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Comparative Thermal Analyses of Adobe and Brick Buildings in Islamabad

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Abstract

Conventional urban buildings in Pakistan built of brick and concrete envelopes without much regard to the climatic events of the region are a common practice prevalent in this country. These buildings, which are normally un-insulated, consume large amounts of electricity or natural gas for heating, cooling and lighting the buildings. Except in the rural areas, where 61.24% (2015, mundi) of the population live, adobe (mud) buildings are not built in these urban areas. At the government level there are plans to build 500, 000 houses for low income families. The thermal characteristics of adobe buildings are considered in this research, which compares the comfort levels and thermal lag between two identical test buildings, one made of adobe and the other made of brick and concrete. Both the buildings are built with heat sensors embedded within the building envelopes and within the building spaces. The thermal behavior of the two test buildings were monitored since October 2011 for more than a year and was intended to encompass all seasons in Islamabad. While substantial data was received – some more than the 40,000 estimated data points – this research focuses on specific winter and summer days to analyze and synthesize the results to arrive at some meaningful conclusions.

Keywords: building envelope, adobe building, brick building, comparative thermal analysis

1. Introduction

This research compares the thermal characteristics of an adobe building to a brick building in Islamabad, Pakistan. The two types of buildings are identical in size, built on the same site, side by side and subject to the same orientation and climatic conditions. The brick structure is a room of 10’l x 10’w x 9’h size with walls built of 9” brick masonry and a reinforced concrete roof as is the common practice in Islamabad and surrounding regions. The adobe structure is of the same internal size as the brick building, and is built of minimum 21” thick adobe cavity block walls, and the roof structure is a combination of a bamboo/steel structure with 12” thick mud topping.

The two test buildings are installed with sensors to monitor ambient air temperatures and humidity on an hourly basis. Sensors, which measure temperature, are installed at various depths within the adobe and brick masonry walls and sensors which measure temperature and humidity are installed within the room spaces. One sensor is installed outside, near the structures, in a shaded location to record the hourly ambient temperatures and humidity. The sensors are connected to a data logger to record the ambient air temperatures and humidity. The data monitored and collected is downloaded onto a computer and wirelessly transmitted to the Research and Development lab. The period of activity for monitoring is for an entire year, which would include autumn, winter, spring and summer seasons. The sensors and data logging instruments were developed at CIIT's Research and Development Lab as well as commercially available instruments.

In addition to the above noted data logging instruments and sensors installed by R & D Lab, the test buildings were also installed with and being monitored by LaCrosse data logging instruments to measure temperature and humidity within the two test buildings as well as the outside temperature and humidity. The readings were monitored at 5 minute intervals and the resultant data was downloaded physically on a laptop.

2. Climate of Islamabad

The city of Islamabad is situated at 33.6 N and 73.11E and is 518 meters above sea level. The climate is subtropical humid type requiring heating in winters and cooling in summers in buildings for thermal comfort. The summer period is from mid April to mid October and winter period is from December to February. The months of March to mid April and mid October to November are transitional periods, when the climate is moderate and may or may not require cooling or heating of buildings. Monthly mean maximum temperatures in May, June, July and August are 38C, 39C, 38C and 35.5C respectively; monthly mean maximum humidity in those months are 38%, 38%, 65% and 75%. July and August are the monsoon months when high relative humidity but low temperatures are experienced. Typically cooling is warranted in the daytimes during mid April till end of September and heating is required from mid November to mid March. Exterior design conditions at 2.5% is 41.5C in summer and 27.2C in winter (BECP). Mean temperatures, relative humidity and wind directions are listed below in Fig. 1.

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Mean Max Temp C	18	18.5	25.5	36.5	38	39	38	33.5	33.5	32	26.5	20
Monthly Mean Min Temp C	1	3.5	10	13.5	18.5	24	24	24	20	13	4.5	-1
Monthly Mean Range Temp C	17	15	15.5	23	19.5	15	14	9.5	13.5	19	22	21
Monthly Mean Max RH %	82	80	63	51	38	38	65	75	60	58	68	85
Monthly Mean Min RH%	46	50	40	30	17	30	48	53	37	30	30	40
Avg RH%	64	65	52	41	28	34	57	64	49	44	49	63
Wind Prevailing	SW	SW	SW	SW	SW	SW	SE	SE	SW	SW	SW	SW
Wind Secondary	W	W	NW	NW	NW	SE	SW	SW	NW	NW	W	W

Fig. 1: Climatic Data of Islamabad (ENERCON)

3. Test Buildings Construction

Adobe Test Case Building (Figs. 2 and 3).

