TOWARDS ENERGY EFFICIENT DESIGN AND SUSTAINABLE BUILDINGS

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has been accepted towards the partial fulfillment

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DEDICATED

TO

MY PARENTS, SIBLINGS and

MY SON

ACKNOWLEDGEMENTS

In the name of Allah, the most merciful, the most compassionate all praises be to Allah, the lord of the worlds and prayers and Peace be upon Muhammad his servant and messenger.

The completion of this project was only possible due to unlimited blessings of almighty Allah and collaboration of many people, to whom I wish to express my gratitude.

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ABSTRACT

With the ever increasing energy consumption around the globe, not only fossil fuels are being depleted but environment is also getting worse as a result of pollution. This increase in energy usage and consumption is leading to greenhouse effect and global warming. It is therefore, need of time to minimize usage of energy with all possible means.

Energy consumption in buildings and infrastructure has increased many folds suggesting design requirement need for a shift towards energy efficiency and conservation as well as operation of buildings through sustainable means. In buildings, energy efficiency can be achieved using insulation materials, improved architectural technique, and modified construction methodology. To reduce the energy demand to operate buildings, means are to be devised that harvest renewable energy and making a building capable of sustaining itself. Such buildings do not require energy to be supplied by external sources; the energy is produced and used at site which is the best option for environment.

To study energy consumption effectiveness, observational and experimental investigations were carried out on four existing buildings and a model based on different contributing parameters such as orientation, construction materials used, type of construction, height, and architectural design. The results show that by using alpolic cladding and double layered windows at outer face of buildings increase thermal efficiency by 8%. The cavity wall construction improves the energy conservation of the building by 6% compared to traditional block construction. The model studies show that, using cavity wall and structural concrete insulated panels (SCIP) as cladding/infill walls in frame structures, can reduce the energy demand of the building up to 3%. Simple techniques such as altering building orientation, architecture, use of latest energy efficient materials, and enhanced construction techniques contribute significantly towards energy efficient and sustainable performance of buildings.

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CHAPTER 1

INTRODUCTION

1.1 General

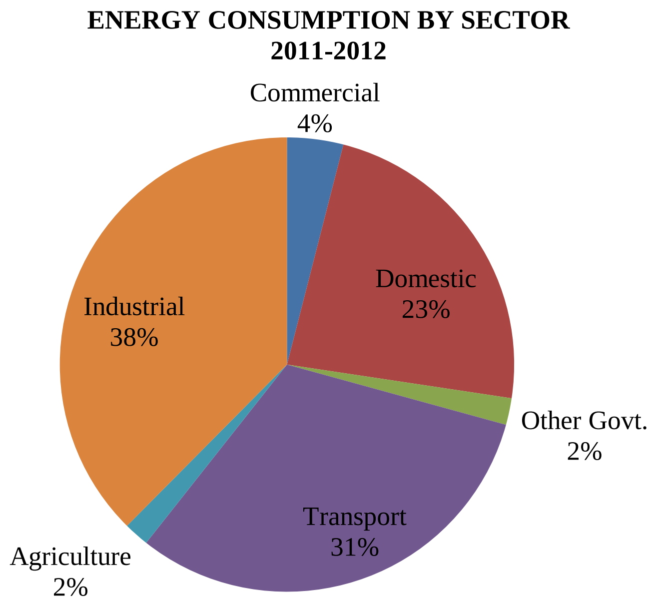
Sustainable and affordable energy supply is essential for the socio-economic development of a country. The severe energy shortage faced by many underdeveloped countries in present times has resulted in economic challenges. The situation continues to aggravate progressively and the gap between energy supply and demand is widening (Wu and Zhou, 2011). There has been an enormous increase in the global demand for energy in recent years as a result of industrial development and population growth whereas, energy production sectors are unable to fulfill that demand. The spontaneous growth in demand of energy is due to the rapid increase in population, improvement in the living standards, industrial development, and expansion of domestic dwellings.

It is without exaggeration and doubt that energy has become one of the most significant needs of humankind in present era. The utility of energy has greatly evolved over the last century. The whole range of human activities including infrastructure, trade and commerce, industry, transportation and agriculture has mostly become dependent on energy. The growing human reliance on energy has been paralleled by a sequence of challenges that are both local and global in nature. It is progressively understood that ensuring availability of sufficient, affordable, and environmentally friendly energy is one of the key challenges faced by the world in the twenty first century.

Energy can be considered to be most crucial and imperative need for human activities not only in present times but in future as well. The accomplishment of human civilization has been achieved through the increasingly efficient and extensive production of various forms of energy to fulfill human needs. Providing adequate and affordable energy is therefore, essential for the eradication of poverty, improvement of human welfare and raising living standards of human beings throughout the world (Vera and Langlois, 2007). Per capita energy consumption is an index that demonstrates the socio-economic prosperity in any society. The human development index of a country has a strong relationship with its energy prosperity (IAEA, 2005). At present, the key factors which drive the growth in energy demand include increasing human population, modernization and urbanization (Vera and Langlois, 2007). According to the United Nations, present world population of 6.5 billion is predicted to reach to 9.1 billion by 2050. Most of this population growth is expected to take place in the developing world such as Asia and Africa (United Nations, 2005). Poor and inadequate access to secure an affordable means of energy is considered one of the crucial factors behind the environmental degradation.

According to Human Development report of United Nations Development Program UNDP (2007-2008) (Watkins, 2007), during the last twenty five years over 1.3 billion people living in developing countries have been provided access to electricity, but more than 1.4 billion people (which is over 21 percent of the world’s population) do not have access to it. With the growing world population and aspiration for improved life, a central and collective global concern in the new century is to sustain socio-economic growth within the constraints of the earth's limited natural resources along with saving the environment. Enhancement of building services and comfort levels, together with the rise in time spent inside buildings has significantly raised energy demand of buildings. An acute energy shortfall is being realized by many nations around the globe. The natural reserves are depleting rapidly, therefore, it is necessary that energy should be conserved, sustained and be produced through alternate or renewable means.

According to the figures taken from Pakistan Energy Book 2012 (latest published) the energy consumed by sector has increased 4.03 Million TOE (Tonne of Oil Equivalent) from year 2007 to 2012. Fig. 1.1 reflects that in year 2012, the energy consumed at industrial and domestic level is 38% and 23% respectively. It shows that more than 60% of the produced energy is consumed in buildings. Hence one should design and construct buildings considering their operation to be sustainable. With the increase in population and occupancy rate of the buildings, it is very essential to focus the saving of energy and fully utilize the natural living conditions.



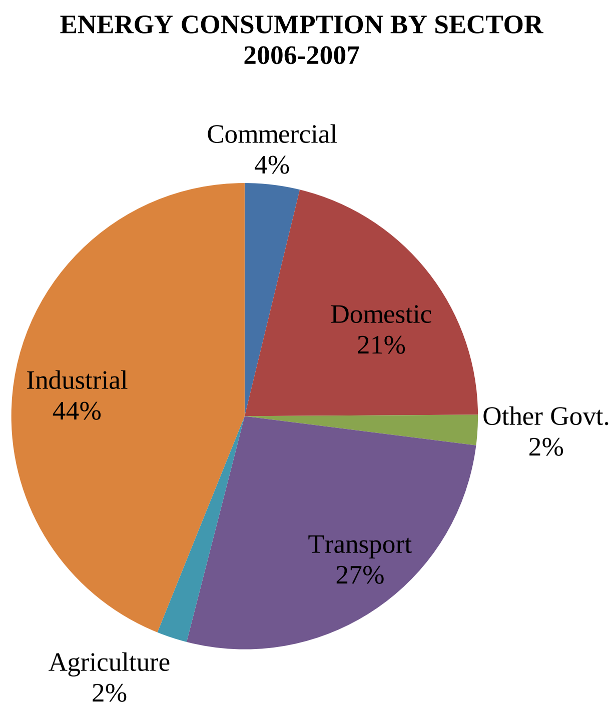


Fig. 1.1 Charts showing energy consumption in different sectors in Pakistan (Pakistan Energy Yearbook 2012).

Over the last 20 years, global primary energy consumption has grown by an average of about 2% a year (IEA, 2014). The world's energy demand in the future is hard to predict. The energy demand is increasing and supply is decreasing with the passage of time as shown in Fig. 1.2. The graph depicts that there will be a increasing gap between energy supply and demand in future.

This gap can only be filled by devising ways of alternate energy production which are sustainable towards future. Presently, around the globe, buildings are assumed to be responsible for 40% of total world annual energy consumption (Omer, 2008).

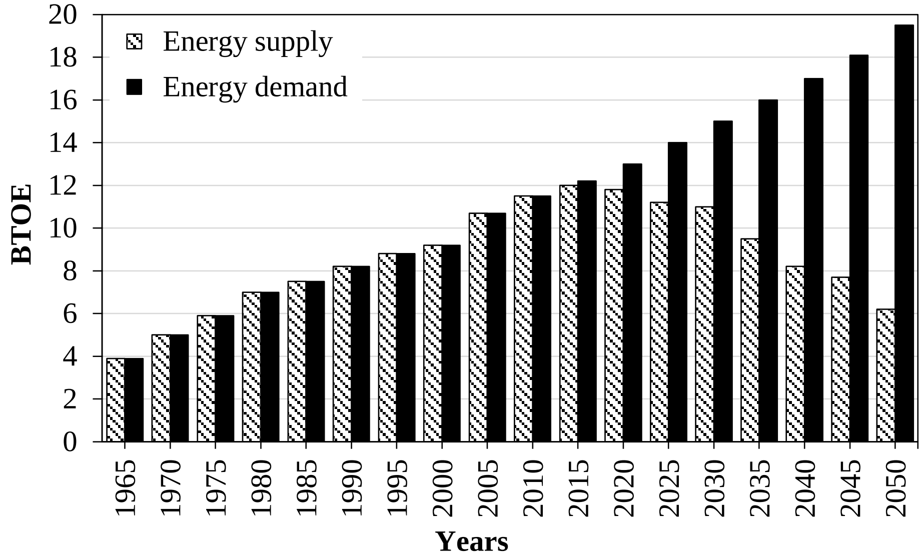


Fig. 1.2 Energy supply and demand trends in billions of tonnes of oil equivalent (BTOE).

It is necessary to minimize the usage of energy with all possible means and wisely consume the available energy sources to fulfill the needs. Although it is challenging to optimize the necessities, but a new culture needs to be developed to conserve energy. Energy efficient buildings are imperative to reduce the energy burden and improve the socio-economic development of a country. Recently this realization is gaining acceptance to design buildings incorporating energy efficiency and sustainability concepts and in this regards the construction industry shall play a vital role (Excellence).

Energy efficient buildings are architecturally altered with modified construction methodology and materials in order to perform efficiently with respect to energy consumption. Energy losses are always envisaged in such energy efficient buildings, however lower amount of energy is required to operate such buildings with same level of living comfort and performance. Use of improved quality construction materials is also helpful for energy conservation in energy efficient buildings. Conversely, sustainable buildings are the one operated with least consumption of natural resources without compromising the operation, services and comfort. The Organization of Economic Co-operation and Development (OECD) recognized sustainable buildings as resource efficient, energy efficient, pollution free, able to harmonize with environment, and the ones that use integrated and sustainable approaches (OECD). These buildings require least energy to be supplied by external sources, as energy is produced and used by such buildings indigenously. Sometimes energy efficient buildings may also be called sustainable buildings or green buildings, based on reduced amount of running energy needs as well as reduction in greenhouse gas emissions. Environment friendly processes are incorporated in design, construction, operation, maintenance and renovation of energy efficient buildings.

1.2 Objectives

Increasing energy consumption around the globe is leading to greenhouse effect and global warming. The major challenge construction industry is facing is to reduce CO_2 emissions and provide the total energy share with renewable energy. Growth in population, enhancement of building services and products, together with the rise in time spent inside buildings, increase in comfort level has raised energy consumption of the building.

In the residential sector, size and location are key factors for energy consumption. Small flats need less energy as there is less conditioned and transfer area, and also less occupation. The amount and type of energy used in dwellings are mainly related to weather, architectural design, energy systems and economic level of the occupants. Within the commercial sector, office buildings are those with the biggest energy consumption and CO_2 emissions.

