

THE ARCHITECTURAL EXPRESSION OF LOCAL CLIMATE RESPONSIVE BUILDING

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Abstract:

The principal aspect in designing a climate responsive building is its comfort criteria. In hot-arid areas climatic factors need integrated treatments to attain comfort. Buildings consume energy mainly in the process of climate control in mediating between external and internal environments, and heat loss or gain through a building envelope is dependent on various paths which need certain design measures. i.e. If the building is shaped to reduce the area exposed to the sun, the walls are insulated, the glazing is properly shadedetc. much of the solar load can be prevented by increasing the cooling requirements . The paper discusses means of defining the relationship between external and internal environments on the one hand and between shape and energy use on the other.

First technological innovative treatments of form needed for hot-arid climate leading to the development of the building envelope are demonstrated, then the paper analyses different treatments of building form and elements for a group of local responsive buildings.

Key words: - Hot-arid climate, Buildings, Forms.

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The Architectural Expression of Local Climate Responsive Buildings

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1-Introduction:

Buildings which use climate as a form determinant result in climate responsive architecture throughout history, local builders have used great ingenuity in providing the most comfortable climate conditions possible with the constraints of the local climate ⁽¹⁾. There had been many local climate responsive practices both traditional and contemporary, reflecting culture, and local climate in the building form. As analytical studies need an awareness of the suitable treatments needed for hot-arid climate conditions, the paper first discusses those treatments and their impact on building form and elements followed by an analysis of a group of local climate responsive buildings.

2-Hot-arid climate Strategies for building form and elements

In hot – arid climate, four main climatic factors concerning the building should be considered to attain comfort: appropriate orientation, building shape, shading of walls and openings and roof treatments all of which affect the architectural expression of the building and are reflected upon the building form, walls and roof of the building.

2-1 Building form:

Buildings can be shaped to allow for maximum exposure to summer breezes and induce air movements through single and multiple courtyard system, open plans and thin plan arrangements. Some architectural forms use the principles of interior energy flow to induce cooling effect which is shown in the section of the building like cool towers which are large vertical tubes at least 25ft. above ground, in top of it is a water soaked air filter that cools air that passes through it . The heavier cool air flows down and out of the tower through a large opening to cool the surrounding space, fig (1). Wind tower ventilators differ from passive stacks in that they are larger in diameter and have dividers to allow them to act as wind driven ventilators ⁽³⁾, they perform both supply and extract, fig (2). Wind catchers can capture breezes above roof level for buildings whose windows have little access to breezes, mean wind velocity increases with height above the ground, so wind towers can admit winds of significantly higher speeds and therefore their openings can be smaller than windows at ground level, wind towers can potentially admit wind from any direction, Fig. (3).

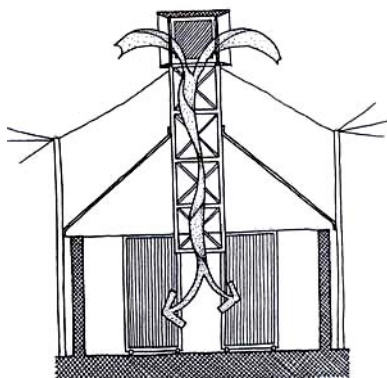


Fig (1) Evaporative cool towers ⁽²⁾

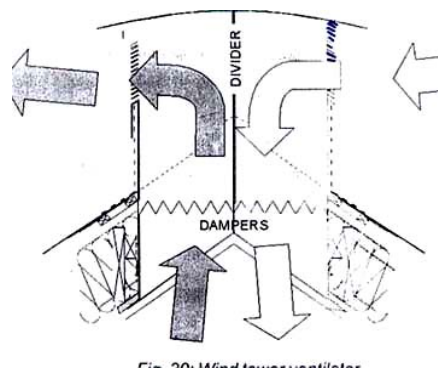


Fig (2) Wind tower ventilator ⁽³⁾

The roof monitors in fig (4) combine the tasks and change their role seasonally; they provide stack ventilation and day lighting in summer and solar heating and daylighting in winter.