The adobe test case building was made of two 9" thick sun baked adobe bricks with a 2" cavity in between, resulting in a 21" adobe cavity wall. The insides of the room measured 10.5' x 10.5' x 10.25' average height. The roof of the adobe building is 12" thick adobe supported by a bamboo and steel beam structural system. The wall surfaces outside and inside were finished with ¾"thick mud plaster mixed with straw and cement for strength. The building faced north direction with the 3'0" x 7'0" steel door and a 3'0" x 3'0" window on the north façade; another 3'0" x 3'0" window was located on the south wall. A sensor to record the inside temperatures and relative humidity at 5 minute intervals was installed in the middle of the room that was wirelessly connected to a data logger to document the results.

Brick/Concrete Base Case Building (Figs 4 and 5).

The brick/concrete base case Building is the conventional constructed type of building in Islamabad, in which the insides measure 10.5' x 10.5' x 10.25' average height. The walls were made out of locally manufactured 9"L x 4.5"W x 3"H bricks. The roof was constructed of 5" thick reinforced cement concrete (RCC). The walls and roof were finished with ½" thick cement plaster inside and outside. The building faced north direction with the 3'0" x 7'0" steel door and a 3'0" x 3'0" window on the north façade; another 3'0" x 3'0" window was located on the south wall.

Similarly, as in the adobe test building, a sensor to record the inside temperatures and relative humidity at 5 minute intervals was wirelessly connected to a remote data logger to document the results. In addition to the above data logging equipment was also a third sensor to record the outside ambient temperatures and relative humidity that was installed in a shaded weather station.

