Desert Architecture Principles

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Abstract:

Harsh conditions in the hot and dry regions make a burden for humans to live and dwell in such areas, as of thermal comfort and water scarcity which are of vital needs. Throughout this research, an introduction about the climate of the desert, what trends arouse like sustainability strategies that were once implemented in the past and thrived again, architects who used these principles in the past civilizations provided us with rich content techniques to be used in concurrent days to further manage the more desert-like places that ultimately will benefit from these principles for more thermal comfort and water availability. Different traditional desert architecture principles were addressed like buildings shapes, buildings Orientation, roofs shapes, and some other factors through climate coordination and using the right materials to further exploit the different natural energies of solar radiation, night ventilation, evaporation and nocturnal sky radiation, Finally a "Sde Boqer" study case which resides in the Negev desert is introduced to demonstrate a lot of these principles that have been implemented in these days.

Introduction:

More people are moving to more developed areas where all services are provided by governments. However, urban cities have become over-populated in some regions and need to be expanded to accommodate more population, and most of the times it reaches the points with Arid and semi-arid regions, which represent about 26% of the land area on earth. In Ancient times, people used to live and dwell in deserts that it is indeed not of a suitable place to survive, especially with its harsh climate and the different characteristics that make the desert a difficult place to adapt. Desert is known for having extreme temperature and scarcity of water, as world temperature might reach over 50 °C (122 °F), and the maximum temperature has reached about 58 in Libya, El Azizia (Live Science Staff, New World's Hottest Temperature Declared, 2012) or according to Guinness records, of 56.7°C (134°F), in California, U.S, 1913. More than that, rain is extremely rare in deserts and has very low precipitation rates of less than 35 cm per year, and some deserts might have years with no rainfall at all. Because of the very high temperature, extreme evaporation rates are happening and can reach up to 10 times the precipitation rate, what cause less moisture in the soil which makes the plant life almost impossible in some areas of deserts [Peterson, 2017].

With the continuous increase in temperatures because of the global warming and overheating around the world, more concerns have been aroused regarding the energy conservation and efficiency, as energy is used almost in any action of human life. Many aspects such as climate coordination, reducing the use of new sources, and meeting residents needs have been addressed along with reaching the point of minimizing energy supply. Thus, getting the optimal use of electricity supply or energy sources as a whole by implementing energy conservation methods and principles, some of which can be used in urban or rural buildings, which eventually have positive financial and environmental impacts [Szokolay, 2004].

Background:

Ancient forms of architecture have been exist for very large periods of time and took place in very different points of the globe. Different kind of architecture styles have been implemented which were reflecting changing fashions, beliefs and religions, emergence of new ideas, technology or materials which made new styles possible, all ancient civilizations that lived in the desert were having into consideration desert qualities, and were trying over time to exploit its benefits as much as possible and to avoid its disadvantages, to reach a point at which they can accommodate its harsh climate conditions, in addition to that, they were aiming at being more sustainable.

Architecture has been around since the deep history of mankind, and many architects used to exist to enrich the traditional buildings with more innovative techniques for better adaptation with the available resources and climate at those times. That is in addition to the new architectural designs and landscapes that were presented as well. In these days, more and more ideas and methods are introduced to be integrated within the modern buildings and urban modernization, and as more people are heading to urban places, the need for more development should be considered which is usually accompanied with the need for more energy. However, some aspects used in buildings like "Building Automation" may introduce energy savings and environment preservation as a concern, though concurrently, it might cost relatively a lot of energy consumption and not considered to be the "ideal option" in energy efficiency, regarding it being more safe and comfortable [Maleki, 2011].

