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Project Report

Use of Solar Passive Concepts in the Avadh Architectural Buildings and their Modified Impact*

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The sun and its energy supply has been a fundamental influence since the origin of the human species. The rise of the first cities between 5000 to 6000 years ago reflected the culmination of a gradual process of proto-urbanization which had been taking place for many thousands of years prior to the formation of urban concentrations. The sun, wind and water were the guiding principles for urban planning. The early settlements in Syria, Egypt, Iran, China, Greece and South and North America were the examples of the period ranging from 3500 BC to 900 AD. The architecture for the agricultural age developed in terms of simulation and comforts. In early modern architecture in India, the building technologies of the Mughals drew considerable attraction. The dream of Mughal architects was to create the ultimate diaphanous wall and powerful rulers spared no expense in creating their palaces. The multi-functional membrane/screen carved out of white marble allowed the greatest comfort in inside/outside spaces.

There was a sudden stalemate in the field of architecture after Shahjahan's death. But, the Nawabs of Avadh kept it alive. In Avadh Rulers era, the field of architecture saw re-interpretation of the existing styles and experimentation in the fusion of the occidental and the oriental style of architecture. The Avadh Rulers beginning from Muhammad Amin Saadat Khan to Wajid Ali Shah built many fascinating structures in the magnificent cities of Faizabad and Lucknow in the period 1720 to 1856. In the beginning, the buildings constructed by them were confined to Faizabad alone, but later on the main centre of architectural activity shifted to Lucknow. These buildings included Gulab Bari, Moti Mahal and Tomb of Bahu Begum in Faizabad and Bara Imambara, Chhota Imambara, Shahnajaf Imambara, Sikander Bagh, Saadat Ali's Tomb, Lakshman Tila, Rumi Darwaza, Jama Masjid, Mausoleum in Kaiserbagh, Dilkusha Gardens and Moti Mahal in Lucknow.

The style of these buildings may be decadent and hybrid but it has its own special characteristics such as fish motif at the gates, domes with golden umbrellas, vaulted halls, arcaded pavilions, underground chambers and labyrinths.

After the Avadh Rulers, came the British era. There was little left in the treasury of the Nawabs of Lucknow to be invested in architectural projects and their days of glory were fast coming to a sad end, precipitated by the British presence. The group of buildings became the stage for the

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most dramatic events of the 1857 Mutiny or Uprising and the siege of Lucknow.

The British Rulers built or modified many buildings at Lucknow, which included the Residency, La Martinere College (built by French adventurer General Claude Martin, it presents a curious mélange of Indian and European architectural features), Clock Tower, Chattar Manzil (at present housing the Central Drug Research Institute), Canning College (which is at present the University of Lucknow), Medical College (which is at present the Chhatrapati Shivaji Maharaj Medical University), the Charbagh Railway Station, the Council House and Banarsi Bagh. General Claude Martin built his own residence now known as Kothi Farhat Baksh. This small but beautiful building is a unique example of Indo-European architecture. The Kothi Hayat Baksh was also built in this era which became the residence of the Governor and came to be known as Governor House.

Some of the concepts used in the planning and construction of the above buildings may be the passive solar cooling or heating techniques being used on modern day architectural buildings for the purpose of energy conservation and use of renewable energy. They may also be bioclimatic concepts for climatic region of Lucknow and Faizabad. However, the British Architectural buildings have some modified or advanced features than those used in Avadh Architectural buildings.

The project is aimed to study the solar passive heating and cooling concepts used in Avadh architectural buildings and also the bioclimatic concepts. The project also aims to analyze the modifications in these concepts in European and British architectural buildings. The project was undertaken by detailed studies of Avadh, European and British era buildings in Faizabad and Lucknow. The Project was carried out under the following chapters:

1. Introduction
2. Climatic Condition
3. Comfort and Solar Passive Techniques
4. Avadh Buildings
5. European Buildings
6. British Buildings
7. Conclusion

1. Introduction

In early years in India there was no electricity but people created shelters in such a way that they fulfilled their need of comfort in the habitat. But today's buildings are energy dazzling. They consume more and more energy to fulfill the need of comfort and also increase emission of greenhouse gases, caused by fossil fuels to power the heating and cooling requirements of the buildings. The design and modeling of low-energy buildings is a challenging and complex problem of increasing importance. Informing the uncertainty of architects during early design stages for decision making is very important. But old architects had the solution of these problems. They had used lots of passive techniques to restrict heat flow to-and-from a building. But today's architects have forgotten all these techniques, so there is a need to study these techniques for modern buildings. The energy crisis, along with concern of emission of greenhouse gases has again brought these techniques in the limelight. Economic benefits of the use of these techniques are also being seen, especially in Third World countries facing energy crisis. Passive solar heating is a well-established concept used in buildings in regions with colder climates. Concepts of passive solar heating are used while developing passive cooling techniques. Passive cooling can be defined as the removal/ restriction of heat from/to the environment of building by utilizing the natural processes of rejecting heat to the ambient atmosphere by convection, evaporation and radiation or to the adjacent earth by conduction and convection. Buildings can be designed and oriented in such a way that windows, doors, indoor spaces, etc. are located and oriented to take maximum advantage of the local climate. The role of landscaping around the building, e.g. trees, vegetation and water ponds have also been used to maximum effect.

In region falling around the tropic-of-cancer, the summer is very hot and indoor air temperatures in single story buildings are well above comfort zone. As an example, in developing countries, in villages where people have started to build houses with reinforced-cement-concrete (RCC) roofs, instead of traditional designs involving high sloping roofs with earthen Mangalore tiles (baked clay roof tiles). These new buildings now need cooling and with power crisis and high energy cost the only option remaining is the adoption of passive cooling techniques. The state-of-art of solar passive cooling techniques has been given by many researchers. Some of the known techniques for passive cooling, viz. Sky-therm, insulated roof and wall, roof pond, earth–air tunnel and ventilation. The discussion regarding such techniques has been widely addressed in a number of experimental and numerical studies. The project reviews various passive-cooling and heating techniques used in our Avadh architectural buildings and how they have been modified in European and British buildings in the composite climate of Lucknow and Faizabad.

