Proceedings of Symposium on Mosque Architecture, Vol. 6B, pp1-14, College of Architecture & Planning, King Saud University (1419H-1999)

The Patrimony of Passive Cooling

Jeffrey Cook

School of Architecture, Arizona State University,
Tempe, Arizona, U.S.A.

Abstract: By examining selected Great Mosques of North and West Africa, this paper explores climate and cultural responses especially related to passive cooling comfort. Integral is accommodation of heat sources, heat sinks, and controls, both in the architectural design, and in building operation, as well as various Islamic customs and practices. Tunsia and Mali, on opposite sides of the Sahara Desert, embrace contrasting earlier cultures. Thus, Ibn Tulun at Cairo, Kairouan in Tunsia, and Timbuktu in Mali are examined. Aspects include:

- Courtyard or prayer court, an open air but walled space, including its porticos, is reviewed as to the effect of sun and wind shadowing, aspect ratio (wall height to court width), orientation and construction materials with their thermal properties.
- Prayer hall or hypostyle room is reviewed as to the effect of proportions, openings, and disposition of construction materials with their thermal properties.
- Natural ventilation, especially connective cooling as a variable thermal control, is examined as a designed strategy. Opening sizes, location, materials, thermal storage, and time management are critical to the cooling of the mosques, especially evident at Timbuktu.
- The use of local vernacular materials such as adobe or rubble determines thermal capacity and time lag. In contrast, the use of fibrous layers in the roof construction, and rush or wool matting on the floor of the prayer hall provide resistive insulation.

This lively tradition continues to inform and inspire, as represented by the rebuilding of mosques in Mali into the 20th century. These architectural typologies are reinforced by religious ritual. Beyond passive comfort concepts of bio-climatic design are commitments about the natural environment and the concepts of wholeness of the earth, vital for a sustainable future.

Introduction

Ibn Khaldun, in his Muqaddima, describes the architecture he knew in this way: 'The craft of architecture is the first and oldest craft of sedentary civilization. It is the knowledge of how to go about using houses and mansions for cover and shelter. This is because man has the natural disposition to reflect upon the outcome of things. Thus, it is unavoidable that he must reflect upon how to avert the harm arising from heat and cold by using houses which have walls and roofs to intervene between him and those things on all sides. [1. p. 201]

The mosque as a global architectural typology had its origins in the arid lands of the mid-East and south of the Mediterranean Sea, in lands rich with legacies of earlier cultures. In satisfying new functional needs, the early mosque synthesized the bio-climatic traditions of these desert lands into a profound system of architectural response to climate, resources, and culture. Today the mosques of desert countries continue these traditions as one of the strongest patrimonies of the human art of building, especially as an ideal model of environmental respect and synergy.

This technical exploration of the bio-climatic aspects of mosques is initiated in contradiction to the Islamic concept of unity. In Islamic religious architecture 'umma' expresses belief in the inseparable unity of all aspects. So to isolate a particular concern ignores the Islamic belief in oneness. Thus, the bio-climatic or human climatic comfort considerations examined here must be recognized as only a subset of a comprehensive architectural manifestation.

The premise of this exploratory paper is that the design of the early Mosque, especially in North Africa, is a synthesis based in part on the bio-climatic traditions of that desert region as they had evolved over millennia. In particular, the remains of Greco-Roman architecture, which had provided a unity of cultural expression from North Africa through to the mid-East, was the repository of well understood bio-climatic responses. It also provided columns and other salvageable architectural stones for recycling in new design configurations. But the new functional needs of the Five Pillars of Islamic Law, especially prayer, salat, stimulated a new synthesis. Thus, religious practice and its new symbolic accommodation included those traditional sensibilities that we today associate with passive cooling and heating. The early mosque synthesized old bio-climatic traditions of these desert lands into a new system of action. In addition, this idea model of environmental respect was in harmony with nature and capitalized on local resources. The use of indigenous materials, sometimes recycled, thus demonstrated today's rediscovered standards of local resource management associated with self-provisioning, self-respect, and sustainability.

A test of this premise is the continuity of North African mosque design traditions south of the Sahara, where there were no Greco-Roman roots, but similar bio-climatic needs. Thus, mosque designs in Mali satisfy similar functional and bio-climatic needs, but expressed in West African construction techniques of sun-dried mud and an indigenous architectural vocabulary.

Method of Investigation

This paper is based on the analytic application of passive cooling and heating concepts to selected mosques by someone who is resident in a similar extreme desert climate to North Africa and Sub Sahara Africa. The building type is the congregational or community assembly mosque whose primary function is the Friday mid-day service--the 'masjid-i Jami', in contrast to daily or neighborhood 'masjid', or "place of prostration". The analysis is on the basis of noon, since the other four times of daily prayer would involve different solar and climatic conditions. The mosques were selected for their historic importance and Islamic influence. Although most of the examples have been visited, they have not been experimentally instrumented. Thus, this paper outlines a premise of bio-climatic performance that should be subjected to field measurement and data reduction to confirm the concepts proposed and discussed.