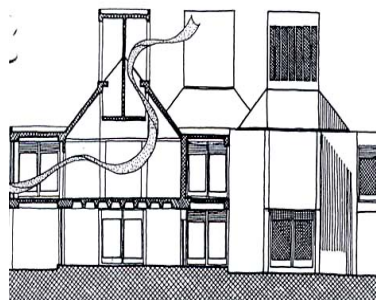


Fig (3): Wind catcher ⁽²⁾

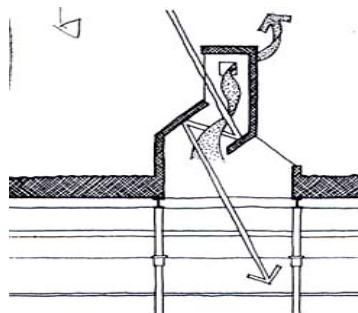


Fig. (4): Roof monitor ⁽²⁾

Exterior surface colour should be light in hot climate to reflect radiation using materials and surfaces that diffuse sunlight. The surface temperature of a material is dependent on both its ability to reject solar radiation (its solar reflectance) and its ability to release back to the environment heat that it absorbs (its infra red emittance ⁽²⁾. In table ⁽¹⁾ it is noticed that materials with higher SRI values are cooler.

Roofing material	Solar reflectance	Infra red Emittance	Temp. rise °C	Solar reflectance index (SRI)
Tiles				
Metal , white	0.67	0.85	16C	82
Clay , red	0.33	0.9	34C	41
Concrete, red.	0.18	0.91	43C	23
Cement , unpainted	0.25	0.9	39C	31
Concrete , light brown	0.42	0.9	29C	49
Metal				
Steel , galvanized	0.61	0.04	31C	46
Aluminum	0.61	0.25	27C	56
Siliconized polyester, white	0.59	0.85	21C	71
Coatings				
White polymer	0.7- 0.85	0.86- 0.91	5-13C	88-107
Light yellow	0.79	0.91	9C	99
Dark blue	0.12	0.91	46C	9

Table (1): Solar Reflectance index of some roofing materials ⁽²⁾

2-2 Main building elements:

- Roof.

Design features like mirror –tube skylights, light wells, light shelves and up lighter glazing panels are used to distribute light further into internal spaces by reflecting daylight off the ceiling . In hot climates double roofs are used in which the outer uninsulated roof reflects the sun's rays, air flows between the two roofs to dissipate the heat emanating from the top roof, and the lower roof (which is insulated) forms a barrier

to the warm air and radiation from the top roof. Night sky radiant cooling utilizes the fact that the temperature of the sky is lower than the temperature of the ground surface, resulting in a net radiant transfer to the sky. The simplest night sky radiant cooling system is a massive roof that is covered with movable insulating shutters during the day and exposed to the space below so the roof can absorb heat from the space. Common systems include roof ponds, where the thermal mass is water enclosed in plastic bags or under glass, supported by a flat roof. Spraying the roof mass with water so it can lose heat by both evaporation and radiation can augment the heat loss. Circulating air past the underside of the ceiling can cool the building. In winter the shutters are removed during the day to collect heat that is then released into the building through the ceiling at night. Fig (5), (6)

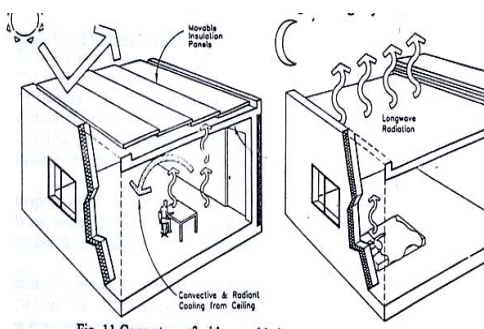


Fig (5): Nocturnal radiator ⁽⁴⁾

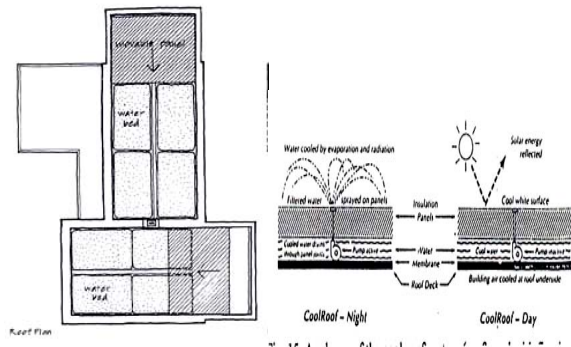


Fig (6): Ventilated roof ponds ⁽⁴⁾

Phase change cooling system draws daytime warm external air by fan over an array of fluid-filled heat pipes ⁽⁵⁾. The pipes conduct heat to storage modules containing a solid phase change material which, located in the ceiling void, absorb the heat as they slowly melt during the day providing cool ventilation air fig (7), during the night the opposite occurs. Shutters to the outside air are opened and the fan reverses direction to draw the cool air over the phase change material causing the material to solidify.