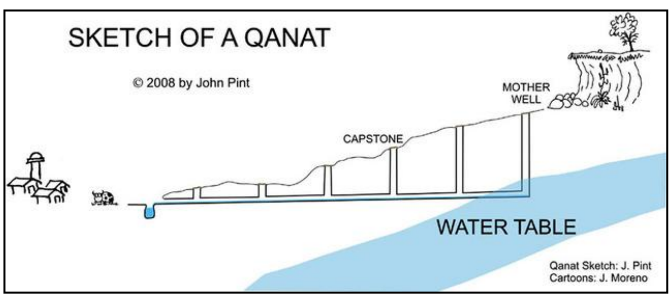
The term "sustainability" is an old term but introduces a new understanding of how to design, build and live sustainably, not greener nor eco-friendly but to be more sustainable as we are pushing up against the resource limits of our planet, thus it can be interpreted as an old word for a new world, these notions of climate change and sustainability became part of the global discourse in the 1990s [Elgendy, 2011]. Nevertheless, there are a lot of debates were aroused that technology can get us greener here and there, but with vision and attention to the fundamental needs of people, true sustainability can be obtained regarding the reduction of energy needed, in addition to have a decent life with fair water source supply.

Desert architecture design should inherently promotes behavioral simplification which will help pre-familiarize ourselves with a low energy future and may create motivated behavior mostly from the benefits derived from the enhanced connection with the local environment, this can done basically by working with local resources and constraints, getting the most out of simplicity and practicality, integrating components for a greater effect, taking a visionary approach, creating opportunities for communities, and lastly using technology wisely, as using more sensors and computerized monitoring systems like the aspects used in "Building Automation" may incur additional energy need and thus additional solar panels which will eventually contradicts the main purpose of embracing simplicity and maintaining the minimal need of energy [Pearlmutter, Erell, Meir, 1997].

Some architectural principles can be used and implemented in buildings, which can use the regional climate for its benefit regarding the natural resources, and the optimal exploitation of the solar and wind energies, and that all these climatic factors can interact effectively with the building design to attain more thermal comfort, which is one of the most important factors for accepting the fact that we can live comfortably in vernacular houses of hot and dry areas. In this study, natural energy sources, which will be mainly harnessed by the implementation of different architectural methods that are used basically to minimize the need for energy and thus for having more energy independence, as according to a study in the U.S it was stated that over 40% of the operational energy being consumed in the residential and commercial buildings are related to heating, cooling and making buildings habitable [U.S Department of Energy, 2008].

In this Study, many aspects have been introduced regarding the traditional architects methods for utilizing simple inactive strategies for attaining more comfort conditions in vernacular houses and confronting with hard situations, such as observing distances between buildings, layout orientation, building orientation and configuration, introversion, very dense texture, using more nature indigenous material, wind catcher, porch, central courtyard, subterranean (Qanat), etc. The existence of spaces such as particular residential spaces for summer and winter, optimal use of wind and solar energy and soil thermal capacity are significant characteristics for vernacular houses in different regions of arid areas, which at the end of the day is demonstrating the harmony between the buildings and its surrounding environment.

Desert Traditional Architecture



1) water channels, Aqueducts (Qanats): It is one of the passive systems used in the desert, as a way to bring water without the use of modern technology or any kind of pumping systems, usually by going underground through mountains or steeps using the gravitational force. in our urban times, there are still some Iranian cities in the central part of Iran that are connected to Qanats by some means of gutters, rivulets and ponds, using the water for Irrigation, cleaning or even drinking. The increasing population in ancient Iran caused an increasing demand to water supply. So, our ancestors made an invention: using a special method, they brought the groundwater to the surface by gravitational force. This invention was unique and was named Qanat [Bakhtiari, 1979].

2) Water reservoirs, cisterns: Water reservoir or cisterns are mainly defined as a water storage that uses natural insulation as by being either partially or completely underground for preventing temperature penetration, surrounded though by a set of walls and soil that adds more resistance to the overall coating of the cistern, they usually have a dome shaped cap that let the heat ascends and leave the reservoir side cool, this as well adds an advantage using this shape that it will not be completely exposed to the sun, thus part of the dome is shadowed in the morning or afternoon times. Another technique that helps cooling the water is Ventilation and wind catchers which basically discharge the hot water below the dome and create an air flow for maintaining the healthiness and cooling of the water [S. Esmaeili1 , S. Litkouhi2, 2013].