The Mosque:The First Mosque

The mosque of the Prophet at Al-Madinah is the primary prototype of the mosques in the Islamic world.[2. p. 20, 21] What started as Mohammed's mosque evolved quickly in the rapid development of the new faith. Unfortunately, a reconstructed plan (Fig. 1) must be based only on written evidence, "...it consisted of a square of sun-dried bricks approximately fifty meters to the side. On the east of the sourthern part of the eastern wall were rooms (nine of them by 632, when Mohammed died) for the Prophet's wives. On the southern and northern sides short colonnades (suffa) of palm trunks supporting palm branches were erected after complaints about the heat of the sun in the court. On each of the other sides was a door; the southern wall had become the qibla." Thus both climatic response and local building materials were inherent in the first mosque. The three rows of columns and shade roof on the south side reinforce and extend the shading of the wall and imply a prayer hall with columns on the southern edge of the compound.

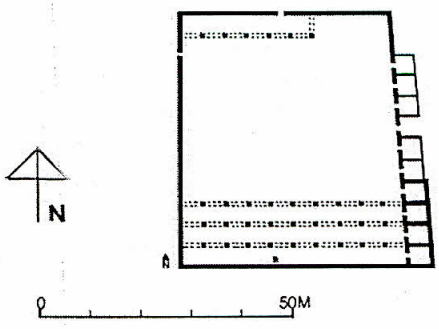


Fig. 1: The First Mosque: House of the Prophet at Al-Madinah. 624, Reconstructed plan. [2. P.2]

The Mosque: An Early Model

Thus, the spatial concept of a walled courtyard open to the sky but with the possibility of a colonnaded porch or portico around the perimeter, and a prayer hall with columns like a hypostyle hall comprise the two distinct architectural spaces of the early mosque. This typology was confirmed in the first religious buildings of Islam, all in newly founded Muslim towns: Basra 635, rebuilt in 665; Kufa 637, rebuilt in 670 (Fig. 2); and Wasit, 702.

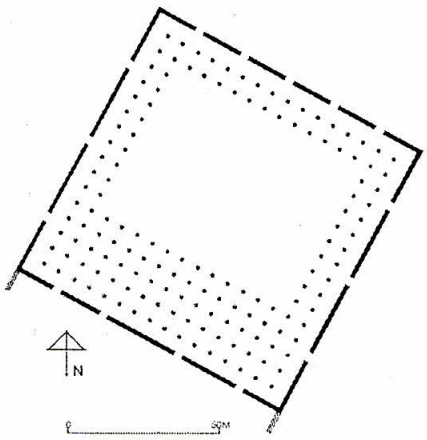


Fig. 2: Prototype Early Mosque at Kufa, 637, rebuilt 670. Reconstructed plan.[2. p. 35]

"They were simple, consisting of a large, generally square, area with a deep portico signifying the qibla side and serving as a covered hall of prayer; eventually shallower porticoes were added to the other three sides of the enclosure, resulting in a central courtyard surrounded by porticoes. At first, the covered parts were set on supports taken from older buildings; later they rested on specially built columns or piers. The method of roofing is uncertain; there may at times have been vaults."[2. p. 35, 36] The qibla wall is oriented about 28 west of south.

At Kufa, a garrison town, the mosque was an almost perfect square, 96 meters on the side. The porch or portico on three sides was 13 meters wide and the prayer hall was 30 meters wide and the full 96 meters long. Obviously preplanned symmetry and regularity were expressive of Islamic harmony and unity.

Ibn Tulun at Fustat, Cairo

Some authorities such as Briggs[3. p. 49] consider the great congregational mosque completed by Ahmed Ibn Tulun in 879 in his new royal suburb of Fustat at Cairo as "perhaps the most important building in the whole history of Arab art" (Fig. 3). The harmonious perfection of its geometry is evident in the clarity of its parts. It was modeled on the Great Mosque at Samarra of 847/861, the largest known in the Islamic world at 376 x 444 meters. A new feature at Fustat seldom copied was the "ziyada", or open linear court, that surrounds the mosque with a 20 meter wide corridor cushion of space. It protects from the outer world and provides a resort for students and beggars. Thus, the plan consists of a square courtyard of 92 meters, and a rectangular courtyard and prayer hall, 122 by 140 meters, nested in a large footprint, a 162 meter square of over 26 hectares. The orientation of the qibla was about 41˚ east of south.

