floor .

Source : The Author.

Fig.4.44 View of stair case with Library(first floor).

Source : The Author.

At mezzanine floor it's noticed that there are two windows for cross ventilation. That keeps the air cool and also provide sunlight to the space. See fig 4.45.

Fig.4.45 Ventilation window in mezzanine floor

Source : The Author.

4.3.5 Techniques used in the building

i-Sustainability system (solar system)in the building

Fig.4.46 Solar heater .

Source: Osman Elkheir, 2016.

There is a solar photovoltaic system in the house and a solar heater at highest area in the building (under the vault roof). See fig 4.46.

The system was perfectly organized in the building by solar mobile kit .See fig 4.47.

The house has two kind of electrical networks When power is cut off, the sustainable system works and with manual switches and batteries which depend on solar power to be charged. Thermal solar energy is also used to supply hot water to the building.

It's notice that the building was built about 20 years ago, that illustrated perfectly Osman Elkheir, passion in sustainable design and passive cooling since a long time ago.

ii- Wind Catcher :

Wind catcher technique is used in the building to supply two rooms (guest room - saloon).

Osman Elkheir wanted to try the passive cooling sustainable system in his house.

Fig.4.47 Solar mobile kit.

Source: The author.

It works as follows

The wind catcher catches air from two opposite sides. Inside it there is a movable flap that helps in catching air. After that air is filtered with a filter, to remove dust. This clean air passes through this diagonal axis in pipes in form of zigzag under two plant beds (see fig 4.49) which helps to moisturize the air, until it pass to the rooms. See figs 4.50- 4.51- 4.52.

Fig.4.48 wind catcher in roof courtyard.

Source: The Author.

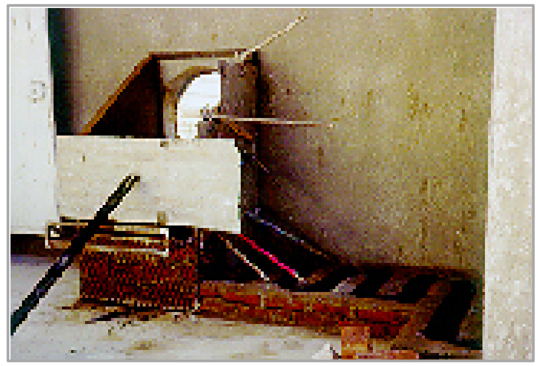
 

Fig.4.49 Wind catcher with plant beds (Before and after execution).

Source: Osman Elkheir, 2016.

