USER COMFORT AND ENERGY EFFICIENCY IN PUBLIC BUILDINGS OF HOT COMPOSITE CLIMATE OF MULTAN, PAKISTAN

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ABSTRACT

The close connection between energy use in buildings and environmental damage arises because energy – intensive solutions sought to construct a building and meet its demands for heating, cooling, ventilation and lighting, cause severe depletion of invaluable environmental resources. Buildings designed with efficient use of energy with low operating cost as well as comfortable for users can contribute to the successful environment friendly design. The paper is an attempt to investigate and evaluate the thermal and energy efficiency of public buildings with reference to its user comfort level. To study the passive design elements of energy efficiency, twelve public buildings have been selected as case studies from colonial and contemporary period in which at least one of the energy efficient means has been used. Paper reviews the data collected for the four hottest months from summer season, of monitoring the buildings located in the hot composite climate of Multan, Pakistan and analyzed against mean temperature and relative humidity values for this season. A questionnaire survey is also conducted from the users to know the desired comfort level of these buildings.

Key words: Energy Efficiency, Environmental Design, User Comfort, Public Buildings

1. INTRODUCTION

Buildings, as they are designed and used today, contribute to serious environmental problems because of excessive consumption of energy and other natural resources. However, buildings can be designed to meet the occupant's need for thermal and visual comfort at reduced levels of energy and resource consumption (Saade and Ramadan, 2008). Therefore, an energy efficient building balances all aspects of energy use in a building-lighting, space-conditioning and ventilation – by providing an optimized mix of passive design strategies, energy efficient equipment and renewable sources of energy. Use of materials with low embodied energy also firms a major component in energy efficient building designs (Okeil, 2010). Climate has a major effect on building performance and energy consumption. The objective of any climatic design is to reduce energy cost of a building and to provide comfortable and healthy environment for its users (Yilmaz, 2007).

In Pakistan, most of the areas come under hot composite climate zone in which hot season dominates with the variation in climate. Nicol and others (1999) concluded that as a result of over heating, there is usually a diurnal temperature variation. Multan, located in Southern Punjab, features an arid climate with very hot summers and mild winters, represents hot composite climate zone. The building construction practices in Multan are an amalgam of building methods and design solutions that range from traditional techniques, materials and spatial patterns to advanced industrial materials and hybrid new building forms. Traditional use of masonry architectural construction in local materials were experienced and they proved to be the reliable solutions to basic building design, construction methods and techniques. But due to colonial construction practices and post colonial socio-economic realities, this tradition has been disintegrated.

The objective of the study is to evaluate architectural design elements of energy efficiency and investigate user perception of comfort in public buildings of hot composite climate of Multan. The study will help the building professionals, authorities, policy makers and concerned citizens to understand the appropriate building design approach with reference to thermal and user comfort.

2. ENERGY EFFICIENCY IN BUILDINGS

The building with minimum negative environmental impact and lowest running energy cost is an energy efficient building. According to Majumdar (2001) energy efficiency in buildings can be achieved through an approach involving adoption of bio climatic architectural principles responsive to the climate of the particular location; use of materials with low embodied energy, reduction of transportation energy, incorporation of efficient structural design, implementation of energy efficient building systems and effective utilization of renewable energy sources to power the building. Energy efficiency in buildings broadly implies three aspects (Agarwal, 2004):

1. Minimize energy waste due to unwanted and non judicious use of electrically operated gadgets.

2. Development of energy efficient appliances.

3. Optimum utilization of non conventional sources of energy through judicious planning and building design.

Ralegaonkar and Gupta (2010) explained about passive techniques with the context of cooling of buildings in hot-dry and warm-humid climates, which aim towards reduction in heat penetration through building envelope and provision of inducing desired natural ventilation indoors. Designing and enveloping new buildings based on sound concepts of sustainability and applying suitable options to existing buildings could substantially improve the energy use efficiency in the building sector. An 'integrated approach' to building design which involves judicious use and application of:

- Efficient materials and construction practices.

- Bio-climatic/Solar-passive architectural principles.

- Efficient systems and equipments.

- Renewable sources of energy.

- Efficient waste and water management practices.

I incorporating above features in a holistic manner in any building, would impose a minimal impact on the environment along with enhancing user comfort and productivity (Figure 1) (Majumdar: 2001).

3. CLIMATE RESPONSIVE DESIGN

The immense increase in built environment has added the concept of climate responsive design. Krishan et al (2001) defined the climate responsive design as an approach to building design that uses the building architecture to minimize energy consumption and improve thermal comfort (Figure 2). Buildings affect the climate by their presence, process of construction and use. Orientation is necessary to avoid direct exposure to solar radiation of maximum building surface. Provision of courtyard or open space inside the building prevents exposure of walls from direct sun. The

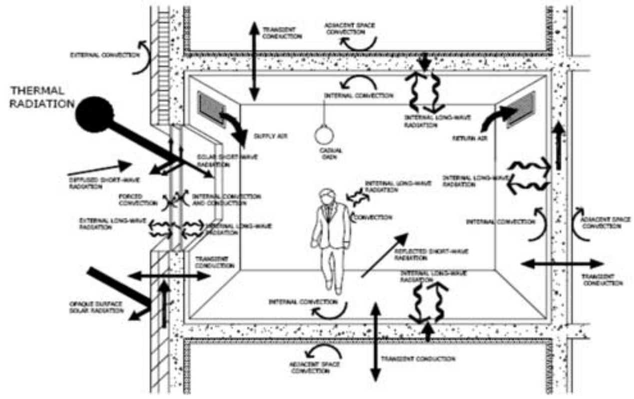

Figure-1: Heat Transfer and Thermal Energy Balance In A Space (Source: Abaza, H. (2002) An Integrated Design And Control Strategy For Energy Efficient Buildings, Virginia Polytechnic Institute and State University, Ph.D. Thesis, Blacksburg, Virginia)

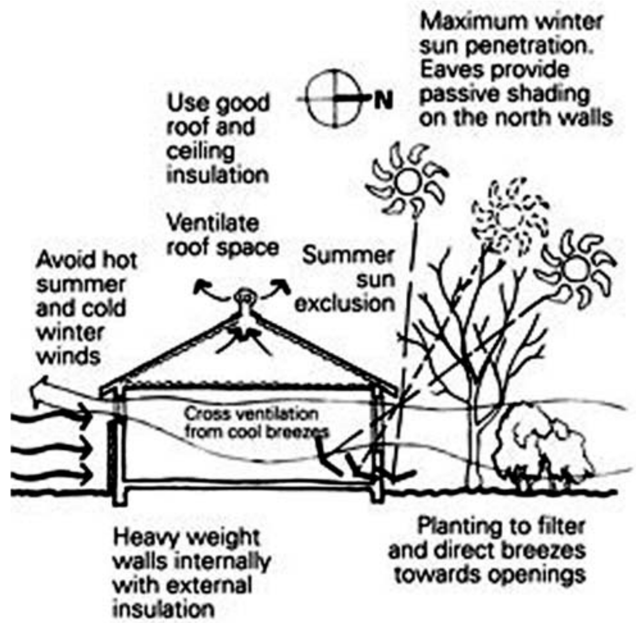

Figure-2: : Climate Responsive Design Solution for Warm Humid Climate with High Diurnal Range
(Source:) http://www.youhome.gov.au)

movement of sun and wind helps to keep the building comparatively cool during the day and to receive cool air in the night from above.