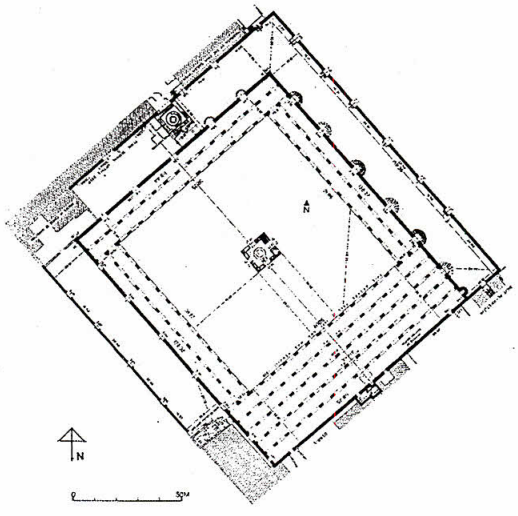


Fig. 3: The Symmetrical Mosque of Ibn Tulun at Fustat, Cairo, 879.[2. p. 91]

Within the perfection of the plan it is surprising to find subtle variations of dimensions that potentially enliven a monumental and somewhat monotonous scheme. Thus, the width of the north porch is from 13.00 to 12.94 meters, the west porch varies from 12.20 to 12.40 meters, and the south porch from 13.14 to 13.35 meters.

The Great Mosque of Kairouan

The Great Mosque at Kairouan, meaning caravan camp, was built in the Tunisian desert against fantastic odds [2. p. 94-101& 4] (Fig. 4). In a region so devoid of all resources, on a site where water, stone, and wood were all lacking, and far from the great trade routes, building a city and its great mosque was a challenge. In A.D. 670, Uqba Ibn Nafi had camped there and decided to found "...a city to serve as a fortress for Islam until the end of time." Legend holds that Uqba ordered the serpents and wild animals to depart from Kairouan, and when they had left, he prayed: "O my God, fill this town with learning and with the knowledge of thy law." It is the oldest place of prayer in the western Moslem world.

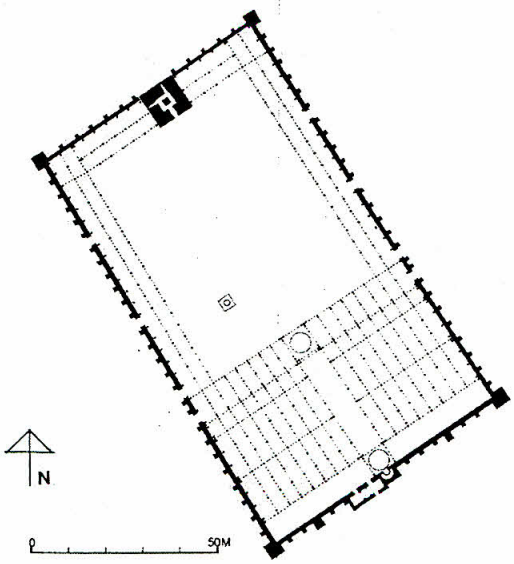


Fig. 4: The Great Mosque at Kairoun, Tunisia (836, 862, 875). [2. p. 96]

Generations came and went, each to add to or rebuild the Great Mosque of Sidi Uqba. In the eighth century alone, the mosque was demolished and rebuilt three times. A major reconstruction in 836 was followed by substantial additions in 862-868 and 875. Columns were brought from a Christian church. More ground was bought. A minaret was added. Steadily, the mosque also grew in splendor.

When peace came to North Africa and the last tribes were subdued, Kairouan became a major cultural center of the Arab world. And between 817 and 902 the Great Mosque took its final shape under three rulers: Ziyadat Allah, Abu Ibrahim Ahmed, Ibrahim Ibn Ahmed. The most recent restoration was in 1972-1980.

Because it had been rebuilt so definitively during the early consolidation of Islam, Kairouan became archtypical. Sebag[4] documents how the Great Mosque became one of the richest museums in the world--incorporating into its very structure the glory that was Carthage...Byzantium, and Rome--columns, capitals, and stones were brought from all over the Mediterranean. The Mosque also represents the particular generosity of Islam. For any art form, any architectural style, that could be reconciled with Moslem belief was welcomed--and here in the great Mosque, the finest religious arts of pagan temple and of Christian church were combined and harmonized into the service of Allah with resplendent success. Yet its fundamental architectural configuration continues and confirms the earlier mosque typology. Begun before the mosque of Ibn Tulun was built at Cairo 876-879, its final form continued and reinforced that plan. As the first mosque in the first town in Ifrigiya, Kairouan became seminal in Africa.

