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Passive Low Energy Architecture in Hot and Dry Climate

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Abstract: Buildings can be designed to require far less than the energy of today's average. Reducing energy consumption of buildings in hot and dry climates by using natural energy sources is the main concern of this study. In this matter design strategies in terms of energy efficiency is considered based on proper building form, material selection and orientation and by taking advantages of passive cooling strategies and ventilation. The study aims to show that the idea of using natural energy and passive cooling strategies came from the vernacular principles.

Key words: Energy efficiency, natural energy, vernacular principles, architectural design strategy

INTRODUCTION

The physical comfort we feel in a building is the result of the heating energy balance between ourselves and the surrounding spaces. In hot and dry regions in order to design energy efficient buildings and keep the inside of the building thermally pleasant, solar gain and heat conduction into the building should be minimized while ventilation, evaporation, earth cooling, and radiant cooling should be promoted. In the past, architects were obliged to observe these factors, without the benefit of technology and without using polluting, mechanical devices, reliant on electricity. Therefore there should be solutions to render inside the buildings thermally comfortable while keeping our environment clean.

2. Energy Efficient Design Strategies in Hot and Dry Climate:

2.1 Minimize Solar Gain:

When solar energy hits a surface, some of the energy is absorbed, some is reflected, and a portion is transmitted. In order to control solar gain there should be either interception, reflection against solar beams or select a proper orientation and size for building shell and openings due to minimizing exposure area to the summer sun.

a) Interception:

In traditional courtyard houses in hot-dry climates trees as interception devices protect buildings from direct sunbeams and make shady area within the courtyard and on the building walls (fig 1). Trees collect solar energy using molecular devices, the photosynthetic reaction centers of chloroplasts, and use that energy to drive molecular machines, which process carbon dioxide and water into the oxygen and molecular building blocks that form the whole plant. A tree is more sophisticates than an aircraft or microchip, created without harmful waste, noise and fumes while consuming its own pollutants (Ivan Margolius, 2002). Therefore the nature can teach us to emulate such a process to creating flexible behavior in man-made devices.

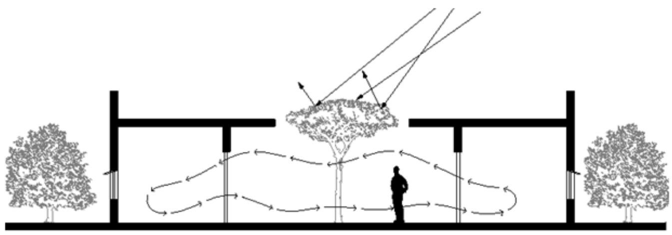

Fig. 1: Using natural element for shading

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Walls and particularly windows exposed to summer sun should be shaded by overhangs and shading devices. A study of the weather condition and the sun angles at various locations between 30° and 50° latitude indicates that a standard 76, 40 cm overhang (horizontal projection of 76 cm located 40 cm above the top of the window) will provide good sun control on south windows for this range of latitudes (Fig 2), when glass doors or tall windows are used it is desirable to increase the overhang to provide more shade (Donald Watson, 1983).

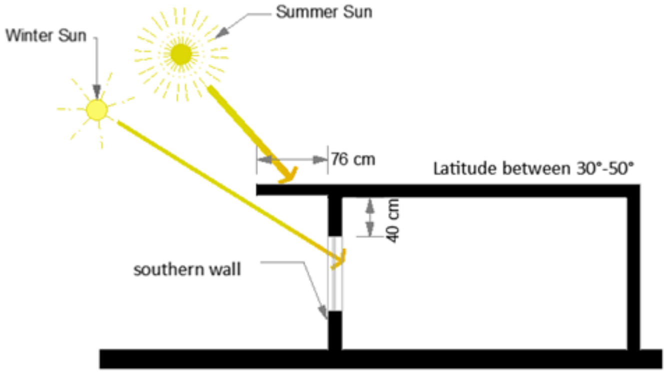

Fig. 2: 76/40 cm overhang is appropriate for south elevations in 30° to 50° latitude

b) Reflection:

The exterior colors of the building's envelope chosen by the architect are among the very distinctive features of the building. When a color absorbs light, it turns the light into thermal energy (heat). The more light a color absorbs, the more thermal energy it produces. Black fabric absorbs all colors of light and is therefore warmer than white fabric which reflects all colors. Figure 3 is the result of experimental studies by Baruch Giovani, (1998) which shows the external and internal surface temperatures of a horizontal roof with white and grey colors. The experiment was carried out in Haifa, Israel which has hot-dry climate in summer. A dark roof can be 50°C hotter than the ambient air temperature while a white roof will be only about 10°C hotter.