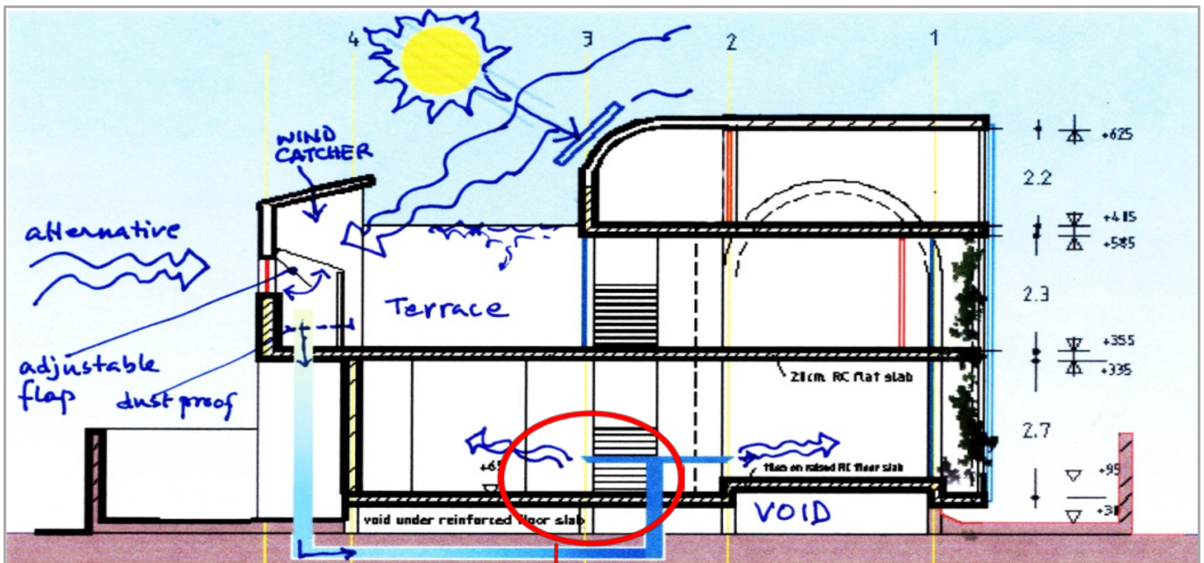


Fig.4.50 Wind catcher air pass technique.

Source: Osman Elkheir, 2016.

Fig.4.51 Wind catcher outlet in guest room .

Source: The author.

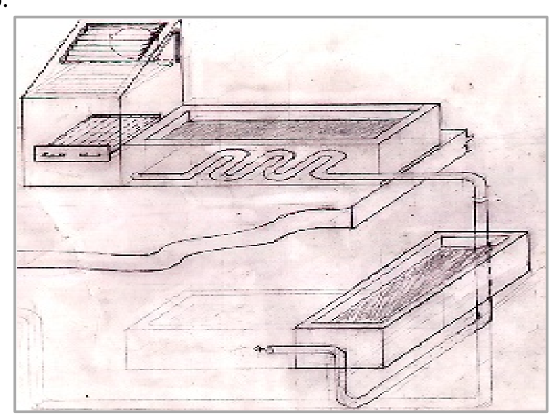


Fig.4.52 Sketch showing wind catcher air pass technique.

Source: Osman Elkheir, 2016.

iii- Use of plant effect

The section below shows the plant locations in the house and the relationship to the LUNG of the house. See fig 4.53 . This arrangement can help in moisturizing the air inside the building .

It's noticed that plants falls down from the balconies of the tripple height hall and they have a very attractive interface with the building.