2. Climate

Climate (from Greek Klima) is defined as certain conditions of temperature, dryness, wind, light, etc. of a region. Different regions of the world have diverse characteristic climates. A place or region’s climate is determined by both natural and manmade factors. The natural elements include the atmosphere, geosphere, hydrosphere and biosphere; while the human factors can include land use and consumption of other natural resources. Changes in any of these factors can cause local, regional, or even global changes in the climate.

The relationship between people, climate and buildings is non-linear and complexly interdependent. Climate also affects the use of land, the type of crop that can be grown or the animal husbandry that can be practiced. These variations in the use of land can cause regional climatic changes- such as the spread of desert conditions due to deforestation. Microclimate variations can be caused by presence of trees, grass and water. Built up areas and cities would tend to have their own microclimate which would differ significantly from the climate of the region. Ground reflecting surfaces and artificial topographical features can affect wind flow, solar radiation and hence temperature patterns. It is now established that the consumption of energy in cities for buildings and transport etc. can make very significant changes to temperature.

The most important strategy for low-energy design of buildings is to design and build according to the climate where the building is located. Geographically, the climatic conditions are diverse and hence the designer is required to describe and interpret climate in ways that are relevant to building design.

2.1 Climatic zones in India

India possesses a large variety of climates ranging from extremely hot desert regions to high altitude locations with severely cold conditions similar to northern Europe. Within India it is possible to define six regions with distinct climates. The six climates are normally designated as Hot and Dry, Warm and Humid, Moderate, Cold and Sunny, Cold and Cloudy and Composite. The criteria of allocating any location in India to one of the first five climate zones are that the defined conditions prevail for more than six months. In cases where none of these categories can be identified for six months or longer, the climatic zone is called Composite. On this basis, Bansal and Minke, 1988, originally produced the Climatic Zones in India Map by evaluation of the mean monthly data from 233 weather stations and then delineating the six climatic zones:

1. Hot and Dry
2. Cold and Sunny
3. Warm and Humid
4. Cold and Cloudy
5. Composite
6. Moderate

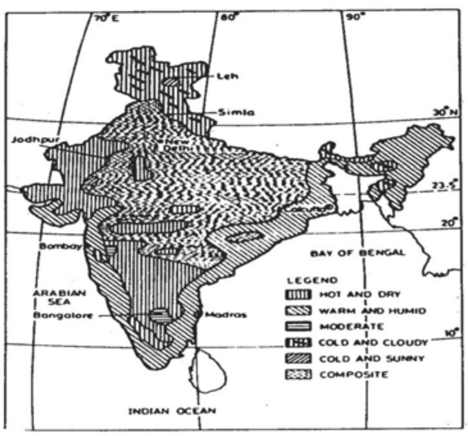

Fig.1. Climatic Zones of India

3. Comfort and Solar Passive Techniques

3.1 Thermal Comfort

Human thermal comfort is defined by ASHRAE as the state of mind that expresses satisfaction with the surrounding environment (ASHRAE Standard 55). Maintaining thermal comfort for occupants of buildings or other enclosures is one of the important goals of Heating Ventilation and Air-Conditioning Design Engineers.

Thermal comfort is affected by heat conduction, convection, radiation, and evaporative heat loss. Thermal comfort is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. Any heat gain or loss beyond this generates a sensation of discomfort. It has been long recognized that the sensation of feeling hot or cold is not just dependent on air temperature alone.

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

A condition of equilibrium is that the heat input and the heat output is zero such equilibrium is a precondition of thermal comfort. However, comfort is defined as ‘the condition of mind that expresses satisfaction with the thermal environment, it requires subjective evaluation (ASHRAE, 1997). This clearly embraces factors beyond the physical/physiological conditions. Thermal Comfort can only be maintained when heat produced by metabolism equal to the heat lost from body.

3.2 Factors of Comfort

The variables that affect heat dissipation from the body (and thus also thermal comfort) can be grouped into three sets:

Environmental	Personal factors	Contributing
Air temperature	Metabolic rate (activity)	Food and drink
Air movement	Clothing	Body shape
Humidity	State of health	Subcutaneous fat
Radiation	Acclimatization	Age and gender

3.3 Psychometric Chart and Comfort Zones

When the designer wants to assess the effect of climatic conditions on the body's heat dissipation processes, he is faced with the difficulty of having to handle four independent variables simultaneously. During the past 50 years many attempts have been made and many experiments have been carried out in order to devise a single scale which combines the effects of these four factors. Such scales are collectively referred to as "Thermal Indices" or 'Comfort Scales'.

In most of these experiments special rooms were built and used, in which any set of indoor climatic conditions could be produced well. A number of experimental subjects were located in the room, and they were asked to record their subjective reactions on a questionnaire after each variation in the conditions, according to a set scale extending from 'very hot' to 'very cold'. The many answers were then evaluated statistically and the results plotted on a graph, in most cases producing a nomogram which defines the experimentally found relationships. Various researchers have devised some thirty different thermal index scales.The first such scale was produced by Houghton and Yaglou in 1923, working at the American Society of Heating and Ventilating Engineers. Their findings were plotted on a psychrometric chart.

3.4 Bioclimatic Charts

Bioclimatic charts facilitate the analysis of the climate characteristics of a given location from the viewpoint of human comfort, as they present, on a psychometric chart, the concurrent combination of temperature and humidity at any given time. They can also specify building design guidelines to maximize indoor comfort conditions when the building's interior is not mechanically conditioned. All such charts are structured around, and refer to, the comfort zone. The range of acceptable comfort conditions is generally referred to as the comfort zone.