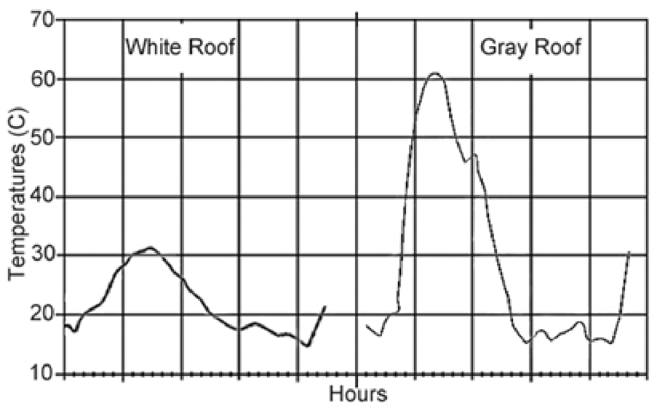

Fig. 3: Exterior surface temperature of white and gray roofs, same day, two roofs Source (Baruch Giovani, 1998)

In traditional houses of hot and dry climate windows' glass were designed in different colors and ornaments in order to provide sufficient sun light and block the intense sunshine (fig4).

The fact that clear glass and other non-opaque materials have relatively little insulation value and transmit solar or short-wave radiation with very little loss in heat energy does not seem to be observed by many architects. The present tent to use more and more glass for high rise buildings is evidence of this. Large buildings, whose exterior walls consist mainly of glass unprotected from the sun in any way, are increasing and are now found in almost every country. There is no doubt that glass is one of the most remarkable building materials and it has several outstanding characteristics, such as its long-term durability, its perfect surface finish, and its ability to transmit visible light and provide view at the same time. By paying careful attention for using glass and other glazing materials, it is still possible to enjoy their advantages, aesthetic and otherwise, without paying too high a price for thermal comfort. The basic differences between the different glasses lie in their transmission characteristics. Clear glass, for example, transmits the major part of the radiation, while the heat absorbing and reflecting glass reduce light transmission (STRAATEN, 1967).

Fig. 4: Traditional windows (*Orsi*) in hot dry climate of Iran

c) ***Size and Orientation of Building Shell and Openings:***

In hot climates, the sun is the major source of heat. To arrange any site, the position of the sun must be considered for all hours of the day at all seasons as well as the direction of the prevailing winds, especially during the hot season. With good orientation the need for supporting heating and cooling is reduced, resulting in lower energy consumption. With regard to the sun factor the best lineup for building is along East-West direction. In fact the length of the building should be along East-West axis and the width of the building along North-South axis. The reason for this is because the northern Façade is least exposed to the sun. In fact, exposure take place only in the early and late hours of summer days when the angle of altitude is low and the angle of declination is such that the sun's rays are almost tangential to the surface of the wall. And since the southern wall absorbs the most of sun energy in winter and because the sun is high over the horizon in summer southern wall can be shaded using a relatively small overhang. Furthermore the eastern and western façades get the undesirable heat in summer therefore they should have less surface exposed to the sun and it is better to cover them with the shadow of trees or nearby buildings. An orientation slightly east of south (typically 15° east of south) is often more effective, because in this way the western façade absorbs lesser sun heats in the summer (Fig 5). The eastern facade is exposed to the sun's rays only from sunrise to noon. The walls cool down considerably by evening, making this exposure more suitable for bedrooms than the western exposure.