Location and optimum thickness of insulation on walls and roof can reduce the space-conditioning load by about 15 – 20% (Sozer, 2010). In hot climates, insulation facing exterior of the walls is recommended. Proper roof treatment depends upon the climatic needs. Roof insulation is imperative to prevent heat gain into buildings especially in hot climates and is achieved by using materials with low conductivity which reduces almost 70% of heat gain. Use of hollow brick constructed roofs and double roofs are effective as thermal barriers (Devgan, et al. 2010). Mathur and Chand (2003) suggested that an appropriate thermal insulation and air cavities in walls reduce heat transmission into the building, especially in hot regions.

By using sun shades and screens the effect of solar radiation can be reduced. Vertical shades are most effective to protect from direct sun on west and east directions. Verandahs located on south provide necessary protection from the hot summer sun and provide suitable sunny space in winters. Traditional use of wooden screens allows a cross air flow and has low thermal co-efficient (Devgan, et al 2010). Effective size of openings also prevents solar penetration into interior spaces of building. Louvers, overhangs or awning with optimum dimensions lined on windows help to control direct sun entry into the building especially during summer (Schiavon, et al 2010).

The choice of materials also helps to reduce the energy contents of buildings and maximize indoor comfort. Use of building material with low embodied energy i.e. energy used in the manufacture of the building material help in reducing energy cost as well as green house gases created by manufacturing processes; for example straw fired brick kilns are more environment friendly as compared to coal fired kilns (Lombard, Ortiz and Pout, 2008). Use of local materials reduces transportation energy consumption levels, reducing environmental degradation.

4. Significance of Daylight:

Sustainable architecture makes an efficient use of lighting through control mechanisms and appropriate design and layout by maximum use of natural daylight in the buildings (Okeil, 2010).

According to Mahdavi and Doppelbauer (2010), Day lighting design approaches include four concepts:

- Penetration: collecting natural light inside the building.

- Distribution: homogenous spreading of light into the spaces.

- Protection: reduction of direct penetration of sun into the building, by shading.

- Control: controlling light penetration to avoid visual discomfort

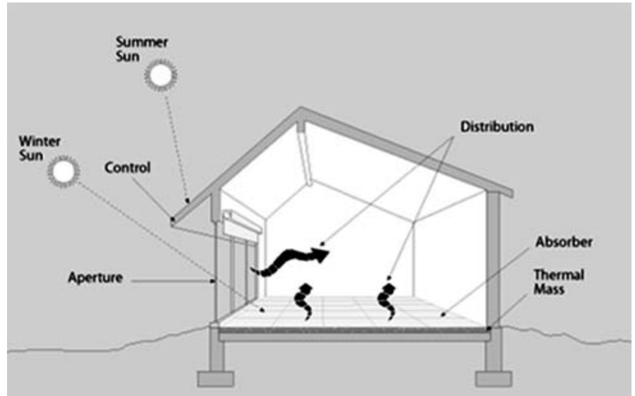

Figure-3: Elements of Passive Solar Design.
(Source: Givoni, B. (1994) Passive And Low Energy Cooling Of Buildings, Van Nostrand Reinhold, New York)

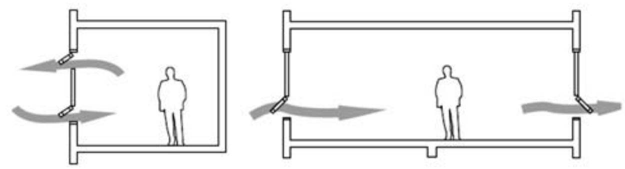

Figure-4: Single Sided and Cross Ventilation
(Source: Mikler, V. and others (2008) City of Vancouver: Passive Design Toolkit – Best Practices, LEED ® AP, Canada)

Passive solar designs (Figure 3) reduce energy consumption and are managed effectively after occupancy (Ralegaonkar and Gupta, 2010).

5. SIGNIFICANCE OF VENTILATION

Dissipation of accumulated heat in buildings can be achieved by introducing cool air flow through proper ventilation (Figure 4). Buildings with mechanical systems to supplement natural ventilation and reduce environmental impact by providing comfortable conditions for occupants, create thermally comfortable indoor environment. By optimizing window size and location, energy can be conserved in most effective way (Givoni, 1994). Ventilators also help to reduce air motion as hot air rises and flows through the ventilators. Schiavon et al (2010) discussed about the openings in the roof which help to induce air movement devoid of windows. Tall shafts with opening on the top help in sucking up the hot air during day and catch cool night air. Wind towers can also be used to control wind in a bio climate house and very effective in hot and dry climate where diurnal variation is high.

6. THERMAL COMFORT

According to ASHRAE[1], "thermal comfort is the condition of mind which expresses satisfaction with the thermal environment". Thermal comfort is a series of conditions in which given population neither feel very hot nor very cold. Comfortable conditions in mechanically ventilated buildings depend on six variables: air temperature, radiant temperature, relative humidity, air velocity, occupant's activity level and occupant's clothing insulation (Figure 5). All conditions effect bodily heat gain by convection and heat loss by evaporation. ASHRAE defines a comfort zone based on these variables where the majority of occupants feel comfortable (ASHRAE, 2004).

There are several models to measure thermal comfort in which two most relevant models are the Fanger Model and Adaptive Models based on ASHRAE Standards. The Fanger Model is most commonly used for typical buildings and defines comfort in terms of air temperature and humidity because these parameters are easy to measure and control. Mikler et al (2008) described the Adaptive Model to measure thermal comfort as function of the building is to provide the occupant with the means to make them comfortable. The current research is based on these two models to assess the thermal comfort in terms of temperature and humidity of buildings and energy efficiency by its function with reference to the provision of comfortable means given in the buildings.