3.5 Olgyay's Bioclimatic Chart with Design Strategies

Olgyay's bioclimatic chart, figure below, was one of the first attempts at an environmentally conscious building design. It was developed in the 1950s to incorporate the outdoor climate into building design. The chart indicates the zones of human comfort in relation to ambient temperature and humidity, mean radiant temperature, wind speed, solar radiation and evaporative cooling. On the chart, dry bulb temperature is the ordinate and relative humidity is the abscissa. The comfort zone is in the centre, with winter and summer ranges indicated separately (taking seasonal adaptation into account). The lower boundary of the zone is also the limit above which shading is necessary. At temperatures above the comfort limit the wind speed required to restore comfort is shown in relation to humidity. Where the ambient conditions are hot and dry, the evaporative cooling necessary for comfort is indicated. Variation in the position of the comfort zone with evaporative cooling, high thermal mass, high thermal mass with night ventilation and mean radiant temperature is also indicated.

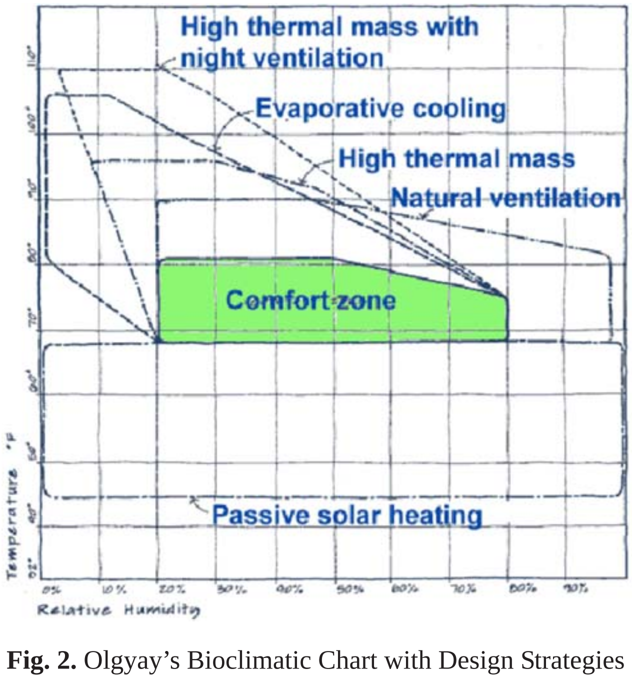

Fig. 2. Olgyay's Bioclimatic Chart with Design Strategies

3.6 Givoni Bioclimatic Chart with Control Potential Zone (CPZ)

Givoni's bioclimatic chart is aimed at predicting the indoor conditions of the building according to the outdoor prevailing conditions. His study is based on the linear relationship between the temperature amplitude and vapour pressure of the outdoor air in various regions. In his chart and according to the relationship between the average monthly vapour pressure and temperature amplitude of the outdoor air, the proper passive strategies are defined according to the climatic conditions prevailing outside the building envelope. The chart combines different temperature amplitude and vapour pressure of the ambient air plotted on the psychometric chart and correlated with specific boundaries of the passive cooling techniques overlaid on the chart. These techniques include evaporative cooling, thermal mass, natural ventilation cooling and passive heating.

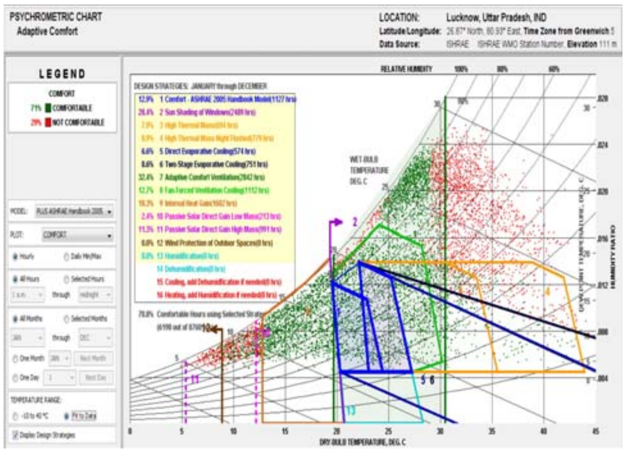

Fig. 3. Comfort Zone and Control Potential Zone for Lucknow

3.7 Passive Control of Heat Flows

In climates where there is a large temperature difference between the inside and the outside (the climate lines extend far from the comfort zone), where some form of heating or cooling will be necessary, thermal insulation of the envelope is the most important means of control. In most countries there are regulatory requirements for the insulation of envelope elements, walls, roofs and windows. These may stipulate a maximum U-value (which must not be exceeded) or a minimum R-value ($R_{a\text{-}a}$) which must be achieved by the construction.

Various passive heating and cooling strategies are:

1. Solar passive heating i.e. Direct gain
2. Solar passive cooling I) The mass effect and night ventilation II)Ventilation cooling by Cross ventilation, Wind tower, Induced ventilation and Nocturnal cooling III)Evaporative cooling IV) Earth coupling
3. Architectural techniques I) Domed and vaulted roof II) Ventilated roof III) Naturally ventilated IV) High roof
4. Microclimatic controls

3.8 Visual Comfort

It is another important parameter for comfort in building. It can be defined in term of day lighting factor.

It can be defined as

$DF = (E_i / E_o) X100\%$

where

E_i = Illumination due to daylight at a point on the indoors working plane.

E_o = Simultaneous outdoor illumination on a horizontal plane from an unobstructed hemisphere of overcast sky.

The outdoor illumination level E_o can be established for a given place by analyzing the long-term illumination record. This is taken as 'design sky illumination' value. For India, it is taken as 8,000 lux for clear design sky.

3.9 Noise Comfort

Noise is any unwanted sound. It may be speech or music, sounds of natural forces such as

Table 1. Recommended Day Light Factor for Various Buildings

Building	Area/Activity	Day light factor(%)
Dwelling	Kitchen	2.5
	Living room	0.625
	Study room	1.9
	Circulation	0.313
Schools	Class room	1.9-3.8
	Laboratory	2.5-3.8
Offices	General	1.9
	Drawing, typing	3.75
	Enquiry	0.625-1.9
Hospital	General wards	1.25
	Pathology laboratory	2.5-3.75
Libraries	Stack room	0.9-1.9
	Reading room	1.9-3.75
	Counter area	2.5-3.75
	Catalogue room	1.9-2.5

wind and rain, or mechanical sounds of electrical engines, gears, fans, etc. A human can hear 20-20,000 Hz. It can be controlled by designing of envelope of building.