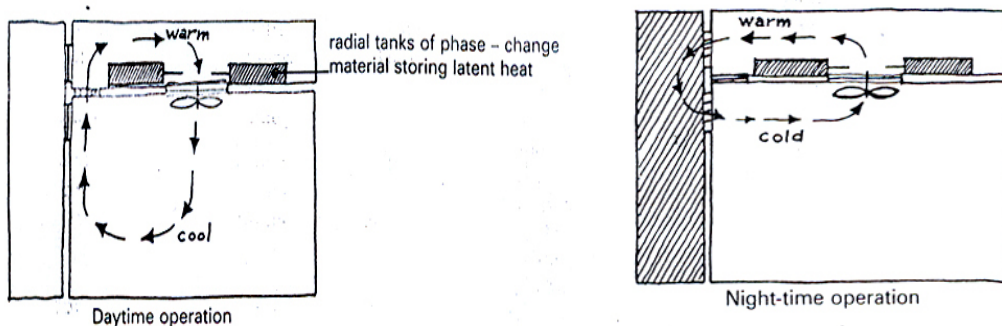


Fig (7): Phase change cooling ⁽⁵⁾

- Walls

Wing walls, fig. (8) can be used to alter the positive and negative pressure zones around the building and induce flow through windows parallel to the prevailing wind direction .

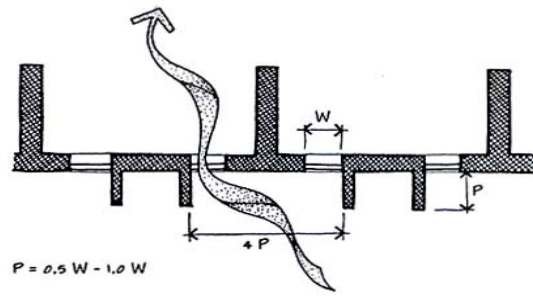


Fig (8): Wing walls induce wind flow ⁽²⁾

Movable shading elements can provide more flexible and responsive control, overhangs that can be extended in summer and retracted in winter or canopies that can be removed entirely in winter are most effective. A layer of overhead shades protects the building and courtyard from the high sun, while a layer of vertical shades can protect from low sun. Light shelves beyond the exterior surface, evenly distribute light and reduce glare if extended into the space. At the same time it can reflect light off its top surface through the upper glazing to the ceiling, where it is then reflected deeper into the space fig. (9). Day light enhancing shades can protect windows from solar gain while preserving sky view, reflecting daylight, and reducing glare. The louvers are tightly spaced near the buildings to shade the high sun and loosely spaced farther away to shade low sun while allowing air circulation within the shade itself to reduce heat transfer from it to the interior space fig. (10).

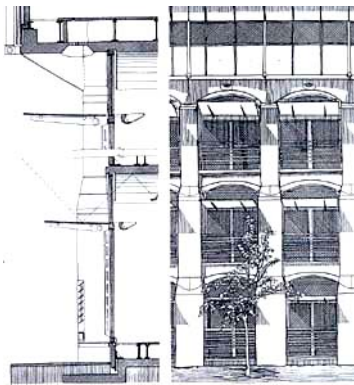


Fig (9): The use of light shelves to distribute light ⁽²⁾

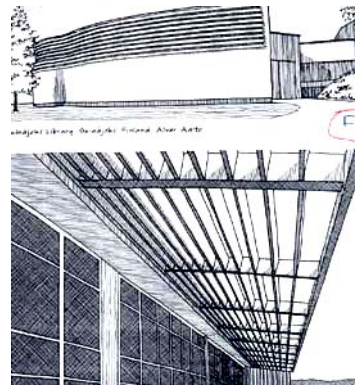


Fig (10): Loosely spaced shades ⁽²⁾

An internal shading layer behind the window or an in-between shading layer separating two glazing panes can reduce solar heat gain. An important consideration with insulation is its placement with respect to the two areas to be thermally separated, the insulation, insulation curtains or panels would function more effectively on the outside ⁽⁶⁾. Double skin materials should be selected to reflect solar heat gain and avoid transmitting heat to the inner layer; this can be attained through absorptivity of outer skin, emissivity of cavity and rate of ventilation in it fig(11). Thermo-chromic glass depends on “clear gel” which is a clear film which when heated above room temperature reflects sunlight by turning an opaque white, turning clear again when cooled. Electro-chromic glass depends on certain compounds that undergo reversible

colour changes when a small voltage is applied across a thin layer causing a change in the oxidation state.