The building plan is 135 by 80 meters on its largest sides, a slightly distorted rectangle of stone with an assortment of buttresses on the outside. The paired columns and capitals of the prayer hall and the courtyard porches are notable for their variety as a collection of recycled parts from diverse antique classical temples. The qibla is not oriented exactly toward Mecca but at 33˚ east of south is too southerly by about 31 degrees. The large trapezoidal courtyard, roughly 52 x 67 m, is unusual in not being a square and not located broadside to the qibla wall. The surrounding porticos dating from the

9th to 13th century have often been repaired and rebuilt. The double arched narthex-like portico to the prayer hall probably dates from 862-868.

The marble paving with underground cisterns probably dates from the Hafsid dynasty, 1230-1574, although it was covered by pottery tiles until the end of the 19th century. The collection and storage of precious rainwater extends the spiritual and practical role of the jami in the community, while adding to its passive cooling potential.

Seventeen portals with richly worked cedar doors, dating from 1828-29, open to the 17 aisles of the prayer hall that run 8 bays, 8 m high, to a broad transverse aisle along the qibla wall, which is 9.6 m high to the underside of the arches. The dome beside the minrab rises inside to 18 m. There are some 420 Roman and Byzantine columns and capitals of many dimensions, recycled from Sousse and Carthage. Paired columns line the higher and wider vaulted central aisle, which is vaulted and terminated on each end by a dome. Sometimes columns are tripled. The floor of the prayer hall is covered with rush matting. Mats also sheath the first meter of the columns.

The Great Mosque at Timbuktu

Islam was adopted in West Africa, south of the Sahara, much later than North Africa. Among the earliest mosque foundations, the Great Mosque at Timbuktu in Mali (Fig. 5) today is among the most impressive large mud buildings anywhere: constructed of round dried mud bricks and stone rubble with clay rendering, the minaret rises to 16 metros.[5] However, the vaulted limestone arches in the most "ancient remains" are unique in West Africa and may be an attempt to simulate North African construction in a regional culture based on adobe. Although Makkah, at 21.5˚ N latitude is to the north of Timbuktu (at 17˚ N), the qibla wall faces about 11˚ south of east.

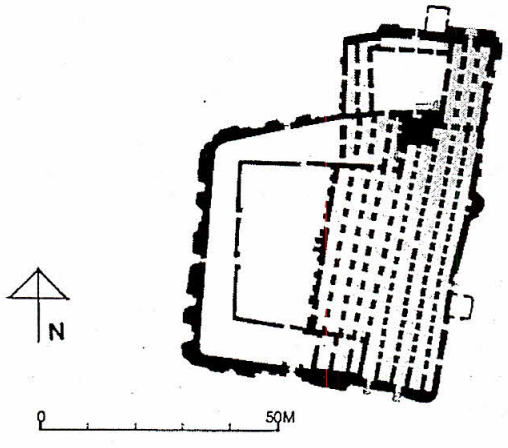


Fig. 5: The Great Mosque at Timbuktu, Mali, 1325, 1569-71, 1828-1853. [5. p. 152]

Founded in 1325 the Great Mosque, Djinguer, Ber, was extensively rebuilt in 1569-71. Further major renovations over the next two hundred years were climaxed by substantial alterations between 1828 and 1853. Thus, its design has evolved until relatively recently. Since it is located on low ground many of these reconstruction's were necessitated by occasional floods. Especially the western boundary was repeatedly washed away and rebuilt.

The Mosques in West Africa are distinct architecturally for the way in which the prayer hall is more completely enclosed: more modest sized doorways provide access. Here the courtyard, sahn, is very small and overshadowed by the pyramidal minaret and the wrap-around bays of the prayer hall. Because the suffa or sufuf, aisles or covered galleries, supported by columns next to the courtyard, are more enclosed than open, it may not be correct to consider them as porticos, either thermally or ritually. The interior prayer hall is distinguished by the density of columns and pilasters, a forest of adobe supports that warrants the association with the ancient hypostyle hall typology. More recently mosques such as those at Djenn,, Mopti and San continue these regional traditions in their remodeling and rebuilding on ancient sites, especially in their expressive style using adobe.

Early Trends of Selected Mosques

By reviewing the architectural configuration of five selected mosques the general patterns of influential designs can be compared. Although the number is statistically insignificant, the choices of early, highly admired, and prototypical designs allow trends and characteristics to be identified and compared. (Table 1) From the beginning the prayer hall was a space filled with columns in which there was no incentive to develop more open spaces by using longer spans. Indeed, the root of potential passive cooling is in the radiator effect of the many exposed surfaces of columns and vertical supports that provide large thermal mass.