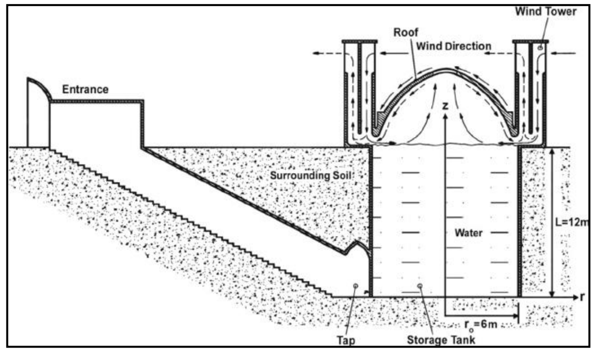


Figure.2 : Underground cold water cistern


Figure.3 : Large cistern


Figure.4 : Water cistern in desert town


Figure.5 : Water reservoir

3) building shapes: In the modern days, many kinds of architectural designs are readily available and more innovative ideas about buildings' design are on the rise and keep progressing every day. Building shapes are important for aspects of energy efficiency, disaster-proof and costs. In the hot and arid areas, what matters most regarding the shape of the building is most likely the energy efficiency, as an early design decision could dramatically affects buildings' performance by different factors including: 1- Interacting with the sun, 2- surface to volume ratios, 3- Heat loss to ground, 4- Potential of self-shading.

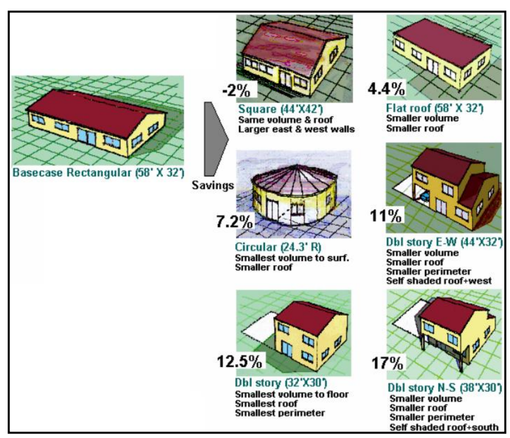


Figure.6 : Energy efficiency impact areas

Energy efficiency impact areas can be more represented in Figure.1 that clearly show different shapes characterized by different values of the previous factors showing the efficiency Role of buildings shapes.

Furthermore, it is noticed in Figure.2 as well that buildings with rounded surfaces is the best in term of energy efficiency, and ultimately the best choice for having a building in hot and arid areas as its surfaces are the least in their vulnerability to sun, possessing an advantage of , with less surface to volume ratio. [Chalfoun, 2003]

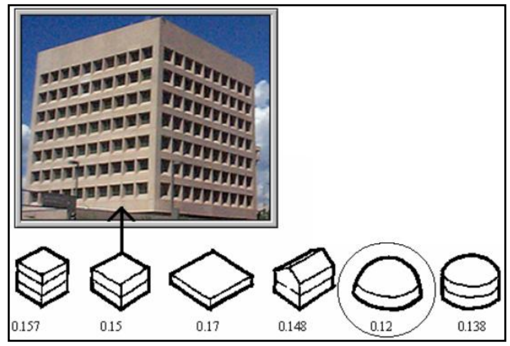


Figure.7 : Surface to volume ratio

4) Roof Shapes: The Shape of the roof plays a major role in maintaining the cooling inside buildings, water reservoirs or any place that requires more conservation of cooling. That is because of its thermo-physical structure especially in the hot and arid regions, where conservation of energy needed for cooling. Domes and Arched roofs are much better structures due to the unbalanced surface, which affects the sunbeam impact on the structure, as part of it will remain in shade during certain times of the day, and releases the sunbeams along with the waves during the night to acquire more cooling. Finally, besides that having rounded houses have many green effects, and have many benefits regarding energy efficiency and nature integration, there are endless design possibilities can be used, in addition that dome-shaped homes look spectacular [Varzaneh, Aminib, Bemanianc, 2014].