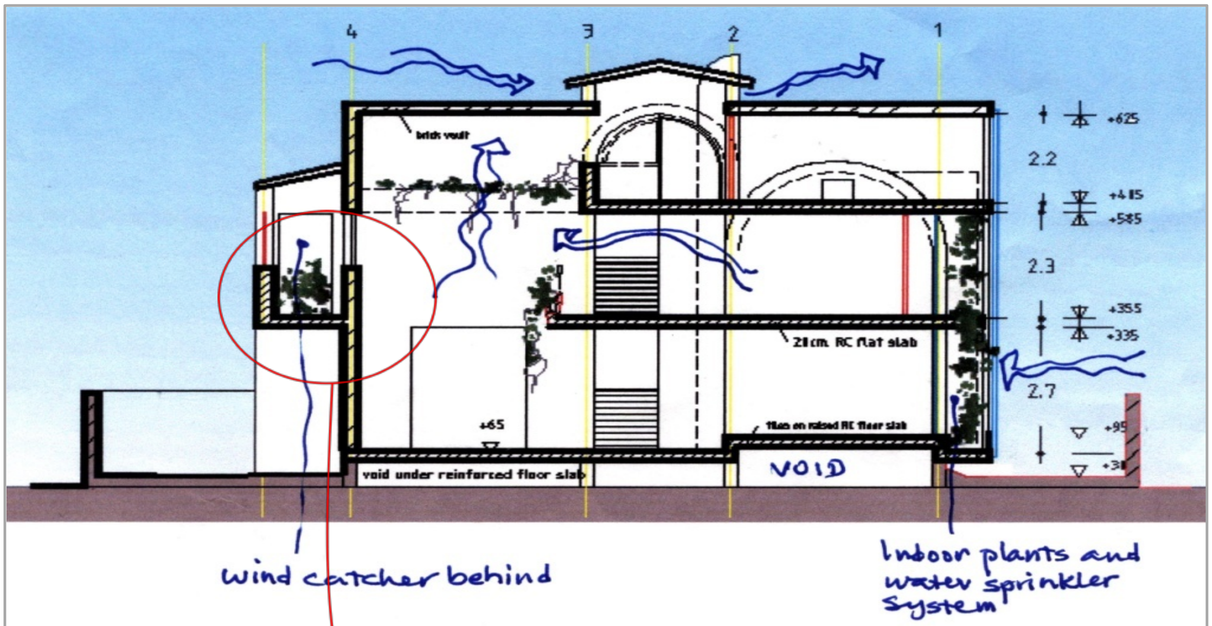


Fig.4.53 Section shows plant location on building.

Source: Osman Elkheir, 2016.

Fig.4.54 Example of plants in the house(in and outside) .

Source: The author.

It's notice that Osman Elkheir decided using plants since primary sketches of his design. See fig.4.55.

Fig.4.55 Elevation concepts drawn by Osman Elkheir (superseded design).

Source: Osman Elkheir, 2016.

iv- Use special kind of roof(vault roof)

The building is based on frame foundation, with concrete columns, in ground floor, other floors with load bearing walls.

building material (brick) for many reasons:

- Keeps the house cool
- Very cheap, that's mean low cost.
- light in weigh.
- Bricks are also less absorptive of heat, white colour reflects most radiation.

Roof has an advantage: Vault roof keeps the heat a way, by removing the heat from the high temperature side to the vault to the low temperature side, then a way from the building and that means less heat will enter the house. See figs.4.56 and 4.57.

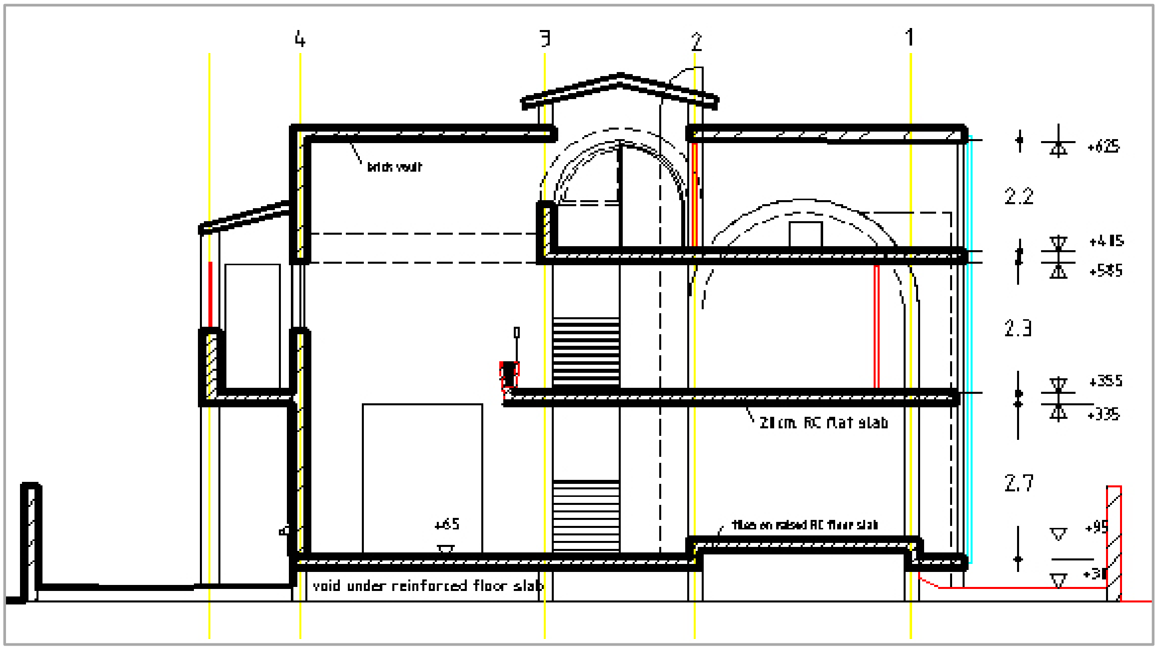


Fig.4.56 Section shows vault roof.