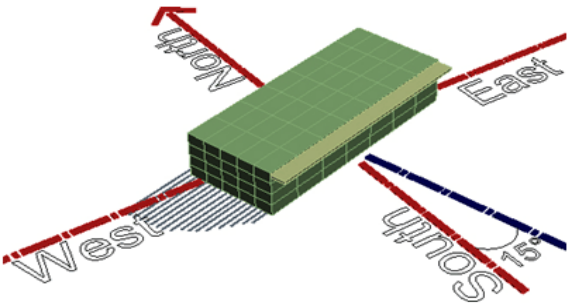

Fig. 5: Building orientation relative to South-north axis 2.2 Reducing conductive heat flow

Thermal conduction is the transport of heat energy from the warmer part to the colder part of the same body or from a warmer to a colder body in physical contact with each other without displacement of the particles of the body or bodies. Thermal control is an essential aspect in all buildings.

a) Constructional material:

The materials surrounding the occupants of a building are of prime importance for protection against heat and cold. Great care must be taken in the choice of the wall and roof materials and their thicknesses with respect to their physical properties, such as thermal conductivity, resistivity and transmission, and optical reflectivity. Using materials with the poor heat conductivity and high thermal mass will reduce the heat flow through the building in hot-dry climates resulting in reducing energy cost inside the buildings. The process of heat transfer through the building materials described as thermal conduction, and the value of heat transfer through a material is the thermal transmission. The thermal conductivity of a material is the amount of heat transfer per unit of thickness for a given temperature difference. Organic materials such as wood tend to be poor conductors. Aerated materials, which have solid conduction paths broken by air or gas gaps such as foam and glass fiber quilt are very poor conductors and they are good insulators as they have low thermal conductivities (Randall Thomas & Max Fordhams, 1999). In hot-dry climate in the past, vernacular architects made use of materials with poor thermal conductions. In traditional houses of hot-dry regions walls were made out of mud, brick clay or mud clay and plaster of straw and mud with high thickness. Thick and heavy walls made of construction materials with the poor thermal conduction provide thermal flywheel effect resulting of cool environment in summer and warm environment in winter. Table1 shows a range of thermal conductivities of some materials. In hot arid climates, the coefficient of thermal transmittance should be about 1.1 kcal/hm²C° for an outer wall to have an appropriate thermal resistance. Table 2 lists the thicknesses of walls composed of various construction materials needed to achieve coefficients of approximately 1.1 kcal/hm²C°. It is apparent from table 2 that thermal transmittance of a 50 cm wall made of concert is 2.40 kcl/hm²C° while thermal transmittance of the same wall made of brick with holes is less than 1 kcl/ hm²C°. The heat flow rate is associated with a property of the materials or assembly section known as its conduction and it is defined by the relation:

$$q = C\ (T_h - T_c)\ A$$

Where q is heat transmission, C is materials' conductance, T_h is temperature of the warmer face, T_c is temperature of the cooler face, and A is surface area. (Donald Watson, 1983)

Table 1: thermal conductivity of some materials

Material	Thermal conductivity (W/mK)
Aluminum	214
Steel (carbon 1%)*	43
Concrete, dense	1.30
Bricks	0.73
Water (20°C)	0.60
Sand (dry)	0.30
Wood (oak)*	0.17
Glass fiber quilt	0.035
Air*	0.024

Source: (Anon, 1988; http://www.engineeringtoolbox.com)*

Table 2: Thicknesses of walls of different material that give coefficients of thermal transmittance of approximately 1.1 kcal/hm²C°

Wall Material	Wall Thickness (m)	Thermal Transmittance (kcal/ hm²C°)
Hollow brick block	0.30	1.10
Double-wall brick with holes and 8-cm cavity	2 x 0.12	1.12
Brick wall with holes	0.38	1.03
Sand-lime brick	0.51	1.25
Hollow block sand-lime brick	0.51	1.16
Lime	0.51	1.10-1.35
Concrete	1.00	1.20

Source: (Hassan Fathy, 1986)

Insulation:

In very broad terms, insulation can be considered as the thermal means by which the transfer of the heat is effectively retarded. Traditionally air has been one of the best insulators and has low heat transfer characteristics. Walls, roofs and windows which made up of two or more layers separated by air space provide resistance to heat flow. Highly reflective materials, such as foil, used in air space can reduce the thermal conductivity of windows by over two or three times lesser. The heat enters through glazed area is trapped and increase the indoor temperature too far above the air outdoors. Nevertheless the indiscriminate use of glass in hot climates produces a giant energy consumer and uncomfortable living space. An improvement that can be made to the thermal performance of insulating glazing units is to reduce the conductance of the air space between the layers (fig 6). Filling the space with a less conductive, more viscous, or slow-moving gas minimizes the convection currents within the space, conduction through the gas is reduced, and the overall transfer of heat between the inside and outside is reduced. The use of low heat conductive gases such as argon and krypton can be an improvement to thermal control. Argon is inexpensive, nontoxic, nonreactive, clear, and odorless. The optimal spacing for an argon-filled unit is the same as for air, about 11-13 mm. Krypton also is nontoxic, nonreactive, clear, and odorless and has better thermal performance, but is more expensive to produce. Krypton is particularly useful when the space between glazings is thinner than normally (6 mm). The optimum gap width for krypton is 9mm. A mixture of krypton and argon gases is also used as a compromise between thermal performance and cost.

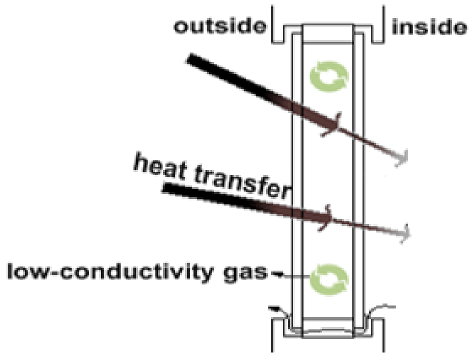

Fig. 6: Double layers window with low conductivity gas filled in between

Promote ventilation:

Ventilation is defined as the act of supplying fresh air and getting rid of foul air. Normally in this process outdoor air is the source of fresh air and the inside air is pollutant air which should be replaced. Building component and technical solutions providing ventilation, both for building and structural cooling, in hot climates were already used in ancient times. For example in Iran, curved-roof air vent systems were incorporated in building as early 3000 BC, and wind tower system, the cistern and the ice maker, may have appeared about 900 AD (Bahadori, M.N 1978). The wind catcher is a shaft rising high above the building with an opening facing the prevailing wind. It traps the air where it is cooler and at higher velocity and channels it down into the interior of the building. This device is used in the hot arid zones of the Middle East.

A wind catcher operates in two different physical mechanisms: First is the function according to the principle of traction of opening facing the wind and the suction of openings back against the wind (Fig 7). Wind catchers mainly perform by this mechanism which works under windy condition. In fact a wind catcher takes the fresh air into the building and sends the hot and polluted air out.

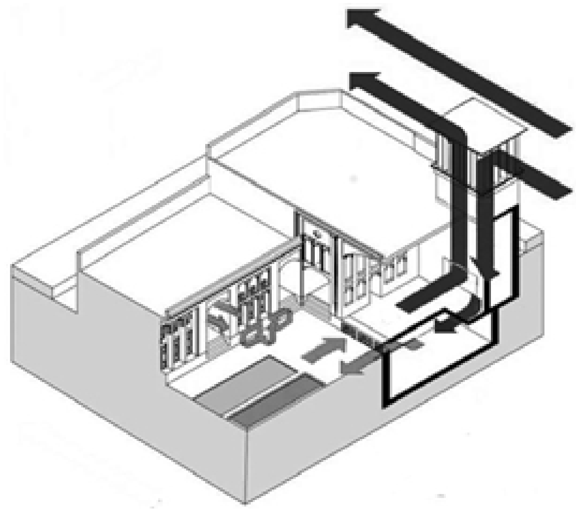

Fig. 7: Function according to the traction and suction

Second is the function according to temperature difference. During the day, when the sun hits on the southern face of the wind catcher, the air heats in the southern shaft of the wind catcher, and goes up. This air is taken above through the inner air of the porch. On the other hand in the morning, hot ambient air enters into the another shaft of wind tower and it becomes cool when it contacts with the tower walls, which have enough thermal inertia to release at night the heat absorbed during the day. In fact it makes a kind of proportional vacuum inside the building, and takes the cool air of the inner court into itself, so the existing air in the northern opening which was cooled is pulled down too. During the night outside temperature becomes cold, and the cold air moves down through the wind tower. This air becomes warm by walls and parapets and then goes up. This circle continues till the temperature of the walls and outside temperature become equal. Therefore in this point night ends and once again the wind catcher act its function as mentioned above (Fig 8).