Not surprising, the size of mosques grew with the rapid expansion of Islam. In addition, the spread of Islam was, at first, to locations that were about 10 further north from Makkah and Al-Madinah. Expanding into the Middle East and North Africa, where sun angles were 10 lower, all still shared climates similar to Makkah and Al-Madinah. It is uncertain and unlikely that the lower sun angles prompted larger mosques in which the open courtyard was also correspondingly larger as a solar aperture. Only later, in the 13th century, did Islam spread to south of the Sahara, to desert locations at latitudes below Makkah and Al-Madinah and corresponding higher sun angles. But in these lower latitudes the courtyards are definitely smaller with a much tighter aspect angle to the sky.

It has been noted that in the growth of individual Friday mosques to meet the expanding needs of a growing community, often parts of the courtyard and porticos were converted to prayer halls. But that adjustment has not happened to these examples. In all these early mosques the prayer hall consistently represents between 25% and 30% of the floor area of the mosque. (Table 2) Open courtyards cover 40% to 50% of the area, and covered porticos adjacent to the courtyards cover 25% to 30% of the area. The exception is south of the Sahara at higher sun angles and more extreme desert conditions where courtyards and porticos become much smaller and more self-shaded. The porticos in Mali become an extension of the prayer hall rather than a shaded part of the courtyard. Windows and doors become much smaller. The emergence of a different typology, one with an extensive open terrace with a low wall, provides a different definition of entry. Thus, it could be argued that traditions of passive cooling are expressed equally strongly, but with a different architecture, transformed in both its whole and all its parts.

Table 1: Dimensions of Selected Mosques
Average dimensions in meters as reported by Ettinghausen and Grabar [2]

Place and Latitude	Footprint Dimensions	Dimensions of Open Courtyard	Dimensions of Porticos	Dimensions of Prayer Hall
AL-MADINAH Lat. 24.5°N.	45.5 x 50	45 x 35	27 x 5	12.5 x 45
KUFA Lat. 32.0°N	100 x 96	72 x 54	13 x 54 13 x 54 13 x 100	30 x 100
CAIRO Lat. 30.0°N	120 x 140 (162 x 162)	90 x 90	15 x 90 15 x 90 15 x 120	35 x 120
KAIROUAN Lat. 36.5°N	135 x 80	52 x 67	9 x 70 8 x 67 8 x 67 9 x 70	36 x 70
TIMBUKTU Lat. 17°N	72 x 28	11 x 14	15 x 17 6 x 15 5 x 14	52 x 28

Table 2: Areas and Proportions of Selected Mosques.[1]

Place and Date	Total	Open Courtyard	%	Porticos	%	Prayer Hall	%
AL-MADINAH **624**	2,275	1,575	**69%**	135	**6%**	563	**25%**
KUFA **637**	9,600	3,888	**41%**	702 702 1,300 2,704	**28%**	3,000	**31%**
CAIRO **879**	16,800 (26,244)	8,100	**48%**	1,350 1,350 1,800 4,500	**27%**	4,200	**25%**
KAIROUAN (836, 862, 875) **902**	10,800	3,484	**42%**	630 536 536 630 2,332	**28%**	2,520	**30%**
TIMBUKTU (1325 1569-71) **1828-1853**	2,016	154	**8%**	255 90 70 415	**20%**	1,456	**72%**

[1] Areas in square meters and proportions of principle spaces. Note that due to architectural irregularities, as well as the thicknesses of walls, not all areas will total 100%.

Bio-climatic Analysis: Urban Context

The Friday mosque, the jami, is the invisible heart of the community, the quiet and even hidden center of the city.[6. p. 68-76] With its solid walls and closed gate it is set aside from the dense encircling marketplace, the Al-Madinah. Whether it is architecturally freestanding such as the Great Mosque of Kairouan (Fig. 6), or is embraced by surrounding buildings with blank shared walls such as the Great Mosque in Tunis, or Ibn Tulun in Cairo, it is bio-climatically isolated from its context. Thermally, and even acoustically, the mosque is deliberately separated by its high walls and tight gates. Thus, any thermal advantage or disadvantage generated by the surrounding urban fabric is of little consequence. In parallel, any bio-climatic benefit generated by the mosque through its architectural form or climate sensitive operation remains within the sacred space.