Source: Osman Elkheir, 2016.

This roof appears clearly at mezzanine floor, and part from first floor (master bed room). See fig 4.57.

Fig.4.57 Vaults used in the house.

Source: Osman Elkheir, 2016.

Fig.4.58 Vault roof .

Source: The author,2016.

4.3.6 Some problems that faced the building

It's noticed that some problems faced the house as follow

- Problems in implementation: the problem of constructing the roof (vault roof), because of the labor who aren't acquainted with the method of construction.

- The presence of a group of networks(3 water network with many valves and 6 electric networks in the ceiling (Telephone - Music - electricity - computer, solar ad T.V), complicated the situation and resulted in problems.
- Problems in the construction and completion of the required specifications.
- Problems because of use: (Use errors from non-residents of the building (the servants - the guests, etc.), who are not acquainted with the system.
- Sound problems, because of open plan system.
- Dust problems and the open kitchen odors .
- Waterproofing problems of the plants inside the building.

It's noticed that all these problems resulted from an inability to deal with the sustainable system at all stages of construction, despite the simplicity of the design.

4.4 Comparison between local and international examples

A method of comparison between the local models and global models is used to arrive at the results of the study.

The comparison will be in passive cooling techniques that are used in the building, points that are focused on are shown in table 4.1.

Table 4.1 Comparison between local and international examples

Source: The author.

Comparison	International examples	Local examples
1) Architectural and building techniques.	Widely used in residential buildings	Widely use in residential buildings more than passive techniques.
A- Form and orientation.	The orientation depends on the direction of the winds in area. Building forms are very simple and has a good orientation.	It's mostly used in local building techniques, in term of orientation of most of building sites to the north and south.
B- Building envelope and glazing.	Widely used local building materials , wooden pergolas helps in cooling and moisturizing the air.	In the past local building materials have been used, but recently there has been more use of glass surfaces and binding aluminum which increases the heat from inside the building.

C- Shading.	Widely used.	Widely used (verandas, trees, pergolas ..etc) ,to create a microclimate zone for the building.
E- Wind-catchers.	Widely used as a source of natural cooling in the house.	These items are not always used, but according to the owner (as in the case study).
F- Natural ventilation(stacked ventilation – cross ventilation – night ventilation with thermal mass).	Sometimes used according to climate conditions.	Widely used and it's the base of natural cooling in Sudan (the cross ventilation) Stack ventilation is rarely used.
G- Courtyard effect.	A few are being used, but is essential in the design of the building.	Used since ancient times, and is still one of the most commonly used techniques It uses elements such as trees and water features in the court to help improve the atmosphere.
2) Natural techniques for cooling (passive cooling techniques)	They are widely used in the global models.	They are rarely used, because of non available potential applications.
A- Evaporation cooling.	It's used	Used moderately.
B- Radiation cooling.	It used but with additional Energy source. (movable insulation panels).	It's used without additional Energy source.
D- Roof Pond.	Used moderately.	Not used at all .
E-Earth Tube.	Used according to client requirements.	Not used at all .

4.5 Conclusion

It's noticed that

- The area of study is located in the center of Sudan, the most densely populated area, and care must be taken to build and provide conveniences for the building occupants.
- The area of study is accommodates old colonial buildings, which took into account the climate and provided thermal comfort for the building occupants.
- The use of some old techniques for cooling in the area of study from the colonial era in Sudan, such as:(selecting suitable construction materials and colors of the outer surfaces, uses of inner courtyards within buildings, uses the effect of verandas and incorporating garden and landscaping in the design.
- The planning of old colonial Khartoum by McLean was influenced by Ebenezer Howard planning, founder of the theory "Garden city ".