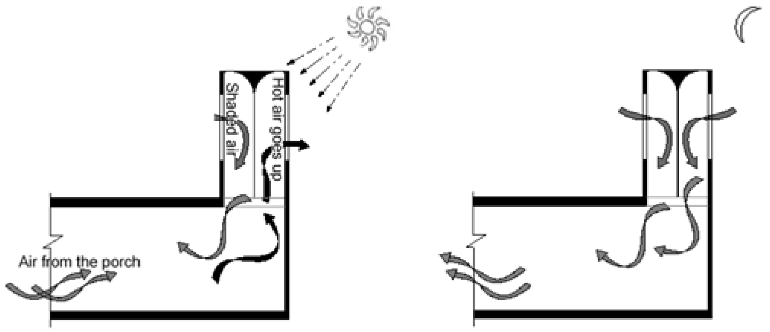

Fig. 8: Function according to the temperature difference

Ventilation appears as a logical and suitable strategy for many types of buildings. Great deal of air flow is needed for summer thermal control of the building in hot and dry climates. Air changes provide people with fresh air to breath, take away pollutants, contribute to the thermal behavior of the building and are an important parameter in the feeling of wellbeing. To increase the amount of air flow through the building few small fans can be added to traditional wind catchers to enhance ventilation within the building (Fig 9).

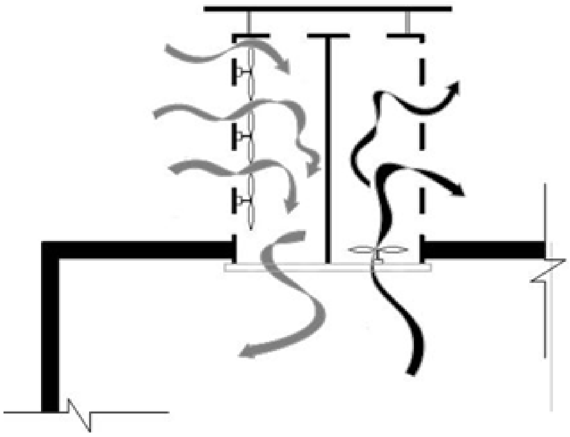

Fig. 9: Adding small fans into traditional wind catcher for increasing the amount of air flow

Promote Earth Cooling (Conductive Cooling):

Air is heated mainly by its contact with the earth; the surface soil temperature is about the same as the air temperature with its large annual fluctuations. However due to the large time lag of earth the soil temperature fluctuates less and less as the soil depth increases at about 6m in depth. In traditional house of hot regions in Iran, there was a space development consists of a room or rooms at 5-10 meters lower than ground surface and ground floor (so called *Sabestan*/*Shavadan*). These rooms have rather the same temperature in all seasons of year and it is equal with the average temperature in a year which is about 22-25°c. In *Shavadan* vertical passages were dug in cylindrical form with one meter diameter for light and circulation of air in this place. These canals connected the upper spaces of houses to *Shavada*n and caused the cool air pass from the deep earth to housing spaces (fig 10).

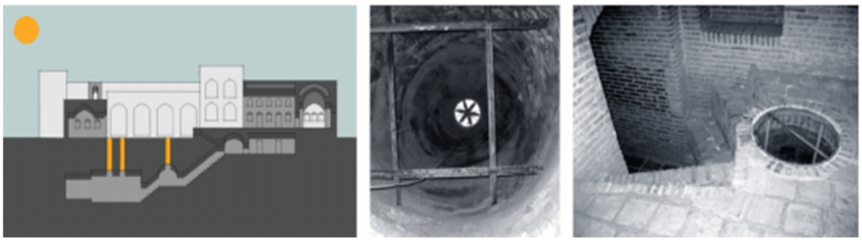

Fig. 10: Traditional underground space planning and vertical passages

Since the ground temperature is always below the maximum air temperature, the deep earth can always be used as a heat sink in the summer. Nevertheless the constant deep-earth temperature which is the coolest available air in summer could be a major source for a passive cooling system. A building can be indirectly coupled to the earth by means of tubes buried in the ground. Slope tubes and sump are required to catch condensation. To get the maximum cooling effect the tubes should be buried as deeply as possible to take advantage of that constant, deep-earth temperature which is the coolest available in summer and the soil is more moist during the summer. When cooling is desired, air is drawn through the tubes into the building. The earth acts as a heat sink to cool the air (Fig 11) (Lechner Norbert, 2009).