It changes colour from clear to blue when a current is passed across it. ⁽³⁾ fig (12). Prismatic glazings are designed to optimize day lighting by high precision coated plastic components fitted to glazing; they act to redirect light from window areas that are too bright further into a room through calculation of light angle. Other types can be used to reject excess sunlight through the same mechanism. Low contrast between the window frame and adjacent walls will reduce glare and improve vision fig (13).

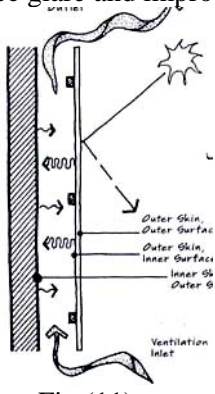


Fig (11)

Section of double-skin wall ⁽²⁾

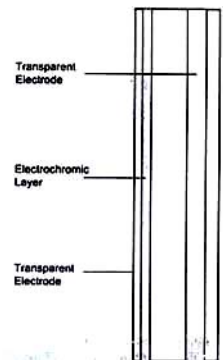


Fig (12)

Electro chromic glass panel ⁽³⁾

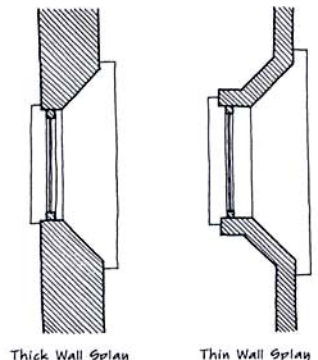


Fig (13)

Low contrast between window & wall

3. Analysis of some local case studies

3.1 Introduction

In hot aid regions, buildings tend to employ a combination of measures to suit local climatic characteristics. Historical studies of pharaonic settlements show that even the ancient civilizations recognized regional climatic adaptation as an essential principle in architecture that was obvious in introducing massive thick wall buildings to make use of the time lag in cooling, using courtyards where cold air accumulates at night and flows to the spaces during the day and provide natural light, vaults reduced the area exposed to direct sun light, wind catchers were used for ventilation, clerestories were introduced for homogeneous natural light, atriums to modify lighting and thermal environment as well as earth sheltered parts of the buildings fig(14).

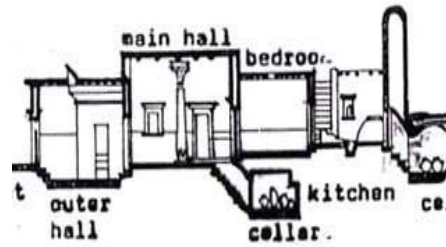
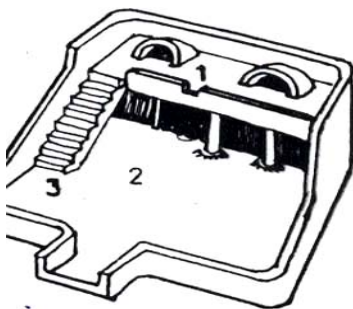


Fig (14): Climate adaptive pharaonic buildings

Islamic buildings used the potentials offered by the climate to produce dramatic designs that enhance the comfort of the occupants. High massive walls were used, multiple courtyard system that accumulates the night cold air and at daytime the cool air flows from deep courts towards larger courts, cross-ventilation was provided also through courtyards.

Also using landscape and water in providing evaporative cooling in buildings and roofing with domes and vaults. Wind catchers, wind shafts and wind towers were built to cool internal spaces and latticework screens were used to shade the interior while allowing sunlight to filter through it fig (15).