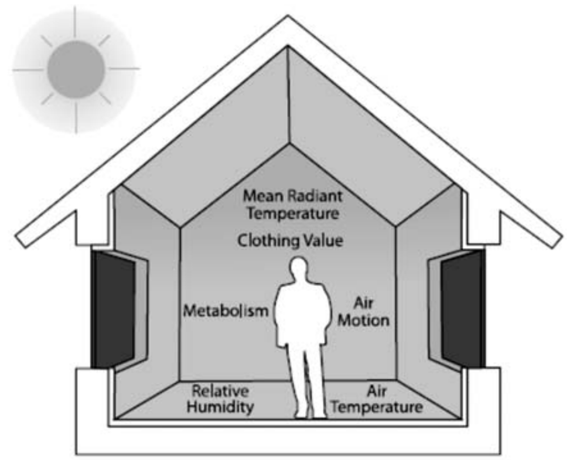

Figure-5: Key Thermal Comfort Parameters
(Source: Mikler, V. and others (2008) City of Vancouver: Passive Design Toolkit – Best Practices, LEED ® AP, Canada)

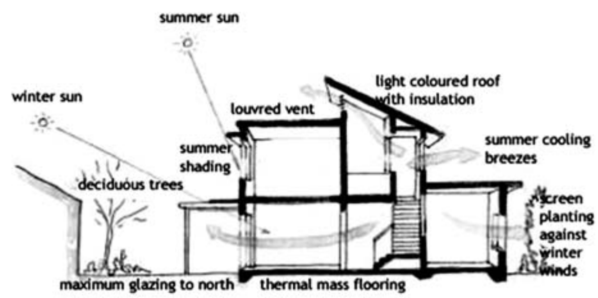

Figure-6: Key Elements of Passive Heating and Cooling
(Source: http://www.smarterhomes.org.nz)

7. PASSIVE COOLING

Passive cooling is a low energy-intensive method of keeping a building cool by relying on architectural design. Passive cooling system often utilize the same building materials found in conventional structures that operate with little or no mechanical assistance and are very unlikely to malfunction. Other key aspects of passive cooling technology described by Givoni (1994) shown in (Figure 6) include the use of insulating materials that retard heat flow, air infiltration, radiant heat transfer barriers under the roof, window design, desiccants for moisture reduction and new types of high performance glass. There is a variety of passive ventilation techniques such as solar chimneys, trombe walls, wind towers and roof vents. Domed roofs resist solar gain and improve ventilation (Chan et al 2010).

8. CLIMATE OF MULTAN

Generally, climate has been classified into six major zones: cold and sunny; cold and cloudy; warm and humid; hot and dry; composite and moderate. The climatic elements are the variables which affect the building performance. The variables which directly affect thermal comfort are temperature, humidity, solar radiation and air movement.

- Air temperature, measured in degree Celsius, determining the requirement of heating or cooling and varied by other climatic parameters of wind speed and directions.

- Air humidity, usually termed as Relative Humidity is a measure of the amount of moisture present in the air and it is expressed as;

1 American Society of Heating, Refrigerating and Air-Conditioning Engineers.

$$RH = \frac{\text{Absolute Humidity (AH)}}{\text{Saturation Point Humidity (SH)}} \times 100\%$$

Where,

AH is amount of moisture actually present in unit volume of air, in terms of g/kg or g/m3.

SH is the maximum amount of moisture that a unit volume of air can hold at that temperature.

- Solar radiation, which falls upon the area during each season and determines the temperature.

- Wind speed, measured in m/s by anemometer while the wind direction is measured by a wind vane.

The climate of Southern Punjab has been classified as 'warm composite climate' in which hot dry, hot humid and cold prevail (SABDSP, 2005). Meteorological Department Lahore (2008) observed the maximum (hot) /peak temperature of Multan in June – July and minimum in Dec – Jan (Figure 7), the relative humidity is lowest during May – June and highest in Dec – Jan (Figure 8) and the normal wind velocity is 3.5 to 5.2 km/h.; also wind storms are frequent during March to August generally from west to south or north to east (Figure 9). The interior comfort level recommended for interior environment has been determined as 28°C for higher limits and 20°C for lower limit. The relative humidity limit ranges from 20% to 80%.

9. CASE STUDIES

Generally in Multan, traditional buildings had evolved an architecture that minimized heat gain by maximum insulation and provided controlled ventilation of interior. Massive walls with mud mortar and plaster, thick mud insulating roofing, limber shutters of doors and windows and use of cross ventilation and stalk effect with the use of 'Mang'[2] contributed to creating a cool interior environment.

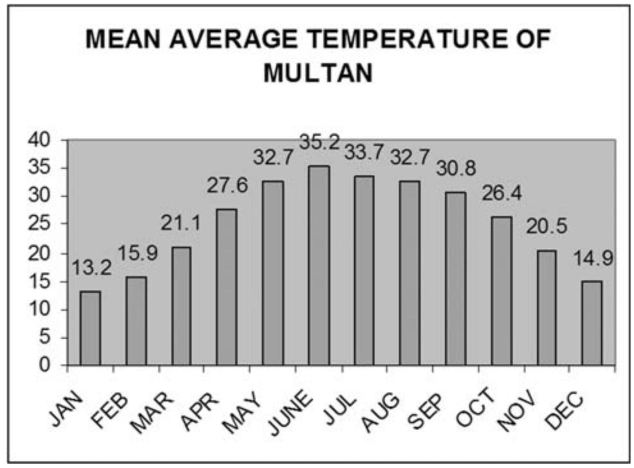

Figure-7: Average Minimum and Maximum Temperatuers in Multan, Pakistan.
(Source: Meterological Station, Lahore)

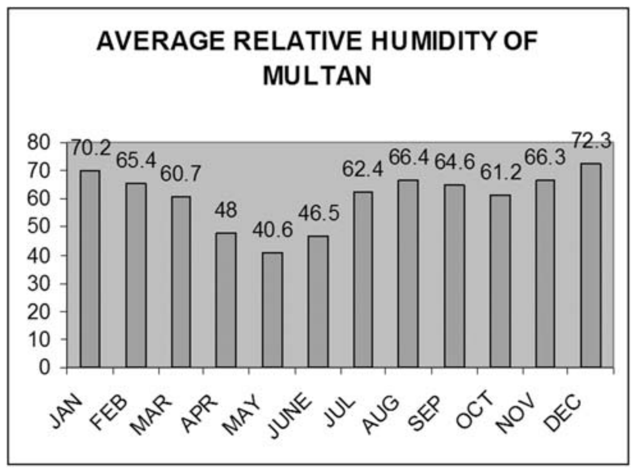

Figure-8: Average Relative Humidity of Multan, Pakistan
(Source: Meterological Station, Lahore)

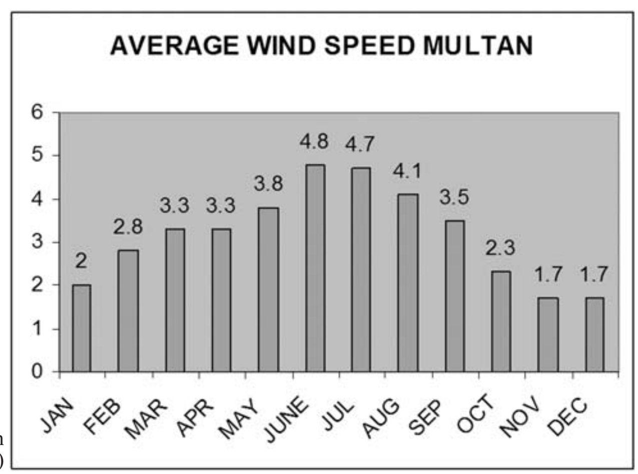

Figure-9: Average Wind Velocity of Multan, Pakistan
(Source: Meterological Station, Lahore)

2 Mang (Mungh) is a traditional term used for an opening made in the roof at the center of the room for air flow stack effect. (Ref: Glossary of Traditional terms for Residential spaces from A Handbook ofÊAppropriateÊBuilding Design forÊSouthernÊPunjab: published by CRC, 6-Temple road Lahore, June 2004.)