- This plan was also interest in the culture of Sudan and the largest Great Mosque of Khartoum(was part of the initial plan for the city of Khartoum) was a very clear evidence to concern within the Islamic faith use of the arches and high verandas shows the passive cooling of the Old era.
- For the era of the early architects (Jack Ashkhanis, Alkhawad) it's found that they were largely concerned with the environment and climate and took advantage of local building materials, and employed concept of the inner courtyard of the building. That clearly means the early architecture took into account the climate and sustainable passive cooling clearly (Use of mashrabiyya, inner courtyard, water bodies , etc.).
- The current situation clearly shows deviation of modern architecture due to non-observance of natural cooling in the building, and the excessive use of glass and aluminum without taking into account the climatic factor.
- In the current situation too, there are some areas which showed high interest in the landscaping of buildings(eg. Alamarat), and that shows the awareness of the importance of cooling in the building.
- As for the case study, Osman Elkheir own house, we notice the influence of the Egyptian architect Hassan Fathi, in terms of: (uses of external garden of the building, vault roof, wind catcher and plants effect – light weight materials).
- Usage of the sustainable system in the building (solar system) contributed saving energy in the building.

- Using several cooling techniques in the building greatly helped to maintain hydration of the building.

- Usage of the open plan system in the building has several pros, but on the other hand there are disadvantages (kitchen odors, the spread of sound, lack of privacy ..etc).
- The house is one of the earliest examples for applications of sustainable passive cooling in the city of Khartoum, (uses of wind catchers, uses of solar system ..etc).
- Comparisons between local and global models illustrated to some of the techniques that can be applied in the similar cases (all kinds of ventilation - wind catchers - inner courtyards - shading etc...) and that there are some techniques which can't be implemented,(earth tube - roof ponds..etc).

Chapter Five

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In this chapter the author reviewed and summarized the most important findings and conclusions that came out of the research and analysis of the case study. The chapter then listed recommendations for different discussed aspects of the research. It then reviewed the references and sources of the research and suggested further researches on related topics.

5.2 General Conclusions

- The area of the study is located in hot -dry climate zone , therefore this aspect must be considered in the design process. The design should adopt to reduce heat gain in such a hot dry climate(roof insulation ,ventilation and orientation, courtyards and water bodies ..etc).

- Thermal comfort for a human depends on the psychological and physical conditions. according to the activity, and the human body generates heat and exchanges it with the surrounding environment through different ways (radiation, conduction and absorption) and this must be considered and provided for.

- Heat gain controls in the design process consists of three factors (site consideration (location, orientation..etc)
  architectural factors (shades, screens, building exposure..etc)
  weather kin features (mass, glazing, insulation..etc).
  These must be taken in to account and utilized to provide thermal comfort.

- Microclimate can be used in buildings by planting and introducing vegetation to decrease the heat entering the building.

- Some architectural and building techniques, can easily be locally applied such as (ventilation of all types (cross , stack, night ventilation), courtyard effect, wind tower shading, orientation and massing in of the building). On the other hand some natural techniques for cooling can't be applied locally, because of constructional complexity the have rarely been implemented (roof ponds, earth tube). Others can be applied such like (cooling tower, evaporative cooling).

- Sustainability Concepts used, varied widely during the last years. Htat means we can apply it in Sudan.

- There are some principles of sustainability in planning that can be locally applied (stacking, Biophilia and sustainable corridors), some can't be applied (high performance building) because of the high potential costs.

- For LEED green building rating should be applied in the designing process (sustainable sites , water efficiency , indoor air quality ,energy and atmosphere , local building materials and innovation in building design) locally.