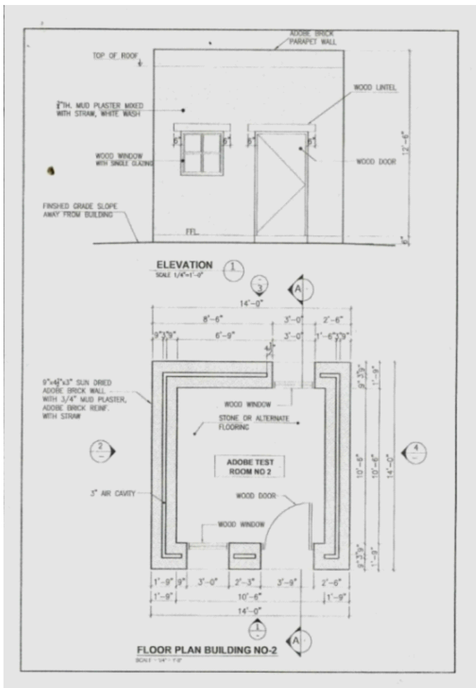

Fig. 2: Adobe and building plan and elevation

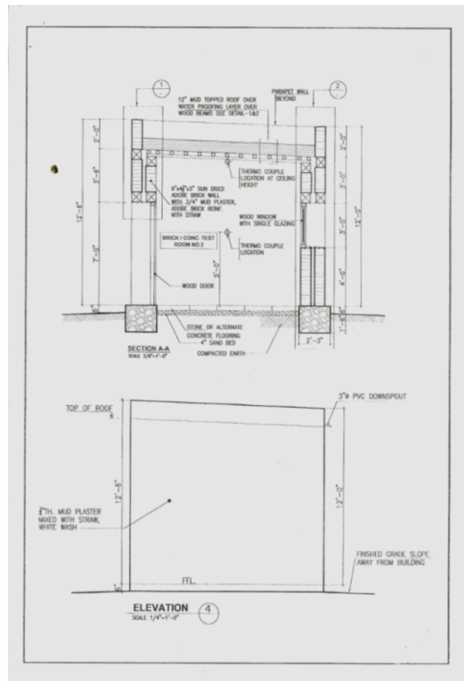

Fig. 3: Adobe bldg section and elevation

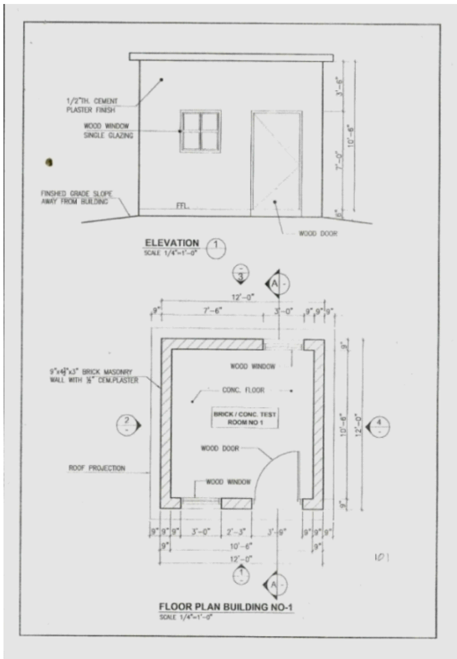

Fig. 4: Brick building plan and elevation

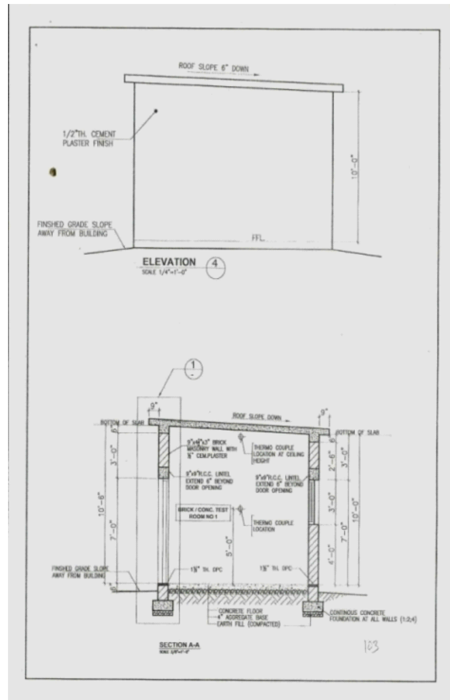

Fig 5: Brick building elevation and section

Fig. 6: Brick building and (left) and adobe building (right) constructed side by side on site for testing

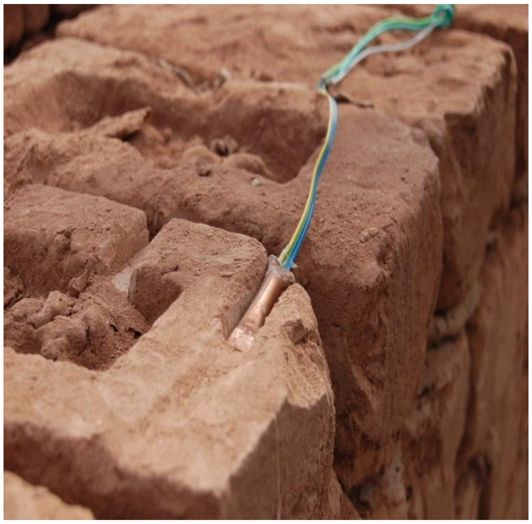

Fig. 7: Temperature sensor embedded in brick wall

Fig. 8: Temperature sensors embedded in adobe wall

Fig. **9: Temperature sensors inserted in RCC ceiling**

Fig. 10: Adobe building with sensors connecting to a transmitting module

Fig. 11: Weather station to monitor outside temperature and humidity

Fig. 12: Sensor inside brick building to monitor inside temperature and humidity.

4. Buildings Performance

March 8, 2011 Trial Run

After the test buildings were completed, trial runs were conducted on a sunny day of March 8, 2011 to measure the temperatures and relative humidity of the adobe Building A and the brick/concrete Building B and outside conditions at 9:0 am and at 1:00 pm. The following static data was derived from the data loggers.