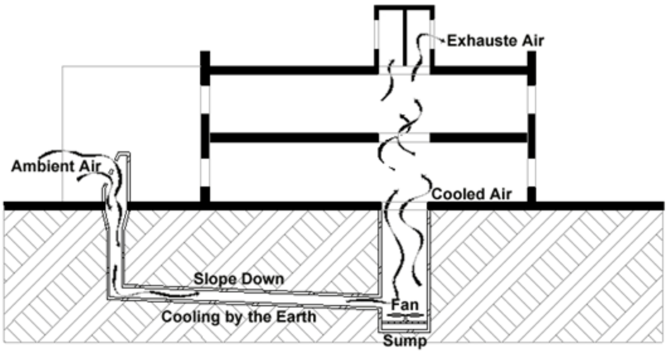

Fig. 11: Indirect earth cooling by means of tubes buried in the ground

Promote Radiant Cooling:

Radiant heat transfer is the exchange of heat energy in the form of electromagnetic waves between two or more objects at different temperatures separated by space or a medium that is transparent or non-absorbing to heat waves. In the past, there were several ways of reducing the heat inside the buildings with the benefit of radiant cooling. In traditional architecture of hot and dry climate, architects used deep courtyards and narrow allay with high walls to minimize hours of direct sunlight during the day. However all of the walls radiated to the cold sky during the night. Thus the walls were quite cool by the morning. In addition domed roofs have been widely used in traditional architecture mainly in hot and dry climates and have had an extreme effect on the reducing the building's loads. The form of domes presents two different benefits. During the day, always some area of the dome is in shadow while at night full hemisphere sees the night sky (Fig 12). Thus, radiant heating is minimized while radiant cooling is maximized.

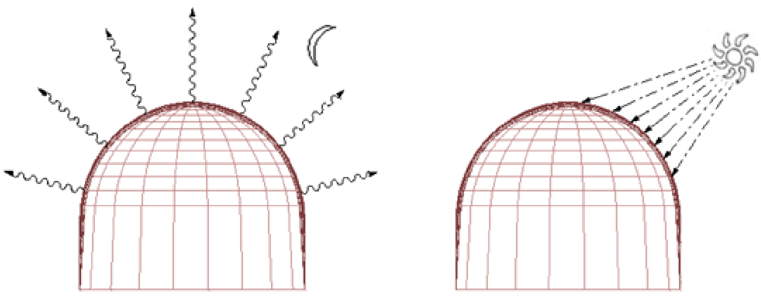

Fig. 12: Low radiant heating during the day and high radiant cooling at the night

Since the roof is the greater surface exposures to the sky, is the best location for considering the long-wave radiant cooling. The most efficient approach to radiant cooling is to make the roof itself the radiator. For example a movable cover on the roof can be designed to prevent the heat radiation during the day and at night by removing the cover, the entire roof surface is exposure to the night. Therefore the roof takes full advantage of radiant cooling while radiant heating decreases (fig 13). Small gap between the cover and the roof is required to allow het convection during the day. Solar panels can be stuck on the movable devises to capture solar energy during the day to provide the electricity needed to move the covers. In this matter high thermal mass materials are the best choice for the roofs. The reason for this is because high thermal mass building materials allow the heating and cooling air to be stored within the home's roof and perform as a cool storage during the night, thus the next day, can cool inside the building gradually.