Table 2. Noise Level

Environment	Decibels
Jet aircraft at close range	140
Threshold of pain	130
Elevated train close by	120
Symphony orchestra	110
Power saw	100
Down town street	90
Shouting at close range	80
Inside automobile, 55 mph	70
Face to face conversation	60
Average office	50
Quiet living room	40
Quiet bedroom	30
Rural ambient noise	20
Rustling leaves	10
Threshold of hearing 14.2	0

4. Avadh Buildings

During the Nawabi Rule from 1720 to 1856, the rulers were increasingly independent of the Mughal court and dependent upon the protection by the British rulers. By the end of the Mughal rule, the Nawabs became nominally independent kings, they declared their independence from the Mughal court. They had in the meantime become virtual subjects of the East India Company. After the Sepoy Mutiny in 1857, the last Nawab was exiled and British rule was established in Lucknow. Lucknow is unique in that it is one of the few Indian cities which used the meeting of two diverse cultures and the shift of Nawabs by Mughals with their seat in Delhi to the British with their seat in Calcutta.

Similar to the culture that existed in the eighteenth and nineteenth centuries Lucknow, the buildings of this period present a medley of forms with both Mughal and European elements. The building of Lucknow built between 1720 and 1947 can be divided safely under three heads-those made by the Nawabi aristocracy, those built by European who came to India as traders and soldiers and those that were constructed after Lucknow was taken over by the British raj. Despite the fact that these buildings were built over a period of nearly 200 years, they all had one common concern: a demand for a new architecture that was different to what existed before. For each faction of patrons the reason for this demand was different although for both, the Nawabs and the British architecture in Lucknow had a strong political agenda.

4.1 Buildings by the Nawabs Aristocracy

For the Nawabs and other newly formed Nawabi aristocracy architecture was a physical manifestation of their newly formed status. The new rulers of Lucknow wanted an architecture that not only symbolized their total dominance in Avadh, but also showed their severance from the Mughal. For them it became important to develop a new architecture vocabulary that could do both of the above. They did this by patronizing the European ideas that were infiltrating the Indian border. European ideas were also employed for their foreignness, novelty and a way of publicly proclaiming their alignment to the new power block. It should be noted that the Nawabs were primarily Muslims and therefore their architecture still portrayed all the basic principles of Islamic architecture, again with a difference. In India, an overwhelming majority of Muslims have been Sunnis including the rulers. Thus the Sunni form of Islam was practiced and patronized. On the other hand the religion of the Shiya sect of Islam was subdued. But the founder of the Nawab dynasty was a Shiya form Iran, as were the subsequent Nawabs.

To immortalize this freedom of faith they erected various Imambaras which were essential and peculiar for their Shiite way of life. Imambaras are the places of mourning for the Shiya Muslim during Moharam.

Imambara or Azarkhana literally means "the hose of mourning and represent a building specifically built to facilitate the mourning ritual during Moharam". It also houses the insignia related with such ceremonies. Imambaras are special to Lucknow and they may range from a small niche in a poor man's house to elaborate complexes. There are many Imambaras in Lucknow but the more famous are the Asfi Imambara (Nawab Asaf-ud-daula: 1784), Husainabad Imambara (Nawab Mohammad Ali Shah: 1837) and Shah Nasaf Imambara (1814). Each Imambara is entered through large garden and flanged by a mosque. These complexes later incorporated the tomb of its patron. The Nawabs developed this new building type form earlier Mughal example of Tomb or Rauza. However, they become formal qualities of the building, like a tomb, derived from square and a cube. But the central hall of the Imambaras is more elongated. The Imambaras are sometimes roofed by dome and sometimes vaulted. The basic vocabulary and architecture of the Imambaras continued to be in the tradition of the Islamic principles but with necessary modifications as now they were brick and stucco instead of in stone like their predecessors.

The Avadh Rulers beginning from Muhammad Amin Saadat Khan (1720-1739) to Wajid Ali Shah (1847-1856) built many fascinating structures in the magnificent cities of Faizabad and Lucknow in the period of 1720 to 1856**.** In Avadh Rulers era, the field of architecture saw re-interpretation of the existing styles and experimentation in the fusion of the western and the eastern style of architecture. In the beginning, the buildings constructed by them were confined to Faizabad alone. Later on the main centre of architectural activity shifted to Lucknow.

Table 3. Avadh Rulers

Muhammad Amin Saadat Khan	1720-1739
Abdul Mansur Khan Safdar Jung	1739-1754
Suja-ud-Daula	1754-1775
Asaf-ud-Daula	1775-1797
Wazir Ali	1797-1798
Saadat Ali Khan	1798-1814
Gbazi-ud-din-Haidar	1814-1819
Nasir-ud-din-Haider	1827-1837
Muhammad Ali Shah	1837-1842
Amjad Ali Shah	1842-1847
Wajid Ali Shah	1847-1856

The buildings in Faizabad included: Tomb of Bahu Begum, Gulab Bari and Moti Mahal.

The buildings in Lucknow included: Bara Imambara, Rumi Darwaza, Asfi Masjid, Chhota Imambara, Shahnajaf Imambara, Tomb of Saadat Ali Khan and Murseer Zadi, Tomb of Aliya Begam, Jama Masjid and Lal Baradari

Although detailed studies were undertaken in all the above buildings, in summary, we are describing one building that is Tomb of Bahu Begum in Faizabad and Tomb of Aliya Begam in Lucknow in details.

4.1.1 Tomb of Bahu Begum – Faizabad

The construction of the tomb of the Ummatual Zohra popularly known as Bahu

Begam (wife of Nawab Shuja-ud-daula), was started by Darab Ali Khan (A.D. 1815) and her advocate Panah Ali and completed by Mirza Haider. The tomb stands in the center within an enclosure wall made of lime plastered lakhuri bricks. It is approached through a lofty (tall) gateway, while the outer complex is further enclosed by arched (curved) cells all along the walls and can be approached through a triple gateway. The square structure is raised over a series of cells. The grave (last resting place) is in the center of this complex and is reached by a passage, while the main hall comprises Shah-n-Sheen with ritual object and the verandah on the sides flanked by four- storied minarets with fluted domes on the decorated by inverted lotus along with petal designs on the bottom of the neck. The walls and ceilings of tomb are adorned with beautiful succo designs painted in bright colours.