9.1 Contemporary Period

Contemporary architecture is applied to a range of styles of recently built structures and space which are optimized for current use. Table 1 shows the selected buildings under contemporary period (Figure 10).

Allama Iqbal Open University, Multan Campus.

Civil Engineering, Department, Bahauddin Zakariya University (BZU), Mutlan.

Punjab College of Information Technoogy, Multan.

Punjab College for Women, Multan.

Institute of Languages, BZU, Multan.

Institute of Management Sciences, BZU, Multan.

Figure-10: Selected Case Studies from Contemporary Period (Photographs by Author)

Building Name	Building Type	Design Features
Allama Iqbal Open University, Mutlan Campus (AIOU)	- Office Building - Education and Examination centre for AIOU, Multan Regional Office.	- Hollow Cement Sand blocks used for thermal insulation on roof - Provision of courtyard and verandahs inside building create cool environment during summer to increase thermal comfort and energy efficiency - Open spaces with sufficient plantation - Provision of sun shades
Civil Engineering Dept., UCET, BZU University, Multan	- North facing engineering education building inside the premises of BZU, Multan	- Vaulted high roofs are used to increase air space inside the building - Provision of courtyard and verandahs inside building create cool environment during summer to increase thermal comfort and energy efficiency - Large open spaces with sufficient plantation
Punjab College of Information Technology, Multan (PCI)	- North facing double storey education building	- Large open spaces with sufficient plantation - Provision of verandahs and central courtyard - No windows provided on east and west side to minimize heat gain during summer - Roof insulation provided with mud filling
Punjab College for Women, Multan (PCW)	- Triple storey east facing education building	- Provision of courtyard and verandahs inside building create cool environment during summer to increase thermal comfort and energy efficiency - Large open spaces with sufficient plantation - Roof insulation provided with mud filling Provision of sun shades
Institute of Languages, BZU, Multan (IOL)	- Triple storey east facing education building in the premises of BZU University, Multan	- Provision of two courtyards and verandahs inside building create cool environment during summer to increase thermal comfort and energy efficiency - Large open spaces with sufficient plantation - Roof insulation provided with mud filling No windows provided towards east and west side to minimize heat gain during summers
Institute of Management Sciences, BZU, Multan (IMS)	- Double storey west facing education building in the premises of BZU University, Multan	- Provision of two courtyards and verandahs inside building create cool environment during summer to increase thermal comfort and energy efficiency - Large open spaces with sufficient plantation - Roof insulation provided with mud filling Provision of water bodies and sun shades

Table-1: Selected Buildings of Conemporary Period.

9.2 Colonial Period

The Colonial age has predominantly buildings in Indo-European style i.e. the mixture of European and Indian-Islamic components. Most of the colonial buildings are still in use today. Multan, being a historic city has many colonial structures from which the following have been selected as the case studies shown in table 2 (Figure 11):

Muslim High School, Multan.

Public Library Langey Khan, Multan.

Civil Hospital, Multan.

District Nazim Office, Multan.

Raza Hall, Multan.

Town Hall, Multan.

Figure-11: Selected Case Studies from Colonial Period. (Photographs by Author)

Building Name	Building Type	Design Features
Muslim HIgh School, Multan (MHS)	- North facing education building	- Provision of two courtyards and large verandahs inside building create cool environment during summer to increase thermal comfort and energy efficiency - Open spaces with sufficient plantation - Roof insulation provided with mud filling - High roofs are used throughout in the building to increase air space inside building. - Provision of water bodies and sun shades
Public Library Langey Khan, Multan (PLL)	- South facing public library adjacent to Bagh Langey Khan, Multan	- Provision of verandah outside building to increase thermal comfort and energy efficiency - Large open spaces with sufficient plantation - Provision of double roof for insulation - Provision of courtyard - High roofs are used to increase air space inside building.
Civil Hospital, Multan (CHM)	- South facing hospital building	- Provision of two courtyards inside building and large verandahs inside and outside the building create cool environment during summer to increase thermal comfort and energy efficiency - Large open spaces with sufficient plantation - Roof insulation provided with mud filling - High roofs are used throughout to increase air space inside building - Provision of water bodies
District Nazim Office, Multan (DNO)	- South facing administrative office adjacent to district courts, Multan	- Provision of large verandahs outside building create cool environment during summer to increase thermal comfort and energy efficiency - Provision of courtyard - Large open spaces with sufficient plantation - Provision of double roof for insulation - High roofs are used throughout in the building to increase air space inside the building.
Raza Hall, Multan (RHM)	- West facing public gathering space	- Provision of large verandahs outside building create cool environment during summer to increase thermal comfort and energy efficiency - High roofs are used in the building to increase air space inside building - Provision of double roof and mud filling for insulation
Town Hall, Multan (THM)	- South facing administrative office	- Provision of courtyard inside the building and large verandahs outside the building create cool environment during summer to increase thermal comfort and energy efficiency - Provision of double roof for insulation - High roofs are used throughout the building to increase air space inside the building

Table-2: Selected Buildings of Colonial Period.

10. DATA ANALYSIS

Examples selected from Multan are based on general impression and professional judgment regarding the use of energy efficient means for achieving thermal comfort. Climatic conditions of summer season are studied in order to evaluate the user comfort level in public buildings of hot composite climate. Metrological Department Data of outdoor temperature of the region was used to determine comfort standards during summer months and further explained with results. Internal temperatures and humidity of rooms and verandahs have been measured by taking 24 readings from selected buildings during peak hot hours of summer in the afternoon time. Questionnaire survey is conducted from 10 randomly selected users of each building to measure the response about the comfort and usage of the building.

To measure the final score of user comfort and energy efficiency in public buildings of the hot composite climate of Multan, structured design and material aspects of buildings are observed on technical basis and weights are assigned to different components. Weighted average is calculated as final score. Final score is further converted into standard scores to find out the important factors and comparison of different aspects.

Comparisons are made from building to building and further between colonial and contemporary periods with respect to measure use of energy efficiency and user comfort achieved through these measures. Finally the colonial and contemporary buildings are compared for their energy efficiency and user comfort score.

10.1 Energy Efficiency of Building

Buildings are studied for use of energy efficient means and analyzed in two groups of contemporary and colonial buildings. Parameters of study with their respective weight-age are identified, in table 3 and corresponding data is collected from every building through field surveys and questionnaire surveys (table 4). Weight-age of each parameter is identified based on professional understanding.