Time	Outside Conditions		Adobe Building		Brick Building	
	Temp C	RH	Temp C	RH	Temp C	RH
9:00 am	19.72	73%	22.5	73%	17.33	78%
1:00 pm	20.72	54%	23.33	62%	31.55	55%

When these readings were plotted on a psychrometric chart (Fig: 13), it was observed that at 9:00 am, while the outside conditions were in the cold and humid range, the adobe building remained in the comfort zone and the brick building was in the cold and humid zone. At 1:00 pm the adobe building managed to still remain in the comfort zone. At the same hour (1:00 pm), even though the outside ambient air temperature was in the cold and humid zone, the direct solar radiation on the building walls, windows, door and roof transmitted enough solar heat into the building within a span of 4 hours to overheat it and move it from the cold humid zone to the warm and humid zone. The heating up of the brick building, even while cold and humid outside conditions prevailed, was due to the very low thermal resistance of the 9" brick wall which typically has a R-value of 0.9. Adobe has an R-value of 0.1 per inch (damp and packed earth, Lechner) and a 3" air space of 0.7 per inch (Lechner) The 21" thick adobe walls with the 3" air space had an approximate calculated R-value of more than 4.2 and the 12" thick adobe roof had a calculated R-value 3.6 (0.3 per inch, dry and loose, Lechner) this adobe envelope fared much better than the brick/concrete building. Moreover, the thermal lag of the adobe building added to the building remaining in the comfort zone for that time at 9:00 am and 1:00 pm. However, in a 24 hour period the adobe building would not fare better than the brick building during the nights and early evening because the adobe building, due to thermal lag, would not lose heat faster than the brick building in the night.

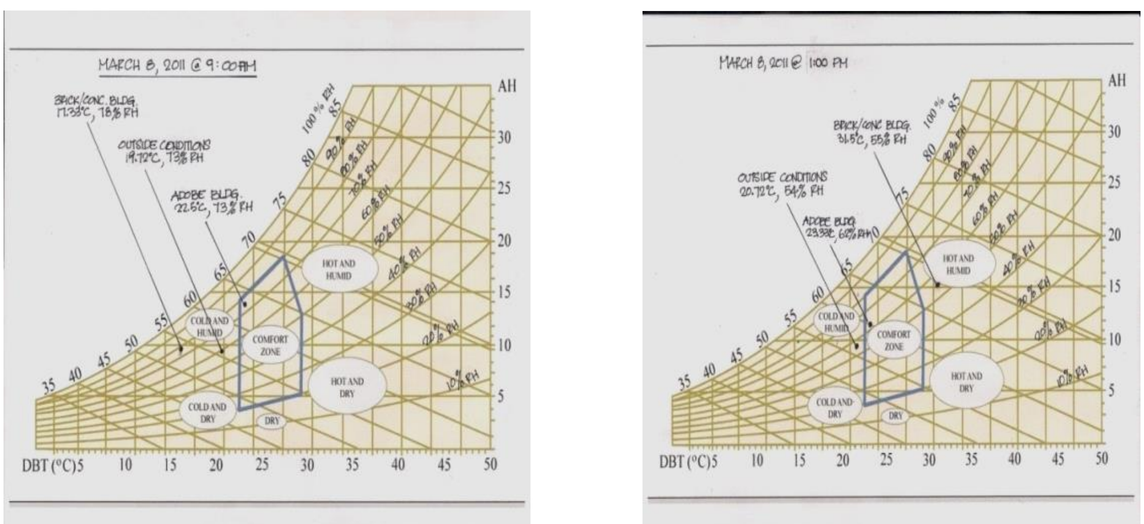

Fig. 13: Trial run on March 8, 2011 at 9:00 am and 1:00 pm showing that when outside conditions were cold and humid at 9:00 am and 1:00 pm, the brick building interior moved from cold and humid conditions at 9:00 am to hot and humid conditions at 1:00 pm; the adobe building interior remained in comfort zone at both times

Winter season

On December 25, 2011: Lowest temperature of the month, the following data was recorded:

Time	Outside Conditions	Adobe Building	Brick Building
	Temp. C, RH%	Temp C, RH%	Temp C, RH%
6:00 am	-3.3, 85%	9.1, 69%	6.5, 60%
	Very Cold Zone	Very Cold Zone	Very Cold Zone

When observed over a 24 hour period on December 25, 2011 from 12:00 am to 11:55 pm (lower temperature), the data recorded was as following in Fig. 14 and Fig. 15.