Fig. 4. Tomb of Bahu Begum (Exterior and Interior)

Passive Concept Used in Tomb of Bahu Begam

There are various passive architectural techniques used in tomb such as curved roof, high roof, natural ventilation, massive thick wall and openings.

Light color exterior: The tomb has light colour exteriors (Fig. 4 & 5).

Fig. 5. Light colour exterior

Openings

The builders have made special arrangement for ventilation in the center room. They have made sloppy window on the top of the wall and they have made adjacent varandah with two room and the door of the both rooms open in varandah and for good cross ventilation they have made an special curved window in such a way that curve is directed toward the varandah by which they bend the air toward varandah and they also made small windows for air input and big door for output of air by which they create pressure difference and by which a cross ventilation is always facilitated (Fig. 6).

High Roof

The height of building is about 10 m. This type of Architecture allows warm air to collect at the top and stratification of warm air maintains cool air at the floor level, thus maintaining air temperature in a comfortable zone and provide good Stack Effect.

Fig. 6. Types of Openings in Tomb of Bahu Begam

Thick wall

The thickness of inner wall is 2.91 m and thickness of outer wall is 1.22 m due to this the U-values of the wall is very low and resistance of the walls are very high (Fig. 7).

Fig. 7. Thick Walls of Tomb of Bahu Begam

Table 4. Physical Properties of the Tomb of Bahu Begum

	Inner wall	Outer Wall	Roof
U-value (W/m^2K)	~ 0.350	~ 0.775	~ 1.399
R-value (m^2K/W)	~ 2.865	~ 1.291	~ 0.715
Time Lag (hours)	~ 80	~ 33	~ 16
Decrement Factor	~ 1.970×10^{-8}	~ 0.0016	~ 0.0735

Table 5. Performance of Building of Tomb of Bahu Begum

Day Light Factor	1.9
Max Inner temp. of Building (^{0}C)	34
Types of Ventilation	Full Cross Ventilation

4.1.2 Tomb of Aliya Begam: Lucknow

Sadr-al-Nisa', known as "Nawab Aliya Begam" (c.1712–1796), was the eldest daughter of Sa′adat Khan (1680–1739). In 1724 she married her paternal cross-cousin, Safdar Jang (c.1708–1754).Tomb of Aliya Begam (Sadr-al-Nisa) was built by Safdar Jang and is located at Lucknow, City of Nawabs.

Passive Concept used in Tomb of Aliya Begam

Curved Roofs

The advantage of this is that curved roofs reflect more radiation than flat roofs due to their enlarged curved surface and reduced local radiant flux on a rounded surface and thus lower surface temperature. The other reason is that in these roofs due to thermal stratification, all hot air within the building with curved roofs gathers in space under the roof, hence creating a significantly comfortable feeling at the floor level. There is opening at top which provide way to escape for hot air collected at the top (Fig. 8).

Fig. 8. Curved Roofs in Tomb of Aliya Begam

High Roofs

The height of building is 12 m. This type of architecture allow warm air to collect at the top and stratification of warm air maintains cool air at the floor level, thus maintaining air temperature in a comfortable zone and provide good Stack Effect.

Openings

The main features of the building are that it has 24 doors and windows. Each door and window placed in such a way that each door and window are in front of each other so by this the building has very good cross ventilation and wind effect. Due to the shape of building, wall shading to each other and the whole wall never become

Fig. 9. Openings in Tomb of Aliya Begam

hot and produced cooling effect. Because of self-shading of building entire wall do not become hot in day time and create cooling effect and reduce indoor temperature up to 6ºC (Fig. 9).

Thick walls

The thickness of inner wall is 2.91 m and thickness of outer wall is 1.22 m. Due to this the U-values of the wall is very low and resistance of the walls are very high (Fig. 10).

Fig. 10. Thick Walls in Tomb of Aliya Begam

Table 6. Physical Properties of the Tomb of Aliya Begum

	Inner wall	Outer Wall	Roof
U-value(W/m^2K)	~ 0.3490	~ 0.775	~ 1.399
R-value(m^2K/W)	~ 2.865	~ 1.291	~ 0.715
Time Lag(hours)	~ 79	~ 33	~ 16
Decrement Factor	~1.970×10^{-8}	~ 0.0016	~ 0.073

Table 7. Performance of the Tomb of Aliya Begum

Day Light Factor	1.8
Max Inner temp. of Building(^{0}C)	39
Types of Ventilation	Full Cross Ventilation

5. European Buildings

The Europeans, mostly French and British who came as traders and soldiers to India in late seventies and early eighteenth century, initially built the buildings out of need. For the composite climate was something which needed getting used of the climate were not only the climatic zone that was hot, warm and very light, but also a cultural zone that was different from their own. So creating familiar environment which was safe from the 'natives' was an important need for the European. Thus with the infiltrating foreigners in Lucknow, one sees the development of fortified and segregated residential areas like Marion Cantonment and Residency. Later with increasing familiarity, more elaborate, free-standing, villa type residency called the *kothis* were built.

The use of European architectural vocabulary in these building reinforced the familiarity and satisfied the nostalgic lyrics of the foreigners. Interestingly, the European vocabulary for both the Indian and European alike was not a synergic set of principals but a jumble of images (be it thirteenth century Gothic, fifteenth century French or contemporary British) transported to India by foreigner and only sometimes substantiated by photograph and drawing. As the European stuff was alien for the Indian, Indian art and architecture was fascinating for the foreigner. By the nineteenth century they were freely, using local 'India' motifs and element to decorate their buildings and to create a fanciful image that was aesthetic and picturesque. However, the playful exchange was either mere ornamentation that did not go more than deep or was a case of direct duplication. The assimilation of Indian and European ideas in architecture happened much when Lucknow was taken over by the British after the Sepoy Mutiny in 1857.