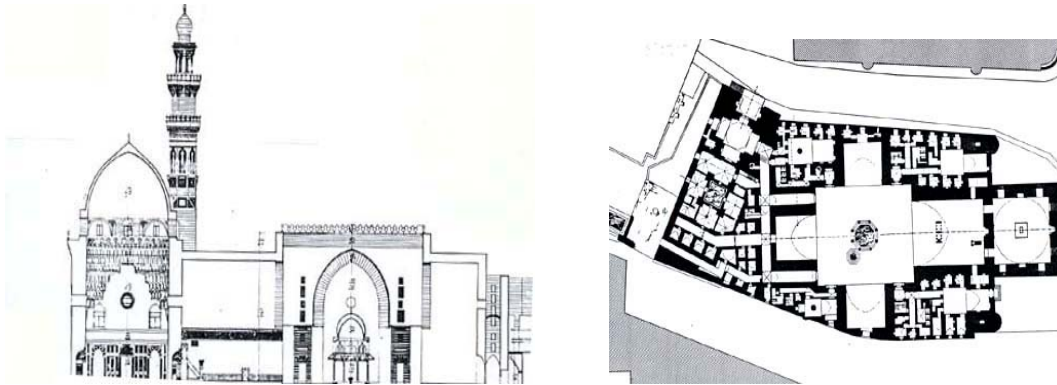


Fig (15): The use of courtyard, wind shafts and domes for cooling purposes in Sultan Hussan Mosque

3.2 Market place at the village of New Bariz Egypt

In his design, the architect decided to employ a system of internal courtyards as a primary means of climate control along with shading. He stressed that thermal comfort in the design he proposed depended on the natural control of air temperature, air movement, relative humidity and radiation fig (16).

Building form

Massive ground coupled buildings of mud brick walls with paraffin and bitumen emulsions used as stabilizers.

Rectangular shape with internal courtyard as means of cooling ventilation and natural light fig (17).



Fig (16): Layout of New Bariz village⁽⁷⁾

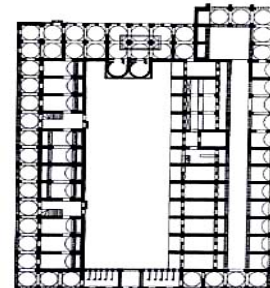


Fig (17): Plan of the market place⁽⁷⁾

A series of unidirectional wind catchers were designed. The shops on the windward direction of the courtyard can be cross-ventilated, but they would block much of the wind to shops on the leeward side of the courtyard. To solve this, wind is captured high and directed down to two

levels, one below ground for storage of food. Air can then exit out an updraft stack ventilation tower that is capped with slated metal louvers to increase suction. To add to their cooling capacity, the windward towers had straw mats hanging inside them which were dampened by a hand pump at regular intervals during the day Fig (18). The courtyard reduces diffused light and glare and contains cooled air from evaporative cooling.

Roof

Vault and dome system in stabilized mud brick offers the maximum radiant surface fig (19).

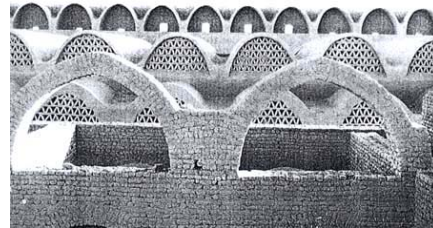
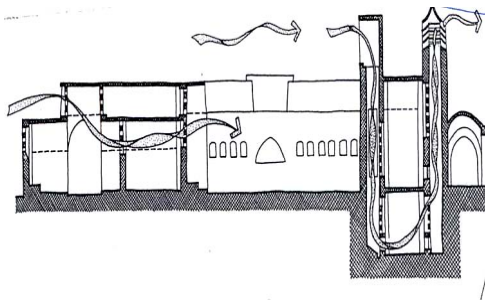


Fig (18): Section clarifying ventilation system ⁽⁴⁾ Fig (19): Roof scape of New Bariz market ⁽⁷⁾

Walls

Solid walls were made of mud brick with paraffin and bitumen emulsions used as stabilizers, small openings admitted night time ventilation.

3.3 Showrooms at Harraneyya Arts Center

The project is adapted to the environment, enhancing the role of earth as a building material and demonstrating organization of volumes and the subtle use of light.

Building Form

Barrel-vaulted block with a series of small domed spaces alongside it. Building material is mud brick laid in mortar, providing time lag insulation fig (20), (21).

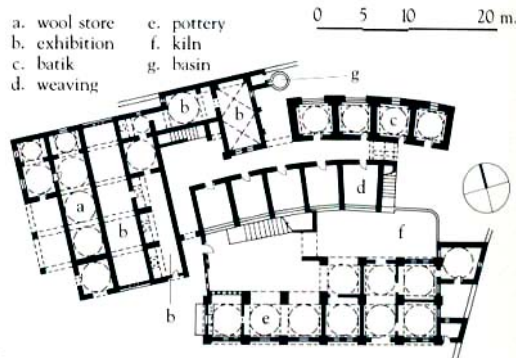
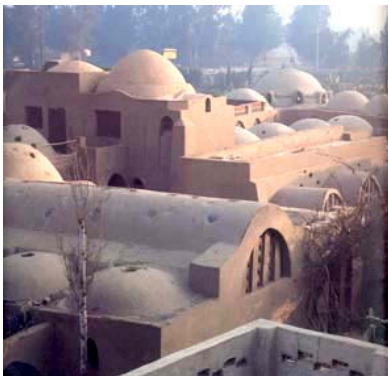


Fig (20): Harraneyya Arts Center Fig (21): Plan of showrooms

The showrooms are lit by shafts of sunlight from oculi in the vaulting roof, fig (22).