Our aim is that without negotiating the strength and serviceability of the building, the architecture and design of buildings can be enhanced/modified which reduces the energy demand of a building and also contributes towards building sustainability. The main objectives of this study are given below:

- Monitoring of the performance of existing building some of which were designed to perform as energy efficient buildings.
- Comparison will be made on basis of construction material used, type of construction selected and architectural techniques adopted.
- A real time energy efficient building model will be monitored constructed on same criteria.
- Based on the results obtained, some construction practices and architectural amendments will be proposed.

- Locally available construction material will be evaluated for its performance and efficiency in construction of energy efficient buildings.
- Means to achieve sustainability will be proposed keeping in view their limited maintenance cost and least environmental hazards.

Based on this study alteration in construction technique and construction materials, along with architectural modifications will be proposed for energy efficient buildings design. Buildings performance will be monitored based on its orientation and height.

The growing trend in building energy consumption will continue to rise during the coming years due to the expansion of built area and energy to operate it, as long as resource and environmental exhaustion or economic recession allows it. Private initiative together with government intervention through the promotion of energy efficiency, new way for energy production, limiting energy use and raising social awareness on the rational use of energy will be essential to make possible a sustainable energy future.

1.3. Organization of the report

Chapter 1:

- Introductory about energy shortfall in Pakistan.
- Energy efficient design and sustainable buildings.
- Objective of the study and thesis overview.

Chapter 2:

- Brief literature review of buildings and factor effecting energy consumption in them.
- Building’s specific components and its benefits.

Chapter 3:

- Methodology adopted to study the existing building and model monitored.
- Details of material or construction technique used.

Chapter 4:

- Experiment observations & results
- Analysis and comparison of test results.

Chapter 5:

- Conclusions based on findings of this research
- Recommendations for field application to achieve energy efficiency and sustainability.

CHAPTER 2

LITERATURE REVIEW

2.1 General

The brief preview of literature is helpful in understanding the energy efficient design and concept of sustainable housing but however it lacks substantial quantification. Although architectural and construction techniques contribute significantly to attain energy efficiency, but comparison is desired to evaluate their contribution in performance. Insulation is an effective way to achieve energy efficiency in buildings, therefore practical demonstration for the most efficient methodology is desired to evaluate its architectural based performance in buildings. In this regards, work has been carried out on different architectural components such as windows, façade, cladding etc., for which energy efficiency needs to be evaluated in buildings with provision of such components.

2.2 Literature Review

Building responsible for energy efficiency and sustainability are associated with their construction methodology, materials of construction and design practices. A brief study review of such factors is given below.

Orientation:

Building orientation is a significant design consideration mainly with regard to solar radiation and wind. In predominantly cold regions buildings should be oriented to maximize solar gain, the reverse is done in hot regions. In regions where seasonal changes are prominent we have to consider both the situations periodically. For a cold climate and orientation, slightly east of south is favored. Specially 15º east of south, as this exposes the unit to more morning than afternoon sun and enables the house to begin to heat during the day. Similarly wind can be desirable or undesirable quiet often as compromise is required between sun and wind orientation. With careful design shading in deflecting devices can be incorporated to exclude the sun or redirect it into the building just as wind can be diverted or directed to the extent desired.

Building envelope and fenestration:

The building envelope and its components are key determinant of the amount of heat gain and loss and wind that enters inside. The primary elements affecting the performance of the building envelope etc

Ventilation:

Natural ventilation has many purposes among which 2 key purposes are:

- Arrange best air quality with least need of electricity.
- To enhance the rate of thermal comfort in the summer by high night ventilation rates and increase in daytime air speed.

Design Recommendations:

- While making decisions, it is essential to benefit from current wind conditions and surrounding site conditions.
- The opening/windows, their sizes and placement tells the extent of ventilation.
- To maximize wind-induced ventilation place the ridge perpendicular to summer winds.
- Make narrow building for naturally ventilated.
- Orient the windows crossways and away from each other to increase the mixing of air in room.
- Minimize the barriers to airflow within the space available.
- Inhabitants should be able to operate window openings.
- Provide elevated cavity.

Natural Ventilation:

Air has a capability to flow due to low friction.it can be directed and deviated easily if design and building form strongly integrate with it. In all over the school, natural ventilation has been done. Building form is capable to provide good air quality with excellent flow. This has been done by applying following strategies.

Cross ventilation:

Two windows in opposite walls have been provided in all rooms in order to create cross ventilation. Air comes from one side and makes the other layer to go out and take its place. This ensures the good air quality as well as provides moisture free air to avoid suffocation and unhygienic air. In washrooms, two light shelves act as a ventilator as well as a passive day lighting tool.

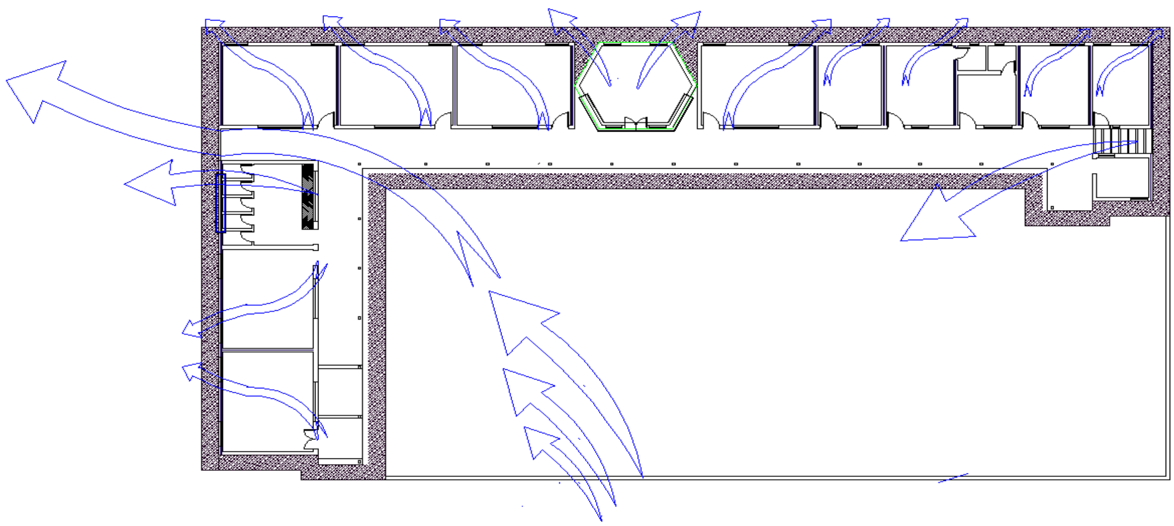


Fig. 2.1 Natural and cross ventilation phenomenon in buildings.

Stack Effect:

Every fluid rises and attains height when absorb heat due to high potential energy so as air do. Stack effect obeys the same. It's a sort of "ventilative cooling". It's basically a phenomenon in which air in the building warms, becomes more buoyant then outside air and rises to escape out of openings high in the buildings."

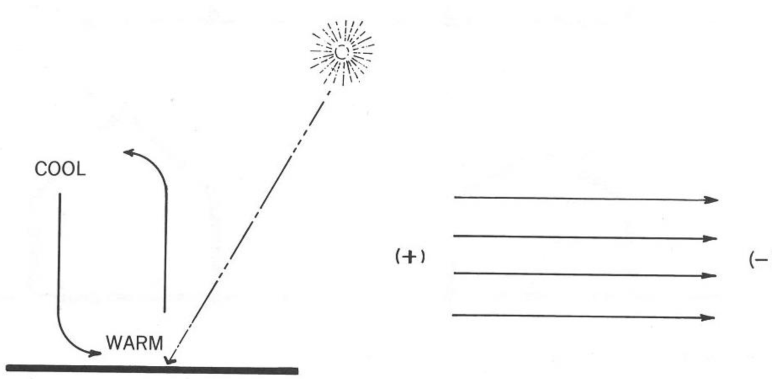


Fig. 2.2. Air circulation due to temperature difference

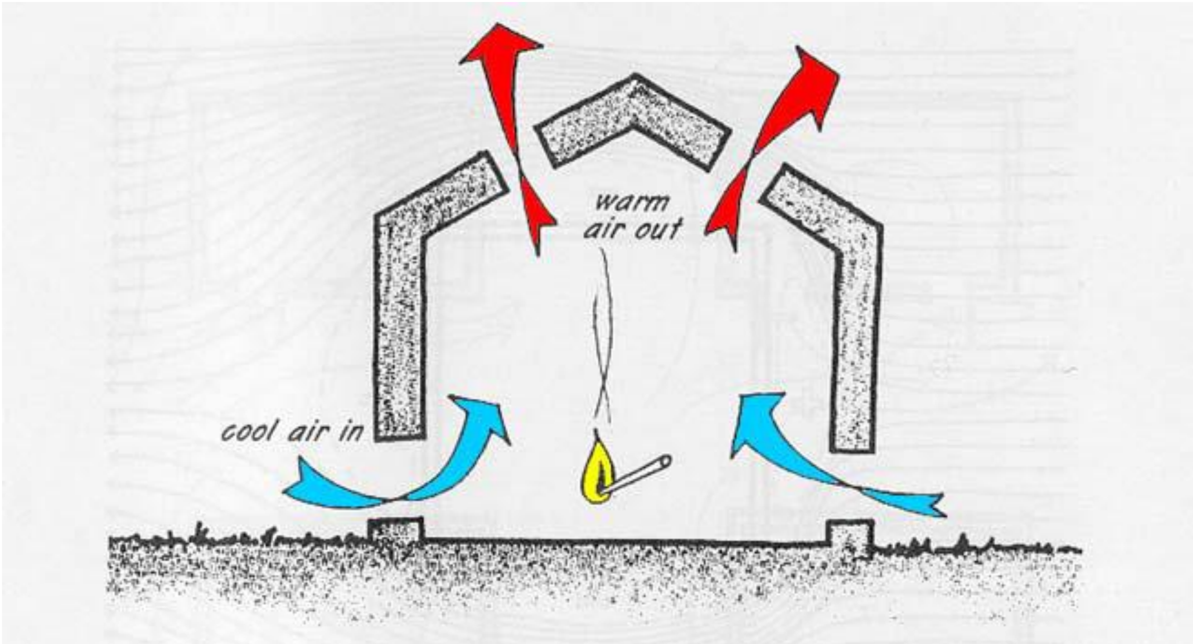


Fig. 2.3 Warm and cool air circulation in buildings.

In our principal office ventilation is done by Stack effect in which air comes inside by south facing window and escapes by rising from ventilator given above. In other rooms, slits are also provided to have the same effect.