Lucknow before the advent of the Nawabi rule, was in its Indian culture and form, an Islamic city with a dense urban fabric in which were embedded courtyard as the basic domestic form. These were inward oriented buildings and favoured for their climatic suitability in tropical climate. Furthermore, they provided safety from outside attack. These houses and the urban fabric were challenged by the European type *kothis* now favoured by the Nawabs and the elite. These free standing, centrally organized, and vertically stacked buildings with dominant facades, unlike the earlier residences had demanded a space around them to be viewed. The designs of these *kothis* are either villas picked up from imported pattern books, like the Dilkusha Palace (designed by Gore Ouseley for Nawab Saadat Ali Khan in 1800) which is a copy of Seaton Delaval (designed by Sir John Vanbrugh for Admiral George Delaval in 1717) in Northumberland, Britain, or they are building assembled together using various element from Indian and European sources like La Martiniere College. Whereas the Imambaras projected an Islamic exterior these *kothis* looked European. La Martiniere College, designed by Claude Martin as his residence and tomb in 1798, has the plan of Palladian villa with the exterior articulated by pilasters of classical columns and statues imported from France. But, although surface articulation and planning makes the building European, on closely examination the building one sees a miniature plan of Taj Mahal embedded within. In more than one instance, one sees that the nineteenth century builder was minutely reading the Mughal structures but was still not able to integrate it in his designs. These *kothis* like Chhatar Manzil formed the main residences of the Nawabs and were the heart of their elaborate palace complexes. These buildings are: Dilkusha Kothi, La Martiniere College, Chhatar Manzil, Residency, Kaisarbagh Baradari

Although detailed studies were undertaken in all the above buildings, in summary, we are describing La Martiniere College in details.

5.1 Constantia (La Martiniere College)

The relationship between the French entrepreneur Claude Martin and Nawab Asaf-ud-Daulah gained for the city of Lucknow a reputation and position of significance for its architecture that is unparalleled. The city which was quite unknown and under-developed suddenly shot into limelight for its grand buildings like the Asafi Imambara and Rumi Gate built by the Nawab and for the European style of buildings that started appearing at the outskirts of the city which were mostly designed and constructed by Claude Martin. However, as fate would have it, one such building, even before its construction, proved a 'bone of contention' between the two great personalities of their time.

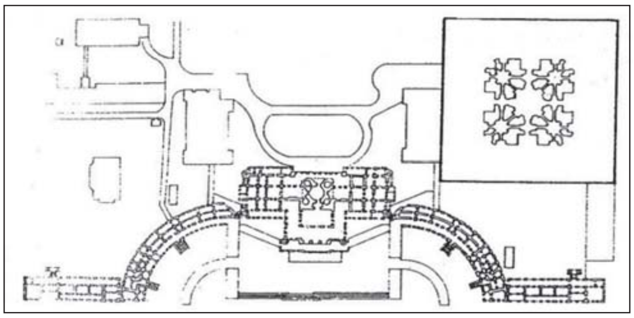

Fig. 11. Site Plan of La Martiniere College

The building in dispute was the 'Mansion of Constantia' (Fig. 11), which Martin planned to build on the banks of the river Gomti, at the extreme eastern end of the city, at a place called Lakhpeda for one lakh trees said to be planted there. When Martin divulged his plans to the Nawab, he was so fascinated with it that he offered one lakh *ashrafi* (gold coins) for it. It was just a chance that the Nawab failed to fortify the offer with an advance and the mansion remained the property of Claude Martin.

The Nawab pressed for its possession on several occasions having been obsessed by it. Meanwhile, Martin also had second thoughts on the idea of selling the building when he intended to make it the 'finale' of his architectural exploits. His buildings were indeed exploits because of typical innovations that were done by Martin in their design and construction. Major General Claude Martin fearing the forcible take-over of Constantia by the Nawab or his descendants

Fig. 12. Panoramic View of La Martiniere College

designed an underground vault as a mausoleum for the burial of his mortal remains and made a specific Will for this purpose.

In his Will, he also made endowments for establishing three educational Institutions for boys, at Lyons in France (his birth place), at Calcutta and at Lucknow, where it was to be established in the Constantia complex. Today this is the 'La Martiniere College' for boys, but its popular name and address still remains as Martin Saheb ki Kothi in Martin Purwa locality, beyond Banarsi Bagh (Fig. 12).

The building which got its name from the motto of Claude Martin 'Lahore et Constantia' inscribed on its exterior towards east is a six storied building (including basement) and has an arrangement of four wells which were sunk 30 feet below the water level of the river. The wells culminate as octagonal towers at the top. They are also meant to cool the basement of the main building.

Constantia is a unique combination of a banquet hall, a mausoleum, a mansion, a palace and a fortress with intricate defense arrangements. One of its attractions is an Obelisk which was erected later. It is a 125 feet high majestic fluted column erected on low ground. It presents a beautiful sight when surrounded with water accumulated due to rains or the back flow of the river. It is ironical that Europeans themselves did not find the Constantia in good taste. James Ferguson who is considered an authority on Eastern architecture, calls the design 'somewhat fantastic in arrangement which sins against the rules of pure Palladian Art to an extent that would not be pardonable except in such climate and under the peculiar circumstances in which it was erected'. Similarly, John Pemble commenting about the Western influence on the Lucknow architecture refers to Constantia as a 'bizarre palace' and reflects that 'Martin's main concern in designing this palace seems to have been to incorporate as many different architectural motifs as he could remember and the result is a weird jumble of classic columns, arches, pediments and balustrades, with Gothic battlements, turrets and statues and heraldic lions'. However, thereafter in the next line, he admits its grandeur.

Even today, Constantia is undoubtedly one of the most spectacular European building and one that is quite well preserved. The La Martiniere College administration deserves accolades for their efforts in this direction and for keeping the Constantia in its original form as built in its first phase in 1800 and later in 1840 when additional structures were added as were planned by Claude Martin.