5) Massive walls: Suitable in climates where the temperatures are disturbingly hot during the day and cool at night. Buildings with thick walls of brick or stone which, in addition to their insulating properties, function as heat reservoirs: during the hot day, the heat flow from exterior to interior is retarded and during cooler hours a given part of the heat which imprisoned in the walls is released towards internal spaces. The consequence is a minimization of temperature rate inside the building. Sundried brick widely used in traditional buildings due to its high heat conductivity and energy storage capacity which allows 80% of the heat from the exterior to be absorbed and only 20% transmitted inside. Provided that the wall thickness should be accurately selected, the coolness stored in a summer night will provide comfortable temperatures for a long part of the following day. Likewise, heating in winter will not be required due to the heat stored in walls and radiated during the night. Today, baked bricks (cond. coeff < 0.66 W /mK) of 30-cm minimum thickness successfully replace adobe vernacular building [Alp, 1991].

The major local building materials in the research region are clay and brick. Because there is little rainfall in the region, most building walls are built with only clay or clay bricks. In some more important buildings, stones may be used to provide stronger and more durable bases for the clay walls above it. The heavy and thick clay or clay brick walls serve as good thermal mass that not only reduces heat transfer between indoor and outdoor spaces, but also modify the indoor temperature. Such material is cheap and easily available in the region so is used in different ways and in different types of buildings. For example, it is popular in the region to use the sun-dried mud bricks to build a cubic structure with hollow-out walls that can air-dry the abundant grapes in the region, clay blocks are also used to build some small structures and facilities for the family, like the arch-style stairs, beds and stoves in the courtyard [Liu, Lib & Fu, 2006].

6) Courtyards: In courtyards the cool night air is stored until the mid-hours of the following day while plants shield the court walls from direct solar heat gain. The internal patio environment is a cooler private area suitable for many uses. It has proven most responsive to the rigorous conditions of hot-arid regions. It helps ventilation and filters dust, sand and noise. It moderates the climatic extremes like -cool air of the summer night is kept for many hours undisturbed by hot and dusty winds provided that the surrounding walls are as tall as the yard is wide. The rooms draw daylight and cool air from the courtyard. During pleasant morning and evening hours, the household gathers in the courtyard safeguarded from sight. Arcades at the perimeter (iwans) are indispensable to shade the overhead midday sun. In dry, dusty climates, running water is imperative to cool the air by evaporation and absorb the airborne sand. [Alp, 1991]

7) Wind catchers: There were one, four or eight per house depending on the size, wind directions, or dust concerns. Mainly, there are three types of wind catchers, the first one is Direct wind entry that forces wind into the house. Towers can be typically swiveled if wind directions change and since wind picks up dust there is a place to collect it, even though the air still hot, a breeze still better than nothing. The second type is wind-assisted temperature gradient, it takes advantage of the Coanda effect to vacuum air out of the tower. A temperature is created when hot air is cooled with water below like the previous type. The towers can swivel if needed since the opening face is away from the wind no dust enters the building if there is no wind no water however the third type works best which is the solar chimney , it gets hot forcing air up which causes a vacuum that draws air from underground tunnels . [Retrieved from : https://www.youtube.com/watch?v=n-HsXzyaYxY]

8) Solar chimneys and induction vents: Solar chimneys make use of solar heat to reinforce natural air convection. The black coated chimney, see Figure(8), is heated during the day and so is the air inside. The latter then expands and rises, tracking the interior air up and out. This is a self-regulating system: the hotter the day, the faster the air motion. A variation is "glazed solar chimney", see figure (9). Such chimneys when facing west are favorable for venting during the hot afternoon part of the day. If a thermal storage mass is added behind the glazing, the system will store heat and keep on exhausting air after