Materials

Structural Concrete Insulated Panel (SCIP)

The Structural Concrete Insulated Panel System is a reinforced sandwich panel used for many building applications. The SCIP consists of a super-insulated core of rigid expanded polystyrene sandwiched between two engineered sheets of steel welded wire fabric mesh. A galvanized steel truss wire is pierced completely through the polystyrene core at offset angles for superior strength and welded to each of the outer layers sheets steel welded wire fabric mesh. Afterwards, a special mix of shotcrete is applied on either side of the panel after being installed in the roof & walls of the building. This concrete is then finished with a trowel to produce a highly insulated energy efficient RCC building with a life of more than 50 years. The overall cost of the grey structure constructed with these panels is around 750 PKR/sft. Transporting cut to size to the jobsite, the panels can be rapidly assembled by workers without extensive training. Wall panels and Roof Panels are manufactured in 4ft. in width and 10 ft. height, available in thicknesses range of 2 in. to 6 in. A typical cross section of SCIP is shown below:

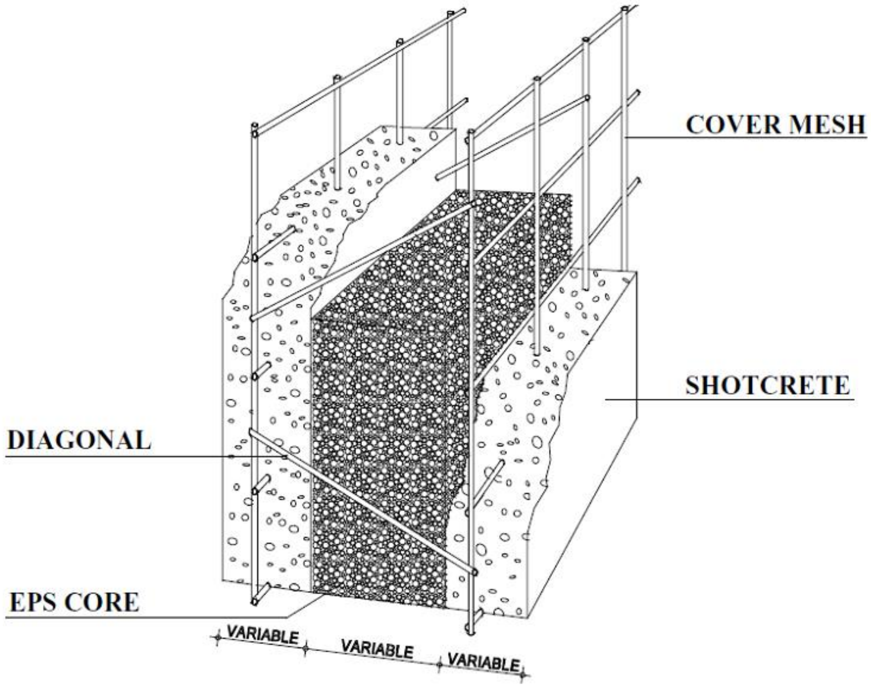


Fig. 2.4. Three dimensional view of SCIP panel.

The SCIP can be used for numerous applications in buildings, such as in floor systems, roofing structure, beams, columns, as well as in stairs and boundary walls, along with many other members. They can be used as a replacement for brick masonry walls & metal framed walls. Single storey, double storey & multi storey buildings can be constructed using SCIP. We know that Concrete and Steel (RCC) are still the best materials known today for the structural strength of the buildings. SCIP utilizes the same materials but with enhanced properties. SCIP construction system ensures economy in the usage of materials. It can satisfy the physical and structural requirement similar to a traditional building system. As compared with traditional building techniques, they can reduce up to 40% of the total weight of construction.

Distinctive Features of SCIP System

SCIP system has a number of advantages, it is cost effective, time & labor efficient and most importantly Energy Efficient. This system is very versatile and offers great flexibility and can be used to produce many creative and complex architectural designs easily. Moreover, its energy savings and structural integrity provide long term benefits to the owner. Some of its distinctive features are given below,

Hurricane & Earthquake Protection of structures built with SCIP have been reported to have survived the severest of the storms and other natural disasters. The SCIP buildings can withstand wind velocities of more than 300 Km/hr. and earthquakes of 0.4g acceleration or more than 7.5 on the Richter scale.

Energy Savings with the use of SCIP can cause a reduction in the utility bills by 50% - 80% because of the requirement of smaller and more efficient HVAC systems due to lower heating and cooling loads. Thus these structures are cooler inside in summers and warmer in winters. The incorporation of expanded polystyrene foam ranging in thickness from 50mm to 100mm provide an excellent thermal barrier. Furthermore, there are no wooden or metal studs to transfer or conduct heat through the walls. Super insulated PS foam cores provide R 4.2 per inch of foam, also the performance of the walls is much greater due to superior sealing and thermal mass. **Lesser Maintenance Cost** of houses and other buildings constructed with SCIP require minimum long term maintenance, especially in areas prone to extreme weather and temperature conditions such as summer heat, winter snow, heavy rains, and high winds. **Time & Labor Savings** as no highly skilled workers are required to place and fix the SCIP. Relatively fewer masons and a few skilled workers can get the job done. **Lesser Construction Cost** as SCIP uses lightweight materials, which reduces the total weight by about 40%, as compared with traditional construction materials. Thus it can be easily used even on soil of low bearing capacity. Furthermore, the economical use of materials and labor further minimizes the cost. **Financial Sensibility** can be achieved by early completion of the project, means that the building can be occupied early, fewer laborers and less equipment means lower cost. Altogether it will result in a lower capital cost. Environment Friendly: As SCIP do not use any wood, therefore this means that it does not cause any depletion of forestry products. The high density polystyrene foam used in it does not contain any Chlorofluorocarbons (CFCs), thus it doesn’t damage the ozone. All the materials are also **recyclable**. Heat & Sound Insulation: Heat transmission through SCIP is about 50% to 80% lesser than that for a traditional building system. Furthermore, it also provides superior sound insulation ensuring comfortable living. Termite Proof: Unlike the other synthetic materials, SCIP are totally resistant to termites, insects and rodents as well as to mold & fungus. Similar Finish: Incorporating all of the above mentioned features, SCIP provide a finish which is similar to any traditionally constructed building. **Additional of floors** is easy as SCIPs are light weight, more floors can be added to an already constructed building without causing the building to collapse. Construction in Remote Areas is easy using a standard 10’ x 4’ SCIP wall panel weighs only 16 Kg (before shotcreting) making it possible to carry the panels to remote areas and at high altitude areas, where traditional building materials such as brick masonry and concrete blocks are either not available or very difficult to transport. Thus the SCIPs reduce the cost required for their transportation. It constitutes **fire resistance properties** as any structure built with SCIP is non-combustible and has a minimum 1.5 hour fire rating and a higher rating can also be easily attained. Thus structures built with SCIP are virtually fire resistant. The thicker the layer of shotcrete on each face of the panel the greater will be the fire resistance. SCIP panel show **high strength** with 50mm polystyrene core using 2mm mesh wire, 2.50 m in height has been tested at a structural load of over 78000 lbs. Thus in strength it is far superior to traditional building system. SCIP walls can carry from 40,000 lbs. to 120,000 lbs. of load per linear foot of wall. Using SCIP **monolithic structure** can be constructed with SCIP panel system right from the foundation to the roof of the house. This ensures proper air sealing, achieving a high degree of energy efficiency. Furthermore, this monolithic construction ensures the structures’ resistance to high level earthquakes and hurricanes.

Properties of SCIP:

A brief description of specifications of SCIP is given below:

- Plain and Reinforced Concrete (ACI-318-08)
- Wire Mesh (ASTM A82 and ASTM A185)
- Polystyrene (ASTM C578)

Hollow Cavity Walls & Roof:

This technology is not a new one, but it still appears to be one of the best solutions to prevent heat loss form a building. This use of a hollow cavity in the walls and roof provides an air cushion all around the building. Air being an insulator also offers some thermal resistance. The greater the thickness of the air cushion, the greater will be the resistance offered by it to heat transfer. Furthermore, this technology also supplements the use of synthetic insulating materials such as loose fill ball insulation, thermopore etc., as these materials can be filled into the cavities. Also, this air cushion provides a greater thermal mass, as a result of which there is a time lag in the transfer of heat, due to which the building remains cool during the day and warm during the night. Also the air current can be used in the hollow cavity roofs for the dissipation of heat.

Provision of Hollow Cavity walls and roof is another way to dissipate the heat that enters into the roof, by using the natural current of air (a phenomenon used in cavity walls). Though there are many synthetic materials (e.g. thermopore, jumbolon sheets etc.) in the market having a high thermal resistance but their life is very short. If due to the development of the cracks in the concrete, water enters the roof, it will be absorbed by the synthetic material and hence the process of decay will begin. This will also cause great difficulty in detecting the point of leakage. These materials are also a little expensive. Another possible remedy is to apply stabilized mud to the roof, but this will result in an increase in the load on the roof, thus more concrete will have to be used in the beams, hence increasing the cost unnecessarily. Therefore, the best possible remedy is to provide air cavity in the roof so that the heat gets dissipated. This method is both, energy efficient and cost-effective."

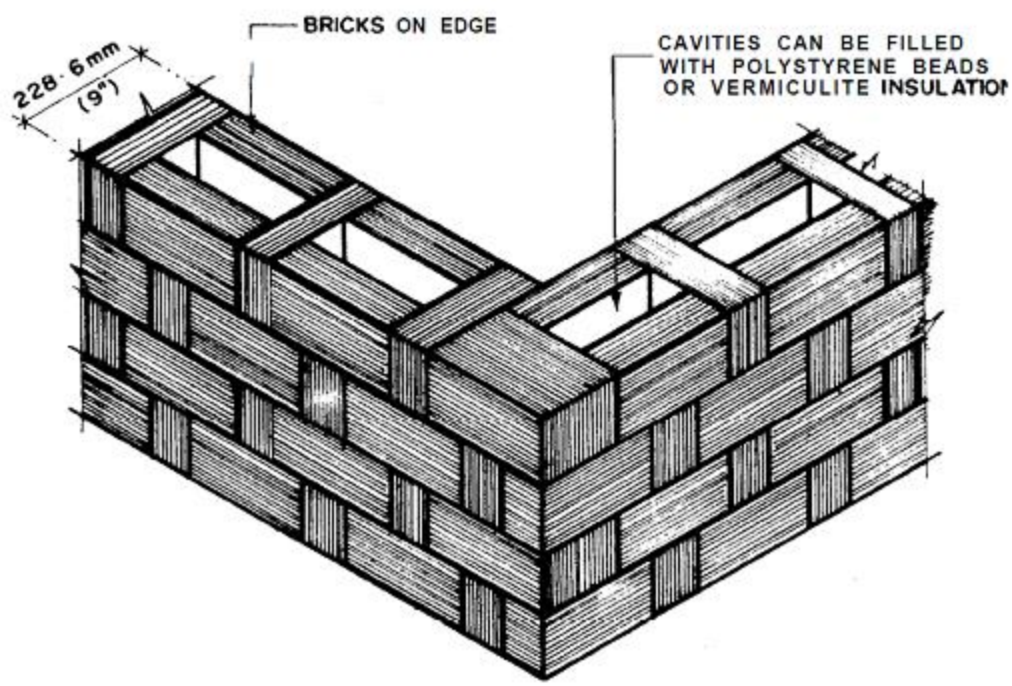


Fig. 2.5 Cavity wall with bricks at edges.

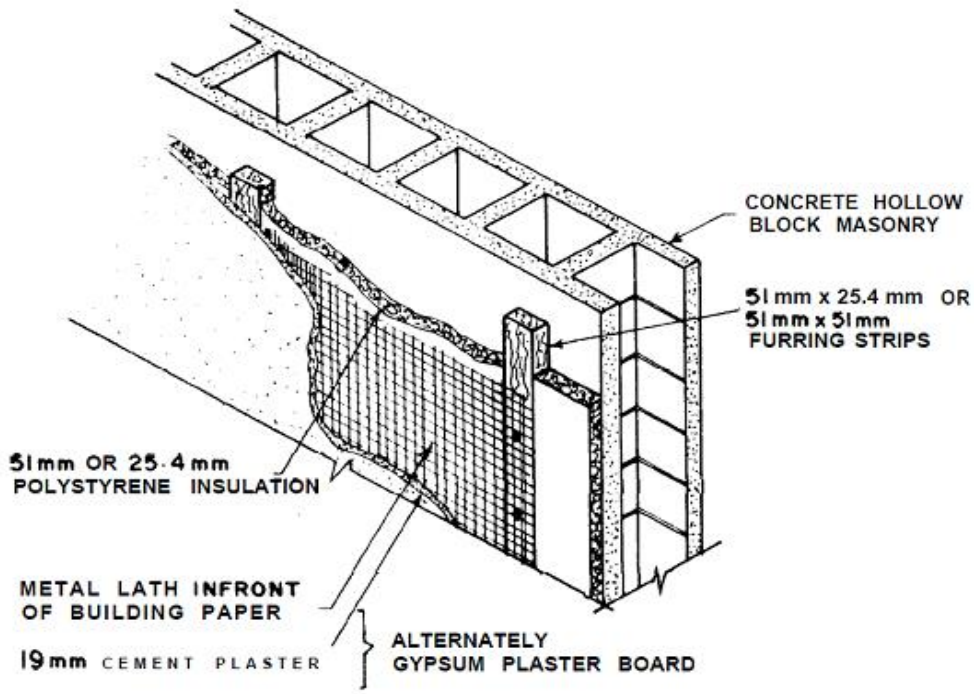


Fig. 2.6 Hollow concrete block wall with polystyrene insulation.