Fig. 6: Kairoun, Tunisia. The Great Mosque and part of the Al-Madinah showing the orientation of the Mosque and of the domestic courtyards. North is at the top. [6. p. 25]

Bio-climatic Analysis: Orientation

It is a critical definition of the mosque that the qibla wall face Makkah. But as can be seen in this brief survey, this is quality honored in intent rather than precise fact. In contrast, bio-climatic buildings are distinguished by their more exact orientation to the forces of nature; responding to sun angles and to the other climatic characteristics of the site. But the traditional mosque has blank walls and exposes only two surfaces to the heavens--its flat roofed prayer hall together with roofed porticos; and the paved floor of its open courtyard. The flat roofs are insensitive to orientation. However, the courtyard can be the sensitive aperture to the passive cooling and heating opportunities of the location. But the orientation of a courtyard, when it has a square plan and has a horizontal aperture, has no effect on performance. For instance, one notes in the city plans of Islamic cities where courtyard houses are characteristic, that domestic courtyards are always square. They can have any orientation, determined by the orientation of streets and neighborhoods, such as at Kairouan (Fig. 6).

Passive Effects of Courtyard and Portico

At noon prayers, the sun is at its maximum height and maximum penetration into a courtyard. In winter the sun's warmth and lower incident angle makes its natural radiant heat welcome. In summer, the sun's heat is unwelcome. The walls and solid gates of the courtyard minimize natural air movement and thus the sun's radiant heat is unmodified. Always in a desert climate a wall is welcome because it will always cast some shadow except at high summer noon. A portico in a desert climate is most appreciated in summer when it provides shaded protection from direct solar radiation. But by providing a space where surface temperatures are close to the temperature of the air, it provides a thermal environment that contrasts with surfaces exposed to the sun. Thus, local or microclimatic air motion is initiated by the temperature differentials.

In a courtyard surrounded by porticos the surface of the enclosing wall is virtually always in shade. Thus, the wall cannot become warmer than the air. So in summer a person standing in the sun in the center of a courtyard with surrounding portico will be cooler than a person in a similar situation without a portico shading the surrounding walls because of the radiant effect of wall temperatures. In all cases the courtyard with surrounding porticos is preferable because a person can chose whether he performs prayers in the sun or shade.

The mosque courtyard is somewhat different in its comprehensive cooling potential in comparison with a domestic courtyard, primarily because of the aspect ratio--exposure to sun and sky. Generally, the incoming radiant energy of the daytime solar heat is much greater than the outgoing radiant heat losses to the sky at night. In typical desert conditions the cooling rate of sky reradiation at night may be 10% of the heating radiation by the sun during the day.[7. p. 33] In a courtyard house the courtyard typically is small and surrounded by high walls, thus limited solar heat gain. Simultaneously, the courtyard house has surrounding roofs which can generate cool air at night by outgoing radiation. This cool air can flow off the roof and collect in the bottom of the courtyard, displacing the warm air of the day.[8. p. 47-49] But the courtyard house in it aspect ratio has vertical proportions that make it a better summer heat defense and heat dissipater than the more horizontal mosque configuration.

To summarize, the wind shading and the lack of sun shading of the mosque courtyard conspire for discomfort for summer noon prayers, but reinforce each other for comfortable winter noon prayers. The persistence of porticos and loggias around courtyards are a potential asset during summer and the transition seasons, and may represent little liability during winter. In Timbuktu, where winter noon is never cold, the smallness of the courtyard and the self-shading from walls and minaret provide bio-climatic relief that favors summer and ignores winter.

Passive Effects of Prayer Halls

Thermally, prayer halls perform similar to porticos but with more controls. Since the interior is always shaded, it should not overheat unless the roof construction allows indirect solar heating. But human use adds metabolic heat. Thus, the high ceilings and openness of doors allows natural convection to develop. Warm air naturally rises, pulling cooling air underneath. This cooler air from the porticos will flow in through the open doorways--the hotter air will exit above if the doorways are tall enough. Some heat can collect near the ceiling but this has a limited time delay potential because air is a poor conductor and the removal of warm air through convection is much easier and more efficient.

The high ceilings in mosques, as in other public buildings, provide the opportunity for convection within the enclosed space. This, if heat is generated near floor level and the air is cooler up higher in the space, connective loops will develop within the space. Especially in prayer halls such as Timbuktu where windows are minimal or non-existent, there is an architectural feature that is an integral part of the ceiling/roof, an opening sometimes call a "wind-window", although they are often assumed to be

only for daylighting. In English, the earlier meaning of 'window' was 'eye to the wind', referring to ventilation, not lighting. These small roof openings covered during rainstorms, provide a dim natural light but avoid solar gain because of their small size. As they are at the top of a tall space they operate as a continuous exit or drain for the hottest air. It is replaced by cooler air coming in through the small doorways off the courtyard or from the roof through the same wind-windows. Although the openings are very small, they operate continuously, driven by the buoyancy of air.