Four broad parameters are taken comprising passive means for energy efficiency, ventilation, exterior of building and visibility (detailed in table 3). Weighted scores of energy efficiency of individual buildings are identified and applied to all buildings (detailed in table 5). After applying Weightage, Standard score for energy efficiency of each building is identified to be used in further comparison with user comfort applying the following formula:

$$\text{Standard Scores} = \frac{\text{Weighted Score} - \text{Mean of Scores}}{\text{Standard Deviation}}$$

After studying the individual building, a comparison of energy efficient means of buildings had been developed (Table 6). Therefore, from this comparison, it is indentified that colonial buildings are more energy efficient than contemporary buildings as additional means of energy efficiency are used in these buildings (Figure 12 & 13).

Proportion of Weightage of Energy efficiency of Buildings		
Passive Means for EnergyEfficiency		50
Orientation	10	
Courtyard	8	
Verandahs	8	
Wall Thickness	8	
Room Height	8	
Insulation	8	
Ventilation		18
Opening	6	
Wall Window Ratio	6	
Sun Shades	6	
Exterior of Building		24
Finish	4	
Vegetation	8	
Open Spaces	8	
Water Bodies	4	
Visibility		8
Natural Light	8	
		100

Table-3: Weightage for use of different engery efficient means in buildings.

S.No.	Building	Orientation	Courtyard	Verandah	Wall thickness	Room Ht.	Insulation	openings	Wall win ratio	Sun shades	Exterior finish	Vegetation	Open spaces	Waterbodies	Natural light
1.	AIOU	2.5	8	6	4	4	5.25	6	6	6	4	8	8		8
2.	CED	7.5	8	6	4	4	2.75	6	6	6	2	4	8		8
3.	PCI	7.5		4	4	4	2.75	3	6	6	4	2	4		8
4.	PCW	7.5		4	4	4	2.75	3	6	6	4	2	4		8
5.	IOL	5	8	8	4	4	2.75	4.5	4	6	2	4	8		8
6.	IMS	2.5	8	8	4	4	2.75	6	4	6	2	4	8		8
7.	MHS	2.5	8	6	6	6	2.75	6	6		4	6	8	4	8
8.	PLL	10	8	4	8	8	8	3	6	6	4	4	6		8
9.	CHM	10	8	8	6	6	2.75	4.5	4	6	4	2	6	4	8
10.	DNO	10		6	8	8	8	6	6	6	4	4	8		8
11.	RHM	10		6	6	8	8	4.5	6	6	4	4	6		8
12.	THM	10	8	8	8	8	8	6	6	6	2		8		8

Table-4: Shows usage of means of energy efficiency in the buildings (based on field survey).

S.No.	Building	Passive Means: 50	Ventilation: 18	Exterior: 24	Visibility: 8	Total	Scores	Std. Scores
1.	AIOU	11	8	10	1	30	75.84	0.2964
2.	CED	12	8	7	1	28	72.17	-0.0818
3.	PCI	10	6	5	1	22	55.17	-1.8339
4.	PCW	11	5	5	1	22	57.17	-1.6278
5.	IOL	12	6	7	1	26	68.17	-0.4941
6.	IMS	11	7	7	1	26	67.17	-0.5972
7.	MHS	12	7	10	1	30	73.17	0.0212
8.	PLL	18	6	7	1	32	83.01	1.0353
9.	CHM	16	6	7	1	30	79.17	0.6396
10.	DNO	18	8	8	1	35	82.01	0.9323
11.	RHM	17	7	7	1	32	76.51	0.3654
12.	THM	20	8	5	1	34	86.01	1.3445
Mean: 72.96417 Standard Deviation: 9.702918								

Table-5: Energy efficiency of selected buildings, standard scores from data collection after applying weightage.

Comparison of Scores

	Contemporary		Colonial	
Passive Means for Energy Efficiency		29.20		40.98
Orientation	5.42		8.75	
Courtyard	6.67		5.33	
Verandahs	6.00		6.33	
Wall Thickness	4.00		7.00	
Room Height	4.00		7.33	
Insulation	3.12		6.23	
Ventilation		15.08		15.67
Opening	4.75		5.00	
Wall Window Ratio	5.33		5.67	
Sun Shades	5.00		5.00	
Exterior of Building		13.67		15.33
Finish	3.00		3.67	
Vegetation	4.00		3.33	
Open Spaces	6.67		7.00	
Water Bodies	0.00		1.33	
Visibility		8.00		8.00
Natural Light	8.00		8.00	
		65.95		79.98

Table-6: Mean weighted scores of different energy efficient means in contemporary vs colonial.

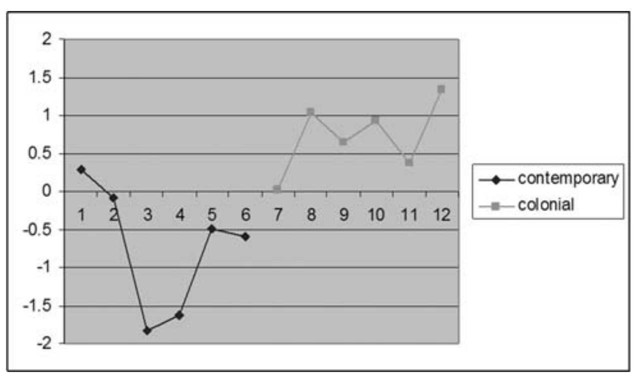

Figure-12: Energy efficiency of Contemporary vs Colonial (Based on Standard Scores).

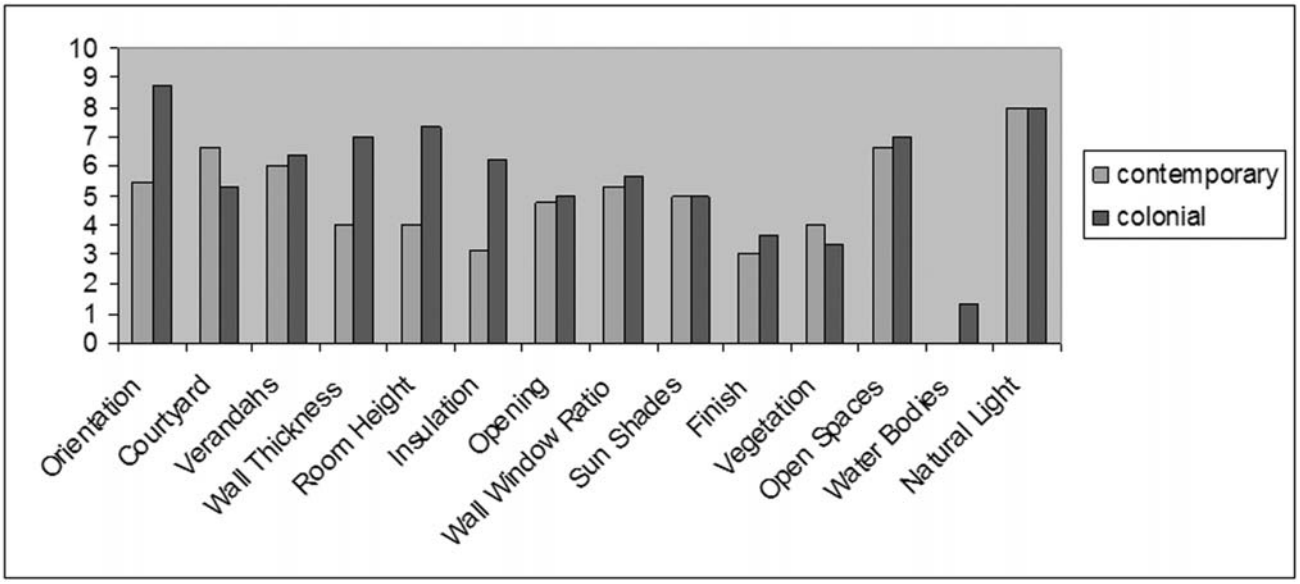

Figure-13: Comparison of means of energy efficiency between contemporary and colonial.