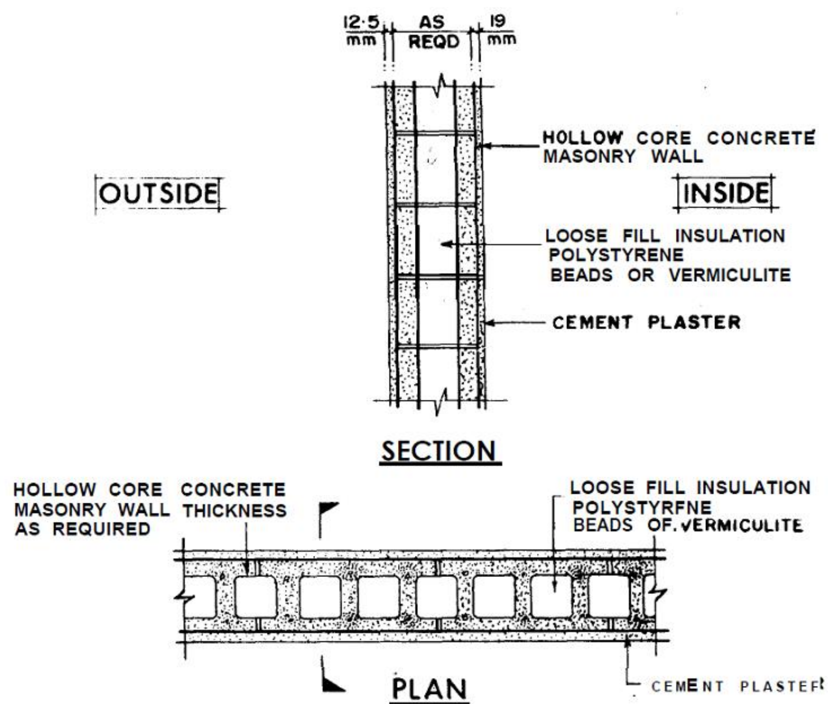


Fig. 2.7 Hollow concrete block wall with loose fill insulation

Architectural techniques for an energy efficient building

The active cooling and heating methods are the ones which require energy to be utilized to keep the temperature with in a comfortable range. Passive cooling and heating methods do exactly the opposite, and they use natural resources and small alterations embedded in the very design of the building to keep it comfortable for human life.

Following are some of the passive cooling and heating techniques, that can be used to make your home energy efficient.

Sunrooms

Sun rooms are generally constructed on the south facade of the house, so that the maximum sunrays are captured. This is a very big advantage in our climatic region, if used properly. Having proper ventilation, this can act as a cushion from the direct heat of the sun as shown in figure 2.8.

Fig. 2.8 Sunrooms

Creepers

The creepers provide a jacket to the building from the heat of the sun, as they allow light, but absorb all the heat, in a way insulating the walls as shown in figure 2.9.

Fig. 2.9 Creepers

Attics

They provide a void on the roof, giving the rooms below insulation from the direct heat of the sun, unavoidable for the rooms on the top floor otherwise. Sometimes whole ventilation systems are also integrated into the attics to make the houses below even better as shown in figure 2.10.

Fig. 2.10 Attics.

Patios and Terraces

Deep terraces and patios are another features which can be added to the west facade of the dwelling to keep out the heat and let in the light. Instead of having properly covered roofs, parts of the terraces, verandas and patios can be wooden pergolas.

Careful Orientation according to Sun

The orientation of the building has to be such that the North and South side have the longer facades, and the East and West side have the shorter facades as shown in figure 2.11. This will allow all the right amounts of heat inside the house, keeping maximum heat out.

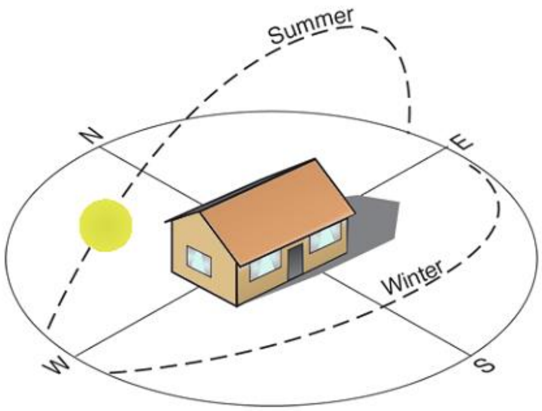


Fig. 2.11 Setting orientation of building according to movement of sun.

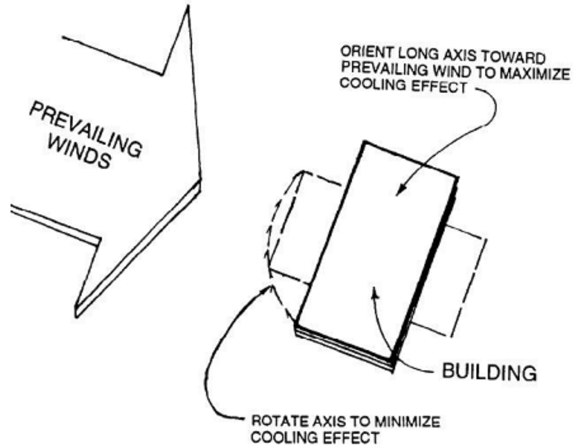


Fig. 2.12 Setting orientation of building according to wind direction.

Careful Orientation according to the Wind direction

Since our climate needs us to take the maximum advantage of the winds blowing, we do need the building such that the longer axis faces the windward side. Also landscaping can be used to channel the winds towards the houses as shown in figure 2.12.

Courtyards

A courtyard is one of the best features in the houses in the climatic condition similar to ours. They provide the best airflow, keeping the houses cold and comfortable even in the hot plains of Punjab, without the need of air-conditioning.

Wind Towers

Wind towers are another very effective method of making the rooms airy and the temp inside to drop dramatically. Combined with ventilators, they can set up a very effective current in the house, cooling its temp down noticeably as shown in figure 2.13.

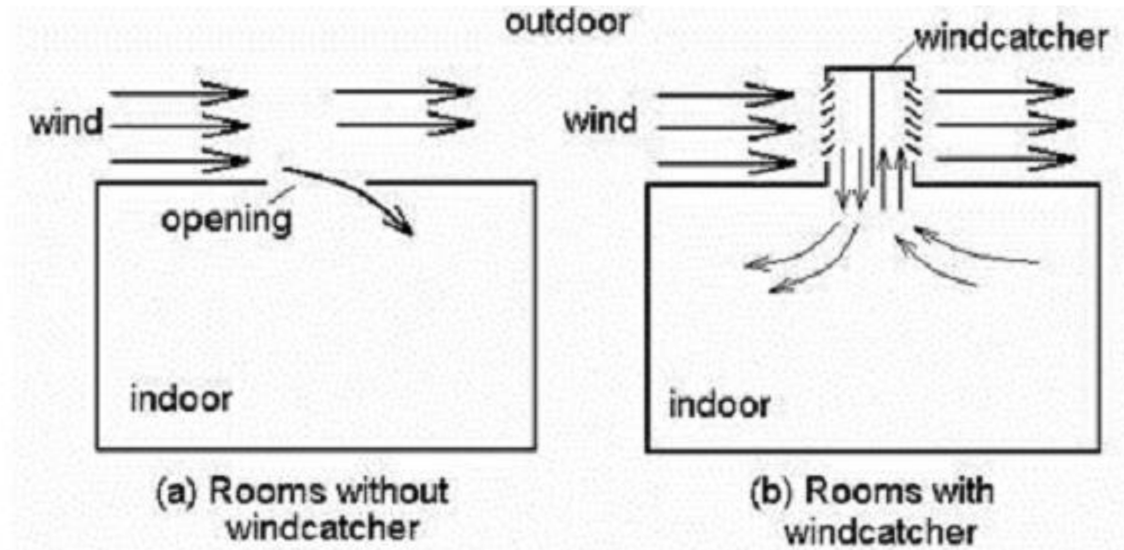


Fig. 2.13 Effectiveness of wind catcher for proper ventilation.

Ponds

Ponds created on the property as a part of the landscaping can be very helpful in making the wind blowing cool down to an appropriate temperature.

Landscaping

Plants have a cooling affect that can be utilized to make the temperature of the house comfortable. More important than 'what is planted', is actually 'where it is planted', and 'how it is planted'. One landscape architect mentioned, "Carefully planted trees save up to 50% of the power we use."=

Shading

Almost 30 percent of the unwanted heat enters the building through windows. Shading is a strategy for preventing solar heat gain and diffusing bright sunlight. Most windows systems are fitted with blinds to provide privacy and aesthetic effects, also to control sunlight. The effectiveness of internal shading device depends upon its ability to reflect incoming solar radiation back through the window before

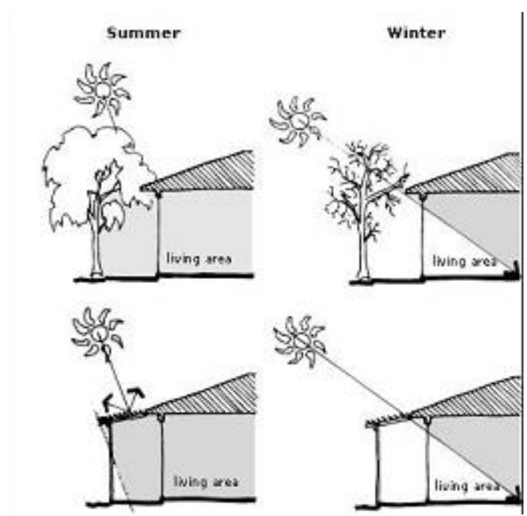


Fig. 2.14 Effect of Plantation on Energy Efficiency of a House.

getting absorbed and rise temperature within the building. The effectiveness of external shading device depends upon setting their orientation with respect to the sun's path and shaded surface.

Venetian Blinds and Shades

Venetian blinds and shades act to reduce solar heat gain by introducing an opaque or translucent surface between the window and the interior of the room. Its objective is that solar radiation is either reflected back out of the window or absorbed by the blind or shade.

Draperies

The function of draperies is to reduce both heating and cooling load in building by as much as 5 to 20 percent. Fabric reflectance is directly related to the ability of fabric to reduce solar heat gain. Based on their appearance it can be classified by yarn color as being light, medium or dark; similarly, they can be classified by inspection as being open wave, semi open weave or closed wave. Double draperies can provide even more control over solar heat gain through a reduced U-value is principally due to addition of the closed air space between the draperies to the thermal barrier.

Exterior Shading

The effectiveness of an exterior shading device depends upon its orientation with respect to the sun and to the surface to be shaded. As we know due to movement of earth during year, the orientation of the fixed surface with respect to the sun changes. During the summer months, the sun appears to be higher in the sky than during the winter months.

At a given time from day to day, the sun's position in the sky is only slightly different. However, over the course of a few months these small daily differences add up to make a significant change. Hence, any fixed object will have a different shadow length and direction at different times during the year. The positioning of the exterior shading device should take into account not only the position of the sun in the sky, but also the local climatic conditions. While the sun is highest in the sky during the summer solstice, the hottest weather generally occurs at a different time of the year. The exterior shading device should be designed to produce the greatest amount of window shading to reduce solar heat gain during these periods of hottest weather.

Overhangs

Over hangs are horizontal projections above a window. Some overhangs may be slanted downwards from the roof or wall surface. It is the overhang's length components which is perpendicular to the wall surface that is used to determine shading, however. Roof eaves or other projections, and balconies can also perform the same function as overhangs. Overhangs are particularly effective for the south side of a building, as they stop the sun rays coming through the window as shown in figure 2.15. While in winter when the sun is low the advantage of sun is to shine lower in sky and give heat through these windows.