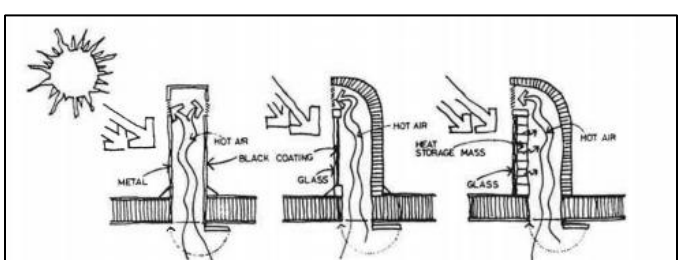


Figure.8: Types of solar chimney to assist ventilation

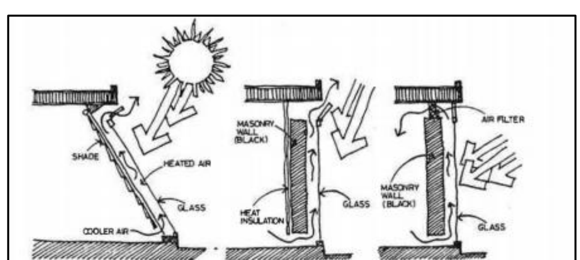


Figure.9: Variations of induction vents for summer ventilation and winter heating

sunset. Induction vents are a "solar air ramp", "windows with radiant barrier curtains", or "solar mass wall". The sunlight is trapped behind south or west glazing, the heated air rises and is allowed to escape outside. This causes the internal air to be pulled in the heated space and exhausted. North-side shaded air may be used to replace the lost quantity inside the building. A mass-wall will serve as a heater during colder times by shutting the exhaust and letting the heated air return back into the space through an air filter. [Alp, 1991]

9) Roof ponds and water walls: Bags containing water are placed on the roof terrace and screened by a movable light insulation layer during the hot day, see figure (10). This setup keeps the roof-generated heat off during the day. When night comes, the insulation is removed or slid aside and the water mass is permitted to lose its heat inertia to the night sky, cooling down the structure underneath. Approximately 15 - 20 cm deep water and a 4 - 8 cm foam insulation appear to regulate the internal temperature between 18 - 21 °C most of the time. [Alp, 1991].

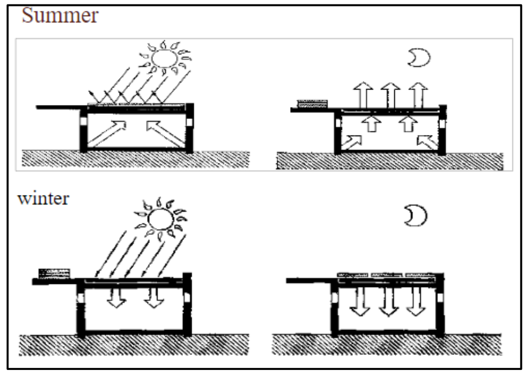


Figure.10: Work principle of roof ponds during summer and winter

10) Windows: Relatively small openings to reduce intense radiation. It should be tight closing as protection against high diurnal heat, and located on South, North, to a lesser degree, on East side's because of the low solar angles may bring radiation deep into the house from windows placed on either the eastern or western sides. Vegetation in turn reduces the temperature and filter’s the dust in and around the house and elevates the humidity level in too dry climates. [Soomro, 2012]

11) Planting: Vegetation may be effectively used to act as a climatic moderator. It shelters from unpleasant winds, filters sand and dust, regulates air temperature through evaporation, reduces glare, and minimizes the heat reflection from ground surfaces. Above all, it shades and thereby cuts down solar heat gain. Roof planting can be beneficial like in dry areas the roof irrigation will cool down the structure through evaporation. A moist roof loses the heat it absorbed during the day to the night sky. [Alp, 1991]

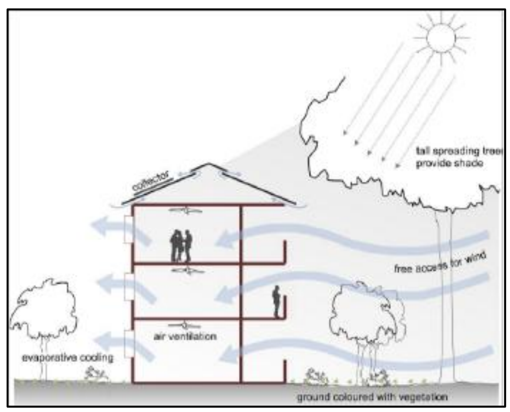


Figure.11: House natural ventilation using vegetation

<u>Negev desert architecture - Study case</u>: Building in Sde boqer [Etzion, Pearlmutter, Erell & Meir, 1997]:

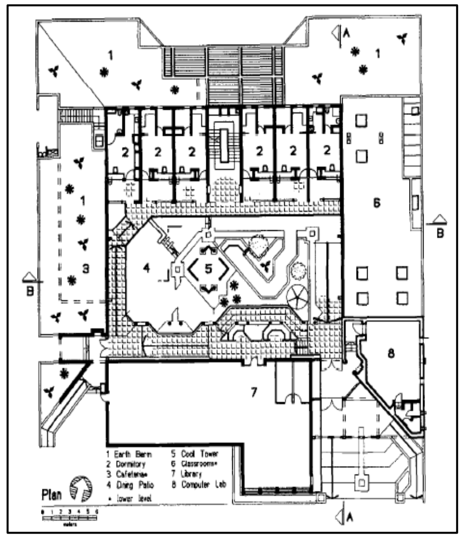


Figure.12 : Building structure: in the middle- atrium and cooling tower

In order to demonstrate desert architecture we will examine the Sde Boqer campus of Ben Gurion University of the Negev. The design of the Blaustein International Center for Desert Studies incorporates several innovative energy saving strategies. The building is multi- functional complex that includes a library, teaching rooms, offices, lounge, cafeteria and rooms for visitor's accommodations. The building is $1100m^2$ and everything is organized around 500m2 central atrium - which provides protection from the climate outside, and even has a semi- tropical garden inside of it. Sde Boqer is located at 30.8˚ latitude, about 480m above sea level. The Negev highlands (above 300m) have cold and sunny winters, and in the summer- hot during the day and pleasant at night. Average annual rainfall is 80 mm (can vary from year to year).

<u>The Summers</u> at daytime are hot and dry with mean daily maximum temperature of 32˚. At night- the mean daily minimum: 17˚. There is an intense solar radiation and global radiation averages 7.7 kwh/m2 per day (June and July) on horizontal surface. Relative humidity is low- but may rise at night (when there is a sharp drop of temperature). The problem is overheated conditions around mid-day so the aim is to low the air temperature and reduce the exposure to the intense radiation.

<u>The Winters</u> at day time are sunny but cool. The mean daily temperature (January) is 9.3˚C, while the mean daily maximum is 14.9˚C. At night time- average minimum temperature 3.8˚C. There are large number of clear days- ideal for passive heating in buildings. Global radiation averages 3.3 kWh/m2 per day on horizontal surface, and 4.6 kWh\m2 for south-facing vertical surface. The problem: the amount of energy that is needed to heat buildings into comfortable level.

<u>The building's design and solutions for climate adaptation:</u>

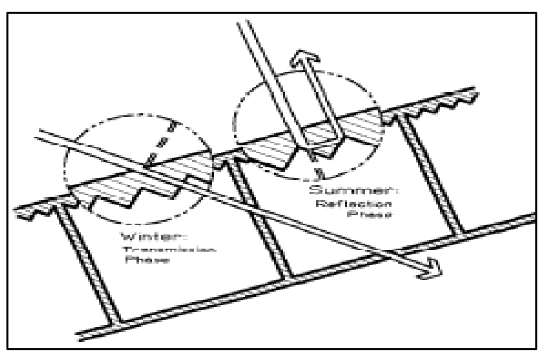


Figure.13 : Selective polycarbonate sheet showing reflection and transmission at summer and wintertime in the tilted roof.

<u>In the summer</u>, thermal comfort achieved through a combination of three ways: Reduction of unwanted heat gains, use of high thermal capacity materials and by passive cooling systems. *The Reduction of unwanted heat gains* is done by treating the walls outside are with smooth stucco painted

white, so 70%-80% of solar radiation is reflected. The bald finish prevent the dust particles stick on the walls and discolor them. On top of that, the orientation of the window opening and glazed areas designed in a way which allows air in but still minimizing the heat gains. There are no windows facing the west or the east elevations- in order to reduce solar radiation going in the summer, and also because in the winter they get less radiation than the south facing wall.