The east-west orientation of the main axis enables catching northerly winds. With the main axis in the shade all day, there is a reservoir of relatively cool air on which the south-facing workshops can draw.

Roofs

Barrel vaults and small domes are pierced by small circular openings to admit shafts of sun light. Roofs are sealed with cement, lime and gypsum rendering to improve insulation, any rain water is thrown clear of the walls by pipes through the parapets, fig (23).



Fig (22): Daylight Shafts



Fig (23): Oculi in the vaulting roof

Walls

Seventy cm thick walls were used, perforated brickwork filters the light, interior walls of workshops are white washed to increase light reflectivity and those of showrooms kept their natural earth colour.

3.4 Egyptian university for science & technology

The building comprises an integral environmental system which provides a balance between natural and built environment and develops traditional climatic strategies into a modern dimension. Fig (24), (25)



Fig (24): The use of multiple courtyards (9)



Fig (25): Building elevation (9)

The use of multiple courtyards in the campus resulted in the variability in the volumes of cold air stored during night and in the variability of shaded areas during day time producing differences in air movement from courts with low air temperature to those with higher air temperature through internal spaces.

The Research Center Building

Building Form

Rectangular with an atrium to modify natural lighting and thermal environment by developing a cool core.

The building has 4 wind catching shafts serving 4 equal zones. The shafts are high enough to scoop cold air coming from the north direction and directs it to different spaces of the building through the corridors to the rooms. The original design of the roof was intended to be double roofing for heat insulation but was cancelled due to budget constraints. Fig (26)

The building is oriented towards the prevailing wind direction to allow air from north in summer and prevent the dusty southerly wind in spring and provide uniform day lighting.

An atrium was located in the center of the building surrounded by all building zones. It is covered by a series of pyramidal shapes, three tilted surfaces of the pyramids are concrete slabs and the fourth glazed vertical surface is oriented towards the north to provide uniform day light and thus glare, Fig (27).

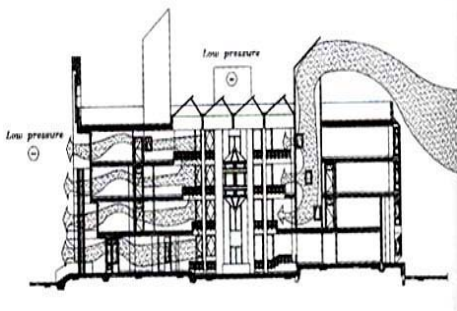


Fig (26): Section revealing atrium and wind shafts (9)



Fig (27): Atrium distributes daylight to building zones

Roof

Flat, light in colour roof to reflect solar radiation, with the exception of the atrium roof covered by pyramidal shapes.

Walls

Walls act as separating units between the inner and the outer environment. Openings were treated by two methods, horizontal louvers for the southern façades and vertical for eastern and western façades. Windows were deeply set surrounded by storage units which act as heat and noise insulation. Areas of openings in the northern façade were twice those in the southern façade and four times the openings in the eastern and western façades.

The University Central Library Building

Building Form

There are two parts with an atrium designed between to provide a cool core over the main entrance hall, fig (28), (29).



Fig (28): The Central Library Building⁽¹⁰⁾

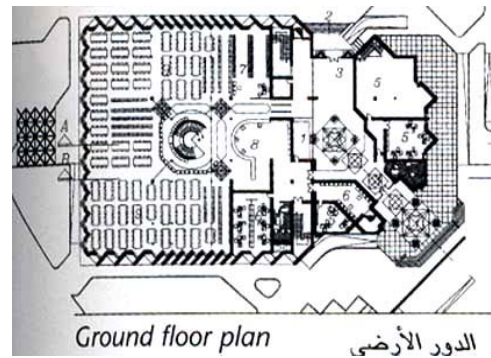


Fig (29): Ground Floor Plan⁽⁹⁾

The atrium is covered with glass domes to provide homogeneous day lighting and chimney effect where it encourages the movement of hot air upwards and out of the space and the hot air is replaced by cold air from northern openings. Book stacks are located south for heat insulation. Fig (30)

The roof of the reading hall is inclined towards north and is covered with pyramidal shapes, three sides concrete and the fourth tinted glazing open towards north for ventilation and homogeneous daylight. In summer, cool air entering the reading areas through the roof will finally exit the building through openings in the glass dome covering the atrium, in winter, air heated by the chimney effect of the glass domes covering the atrium is used to heat the buildings, fig (31).