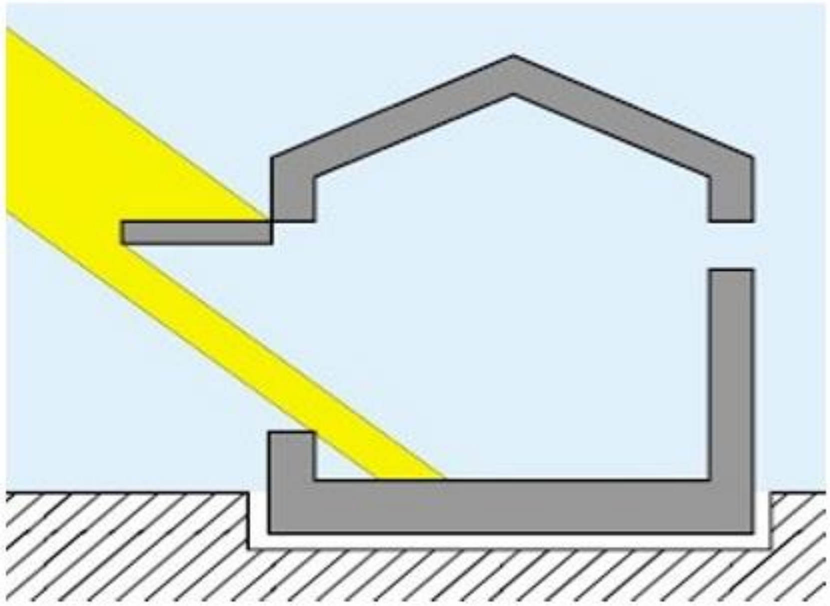


Fig. 2.15 Overhangs blocking the sunlight causing heat.

Fins

Fins are vertically oriented projections that are placed at the sides of the windows as shown in figure 2.16. They are useful in obstructing the direct rays from the sun from entering the window when the sun is low in the sky and at an slanted angle to the window.

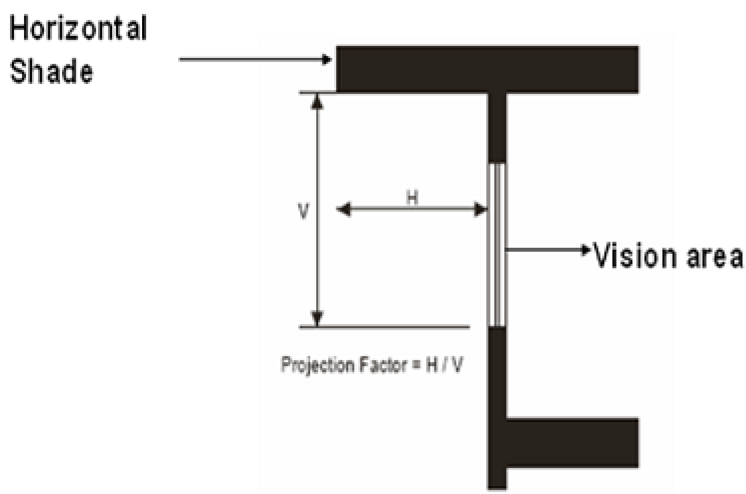


Fig. 2.16 Fins.

Balconies

Balconies incorporated into new multistory building construction can also provide the benefits of overhangs and fins. A properly designed balcony can effectively block the solar heat gain from the sun during the summer months, while allowing solar heart gain during the winter.

Recessed Windows

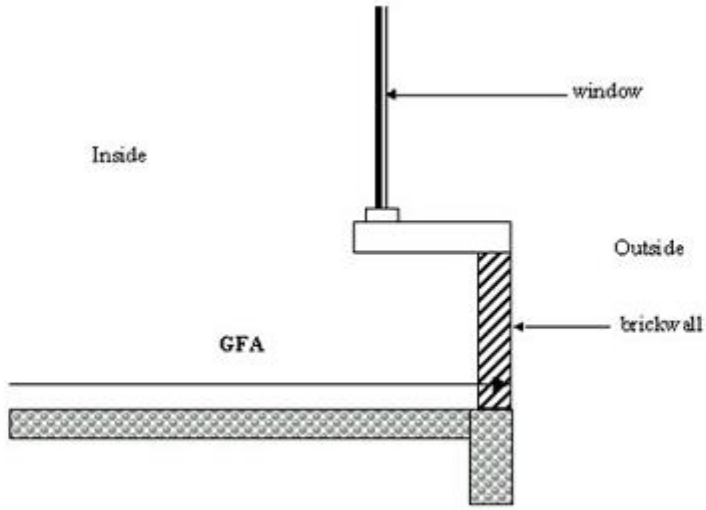


Fig. 2.17 Recessed windows.

The same benefits of overhangs and fins can also be achieved by the use of recessed windows. The window is recessed from outside wall of the building and the wall surface to the sides and above the window provided the equal protection of externally positioned overhangs and fins. There is another approach to recessed windows which is particularly effective on western building exposure in new building construction. For these exposures, the windows may be recessed, but an angle to the wall surface so that the windows have more of a northern orientation, this “saw tooth” style shades the windows from the direct rays of the sun during the summer mornings and afternoons as shown in figure 2.17. The design also has the advantage that it allows for entry of solar heat gain to supplement building heating system during the winter when the sun is in the northern part of the sky.

Awnings

Awnings are attached above the window and are designed to extend down and away from the window to block direct sunlight as shown in figure 2.18. Awnings may be either of the fixed type or of the retractable or removable types is preferred where winter heat is desired. Regardless of the type of awning employed, the awning itself should be of a light color to increase the reflection of heat.

Awnings may be either solid, such as wood, or may be constructed of fabric stretched over a metal or wood frame. Solid surface awnings may require that an opening be placed between the top of the awning and the side of the building to allow the circulation of air so that the hot air trapped under the awning can escape. Fabric awnings allow the circulation of air through the cloth, but are not as able to endure exposure to the sun, wind and rain as solid awnings.

While fixed overhangs and fins are best are best for south facing windows, those that face east or west are subjected to the effects of solar heat gain during the early morning or late afternoon hours when the sun is relatively low in the sky. Because of the nearly horizontal orientation of the sun with respect to east and west facing windows during those times of the day, overhangs and fins are not effective for those exposures. The best way to shade these windows is with that type of shading devices which cover the window itself.

Fig. 2.18 Awnings at different positions.

Shutters

Shutters are wooden or metal coverings for windows. When closed, the shutter is designed to completely cover the window and prevent sunlight from entering the building as shown in figure 2.19. Shutters not only block out summer heat, but in winter also provide some insulation value for the window.

Fig. 2.19 Shutters.

Louvers

Fig. 2.20 Louvers.

Louvers have slats, and in that respect they are similar to shutters. However with louvers, instead of having to move the entire shutter, the slats alone can be adjusted to prevent sunlight from entering the room. The slats may either be vertical or horizontal. Typical louver with horizontal slats is as shown in figure 2.20.

Exterior Roller Blinds

Exterior roller blinds also have slats, but the slats are not fixed in the same manner as louvers. For this kind of shading devices, the salts are lowered along a track when shading is desired. The lower the shade is pulled, the further closed the slats become. When the roller blinds are fully extended, no light is allowed to enter the building. In this regard, they are similar to shutters and may also provide some measure of insulation during the winter season.

Screens

Solar screens, such as jails are a traditional type of shading devices. These are opaque construction forms that have patterned openings which admit only a fraction of the direct sunlight. They are generally placed several feet in front of the window. This allows space for air to circulate between the screen and the window or wall, which permits trapped hot air to escape.

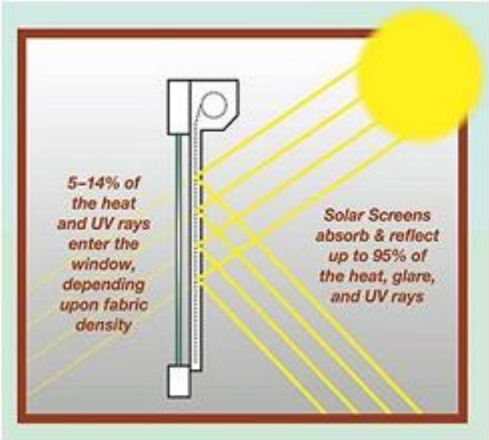


Fig. 2.21 Screens.

2.3 Previous studies on energy efficiency and sustainability

A number of research studies have been carried out on buildings and its components demonstrating energy saving. Few of important studies are presented here:

(Knudstrup et al., 2009) in his study demonstrated the concept of new Danish housing projects which plays an important role in minimizing the energy required to operate buildings. The orientation of windows, position of sunshades and proper ventilation concept in such building can perform as a key role for reduction in CO_2 emissions and ultimately controlling global warming. Energy efficiency and sustainability can be achieved with concept of renewable energy production incorporated in building construction industry. In order to reduce the energy consumption in housing projects, provisions must be kept during early planning and design phase. Sustainable housing development provides a framework for the integration of environmental policies and development strategies. Housing industry is responsible for causing environmental problems through increasing energy consumption and pollution to the surrounding environment. Although his study was very helpful in determining the importance of the building components and their role in developing energy efficiency in buildings, but not practical demonstration is shown in this study. Also properties of the materials used in not signified, which resulted in failing to understanding their response towards energy conservation.

(Zhang et al., 2011) in his study related optimization of building orientation and configuration is important to increase the thermal performance and energy conservation. Windows offering insulation against heat and cold used together with green roof provide concept of energy conservation and housing development. Insulation of various components of buildings including roofs, windows, floors, walls and exterior doors creates a barrier for loss of energy. Also it is essential that during the design of building its location and vicinity must be considered. Such buildings based on their performance are labeled as green buildings as it is effective to reduce energy consumption in building. These green buildings can help lower the temperature inside the building, thus reduce the time of using air-conditioning system. The brief preview of literature is helpful in understanding the energy efficient design and concept of sustainable housing but however it lacks substantial quantification. Although architectural and construction techniques contribute significantly to attain energy efficiency, but comparison is desired to evaluate their contribution in performance. Insulation is an effective way to achieve energy efficiency in buildings, therefore practical demonstration for the most efficient methodology is desired to evaluate its architectural based performance in buildings. In this regards, work has been carried out on different architectural components such as windows, façade, cladding etc., for which energy efficiency needs to be evaluated in buildings with provision of such components.

(Menzies and Wherrett, 2005) in their study has emphasis on the application of natural ventilation via windows and ventilators for maintaining a less humid and comfortable environment. Thermal performance of a building can be controlled during the design phase by evaluating the solar heat gain. Also it is of prime importance that size and design of windows must be properly evaluated so that its presence results in achieving economy. Due to the large size of installed windows more natural sunlight will enter in the rooms and ultimately less use of electricity. Windows installed at right location provide proper ventilation resulting in less use of air condition and artificial heating and cooling systems. Keeping in view both aspects of windows, comfort and productivity of the occupants are of main importance and windows are one of the controlling entities in this aspect.

In the study done by (Roufechaei et al., 2014) energy demand of a building decides its usage and purpose of construction. Architectural, mechanical and electrical requirement of a building decides its energy demand based on its usage and purpose of construction. It is collective effort of all these three parameters which are directly or indirectly linked with energy efficiency. In his study it is also emphasized that energy efficient design depends upon different parameters which leads towards sustainability. Different model were considered, based on them strong relationship with social, environmental and economic sustainability are developed. His work concluded that based on above mentioned parameters buildings model demonstrate sustainability.

2.4 Summary

The previous studies carried out in this area lack practical evaluation of the effect of materials and the architectural technique used in construction and means to achieve sustainability in built infrastructure. Details on performance and significance of construction material used to achieve energy efficiency and sustainability were also missing in those studies. In this regards, work has been carried out on different architectural components such as windows, façade, cladding etc., for which energy efficiency needs to be evaluated in buildings with provision of such components.

CHAPTER 3

METHODOLOGY

3.1 General

To study the effects of energy being used by buildings it was important to carry out comparison of energy efficient and non-energy efficient buildings. Hence four existing buildings in Islamabad were chosen to evaluate the performance of buildings having difference in orientation, construction materials and architecture especially height. Nespak House and Telecom tower were designated as energy efficient while Judicial complex and SaudiPak tower were selected as non-energy efficient buildings. A special permission was processed from NICE department to responsible persons in respective buildings to carry out the task with ease. The importance of this activity was also demonstrated to the manager/maintenance head of the buildings.