The residential rooms are open to the atrium and have only small windows facing north- the main direction of the wind at summer time in the area, helps ventilation. Also, there are operable windows installed along the length of the south side of the atrium and along the apex of it, which are opened during the summer and allow the removal of excess heat trapped in the upper parts of the atrium by cross ventilation. Besides, the roof surface and additional internal shading beneath the glazed surface avoid the transmission of solar radiation. The roof is glazed with special sheet made in Israel that is made from two polycarbonate layers that has small triangular prisms along the interior surface of the outer layer, which has a selective transmitter of solar radiation. The tilt angle of the roof is facing south and the direction of the prisms is east- west. The geometry of it allows more solar transmission in at the wintertime while in the summer large amount of the radiation is reflected from the roof (the glazing panel was found to transmit more radiation than expected, probably because indirect diffuse radiation that entered the roof).

The second way is to *use high thermal capacity materials*. The building has a thermal capacity that should contribute to stabilize the daily fluctuations in the desert. The building exterior conclude insulation and thermal mass. The internal layer build from concrete walls and to the external insulating layer is attached. In addition, the exterior walls are covered with earth until the second floor windows- what reduces significantly the extreme thermal conditions of heating and cooling from outside, what saves energy.

The third way to achieve thermal comfort is by *passive cooling systems*. An evaporative tower is located in the cafeteria in the atrium. The tower has at the top of it propeller fan and water sprayers/ injectors, causing intense evaporation so the air from outside is cooled significantly, and getting colder as you go down. The excess water do not get lost- it falls into small collection pond at the bottom in order to be pumped and recycled. The quantity of water evaporated is about 1-1.5m3, depending on the external conditions. The height: 12 meters horizontal. In the mid-day period of highest heat stress in the summer air temperature at floor level were up to 4° lower than the ambient where as in the atrium apex it was slightly higher than the surrounding. At mid-day, the temperature of the air coming in is 35°-36° and the exhausted is 21°-22° C. The mix with the internal air makes humidity drop resulting humidity value less than 65%. The total daily cooling is 940 kWh. The systems efficiency was found to exceed 85% during operation hours. The balance between using the cool tower to the use of natural airflow ventilation in the summer still not been resolved. Besides, in order to make it more efficient there is experiment to develop wind capture at the head of the tower (that will reduce system dependence on mechanical means).

In the winter the thermal comfort is achieved in passive ways. First, by maximizing gains from solar heat and finding a way to store them, and second by minimizing loss of heat by designing the building's cover. Maximizing is done through roof glazing (as mentioned before), which allows the atrium to function in this period as a greenhouse. That way, in the winter the roof glazing transmits around 60% of solar radiation so the temperature inside at the floor level is 5-15˚ C higher then it's surrounding (20-25˚C at daytime and 12-15˚C at night). The warm air from there is used to heat the spaces besides it. The guest accommodations in the upper stories of the north are heated by drawing in warm air from the apex of the atrium, supported by small air turbines. The well-insulated rooms remain at stable temperature of about 16˚ whereas the ambient air fluctuates between 8˚- 18˚. The system provide heating power of about 600W, requiring only 40W electric power what makes it cost- effective. All of this is supported by building with high thermal material capacity and insulation material. The external walls have a layer of polystyrene insulation of 5cm, the roof has 10cm, and the building is composed from concrete and earth cover that increase the building storage capacity.

To sum up the Negev study case, we can see that some of the elements such as the evaporative cool tower and the solar heated air system appear to be successful and cost effective for thermal comfort in the desert climates. The selective glazing also benefit the structure and is worth to consider in other projects. Features such as cool tower and earth cover can be researched more in order to optimize it, like in the mean of involving wind capture mechanism in the cool tower that can enhance the thermal conditions in the atrium and the complex in the summer, in order to use as much as possible the alternative natural energies in the desert.

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