Claude Martin must indeed be given due credit for utilizing local talent in ail his constructions. He thus, dispelled the prevalent myth that anything out of the ordinary could only be built by the Europeans. In fact, he left emphatic instructions that after his death, Constantia should be completed by two of his faithful native servants, Mutchoo and Chhota Qadir, who were brothers and who according to Martin 'were well acquainted how and in what mode I carry these buildings, as well as in buying materials or in paying the workmen'.

Passive Concept used in La Martiniere College

Vegetation and Water bodies

Building is situated near the river bank of Gomti and surrounded by the vegetation by which is become cool in summer by evaporation process from both river and vegetation.

Fig. 13. Vegetation and Water bodies in La Martiniere College

Light Colour Exteriors

Building is light coloured which has low absorption and high reflectivity so building does not become hot in the summer.

Fig. 14. Light Colour Exteriors of La Martiniere College

Openings

Size of the windows and doors are very large by which it facilitate very good day light factor and ventilation.

Fig. 15. Openings in La Martiniere College

High Roofs

Roofs of the building are very high so it facilitates good Stack effect in the building.

Fig. 16. High Roofs of La Martiniere College

Wind Tower

They have created wind tower in the building for cooling the basement of the building in which the tomb of the Martinera is placed that is very good for fresh air supply in the basement and also cooling the basement of building.

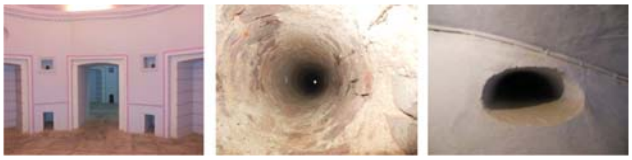

Fig. 17. Wind Tunnels in La Martiniere College

Table 8. Physical Properties of La Martiniere College

	Wall	Roof
U-value(W/m^2K)	~ 0.875	~ 1.399
R-value(m^2K/W)	~ 1.191	~ 0.715
Time Lag(hours)	~ 30	~ 14
Decrement Factor	~ 0.0013	~ 0.063

Table 9. Performance of the Tomb of La Martiniere College

Day Light Factor	1.9
Max Inner temp. of Building(^{0}C)	31
Types of Ventilation	Full Cross Ventilation

6. British Buildings

The conquest of India after the Sepoy Mutiny in 1857 changed the general political and thereby architecture scenario. Initially in the late eighteenth and early nineteenth century using anything foreign, Indian or European, was experimentation with novelty. But by the late nineteenth century the British had made a careful study of India, which included a study of art and architecture, thereby dispelling all romance that shrouded the mind and judgment of the eighteenth century Briton. Added to this was their political agenda of being the next legitimate rulers of a country earlier ruled by the mighty Mughals. India and her cultural past became a part of the British and Indian history. Now the knowledge about India was used to construct the notion of an empire that was both romantic and critical, depending on whether its purpose was to show off triumphs and glories of the colonizers or to offer an excuse for their colonization.

In either case there was a systematic study and integration under the head of Indian styles (which included temples from both North and South India, buildings of the Mughals and the early Muslim rulers, etc). The British thus presented India with the Indo (India) - Saracenic style that represented her own heritage.

The British Rulers beginning from 1857 to 1947 built many fascinating structures in the magnificent city of Lucknow**.** There are few buildings in Lucknow built by the British Rulers, which are typical examples of the British architecture in India. The examples of these buildings are: University of Lucknow, Charbagh Railway Station and King George's Medical University

Although detailed studies were undertaken in all the above buildings, in summary, we are describing the University of Lucknow in details.

6.1 University of Lucknow

The idea of starting a University at Lucknow was first mooted by Raja Sir Mohammad Ali Mohammad Khan, Khan Bahadur, K.C.I.E. of Mahmudabad, who contributed an article to the columns of "The Pioneer'' urging the foundation of a University at Lucknow. A little later Sir Harcourt Butler, K.C.S.I., K.C.I.E, was appointed Lieutenant-Governor of the United Provinces, and his well-known interest in all matters under his jurisdiction, especially in matters educational, gave fresh life and vigor to the proposal. The first step to bring the University into being was taken when a General Committee of educationists and persons interested in university education appointed for the purpose, met in conference at Government House, Lucknow, on November, 10, 1919. At this meeting Sir Harcourt Butler, who was in the chair, outlined the proposed scheme for the new university. A discussion followed, and it was resolved that Lucknow University should be a Unitary, Teaching, and Residential University of the kind recommended by the Calcutta University Mission, 1919, and should consist of Faculties of Arts, including Oriental Studies, Science, Medicine, Law, etc. A number of other resolutions were also passed and six sub-committees were formed, five of them to consider questions connected with the University and one to consider the arrangements for providing Intermediate Education. These sub-committees met during the months of November and December, 1919, and January, 1920; and the reports of their meetings were laid before a second Conference of the General Committee at Lucknow on January 26, 1920; their proceedings were considered and discussed, and the reports of five of the sub-committees were, subject to certain amendments, confirmed. The question of incorporation of the Medical College in the University, however, was for the time being left open for expression of opinion. At the close of the Conference donations of one lakh each from the Raja of Mahmudabad and Jahangirabad were announced.

The resolutions of the first Conference together with the recommendations of the sub-committees as confirmed at the second Conference were laid before a meeting of the Allahabad University on March 12, 1920, and it was decided to appoint a sub-committee to consider them and report to the Senate. The report of the sub-committee was considered at an extraordinary meeting of the Senate on August 7, 1920, at which the Chancellor presided, and the scheme was generally approved. In the meantime the difficulty of incorporating the Medical College in the University had been removed. During the month of April 1920, Mr. C.F. de la Fosse, the then Director of Public Instruction, United Provinces, drew up a Draft Bill for the establishment of the Lucknow University which was introduced in the Legislative Council on August 12, 1920. It was then referred to a Select Committee which suggested a number of amendments, the most important being the liberalizing of the constitution of the various University bodies and the inclusion of a Faculty of Commerce; this Bill, in an amended form, was passed by the Council on October 8, 1920. The Lucknow University Act, No. V of 1920, received the assent of the Lieutenant-Governor on November 1, and of the Governor-General on November 25, 1920.