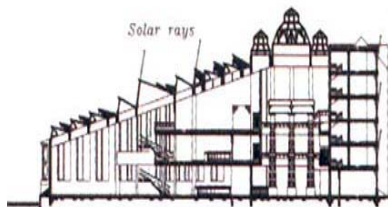


Fig (30): Section of atrium and inclined roof⁽⁹⁾



Fig (31): Pyramidal roof shapes⁽⁹⁾

Walls

Eastern and western façades have vertical louvers to prevent direct sun radiation and provide northern orientation to eastern and western façades.

3.5 New and Renewable energy Authority Building

The building was designed as an application of passive cooling methods of double walls, heat insulation, ventilation pipes. Passive cooling proved effective in reducing temperature inside the building 10°C as long as the outside temperature does not exceed 35°C where central air conditioning is applied.

Building Form

Earth coupled mass, well shaded by corbel and insulated by double roof and cavity walls the external of cement aggregate and the internal of gypsum blocks and polyurethane insulating sheet in between, fig (32).

U Shaped building of thin plan depths to facilitate ventilation, fig (33).

The double roof system formed tunnels in the north south direction. Electric fans are used on the north end of the tunnels to enhance air movement and thus cool the air inside the tunnels at night. In the morning these fans are closed by shutters to keep cool air inside.

The eastern and western façades have openings in the external part of the double wall covered by aluminum louvers beneath and above the window. This facilitates the movement of the cold air from the louver opening to ventilate the double wall and then goes out as hot air from the upper openings, fig (34),(35).

The space system used in the ground floor is composed of a series of air ducts under ground floor to get fresh air through electric fans to force the air from the air inlet through an air filter to remove dust and small particles then the air passes through a series of air ducts of C.S.A of 40 x 40 cm² by the whole length of the building. These ducts reach vertical shafts to transfer air to the different rooms in different levels of the building. This system makes use of the low constant temperature of the ground so that the air loses temperature during its movement through the long ducts in the ground floor to earth by conduction. The courtyard attracts the air through its location in north direction towards air electric fan which takes the cooled air from lower level of the courtyard through an air filter to remove the dust and then supply cold fresh air to laboratories in the ground floor. The hot air which accumulates in the laboratories is sucked through openings in the suspended ceiling to outside the building by means of electric fans.

The U shaped building is located towards prevailing wind direction.

The courtyard is located towards the north direction to make use of the cold air to ventilate this part of the building through lower openings in the wall to attract the air by means of an electric fan. Fountains and green areas are used to enhance evaporative cooling.

Roof

A double roof was used, the lower part is a structural concrete slab while the upper one is made of precast units settled on brick masonry walls of height 80 cm forming tunnels in the north-south direction, fig (36).