10.2 Climatic Studies of Buildings

From the case studies, verandah had been observed as a constant architectural element. Therefore, Temperature and Humidity are measured from rooms and verandahs of buildings to calculate the difference between outside and inside temperature and humidity twice a day in afternoon from May to August 2008 shown in (Table 7). Digital Hygro-Thermometer[3] has been used to measure the air temperature and relative humidity. This temperature is further compared with standard temperature derived through Adaptive Mean Vote (AMV)[4] to know the actual discomfort level (Table 8). Data of Temperature and Humidity levels of buildings is compared with the Standard Comfort levels. Standard scores are also calculated for further comparisons (Table 9). Therefore, it is found that both the temperature

		Temperature			Humidity		
S.No.	Building	Verandah	Room	Difference	Verandah	Room	Difference
1.	AIOU	35.20	34.50	0.70	49.04	47.21	1.83
2.	CED	35.33	34.70	0.63	52.67	48.21	4.46
3.	PCI	35.26	34.61	0.65	46.92	47.50	-0.58
4.	PCW	35.18	34.54	0.64	47.50	47.54	-0.04
5.	IOL	34.79	34.65	0.15	51.38	47.96	3.42
6.	IMS	34.73	34.44	0.29	51.96	48.50	3.46
7.	MHS	34.97	34.30	0.67	48.50	47.25	1.25
8.	PLL	354.42	34.50	0.92	48.25	46.79	1.46
9.	CHM	35.29	34.44	0.85	47.04	46.50	0.54
10.	DNO	35.75	34.45	1.31	46.75	45.71	1.04
11.	RHM	34.92	34.34	0.58	46.08	46.08	0.00
12.	THM	35.52	34.34	1.18	46.04	46.83	1.21

Table-7: Shows average of temperature and humidity from rooms and verandahs of selected buildings.

3 Hygro-Thermometer meets the GLOBE Protocols for air temperature, relative humidity, soil temperature and maximum-minimum and current temperatures.
4 AMV is calculated from Mean Temperature of the city measured by Meteorological Department Office, Multan

Months	Max T °C	Min T °C	Mean T °C	AMV °C
May	40.16	26.4	33.28	31.47
June	39.39	29.56	34.48	32.12
July	37.97	28.79	33.38	31.53
August	36.15	27.46	31.81	30.68
Mean	38.42	28.05	33.24	31.45

Table-8: Mean temperatures AMV of summer months for Mutlan.
(Source: Metrological Office, Multan).

Average Outdoor Temp. 33.24 Humidity Outdoor 39.73% AMV 31.45						
Buildings	Room Temperatyure	AMV Room	Standard Scores	Humidity Room	50-HR	Standard Scores
AIOU	34.50	-3.05	-0.05	47.21	2.79	0.02
CED	34.70	-3.25	-1.63	48.21	1.79	-1.20
PCI	34.61	-3.16	-0.94	47.50	2.50	-0.34
PCW	34.54	-3.09	-0.41	47.54	2.46	-0.39
IOL	34.65	-3.20	-1.24	47.96	2.04	-0.89
IMS	34.44	-2.99	0.41	48.50	1.50	-1.55
	34.57	-3.12		47.82	2.18	
MHC	34.30	-2.85	1.47	47.25	2.75	-0.03
PLL	34.50	-3.05	-0.05	46.79	3.21	0.52
CHM	34.44	-2.99	0.38	46.50	3.50	0.88
DNO	34.45	-3.00	0.35	45.71	4.29	1.84
RHM	34.34	-2.89	1.17	46.08	3.92	1.38
THM	34.34	-2.89	1.17	46.83	3.17	0.47
	34.40	-2.95		46.53	3.47	
Mean	34.49	-3.04		47.22	2.78	
Standard Deviation		0.1263			0.823153	

Table-9: Difference from comfortable temperature and humidity of buildings.

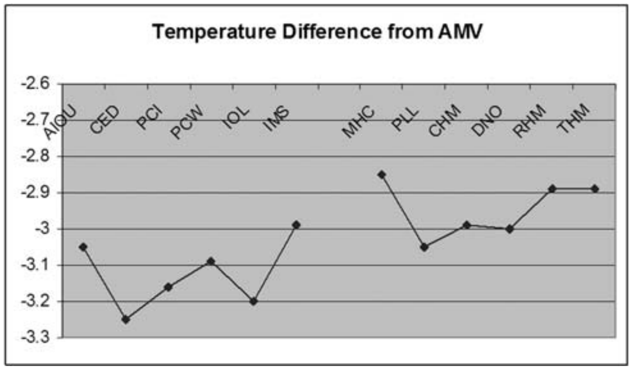

Figure-14: Comparison of temperature and AMV of buildings.

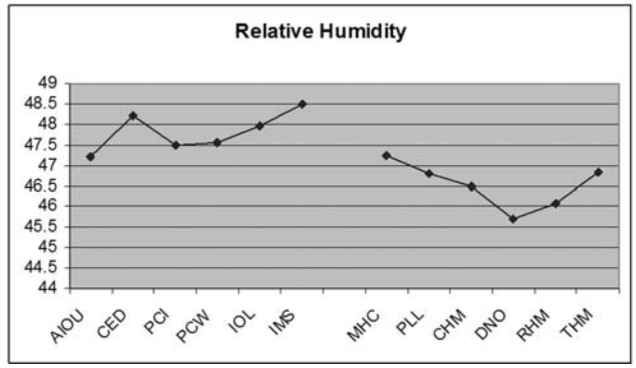

Figure-15: Comparison of humidity from comfortable lvel i.e. 50^{o}C of buildings.

and humidity of colonial buildings are more close to comfortable standards as compared to contemporary buildings (Figure 14 & 15).