- The area of the study is affected by the old colonial buildings, which took into account the climate and provided thermal comfort for the building occupants. They applied some techniques (such as:(selecting suitable construction materials and colors of the outer surfaces, uses of the inner courtyard of the buildings, use the effect of verandas and the use of the garden and landscaping in the buildings).

- For the era of the early architects (Jack Ashkhanis, Alkhawad) it's found that they were largely concerned with the environment and climate and took advantage of local building materials, and employed concept of the inner courtyard of the building. That clearly means the early architecture took into account the climate and sustainable passive cooling clearly (Use of mashrabiyya, inner courtyard, water bodies , etc.).
  ,on the other hand in the current situation clearly shows the deviation to the modern architecture and the use of glass and aluminum in abundance in interfaces without taking into account the climatic design.

- Osman Elkheir own house, has been influenced by the architecture of the Egyptian architect Hassan Fathy, in terms of: (uses of external garden of the building, vault roof, wind catcher and plants effect – light weight materials).
  Using of several cooling techniques in the building usage of the sustainable system in the building (solar system) strengthened the process of saving energy in the building.(uses of wind catchers , uses of solar system ..etc).

- Usage of the open plan system in the building has several pros, but on the other hand there are disadvantages (kitchen odors, the spread of sound, lack of privacy for vacuum..etc).

- Comparisons between local and global models illustrated to some of the techniques that can be applied in the similar cases (all kinds of ventilation - wind catchers - inner courtyards - shading etc...) and that there are some techniques which can't be implemented,(earth tube - roof ponds..etc).

5.3 General Recommendations

The researcher has divided these recommendations into several entities as follows

5.3.1 Ggovernmental institutions (ministries - decisions makers - state policies, etc.)

- To benefit from the Egyptian experience in architectural reign of Hassan Fathy, the goal is to provide the appropriate environment and culture of housing, let the priority be the comfort of the individual rather than investment and exploiting individuals for business interests assimilated in contractors from government agencies.
- The importance of making the principles of sustainability and passive cooling as part

of the requirements to the ratify the plans, even if it's with a simple proportions as a beginning of their application. With an attempt to be entered in the building regulations at the nearest amendment.

- Oblige the landlord or the building owner to design with optimum orientation and take into account the repercussions and the openings of the building.
- Supervising buildings during construction and plans upon ratification. (do not adopt any of the engineering plans that doesn't take into account sustainable passive cooling).
- The application of fines for designs that are not consistent with the climate of the region, to enact strict measures in this regard.
- To work on studying optimal planning that fits the climate of the region and to provide an advanced structure plan which contain spaces and green open areas.
- Get rid of the elements on the facade, which is one of the factors that works on collecting the heat and allowing it to penetrate the building.
- Support the provision of alternative means of energy at an affordable cost.
- To add Sustainability and passive cooling in university syllabus.
- To be concerned about increasing the green spaces (parks and gardens) and to create an outlet for residential areas on the planning and design level, with an attempt to exploit the energy wasted.
- To encourage scientific research in this area and be concerned about it to the maximum which reduces export, installation and commissioning of mechanical mechanisms that are used in the present.
- To provide materials that limit the use of mechanical devices such as insulations ,reducing its cost and availability ,to establish factories that provides it so it can commensurate with the climate, design and cost.
- To determine open space and reduce the amount of car parings that run to generate the amount of heat that are difficult to control thereby increasing the heat inside the building.

5.3.2 University institutions

University institutions are the primary source of providing knowledge, enlightenment and environmental awareness, so it should pay attention to the function and the environment as the basis for the design, as the attention given to the jobs can give birth to architect for all segments of society with different strata which takes into account the economic aspect of individuals, but the attention give the form gives birth to architects for certain strata's of the society. Therefore it is a must :

- Sustainability and passive cooling standards should be an integral part in the curriculum, and provide an opportunity for students to be create by using these technologies.
- Increase and develop the curricula (Architectural science and Building Services) in this regard.
- To Focus on classes in the early years in the architecture studies, on the importance of architectural designs suiting the local climatic environment, training the students on the basis of sustainability and passive cooling, with small doses in the early stages.