This thermal behavior is reinforced by the material of the mosques. Typically, walls, piers, and columns are masonry, whether adobe, brick, or stone, that have a high heat capacity that regulates heat flow. Unlike most public interiors, mosque prayer halls are often called hypostyle halls because, although large spaces in all dimensions, they are typically filled with columns. This is more noticeable in the reality of Kairouan since in the plan (Fig. 4) only the center point of columns is shown, not the perimeter. In Timbuktu, Fig. 5, the vertical supports of adobe seem so dense that they half fill the space. Their extensive surfaces are in constant radiative thermal exchange. Thus, if there are apertures for hot air to exit and cool air to enter at any time, especially during the night when outdoor conditions are coolest, then heat can be discharged and coolness can be stored against the solar heat and human metabolic gains of the next day.

In contrast, the deliberate use of fibrous layers as part of the ceiling construction reduces conduction of solar heat gain through the roof. The floor of the prayer hall, covered with a matting of rush or wool carpets, provides another thermally neutral architectural surface. Especially the floor is well insulated to minimize conductive or radiative heat transfer.

An indication of sensitivity to the mechanics of passive cooling is the daily operation of the mosque. The entry gates to the mosque are never wide open. Typically, they are snug fitting doors of which only one might be in use. Even during times of heavy traffic it might be left ajar, but not wide open, thus not disturbing the microclimate inside. In contrast, the doors between the courtyard and the prayer hall are typically standing wide open during prayers, the period of rapid metabolic heat gain and thermal transfer. There are symbolic, as well as practical reasons to manage doors in this way, but simultaneously this program of ritual also best serves thermal management.

Passive Cooling by Cultural Practice

Within Islamic life there are many cultural practices, both sacred and domestic, that reinforce a human life accustomed to a desert climate. These are practices which in the 20th century may be analyzed scientifically. But they often originated in a preliterate and prescientific desert society, based on the repetitive observation and experience of what is bio-climatically most reinforcing.

For instance, the habit of typical Islamic desert clothing is ideal for arid overheated conditions. Loose clothing of natural fibers such as cotton that cover arms, legs, neck, and the top of the head provide radiative protection while allowing the ventilation of the skin through body movements. The cooling effect, and the heat avoidance of these arrangements, are reinforced by the religious ritual in the sequences of prayer, especially rites that include circumambulation and prostration.

Similarly, the ritual acts of cleansing and absolution support health and well-being in a desert climate. Face, hands, and feet are the locations of extensive sensitive nerve endings and are also by far the most exposed parts of the human body, and thus subject to soiling and contamination. This contamination reduces both their sensitivity and their special function as the location for the extra thermal transfer of metabolic heat. The ritual of shoe and footwear removal has the function of exposing the sensitive skin area of the feet.

Beyond the initiative and symbolic use of water are the physical facts: Water is the ultimate cleanser, ideal for conducted heat transfer, and efficient for evaporative heat loss. These are inseparable experiences in the act of absolution. Among secondary effects are the psychological effects in the

presence of fountains, taps, and pools; as well as the secondary physiological cooling effects from the evaporation of wetted architectural surfaces as well as from water surfaces. And although the wet zones of the mosque may be architecturally defined, they are not thermally isolated.

All of these thermal transfer events have immediate interactions with human participants. They also have measurable secondary cooling and refreshing results as heat sinks or cool sources. Within the architectural enclosures of the mosque, warm air will rise and cool air will sink. The generation of cool air is necessary to develop a cool microclimate. Because of the architectural enclosure of the mosque, the air that is conditioned by these natural thermal processes is not disturbed or mixed by breezes or wind from outside.

Future Research

The technical explorations of this paper come from a scant knowledge of selected mosques and an imprecise definition of their daily and seasonal use patterns. Thus, field studies that would document both the physical aspects of the buildings and the social or ritual use of those facilities could reveal the degree to which passive cooling opportunities are present, and the extent of their appreciation.

Even before field studies, a more thorough exploration of existing documentation could substantially improve the data base and add to the viability of these propositions. Thus, although this author is unaware of specialists in passive cooling who have examined early desert mosques, there have been many researchers who have examined the fabric of these buildings from a more architectural or constructive point of view. However, where detailed drawings exist that document all the interior surfaces of a prayer hall, it would be easy to take off the quantities and test by calculation the potential thermal capabilities based on various possible construction materials.

Concluding Remarks

Based on a review of selected influential early mosques in desert climates, there is strong evidence of knowledge and practice of passive cooling. This patrimony, which is often discussed in relation to the courtyard house so favored by Islam,[8] has had little attention in relation to the mosque, the prime architectural repository of the faith. Especially a review of mosques south of the Sahara confirms this aspect of mosque design. The emergence of a distinctive mosque style in Islamic world[9-12] and especially in Mali and its confirmation in the recent extensions and rebuilding in the 20th century at places such as San, Djenne, and Mopti reveals a living and continuing tradition that extends this patrimony in an indigenous style.