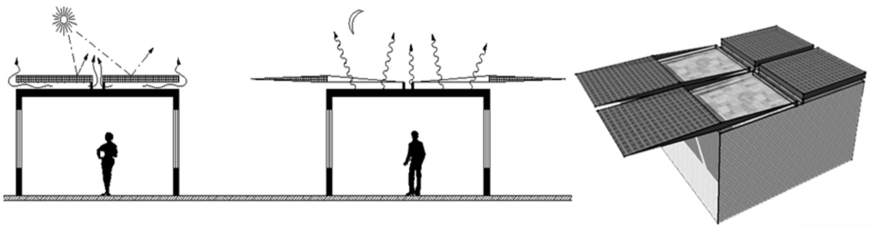

Fig. 13: Movable cover on the roof can reduce radiant heating and increase radiant cooling

Promote Evaporation:

Evaporation is an example of mass transfer, which is of vital importance as far as the functional design of building is concerned and which has an important bearing on psychological process. Evaporative cooling is a natural phenomenon that occurs when moving air passes over a wetted medium or water source, i.e. fountain, river, sea, shower, etc. The evaporation of water from surfaces in evaporative coolers is an important method for cooling buildings in arid part of the world (Jan *et al.*, 1994). Traditional wind catchers can be turned into evaporative coolers. This is possible by adding a pump and a fan directly in the entrance duct. The fan is used to flow greater amount of air into the building and the pump is moisturizes the dry air (Fig 14). To maintain comfort, a high rate of ventilation is required during the day. This phenomenon which cools the indoor air through the increasing humidity called direct evaporative cooling system.

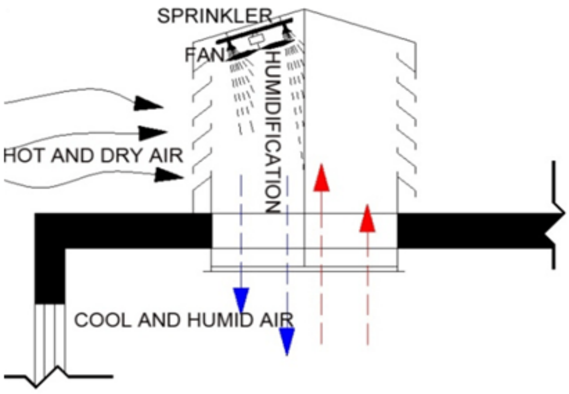

Fig. 14: Adding moisturizing element into traditional wind catcher

Evaporation can be highly promoted by means of sprinklers and a small pond on the roof. A slight slope is required on the roof to lead the water into the pond. Thus the roof is always wet and additional water is kept in the pond. Water from the pond is directed to the court yard over a solid surface. This surface keeps the wall safe from water penetration. Then water bunch up in the central pool in court yard. At all the time in this process the water is being evaporated. The amount of heat needed to vapor water is taken from the ambient air, thus the surrounding area is getting cool and moisturize (Fig 15).

Conclusion:

Before using high technology and mechanical devices to render the inside condition of the buildings pleasant vernacular solution should be examined. The paper pointed out the simple strategies that can be impressively improving contemporary buildings of hot and dry climate without the benefit of high technology devices. Strategies that can struggle with harsh climate of hot and dry regions such as interception from the sunbeams before getting heat and using cooling devices, raising the amount of air flow and ventilation, moisturize the dry air and etc. Traditional architects of the hot and dry climate presented numbers of logical methods into the building to provide thermal comfort for residents. To decrease the cost of the today's energy and in order to keep our environment clean, those methods can be evaluated and implemented into the contemporary buildings. If traditional solutions are not enough, then they can be integrated with the minimum technology.

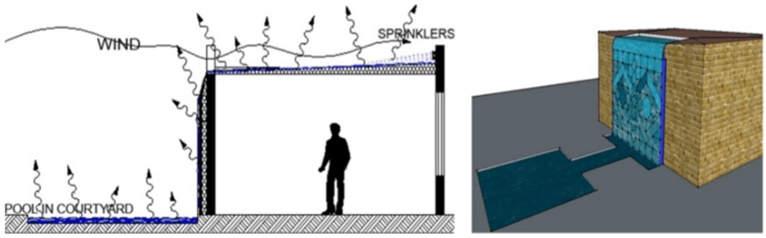

Fig. 15: Promote evaporation over the building's envelope

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