- Non-receipt of any engineering plans depends only on artificial ventilation (especially residential buildings).
- To work on providing innovative and environmental studies and solutions, to establish workshops and lectures regularly for students and to establish the universal principles of sustainability and passive cooling for students to learn about the importance of saving energy.
- To conduct contests for the best projects that takes into account the passive cooling and sustainability.

5.3.3 Industrial Institutes

- To use the recycling principle for industrial waste.

5.3.4 private institutions

Private institutions are in a great challenge between the customers desires their duties towards the environment and society, therefore there must be:

- To direct Investment in the application of sustainable cooling techniques and Support projects that helps in preserving the environment.
- No construction of the project in which the climate of the region is not taken into consideration.
-
- Establishing the understanding of passive cooling and Sustainability to customers and to provide studies and financial expenses for the client, and to clarify the difference between the use of natural ventilation and the application of passive cooling in the building from artificial ventilation.

5.3.5 Professional entities (Engineering councils - Engineering Society)

- To conduct seminars, workshops and conferences in this area and to display models that succeeded in this field; to fix an annual workshop in this field to install the awareness to form cultural and enlightening seminars about the importance of sustainability and passive cooling on the design and planning level.
- Support specialists in this field and provide them with information, experiences and similar models.
- Try to find the current problems of housing in buildings and to improve the current situation.
- To conduct shows in partnership with academic institutions to simplize these studies, and turn it into the reality, to host the financiers and investors
- To Spread awareness to the community of engineering and architects, especially to link between local and global foreign academic groups.
- To outreach programs to the community as a whole because of the needs for these special sustainable and passive cooling understanding and their importance to the

environment, human and economic benefits in the long term concepts.

- Engage engineering students and qualified cadres in the process of raising awareness in the neighborhood ,universities and the states as a whole.

5.3.6 Architects

The author targeted architects, whether they are designers or city planners , because they represent the essential foundation for change to the better.

Because the architect are shaped by the university, the community and the science that is self-received, if architects underwent science in an appropriate way he won't be affected by aesthetic aspects more than the function, the author believes that an architecture should not turn a blind eye to the marginalized groups of the society that needs environmental social housing.

Therefore the author recommend the following :

- Not neglecting sustainability techniques and passive cooling in the processes of design and planning, and select the style of buildings that suits the environment.
- To use building materials that is eco friendly, and to make use of the renewable energy in the building.
- To be concern about the functional aspects in the designs and to direct the owner about the importance of the orientation.
- Indispensability interest in functional aspect in the design and the reference to the owner of the importance of proper guidance.
- to educate the community through seminars or lectures, or even through the simplest types of social network to make awareness to the client.

5.3.7 Individuals

- To be concerned about the surroundings environment.
- Participate in improving the urban environment.
- Interest in energy savings, by reducing the use of mechanical devices in building.
- Maintaining public spaces such as streets and public outlets.

5.4 Recommendations for the case study area

- Taking into account the climatic design requirements in the area of study (hot dry climate), and all its requirements and interest in plantation, water bodies and promote the idea of the inner courtyard.
- Provide comfort kinetic users as much as possible in residential buildings and balancing the temperature between the inside and outside of the building.
- Interest in heat gain control and work factors influencing them in both the processes of design and planning. for it benefit in cooling the building and tempered process.
- Develop the concept of microclimate and try to private residential buildings in its application.