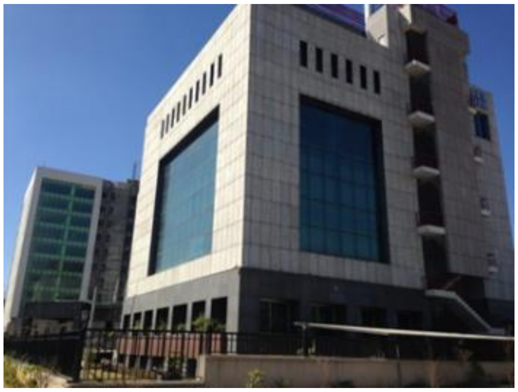
3.2 Buildings and its properties

Buildings were designated keeping in view their behavior and performance. A brief details of each building is given below in Table 1.

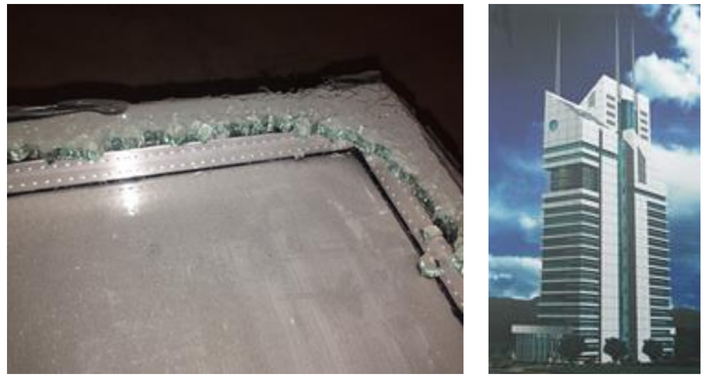
Type of Behavior	**Buildings**	**Height**	**Floors**	**Type of Construction**	**Materials and Construction Techniques**
Energy efficient	Nespak House	Low rise	7	Frame structure	Cavity walls with external panels 40 mm thick jumbolon sheet in roof
	Telecom Tower	High rise	24	Frame structure	Alpolic cladding with double layered glass
Conventional	Judicial Complex	Low rise	7	Frame structure	Block masonry and external plaster
	Saudi Pak Tower	High rise	19	Frame structure	Polystyrene in roof, terrazzo panels and thick glass used

Table 3.1. Data of various buildings investigated for energy efficiency

Above given are the details of architectural and construction techniques, height and type of buildings and construction materials used in buildings under investigation. Same are being snapped and shown below in figure 3.1.



(a) Nespak house building facing sunlight few hours into the day



(b) Two layered thick glass with air cavity used in Telecom tower for heat insulation

(c) Judicial complex with reduced sunlight exposure due to adjacent buildings

(d) External terrazzo chips panels used all around the Saudi Pak tower building

Fig. 3.1. Different architectural and construction techniques used in buildings under consideration

Nespak house comprises of 7 floors out of which 1 is basement & 6 are above ground, was constructed having cavity in external walls and exterior panels covering all over the building. Thick glass mirrors were used as architectural beautification and energy conservation at the same time. Jumbolon sheets were provided in the roof for heat insulation. Due to the non-presence of any buildings in vicinity the Nespak house gets fully exposed to the sunlight during morning, anyhow due to its orientation it faces sunlight from front in afternoon as shown in figure 3.1(a).

Judicial complex comprises of 7 floors out of which 1 is basement & 6 are above ground, was a conventional construction using masonry blocks and cement-sand plaster at both interior and exterior faces. No energy efficient technique was adopted during its construction and architectural was also traditional. Somehow shading is maintained at back and side due to the presence of building in vicinity as shown in figure 3.1(c).

Telecom tower comprises of 28 floors out of which 24 are above ground, is designated as energy efficient building due to its construction and architecture. This high rise building is totally covered with Alpolic cladding and double layered glass as shown in figure 3.1(b). Alpolic is an aluminum composite material (ACM) having high fire resistant core can be used as exterior and interior cladding and roof covering. It is manufactured by Mitsubishi Plastics, Inc., and provided by approved distributors. Double layered glass helps in insulating the building and creating a temperature barrier between inside and outside. Properties of these materials being used make this construction energy efficient.

SaudiPak tower comprised of 19 floors and falls in category of high rise buildings. Its external walls are covered with terrazzo panels for architectural purpose and polystyrene is used in the roof for insulation purpose. Moreover, glass used in windows of the building is of superior quality and varying thickness. Few areas of SaudiPak towers remain in shade due to presence of buildings in vicinity. Orientation of this building is such that, it does not fully face sunlight with the elapse of day as shown in figure 3.1(d).

While monitoring these buildings, temperature and humidity measurements were recorded with respect to time. The Heat, ventilation, and air conditioning (HVAC) systems were intentionally shutdown during course of the study to investigate temperature and relative humidity parameters. The timings for collection of environmental data in the buildings were selected from 8 am to 5 pm due to working hours and full occupancy keeping in view the importance of comfort level and performance of building. The HVAC system was turned off to monitor the natural behavior of buildings. Gauges (digital thermometers) were installed at different floor levels to study the temperature and humidity variation with respect to height and location. For low rise buildings i.e. Nespak house and Judicial complex, inside and outside thermometers were installed at all 6 floors (1-6 floors), while for high rise buildings i.e. Saudi Pak tower and Telecom tower, thermometers were installed at floors 1, 4, 8, 12, 16 and 20 to record temperatures. Thermometers were placed keeping in view the exposure of building to sunlight, shading effect from buildings in vicinity and building itself performing either from inside or outside. This arrangement of setting up thermometers allowed covering the whole building leaving no unmonitored areas. Settings of thermometers inside and outside are shown in figure 3.2 given below.

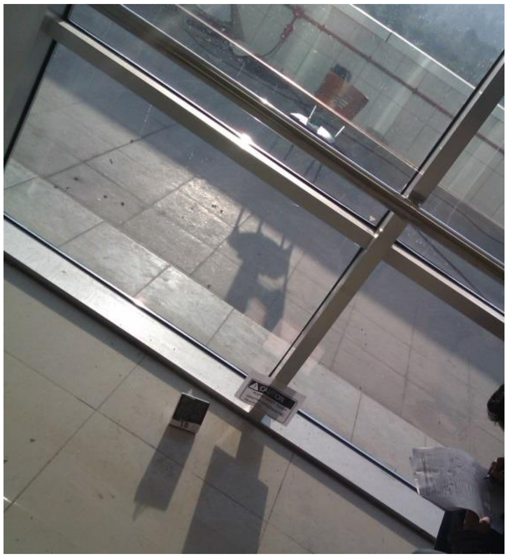


Fig. 3.2 Inside and outside readings being taken at 6th floor of Nespak house

Fig.3.3. Thermometer installed near double layered glass inside Telecom tower

Temperature and humidity measurements were recorded at the side of the building on which exposure of sun with respect to time and its impact with orientation of the building could be easily monitored. The orientation was recorded with compass and compared with direction and movement of sun. This helped to analyze the effect of building orientation and its importance when considering the architecture of the buildings. The amount and duration of sunlight exposure to buildings were also monitored and recorded. After each hour the readings were noted and observations were recorded including the sun exposure, building vicinity and any additional relevant data considered important. Some difference in observations occurred as the indoor temperature readings in building at same floor were different at different locations due to shading and building orientation facing sun, such data was also consciously recorded. Recording format of temperature and humidity (Inside/outside) for a specific building and from 8:00 AM to 5:00 PM is as shown in Table 3.2.

Energy Efficient Design and Sustainable Buildings					
Building :	JUDICIAL COMPLEX				
Start Time :	8:00 AM		End Time :	5:00 PM	
Weather Condition :		Partially Clouded			
Temp :	Max		Humidity :	Max	
	Min			Min	
Thermometre No :		Floor :			
Sr No	Hours of day	Temperature		Humidity	
		°C	Observed	%	Observed
1	8:00:00 AM	Inside		Inside	
		Outside		Outside	
2	9:00:00 AM	Inside		Inside	
		Outside		Outside	
3	10:00:00 AM	Inside		Inside	
		Outside		Outside	
4	11:00:00 AM	Inside		Inside	
		Outside		Outside	
5	12:00:00 PM	Inside		Inside	
		Outside		Outside	
6	1:00:00 PM	Inside		Inside	
		Outside		Outside	
7	2:00:00 PM	Inside		Inside	
		Outside		Outside	
8	3:00:00 PM	Inside		Inside	
		Outside		Outside	
9	4:00:00 PM	Inside		Inside	
		Outside		Outside	
10	5:00:00 PM	Inside		Inside	
		Outside		Outside	
Remarks/ Observation :					

Table. 3.2 Format of table for recording readings

3.3 Model Studies

In order to quantify the effect of materials on building efficiency, a model study was also carried out. This model study was conducted to fully understand the behavior of energy efficient technique being applied in buildings. A comparison is to be drawn between existing buildings and building having SCIP technique so that it can be quantified.

In this study, an under construction poultry farm was applied with energy efficient materials such as structural concrete insulated panels (SCIP), an effective component to provide strength along with energy conservation. This poultry farm is double storied and has the dimensions of 200’x50’. There is also a kitchen and a store room being constructed. The specifications of the structural concrete insulated panels being used here are given below:

Wire Mesh: (ASTM A82 and ASTM A185)

Diameters:

- Longitudinal wires: 2.6 mm diameter
- Transverse wires: 2.6 mm diameter
- Joint wires: 2.6 mm diameter

Strength:

- Yield Strength: > 6,500 psi
- Ultimate Strength: > 7,500 psi

Plain and Reinforced concrete: (ACI-318-05)

Compressive Strength:

- Reinforced Concrete = 3,000 psi
- Blinding Concrete = 1,000 psi
- Shotcrete = 3,000 psi (Polypropylene PP fibers must be added)

Polystyrene: (ASTM C578)

- Minimum Density = 15 Kg/m^3

The environment in poultry farm was controlled in which the temperature and humidity were regulated manually. The insulation material used in walls was polystyrene encased in wire mesh and strengthened with plain and reinforced concrete.

SCIP panels were prefabricated and ready to be placed at site. These panels are usually of 3 m long by 1.2 m high and 200 mm thick, and can also be modified as per requirement. These panels consist of high density thermopore with the wire mesh on either of its surfaces supported by steel wire. Figure 3.3 shows a sample of SCIP panel, and its installation on the first floor of the model building. It can also be seen that all the walls and doors had already been cut in the SCIP panels.

(a). Sample of SCIP panels installed in model

(b). Installation of SCIP panels in the model

Fig. 3.3 Structural concrete insulated panels SCIP

The high density thermopore used in walls and roof holds characteristics to create a temperature barrier between inside and outside of the building. Prefabricated concrete blocks incorporated with polystyrene foam were used at periphery of the structure. Monitoring of temperature and humidity was carried out in model building to carry out comparisons. Thermometers were set at different locations including front, back and sides of the model structure, keeping in view the exposure of building with sun and its movement throughout the day. Setting orientation of the building with respect to movement of the sun is of major importance. Readings at different time intervals were taken starting from 8:00 AM to 5:00 PM and observations were recorded for studying the response of the model structure.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 General

The data collected as a result of experimentation previously mentioned are presented and discussed here to determine the efficiency of most suitable architectural and construction technique. The time versus temperature difference and time versus humidity difference graphs are plotted and analyzed so that the difference between each technique is known and the materials efficiency can be judged. Moreover these plots are added with the range of comfort level of the occupants. Buildings under consideration are being evaluated on basis of the material used in their construction. Hence, each building can be evaluated based on the selected criteria and its results can be studied easily.

4.2 Temperature and humidity analysis

Through the data collected from buildings after being monitored, inside and outside values of humidity and temperature are plotted separately. These values are plotted for each floor of buildings under consideration and trends are being studied keeping in view the behavior of each building individually. These graphs are as shown in figures 4.1 to 4.24.