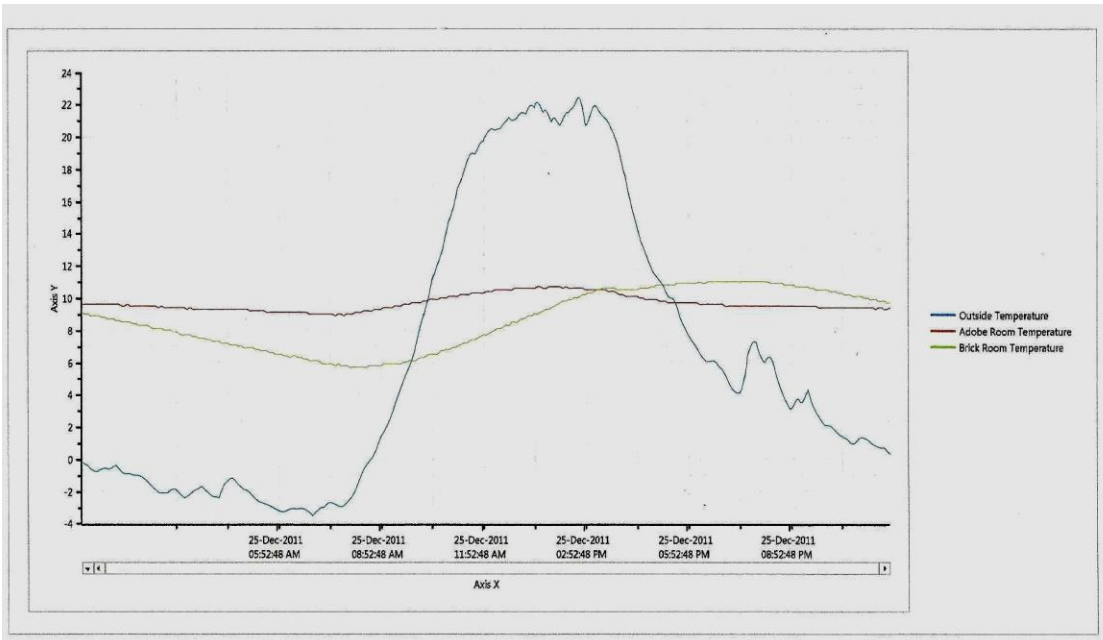

Fig. 14: Exterior, adobe room and brick room temperatures for a 24-hour period on December 25, 2011