Potentially, the values represented in all these mosques reinforce the faith, in terms of traditional or fundamental beliefs. However, in a world of exploding populations, environmental degradation, and resource depletion, these values also have great potential toward a healthy and sustainable future at one with the earth.

"A race of fanatics, nomads scarcely able to build walls, coming to a land covered with ruins left by their predecessors picked up here and there whatever seemed most beautiful to them, and in their turn, with these debris all of one style and one order, raised, under the guidance of heaven, a dwelling for their God, made of pieces torn from crumbling towns, but as perfect as the purest conceptions of the greatest workers in stone." Guy de Maupassant, La Vie Errante, 1890.

References

[1] Michell, George, ed. *Architecture of the Islamic World.* New York: William Morrow and Company, Inc. 1978.

[2] Ettinghausen, Richard and Grabar, Oleg. *The Art and Architecture of Islam 650-1250.* New Haven and London: Yale University Press, 1987-1994.

[3] Briggs, Martin S. Mohammedan. *Architecture in Egypt and Palestine.* New York: Da Cato Press. 1974-1924.

[4] Sebag, Paul. *The Great Mosque of Kairouan.* London: Collier-Macmillan; New York: The Macmillan Company, 1965.

[5] Prussin, Labelle. Hatumere: *Islamic Design in West Africa.* Berkeley: Los Angeles, London, University of California Press, 1986.

[6] Santelli, Serge. *Medinas - Traditional Architecture of Tunisia.* Tunis: Dar Ashraf Editions. 1992.

[7] Cook, Jeffrey. *Passive Cooling.* Cambridge, Massachusetts: MIT Press, 1989.

[8] Ellouze, Jamel. *Climatic Performances of Courtyard Houses in Tunis.* Los Angeles, California: UCLA. Unpublished Master of Architecture thesis, 1985.

[9] Al-Bayaati, Basil. *The City and The Mosque.* Oxford: UK. aarp. 1984.

[10] Dunham, Daniel. "The Courtyard House as a Temperature Regulator." *New Scientist,* [4] Sept. 1980. pp. 663-665.

[11] Hill, Derek, and Golvin, Lucien. *Islamic Architecture in North Africa.* Hamden, CT., Archon Books. 1976.

[12] Hutt, Antony. *Islamic Architecture*: *North Africa.* London: Scorpion Publications, Ltd. 1977.

أثر التبريد الكامن على تبريد المساجد

جيفري كوك

كلية العمارة، جامعة ولاية أريزونا

تمبي، أريزونا , الولايات المتحدة الأمريكية

ملخص البحث: تقدم الورقة دراسة مبدئية للاستجابة المناخية والثقافية المتعلقة بالراحة الناتجة عن التبريد الكامن لبعض المساجد العظيمة المختارة من شمال وغرب إفريقيا ، وذلك باختيار تكامل مصادر الحرارة والمخزون الحراري بالتحكم فيهما بواسطة التصميم المعماري وتشغيل المبنى المنبثق من العادات والممارسات الدينية الإسلامية لتلك البلدان.

وقد اخترنا بجانب جامع ابن طولون في القاهرة ، جامع القيروان في تونس وتمبكتو في مالي . وشملت الدراسة الأوجه التالية:

١ - دراسة تأثير الشمس والرياح على الأفنية والقاعات المعمدة بخاصة نسبة ارتفاع الحوائط إلى عرض الفناء بجانب توجيه المبنى والخواص الحرارية لمواد البناء.

٢ _ دراسة تأثير نسب الفتحات وفعالية الخواص الحرارية لمواد الإنشاء على فراغ قاعة الصلاة.

٣ - التهوية الطبيعية والتبريد بواسطة تيارات الحمل كمتغيرات للتحكم الحراري كاستراتيجية تصميمية، ويعني ذلك أحجام الفتحات العازلة وأحجامها وموضعها والمواد المستخدمة والسعة الحرارية التي تؤثر على تبريد المسجد ، وأصدق دليل على ذلك تمبكتو.

٤ - استخدام المواد المحلية مثل الطين أو الحجارة يحدد السعة الحرارية والتباطؤ الزمني ، وعكس ذلك فإن استخدام الألياف العازلة في طبقات السطح والحصير والسجاد الصوفي على أرضية المصلى يزيد من العزل الحراري.

وقد استمر استخدام هذه الأشكال التقليدية في البناء حتى القرن العشرين في بناء المساجد في مالي. وبعد، فإن وراء مفهوم الراحة الناتجة من التبريد الكامن والتصميم المناخي الحيوي هو الالتزام لمفهوم البيئة الطبيعية الشامل لكوكب الأرض والمحافظة على مستقبلها.