- Develop natural techniques and try to apply other techniques which can't be provided.
- Application of sustainability concepts in the study area and make it part of the basic laws of the two process designing and planning.
- Applied sustainability concepts in the planning and work to try to apply high-performance buildings in the case of the study and provide support for them at the lowest cost.
- Make LEED standards of the Ministry of Planning laws in the ratification of engineering maps.
- Maintaining the techniques used in ancient times (the colonial period) and the development of concepts that were made.
- For the first era of Architects, promote techniques that have been used and developed (inner courtyard - the use of local building materials - Attention to forestation), and avoid modern concept of building without a thorough study.
- For Osman Elkheir own house, the researcher recommends the development of irrigation drip system indoor plants to essay control process in the privacy of the building.
- Also recommend using Sound insulation system in the building in the places that need to be calm like (the library - on the first floor) or can break an act of insulating material of sound.
- Try to develop the techniques used in the area of study, and try to apply techniques that require high costs of traditional ways to get to the proper purpose.

5.5 Further research suggestion

After the author completed writing of the thesis, it was found that there were topics that could be recommended for future research in this area:

Passive cooling techniques calculations, Heat gain control, Application of sustainability in residential buildings in Sudan, Designing strategies in hot dry climate, Climatic design and Microclimate for residential building in Sudan, all are areas that require in depth investigation and are suggested for further research.

List of references

1- Abass A.S.Al.Jebbri : 2014 Fundamentals of air conditioning and refrigeration, Dar Elsadig Publishers , First edition.

2- ASHRAE, 2004: ANSI/ASHRAE Standard 55-2004 Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.

3- ASHRAE, 2009: 2009 ASHRAE Handbook – Fundamentals (SI Edition). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta**.**

4- ASHRAE, 2010: ANSI/ASHRAE Standard 55-2010 Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc Atlanta .

5- ASHRAE, 2012: ANSI/ASHRAE Addendum c to ANSI/ASHRAE Standard 55-2010 Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.

6- Balaras,C., 1996: Cooling in buildings. In: Passive Cooling of Buildings[Santamouris, M. and D .Asimakopoulos (eds.)]. James & James (Science Publishers) Ltd., London.

7- Cook, J. (ed.), 1989: Passive Cooling. The MIT Press, Cambridge, Massachusetts and London ,England.

8-Dimoudi,A., 1996: Passive cooling of buildings. In: Passive Cooling of Buildings[Santamouris, M. and D. Asimakopoulos (eds.)]. James & James (Science Publishers).

9- Fathy, Hassan, Architecture for the Poor, Chicago: University of Chicago Press, Chicago 1973.

10- Fathy, Hassan, Natural Energy and Vernacular Architecture,University of Chicago Press, Chicago, 1986.

11- Givoni, 1994: Passive and Low Energy Cooling of Buildings, Van Nostrand Reinhold, New York.

12- Michael J .Holtz ;1979 : Passive technology branch ,solar energy research instutute golden ,Colorado NY washington.

13- Koenigsberger' O.H . sManual of Tropical Housing and Building, PartOne: ClimaticDesign.

14- Olgyay, V., 1963: Design with Climate: Bioclimatic Approach to Architectural Regionalism. Princeton University Press, New Jersey.

15- Szokolay, S.V, 2008: Introduction to Architectural Science: The Basis of Sustainable Design, second ed. Architectural Press, Oxford.

Websites :

16- William S. Hoffman (www.hoffmanarchitecture.com).

17- Https://www.Research gate.net. on October ,13 ,2016.

18- PLEA,2013: About PLEA. <http://plea-arch.org/>, accessed on June 20, 2016.

19-Https://www.archdaily.com/789395 , accessed on September ,13 ,2016.

20[https://ar.wikipedia.org/wiki/%D8%B9%D9%85%D8%A7%D8%B1%D8%A9_%D9%85%D8%B3%D8%AA%D8%AF%D8%A7%D9%85%D8%A9].

Papers:

21- Osman, Amira, Greater Khartoum, a paper presented to African CBD Workshop, Durban, April 2000.update 2016.

22- Omer S. Osman; Ibrahim Z. Bahreldin; Amira O. S. Osman, Architecture in Sudan 1900-2014; An Endeavor Against the Odds, 3 may 2015.