10.3 Comfort Levels of Buildings

As this research is designed on a case study approach, ten users (employees) from each building between the age group 25-55 have been randomly selected for the questionnaire survey to assess their personal experience of comfort in reference to the selected buildings (Table 10), using respective form placed in (Figure 16). The user comfort components are assigned weights and weighted average scores of buildings are computed with results. Weight-age of each parameter is identified based on professional understanding (Table 11). Weighted scores of user's comfort of individuals are identified by applying the scores in the data collected from surveys (Table 12). Standard score for user comfort of each building is identified to be used in further comparison with energy efficiency applying the following formula:

$$\text{Standard Scores} = \frac{\text{Weighted Score} - \text{Mean of Scores}}{\text{Standard Deviation}}$$

S.No.	Building	Temperature	Humidity	Air Move	Air Quality	Bldg Space	Interior	Visibility	Color	Acoustic	Furniture	Access	Space R	Wind Flow	Score
1.	AIOU	6	1	4	4.5	1.5	0.5	1.75	1.25	9	1	0.25	0.75	1.5	33
2.	CED	-2	1.5	0	-1	1	-0.75	0	1	-2.5	-0.25	0.75	-0.75	-1	-4
3.	PCI	-1	1	1.5	0.5	-1.25	1.75	1.25	-2.5	2	3.25	-1	-0.75	-0.5	4
4.	PCW	-4	-1.5	-6	-5.5	1	2	1.25	3	2	4.25	2.5	2.25	2.5	4
5.	IOL	-1	-2	1.5	1	1	-0.75	0.75	-1.25	0	-2	-1.5	-0.5	0	-5
6.	IMS	-7	-1.5	-1	-0.5	0	-0.25	0	1	-1	-2	-1.75	-0.25	0.25	-14
7.	MHS	6	2	4	2.5	3	-1.5	-0.25	-2	4	-2	0.5	1	1.25	19
8.	PLL	-2	0	3.5	1	2.25	2	0.25	-0.75	-1	2.25	0.5	1	1.75	11
9.	CHM	1	0.5	-0.5	-1.5	0.75	-1.25	0.75	0.25	4	-0.5	1.25	1.5	1.5	8
10.	DNO	-1	1	3.5	1.5	4.25	2	2	1.75	4	2.75	2.25	2.5	3	30
11.	RHM	-2	0	-0.5	5.5	0.25	-0.75	2.75	0.75	2.5	-1.75	-0.75	-0.25	1.75	8
12.	THM	6	2	4	2	2	-1.75	0	-1.25	0	0.25	0	0	0.75	14

Table-10: User's Comfort Level of Selected Buildings (Through Questionnaire Survey).

User Comfort and Energy Efficiency in Public Buildings of Hot Composite Climate

Building: ______________________________

Name: ______________________________

Organization: ____________________ Designation: ______________

Age Group: < 20 ☐ 20-30 ☐ 30-40 ☐ 40-50 ☐ > 50 ☐

User Comfort Assessment

Thermal comfort

	Highly Uncomfortable	Uncomfortable	Not Bad	Comfortable	Highly Comfortable
Temperature (High, Low)	-2	-1	0	+1	+2
Relative Humidity (Humid, Dry)	-2	-1	0	+1	+2
Air Movement (High, Low)	-2	-1	0	+1	+2
Air Quality (Pleasant, Stagnant)	-2	-1	0	+1	+2

Visual comfort

	Highly Uncomfortable	Uncomfortable	Not Bad	Comfortable	Highly Comfortable
Building space	-2	-1	0	+1	+2
Interior	-2	-1	0	+1	+2
Visibility	-2	-1	0	+1	+2
Colour scheme	-2	-1	0	+1	+2

Acoustic Level:

	Highly Uncomfortable	Uncomfortable	Not Bad	Comfortable	Highly Comfortable
(High, Low)	-2	-1	0	+1	+2

Usage Comfort:

	Highly Uncomfortable	Uncomfortable	Not Bad	Comfortable	Highly Comfortable
Furniture Arrangement	-2	-1	0	+1	+2
Access to the space	-2	-1	0	+1	+2
Space Relationship	-2	-1	0	+1	+2
Work Flow	-2	-1	0	+1	+2

Figure-16: Sample of Questionnaire.

Proportion of Weightage of User Comfort of Buildings

Thermal Comfort		50
Temperature	20	
Humidity	10	
Air Movement	10	
Air Quality	10	
Visual Comfort		20
Building Space	5	
Interior	5	
Visibility	5	
Color Scheme	5	
Acoustic Level	10	10
Usage Comfort		20
Furniture Arrangement	5	
Access to the Space	5	
Space Relationship	5	
Work Flow	5	
		100

Table-11: Weightage for user comfort parameters in the buildings under study.

S.No.	Building	Thermal Comfort	Visual Comfort	Acoustic Level	Usage Comfort	User's Comfort
1.	AIOU	25	20	18	14	77
2.	CED	-1	5	-5	-5	-6
3.	PCI	5	-3	4	4	10
4.	PCW	-30	29	4	46	49
5.	IOL	0	-1	0	-16	-17
6.	IMS	-13	3	-2	-15	-27
7.	MHS	23	-3	8	3	31
8.	PLL	7	15	-2	22	42
9.	CHM	-2	2	8	15	23
10.	DNO	11	40	8	42	101
11.	RHM	8	12	5	-4	21
12.	THM	22	-4	0	4	22

Table-12: User comfort level of buildings under study (Through Questionnaire Survey).

After studying individual buildings, a comparison of user comfort in buildings had been developed (Table 13). Therefore, from comparison, it is found that colonial buildings are more comfortable than contemporary buildings as more users of these buildings mentioned their satisfaction in the questionnaire survey (Figure 17).

10.4 Comparison of Energy Efficiency and User Comfort

Energy efficiency, temperature, humidity and user comfort of buildings are calculated through scores from data collected and converted into Standard score for comparison with comfort levels for hot composite climate. Individual scores are identified by field survey and questionnaire survey (Table 14).

$$\text{Mean Score} = X = \frac{\varepsilon X}{n} = \frac{\text{Sum of Scores}}{\text{Number of Scores}}$$

Standard Scores are derived through Standard deviation and mean values from scores (Table 15).

$$\text{Standard Score} = \frac{\text{Weighted Score} - \text{Mean Score}}{\text{Standard Deviation}}$$

By comparison of standard scores, it is found that all three factors studied are directly proportional and support each other. The buildings using more energy efficient means are more comfortable; study further asserts that colonial buildings are more energy efficient and comfortable than contemporary buildings (Figure 18).

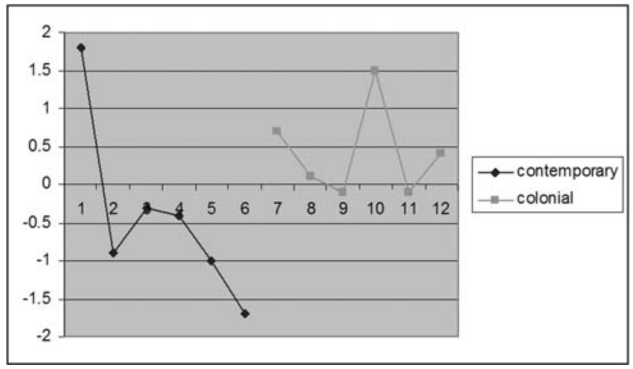

Figure-17: User comfort of contemporary vs colonial (based on standard scores).