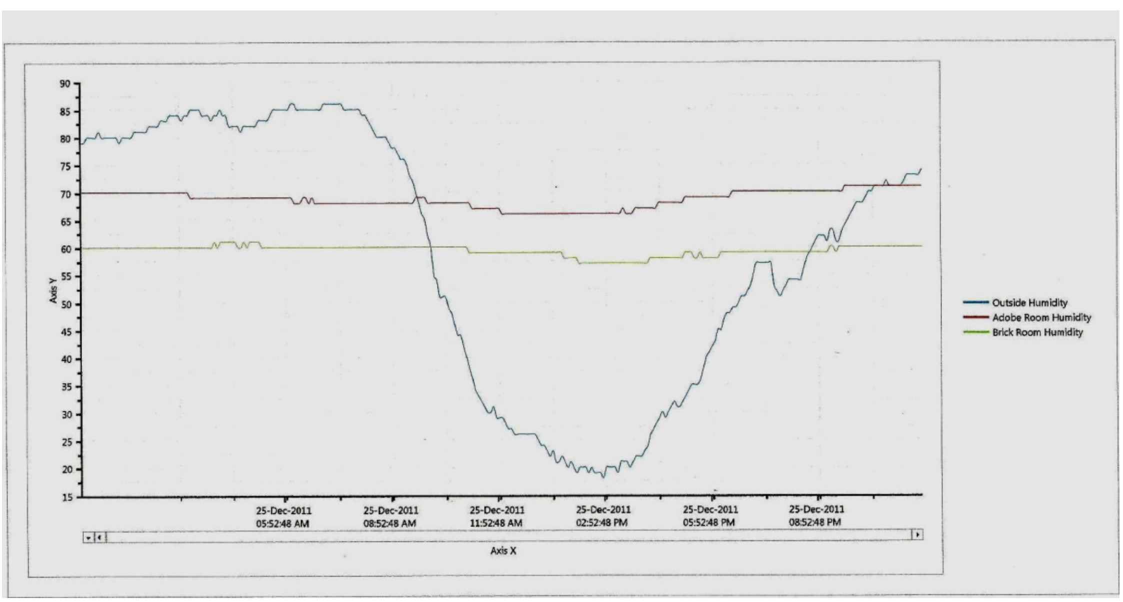

Fig. 15: Exterior, adobe room and brick room relative humidity for a 24-hour period on December 25, 2011

The outside diurnal temperature varied by as much as 26.1C during the entire day of December 25, 2011 between a low of -3.3C (85% RH) and a high of 22.8 C, (19% RH); the brick building varied as much as 5.3C inside temperatures in this 24-hour period between a low of 5.7C (60%RH) and a high of 11.0C (59% RH); the adobe building maintained steady temperatures between a low of 8.9C (68% RH) at 7:50 am to a high of 10.7C (66% RH) at 1:30 pm, thereby varied only 1.8C in a 24-hour period.

Using 23C as the bench mark in winter for human comfort condition, the ambient outside temperatures remained in the uncomfortable range for the entire 24 hour period, and the brick and adobe buildings remained in the uncomfortable range for the entire 24 hour period also. The conclusion again is that, while some form of heating would have been required in the adobe and brick buildings to maintain comfort conditions in a 24-hour period on that day, there would not have been much benefit derived from the adobe building, when compared to the brick building, in terms of additional heating energy savings to maintain comfort conditions on that day.

Summer Season

The months of July and August are typically the monsoon months when Islamabad is visited by rains and thunderstorms. The humidity increases substantially, while the temperature drops considerably, when compared to the hot and dry months of May and June. There was intermittent data received and loss of data particularly in August that was probably due to the high humidity causing the loss of transmission from the sensors to the base data logging unit. Meaningful and readable data was only received from July 28, 2012 till August 3, 2012. On July 31, 2012 the highest outside temperature was 41.3C at 2:35 pm and the lowest temperature was 25.1C at 3:00 am.

When observed over a 24 hour period commencing on July 31, 2012 from 12:00 am to 11:55 pm (highest temperature) the following data was recorded:

July 31, 2012, Highest temperature of available data

Time	Outside Conditions Temp. C, RH%	Adobe Building Temp C, RH%	Brick Building Temp C, RH%
2:35 pm	41.3 41% Hot/Humid Zone	35.7, 57% Hot/Humid Zone	36.1, 52% Hot/Humid Zone

The outside diurnal temperature varied by as much as 26.2C during the entire day of July 31, 2012, the brick building varied as much as 5.5C inside between the lowest (30.9C, 62% RH)) and highest temperatures (36.6C, 51% RH) in this 24-hour period; the adobe building maintained steady temperatures between a low of 33.7C (61% RH) at 4:40 am to a high of 35.7C (57% RH) at 2:35 pm, thereby varied only 2.0C in a 24-hour period.

Using 25.5C as a benchmark for summer comfort level, the outside conditions are in the comfort zone for just 1 hour and 25 minutes in a 24-hour period that ranged from a low of 25.1C (86% RH) to a high of 41.3C (41% RH). The brick building is not in the comfort zone for the entire 24-hour period that ranged from a low of 30.9C (62% RH) to a high of 36.6C (51% RH). The adobe building did not fare any better than the brick building as it too did not remain in the comfortable zone during the entire 24-hour period with a low of 33.7C (61% RH) to a high of 35.7C (57% RH); however, the temperature difference was only 2.0C, which was less than the brick building with a temperature difference of 5.7C and the outside conditions with a diurnal temperature difference of 26.2C. Although both the adobe and brick buildings did not afford any comfortable conditions within the rooms, it could be concluded that if both the buildings were using energy for cooling, the adobe building with 12" cavity walls and a 12" thick adobe roof would have been better than a brick building in terms of energy savings. It can thus be concluded that the adobe building performed slightly better than the brick building; this was mainly due to fact that the 21 inch adobe wall system with a 3"cavity, afforded thermal lag to the heat throughout the day. However, if the adobe building was of just 9" adobe sun baked brick, the thermal performance would have been nearly the same as the brick building.