The Court of the University was constituted in March, 1921, and the first meeting of the Court was held on March 21, 1921, at which the Chancellor presided. The other University authorities such as the Executive Council, the Academic Council, and Faculties came into existence in August and September, 1921. Other Committees and Boards, both statutory and otherwise, were constituted in course of time. On July 17, 1921, the University undertook teaching — both formal and informal. Teaching in the Faculties of Arts, Science, Commerce, and Law were being done in the Canning College and teaching in the Faculty of Medicine in the King George's Medical College and Hospital. The Canning College was handed over to the University on July 1, 1922, although previous to this date the buildings, equipment, staff, etc., belonging to the Canning College had been ungrudgingly placed at the disposal of the University for the purposes of teaching and residence. The King George's Medical College and the King George's Hospital were transferred by the Government to the University on the March 1, 1921.

The following three Colleges provided the nucleus for the establishment of the University:

- The King George's Medical College. (Now Known as King George's Medical University)
- The Canning College (Lucknow University).
- The Isabella Thoburn College.

This was a rich inheritance for the new-born University in 1920, both materially and intellectually, and it brought with it also the richest of all heritages "a fine tradition of some fifty-five years in the case of the Canning College and some nine years in the case of the King George's Medical College." To this the generous taluqdars of Avadh added an endowment of nearly thirty lakhs. The support from Sir Harcourt Butler's Government was strong and hearty. Since then the Government of the United Provinces has annually contributed a substantial share towards the maintenance of the University.

Passive Concepts used in University of Lucknow

High and Domed Roofs

Heights of the buildings are about 20 feet which facilitate very well Stack effect in buildings.

Fig. 18. High and Domed Roofs of University of Lucknow

Fig. 19. The Openings at the Roofs of the University of Lucknow

Openings on the Top

There are openings on the rooftop of the building by which Chimney effect in the building creates and removes the hot air collected in the top of the roof and create a space for the new fresh air in the bottom and make a continuous flow of the fresh air. It also facilitates the day lighting in buildings.

Thick walls

Walls of the University of Lucknow are very thick by which they prevent thermal heat transfer from atmosphere to buildings, and time lag is very high and decrement factor is low.

Chajjas all around the Buildings

Buildings are surrounded by chajjas on the windows and roofs by which windows and walls of the buildings do not become so hot.

Cluster Pattern of the Roofs

The roofs of the buildings are clustered so as to provide shadings of the buildings.

Table 10. Physical Properties of the University of Lucknow

	Wall	Roof
U-value(W/m^{2}K)	~ 0.965	~ 1.717
R-value(m^{2}K/W)	~ 1.009	~ 0.521
Time Lag(hours)	~ 25	~ 11
Decrement Factor	~ 0.0074	~ 0.083

Table 11. Performance of the University of Lucknow

Day Light Factor	1.8
Max Inner temp. of Building(^{0}C)	35
Types of Ventilation	Full Cross Ventilation

7. Conclusion

During the study of this project, we have found that in Avadh buildings mostly used solar passive concept are domed roofs, heavy mass of the buildings, thick walls of the buildings, placing of the of the doors and windows in such a way that each door and window is placed in front of the each other, etc. In Avadh buildings, we have found that provisions of water bodies has been a predominant factor which has been more or less absent in the European and British buildings.

In British buildings mostly used solar passive concepts are clustered roofs, heavy mass of the buildings, thick walls of the buildings, openings on the top of the roofs and clustered patterns of the roofs and provision for chajjas in buildings of the British era. This means that the builders have modified the openings on the top of the roofs and added the chajjas in the buildings and they have modified the placing of the doors and windows.

The main features of solar passive heating and cooling techniques from Avadh Architectural Buildings to European Architectural Buildings and British Architectural Buildings are summarized in the Table 12.

Table 12. Solar Passive Concepts – Changing Trends from Avadh Buildings to European/British Buildings

S No	Solar Passive Concepts	Avadh Buildings	European Buildings	British Buildings
1.	Roof	Parabolic dome type roofs.	Slightly curved roofs.	Slightly curved roof with dome on the roofs.
2.	Walls	Thicker walls with Lakhori bricks, some buildings have cavities in walls.	Thicker walls but not so thick as Avadh buildings, wind tower concept integrated with the walls.	Thicker, not as thick as European buildings.
3.	Windows and Doors	Symmetrically placed and large windows with concrete jalis. Some buildings have small curved windows placed on walls (Jharokha) for cross ventilation.	Large windows with Roshandans and large doors, asymmetrical arrangement of windows and doors	Large windows with Roshandans and large doors, asymmetrical arrangement of windows and doors
4.	Floor	Elevated floors	Not so elevated	Slightly elevated
5.	Colours Exteriors	Mostly white or pale	Mostly white or pale	Mostly white or pale
6.	Colours Interiors	Mostly white	Mostly white	Mostly white
7.	High thermal mass with night ventilation	High thermal mass and night ventilation by the Roshandans and Jharokhas	High thermal mass and night ventilation by Roshandans	High thermal mass and night ventilation by Roshandans
8.	Chajjas	Not present widely	Started using Chajjas	Present widely
9.	Acoustics	Small concept use in these buildings	Not much focus on acoustics of the building	Main emphasis on acoustics of the buildings
10.	R- values of the wall(m^2K/W)	~1.530	~1.005	~1.010
11.	R- values of the Roof(m^2K/W)	~0.715	~0.515	~0.520
12.	U- values of the wall (W/m^2K)	~0.560	~0.965	~0.975
13.	U-values of the roof (W/m^2K)	~1.400	~1.730	~1.720
14.	Vegetation	Dense vegetation around the building	Not so dense vegetation around the building	Not so dense vegetation around the building
15.	Water bodies	Water bodies present in excess	Not much arrangement of water bodies	Not much arrangement of water bodies
16.	Day lighting	Good day lighting	Very good day lighting	Very good day lighting
17.	Openings on the top (Roshandan)	Openings are placed on parabolic dome of the roof (Mostly curved)	Openings are placed on top of the wall (Small windows)	Openings are placed on the roof with shading
18.	Buffer Zones in buildings	Widely available	Not much available	Not much available

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