11. CONCLUSIONS

1. The design, optics, building materials and construction techniques of public buildings reflect the measure of advancement of a society or a nation. There is a need to recognize that public buildings influence broader cross-section of community and make lasting contributions to enhance our quality of life.

2. Global warming appears to be apparent in the climatic

S.No.	Building	Thermal Comfort	Visual Comfort	Acoustic Level	Usage Comfort	User's Comfort	Standard Scores
1.	AIOU	15.5	5	9	3.5	33	1.8
2.	CED	-1.5	1.25	-2.5	-1.25	-4	-0.9
3.	PCI	2	-0.75	2	1	4.25	-0.3
4.	PCW	-17	7.25	2	11.5	3.75	-0.4
5.	IOL	-0.5	-0.25	0	-4	-4.75	-1.0
6.	IMS	-10	0.75	-1	-3.75	-14	-1.7
7.	MHS	14.5	-0.75	4	0.75	18.5	0.7
8.	PLL	2.5	3.75	-1	5.5	10.75	0.1
9.	CHM	-0.5	0.5	4	3.75	7.75	-0.1
10.	DNO	5	10	4	10.5	29.5	1.5
11.	RHM	3	3	2.5	-1	7.5	-0.1
12.	THM	14	-1	0	1	14	0.4
Mean: 8.9 Standard Deviation: 13.66917							

Table-13: Comparison of user comforts in buildings after applying weightage.

S.No.	Building	Energy Efficiency	Temperature	Humidity	User Comfort
1.	AIOU	75.84	0.06	2.79	33.00
2.	CED	72.17	-0.14	1.79	-4.00
3.	PCI	55.17	-0.05	2.50	4.25
4.	PCW	57.17	0.02	2.46	3.75
5.	IOL	68.17	-0.09	2.04	-4.75
6.	IMS	67.17	0.12	1.50	-14.00
7.	MHS	73.17	0.26	2.75	18.50
8.	PLL	83.01	0.06	3.21	10.75
9.	CHM	79.17	0.12	3.50	7.75
10.	DNO	82.01	0.11	4.29	29.50
11.	RHM	76.51	0.22	3.92	7.50
12.	THM	86.01	0.22	3.17	14.00

Table-14: Comparison of Raw scores for energy efficiency and user comfort.

S.No.	Building	Energy Efficiency	Temperature	Humidity	User Comfort
1.	AIOU	0.30	-0.10	-0.04	1.77
2.	CED	-0.08	-1.64	-1.23	-0.94
3.	PCI	-1.83	-0.97	-0.39	-0.34
4.	PCW	-1.63	-0.45	-0.44	-0.37
5.	IOL	-0.49	-1.26	-0.94	-1.00
6.	IMS	-0.60	0.35	-1.58	-1.67
7.	MHS	0.02	1.38	-0.09	0.71
8.	PLL	1.04	-0.10	0.46	0.14
9.	CHM	0.64	0.32	0.80	-0.08
10.	DNO	0.93	0.29	1.75	1.51
11.	RHM	0.37	1.09	1.30	-0.10
12.	THM	1.34	1.09	0.41	0.38

Table-15: Comparison of standard scores for energy efficiency and user comfort (calculated from data collected through surveys).

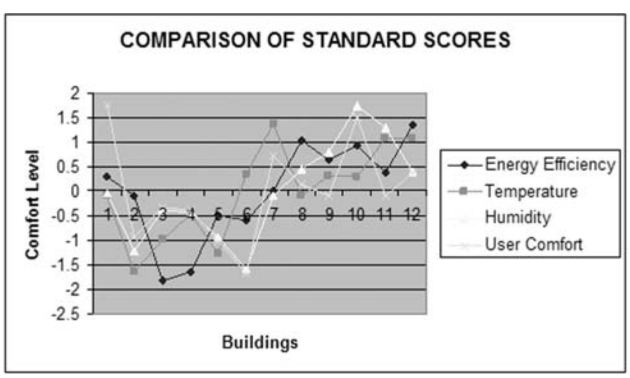

Figure-17: User comfort of contemporary vs colonial (based on standard scores).

cycle of Pakistan. Due to very hot summers in Pakistan, buildings especially public buildings tend to produce internal temperatures close to or exceeding the upper limit of comfort.

3. By adopting some simple passive features like most climatically favorable orientation, adequate shading of windows, reflective coatings on exterior surfaces, greenery cover over the building, roof and wall insulation, energy efficient window system, judicious provision of windows for ample natural ventilation etc results in significant saving in the energy consumed while creating comfortable environment indoors.

4. Energy efficiency measures for buildings are approaches through which the energy consumption of a building can be reduced while maintaining or improving the level of comfort in the building. They can typically be categorized into:

- Reducing heating and cooling demand;
- Reducing energy requirements for ventilation, lighting and heating water;
- Reducing electricity consumption of equipment and appliances;.

5. Buildings surveyed from colonial period are equipped with more energy efficient elements and are more comfortable than the buildings from contemporary period.

6. Buildings in which no passive elements had been used were made comfortable through active means of thermal comfort by excessive energy use.

7. Issues of thermal evaluation regarding energy optimization are not fully considered during the design, in most cases. These issues rely on the holistic understanding of building thermal behavior, which depends on the interaction of building elements with outside and inside variable conditions.

8. In subjective approach of research it is found that human body tends to adjust with the local climate by using adaptive mechanism to achieve their desired comfort conditions much earlier than the logical calculated physiological comfort values. This point is further supported by Adaptive Mean Vote (AMV) of this area.

9. In objective approach of thermal comfort, AMV[5] is closer to the required comfort levels, as compared to standards of Predictive Mean Vote (PMV)[6], confirmed through questionnaire survey.

10. Field studies clarify that results from local climatic setup are different from generalized standards and are more economical and acceptable by users.

12. RECOMMENDATIONS

1. Thermal standards for buildings that can promote use of some simple passive energy efficient elements should be formulated. If buildings are designed and built to incorporate the right mix of these characteristics, the occupants will be able to make themselves comfortable in these buildings using minimum energy.

2. The governmental department should improve the legislative system, mechanism and legal system of energy efficiency in the buildings.

3. Establish and improve the technology on energy efficiency in building through research on energy saving technology and new materials combined with the local climatic characteristics.

4. Use of local resources and materials should be optimized to design buildings based on the principles of thermal comfort.

5. Monitoring and evaluating the energy efficiency in newly-built buildings.

6. Promoting the energy efficiency measures in large public buildings.

7. Enhance research to develop energy saving strategies in buildings and disseminate its application.

8. Building designers should estimate the indoor temperature that building occupants find comfortable and creative ideas should be applied to provide comfortable indoor environments with minimal energy usage.

9. Further studies can be performed considering other aspects of user comfort and energy efficiency considering different energy efficient elements separately.

5 Demonstrates that people are more tolerant of temperature changes than laboratory studies suggest.
6 Based on ASHRAE standards and derived from studies of individuals in tightly controlled conditions.

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