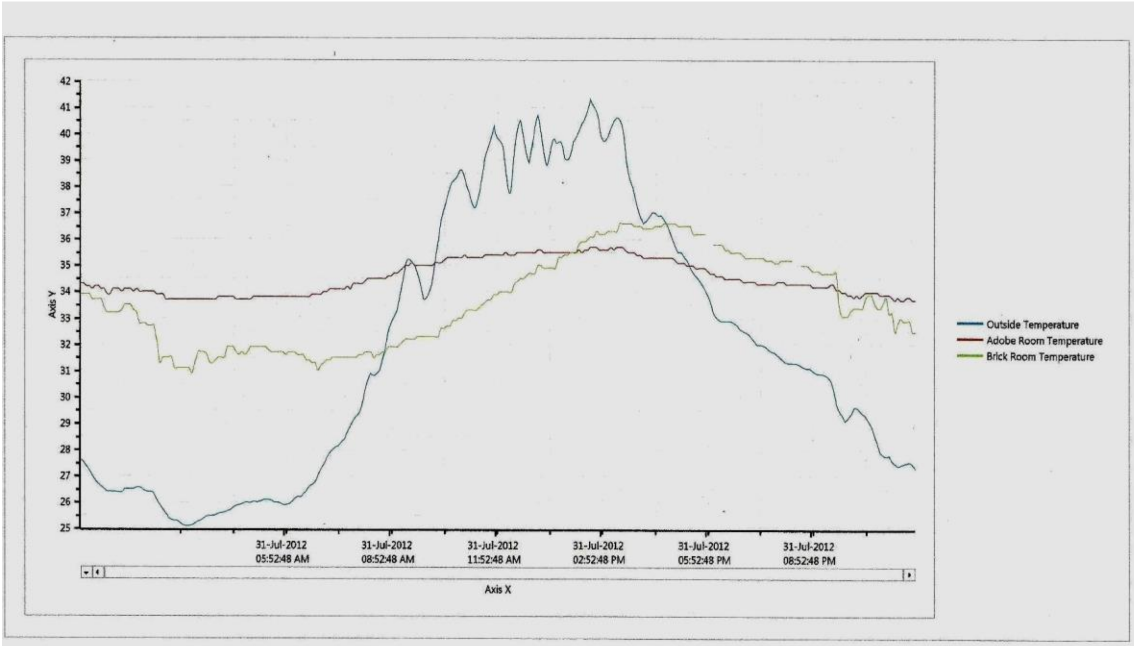

Fig. 16: Exterior, adobe room and brick room temperatures for a 24-hour period on July 12, 2012