Fig (32): Corbel and protruding concrete shades



Fig (33): Thin plan depths

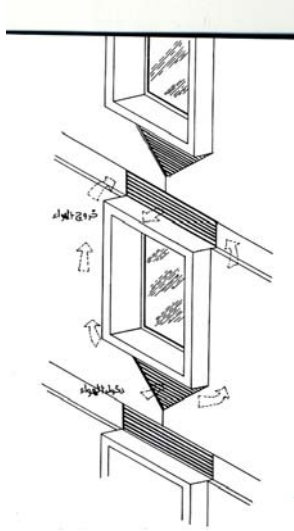


Fig (34): Window Isometric

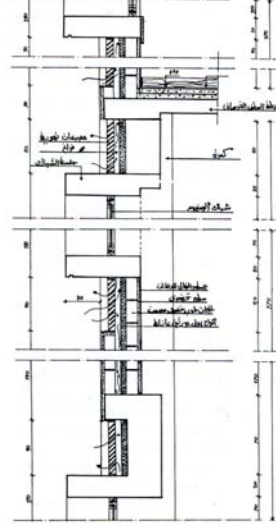


Fig (35): Window Section

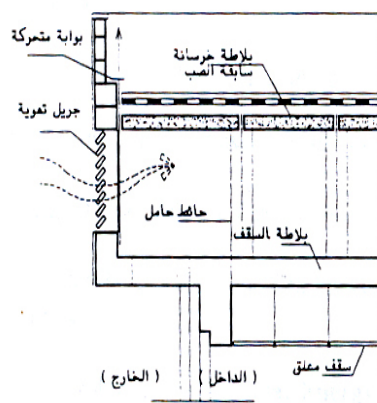


Fig (36): Roof detail

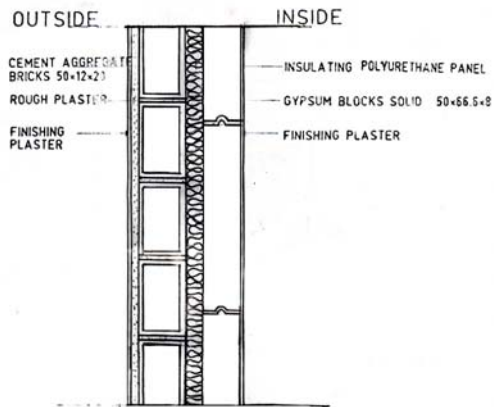


Fig (37): Northern-Southern Wall

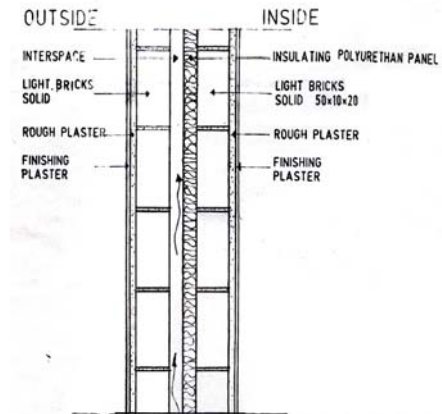
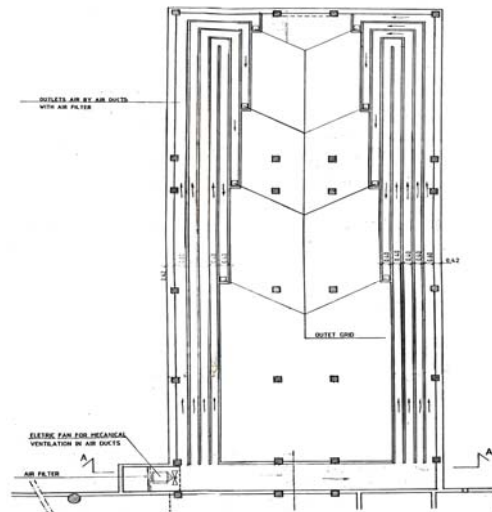


Fig (38): Eastern-Western Wall



Walls

External walls differ in thickness and material according to the orientation and to the thermal load. East and west walls were designed as cavity walls of total thickness 35 cm with an insulation sheet of polyurethane panel of thickness 5 cm in between.

Air movement through the cavity is provided by means of an air inlet in the walls under the windows and outlets above them. All windows have precast concrete sheds protruding 30 cm from all sides.

Corridor windows are covered by an aluminum grid of thickness 6cm to prevent direct sun radiation, fig (37).

Northern and southern double walls consist of cement aggregate external wall and internal solid gypsum blocks with insulation of 5cm polyurethane between them. The total thickness of the wall is 30cm, fig (38).

4. Conclusion:

Climatic responsive design is considered one of the elements of the ongoing sustainable development adopted now in Egypt: The government started to encourage this approach for its positive environmental impact; this comes after the vast increase since 1985 in both research and applications of climatic design, especially in the areas of passive cooling and day lighting. The timing of the consideration of climatic issues in the design process is very important. Most decisions that affect building's energy use occur during the schematic design stage of the project. The designer has to think about cooling, ventilation and day lighting within the context of thinking about architectural elements and their relationships and that helps the designer to fit the forms generated by energy concerns with forms generated by other architectural issues. For the effectiveness of climatic treatments the architect has to ensure that the building envelope should be capable of constant adjustment to accommodate climatic changes through the flexibility of the systems used as shading devices and using high-rate building materials insulation. Building rules and regulations have to be reconsidered taking into account the climatic criteria of different sites along with the use of local building materials coping with the community needs and capabilities.

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