4.2.1 Temperature and humidity (inside-outside) graphs for Nespak house:

Initially the graphs were plotted to compare the outside and inside environment with the passage of time. Provision of cavity wall and jumbolon sheet in the roof has enhanced the insulation performance of buildings. Graphical representation shows that the outside temperature is more than inside because cavity has provided a heat barrier. Moreover, at some location the outside temperature is recorded slightly less than the inside temperature. This is due to self-shading effect of Nespak building. Also, it is noted that humidity values are high at the corresponding points of temperature because, when there is no sunlight approach low temperature will generate humid air effect. Due to this behavior Nespak house is categorized as energy efficient building.

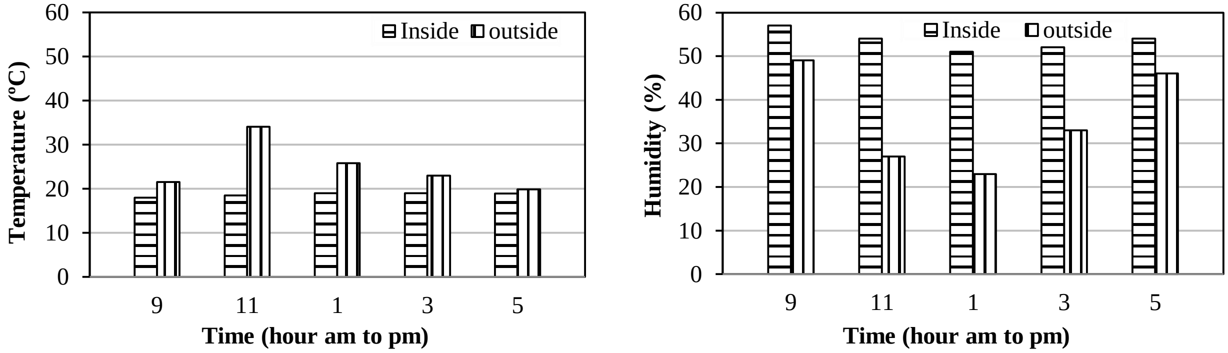


Fig. 4.1 Comparison of indoor and outdoor temperature and humidity values with time at ground floor of Nespak house.

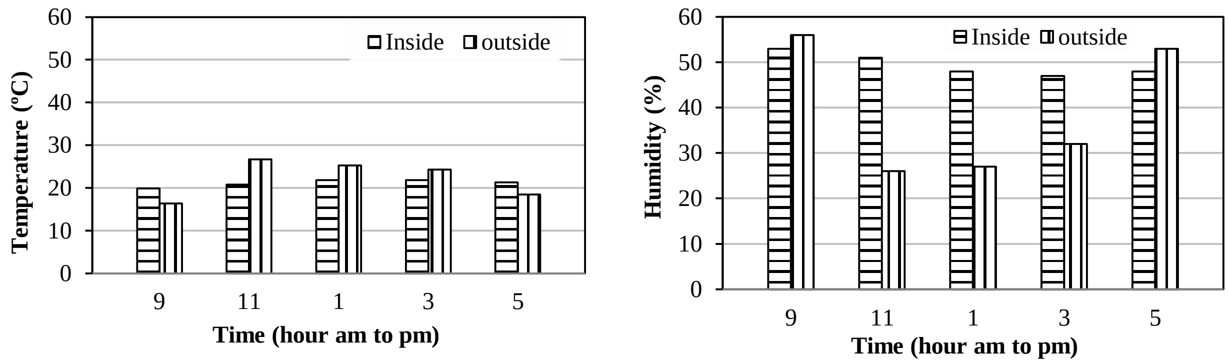


Fig. 4.2 Comparison of indoor and outdoor temperature and humidity values with time at first floor of Nespak house.

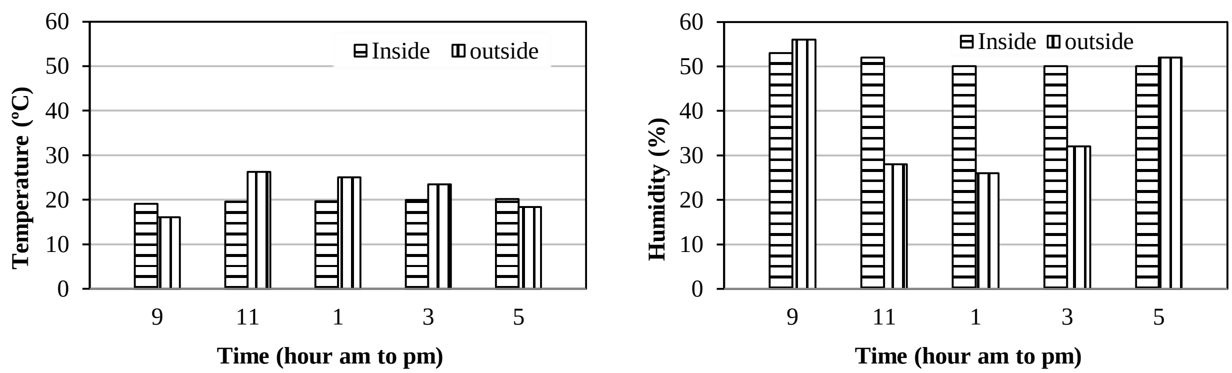


Fig. 4.3 Comparison of indoor and outdoor temperature and humidity values with time at second floor of Nespak house.

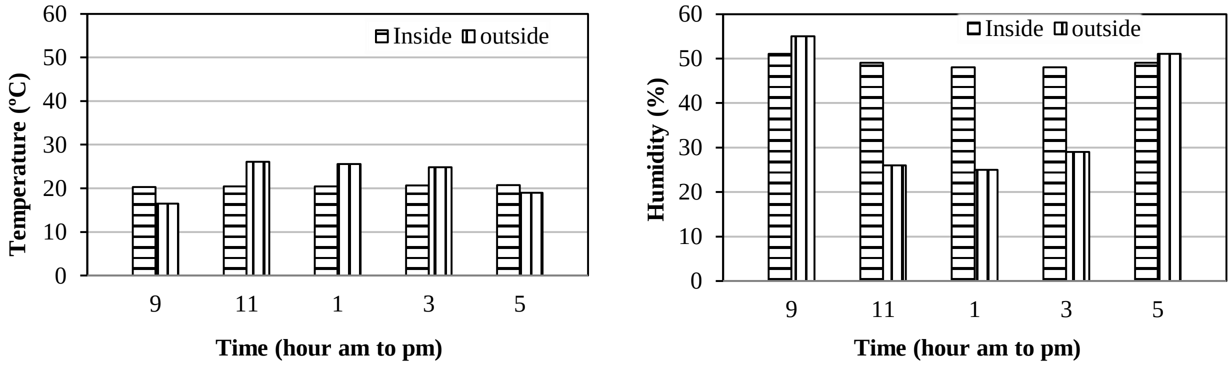


Fig. 4.4 Comparison of indoor and outdoor temperature and humidity values with time at third floor of Nespak house.

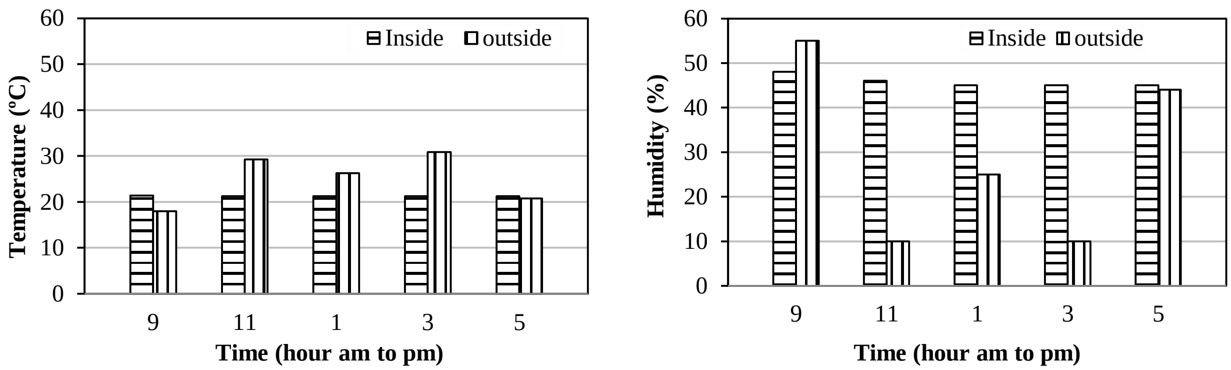


Fig. 4.5 Comparison of indoor and outdoor temperature and humidity values with time at fourth floor of Nespak house.

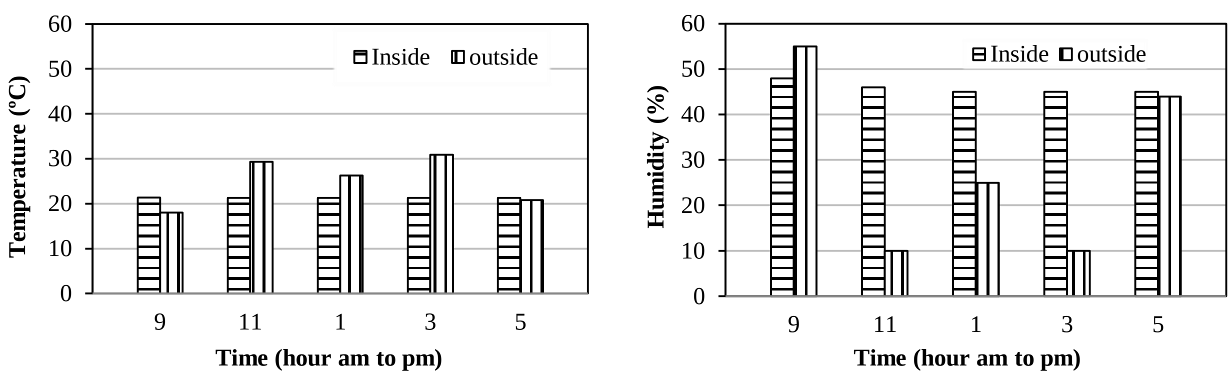


Fig. 4.6 Comparison of indoor and outdoor temperature and humidity values with time at fifth floor of Nespak house.

4.2.2 Temperature and humidity (inside-outside) graphs for Judicial complex:

This construction being a traditional one comprises of block masonry and common cement-sand plaster. Without the addition of any enhanced material or architectural amendment the performance of this building is ordinary. At the starting hours of the day, one side of the building gets shades from vicinity, that's why the outside temperature is less than inside. But with the passage of day and movement of sun, this trend changes. It is clearly shown that high values of humidity recorded in this building are dis-comfort for the occupants and artificial means like air conditions or HVAC controllers are essential for successful operation of this building.

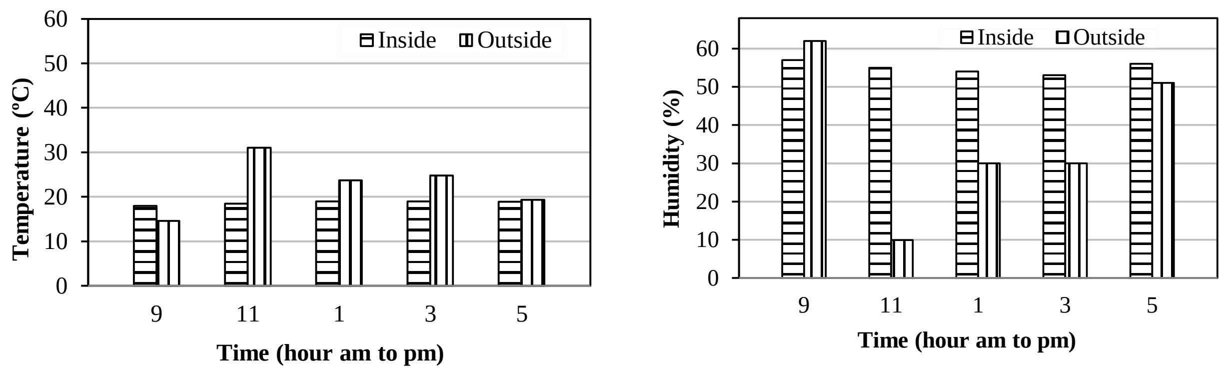


Fig. 4.7 Comparison of indoor and outdoor temperature and humidity values with time at ground floor of Judicial complex.