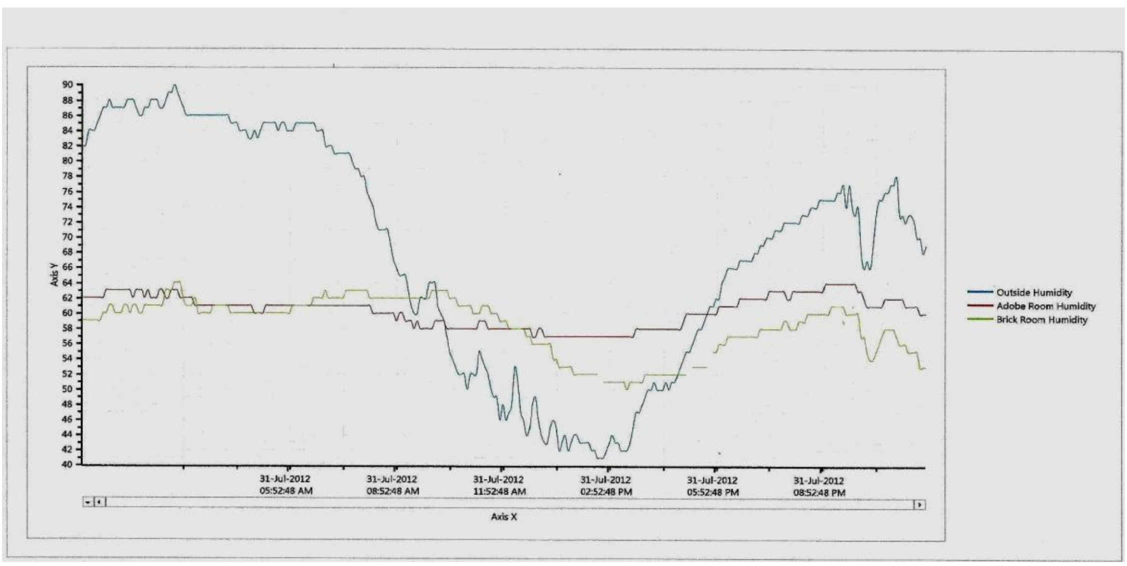

Fig. 17: Exterior, adobe room and brick room relative humidity for a 24-hour period on July 12, 2012

5. Conclusions

Adobe construction has been much touted for its advantages in buildings for human thermal comfort, this being the material used in the past and even today, being the primary building material in Pakistan's rural areas. This research sought to investigate the thermal advantages of adobe building by comparing it with a similar brick/concrete building, which is the current building practice in Pakistan. Two similar buildings, in terms of building size, orientation and number of fenestrations, were constructed side by side. The brick building was the usual 9" brick masonry unit wall with a 5" thick concrete roof, whereas the adobe building had 21 inches thick cavity walls with and an adobe roof 12 " thick. Sensors were installed in the space of the two test buildings to monitor temperatures and humidity in the building spaces. A weather data monitoring station was installed at the site near the buildings.

Winter day on December 25, 2011:

On this day, when the outside temperature dropped to –3.3C (85%RH) at 6:00 am, the adobe building maintained a temperature of 9.1 C (69%RH) at that time, and maintained a temperature swing of only 1.8C in a 24-hour period. The brick building, at that time, remained at a low of 6.5C (60% RH) with a temperature swing of 5.3C. The adobe building, only very slightly, performed better than the brick building with a low despite the fact that both buildings were in the uncomfortable zone in the night.

On this day, when the outside temperature was highest at 22.8C (19% RH) at 2:45 pm, the adobe building maintained a temperature of 10.6C (66% RH) at that time. The brick building at that time logged at 10.1C (57% RH). In this instance, in the daytime, the brick building performed slightly better than the adobe building, but both of them were out of the comfort range. It seemed that there were not much advantages of one building over the other either in the night time or day time. However, if the adobe building was using solar energy or any conventional energy for heating, it could have retained the heat within the room for a longer time than the brick building due to the high mass walls of the adobe building.

Summer day on July 31, 2012:

On this day, when the outside temperature dropped to 25.1C (86%RH) at 3:00 am, the adobe building maintained a temperature of 33.7 (62%RH) at that time, with a temperature swing of only 2.0C in a 24-hour period. The brick building remained at 30.9C (62% RH) at that time with a temperature swing of 5.5C in a 24 hour period. The brick building, only very slightly, performed better than the adobe building despite the fact that both buildings were in the uncomfortable zone in the night. The heat collected during the previous day was precluded from dissipating in the night time due to the adobe mass walls. However, if the adobe building was using natural ventilation or any conventional energy cooling, it would retain the cooling in the mass walls and performed better in the night time

On this day, when the outside temperature was highest at 41.3C (41% RH) at 2:35 pm, the adobe building maintained a temperature of 35.7C (57% RH) at that time. The brick building at that time logged at 36.1C (52% RH). In this instance, in the daytime, the brick building performed slightly better than the adobe building, but both the buildings were out of the comfort range. It seemed that there was a slight advantage of the adobe building over the brick building in the day time, since the adobe mass walls precluded the daytime heat gain better than the brick building. But then, as pointed out in the previous paragraph, the opposite was true in the night time, when the heat in the adobe building interior was not easily dissipated during the night time due to the adobe mass walls.

6. References

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