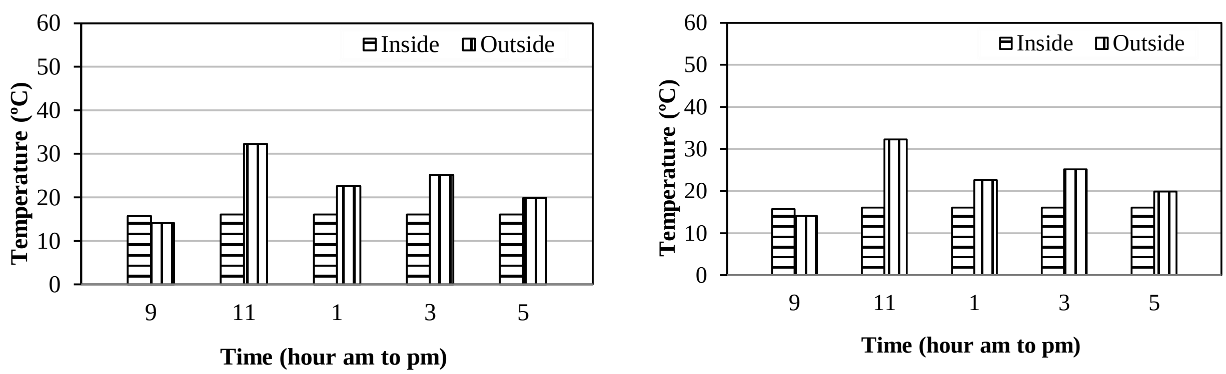


Fig. 4.8 Comparison of indoor and outdoor temperature and humidity values with time at first floor of Judicial complex.

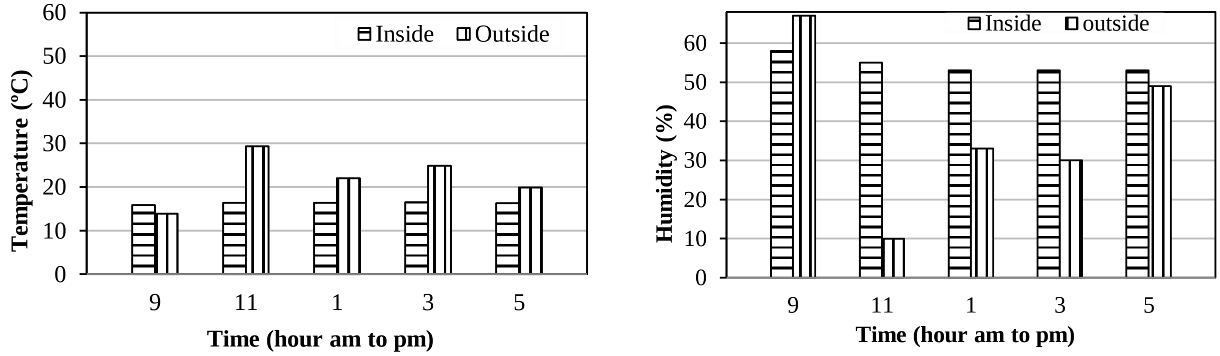


Fig. 4.9 Comparison of indoor and outdoor temperature and humidity values with time at second floor of Judicial complex.

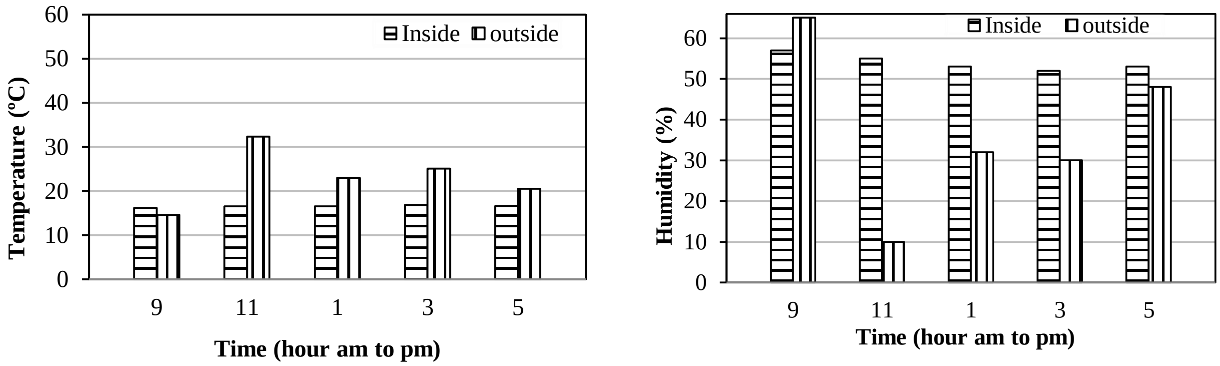


Fig. 4.10 Comparison of indoor and outdoor temperature and humidity values with time at third floor of Judicial complex.

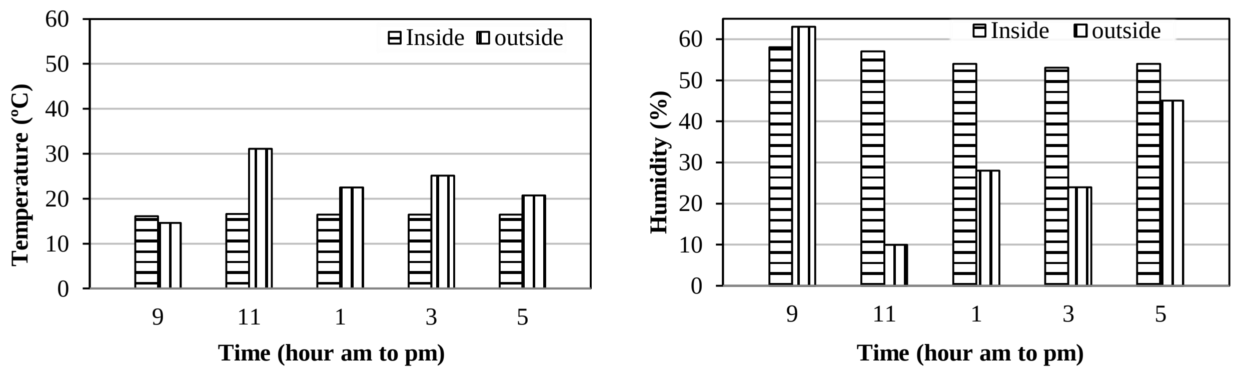
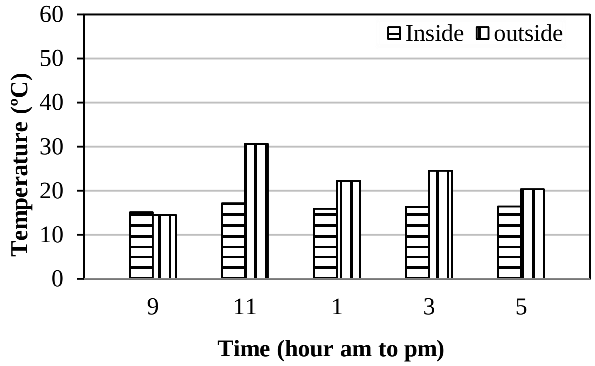


Fig. 4.11 Comparison of indoor and outdoor temperature and humidity values with time at fourth floor of Judicial complex.



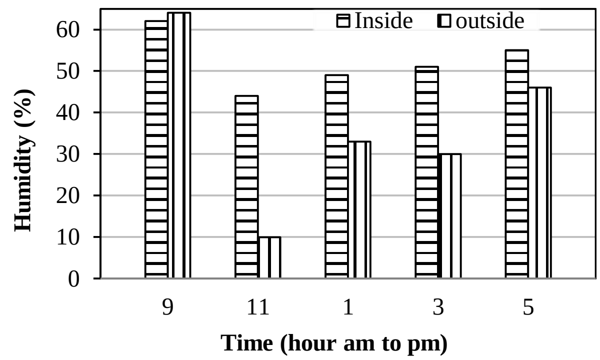
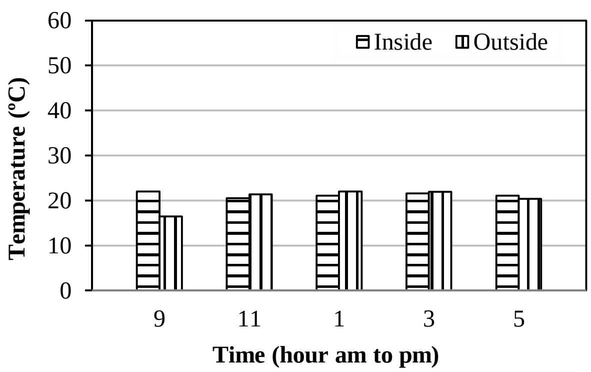


Fig. 4.12 Comparison of indoor and outdoor temperature and humidity values with time at fifth floor of Judicial complex.

4.2.3 Temperature and humidity (inside-outside) graphs for SaudiPak tower:

As clear from the graphical representation, the humidity and temperature ranges in medium zone. It can easily be judged that somehow the terrazzo panels and thick glass used in windows are responsible for this behavior. Also, some corridors/terraces are providing proper ventilation to subject areas and maintaining the environment comfortable. Being an old construction and out-dated architectural technique applied for energy conservation, its performance is currently being enhanced with the cooling and heating systems installed on different floors.



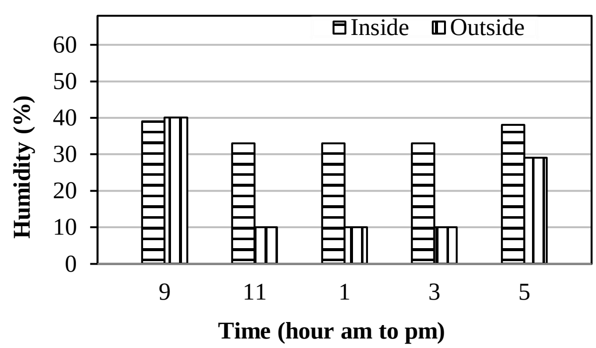


Fig. 4.13 Comparison of indoor and outdoor temperature and humidity values with time at first floor of SaudiPak tower.

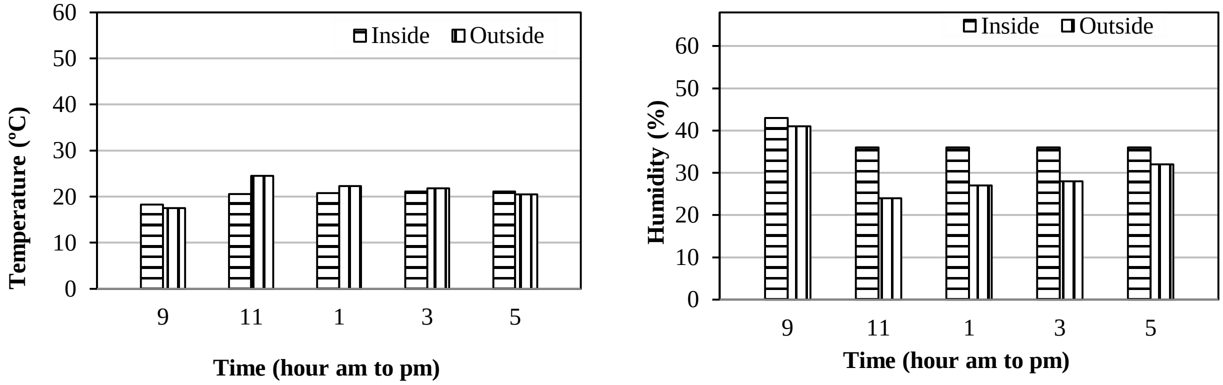


Fig. 4.14 Comparison of indoor and outdoor temperature and humidity values with time at fourth floor of SaudiPak tower.

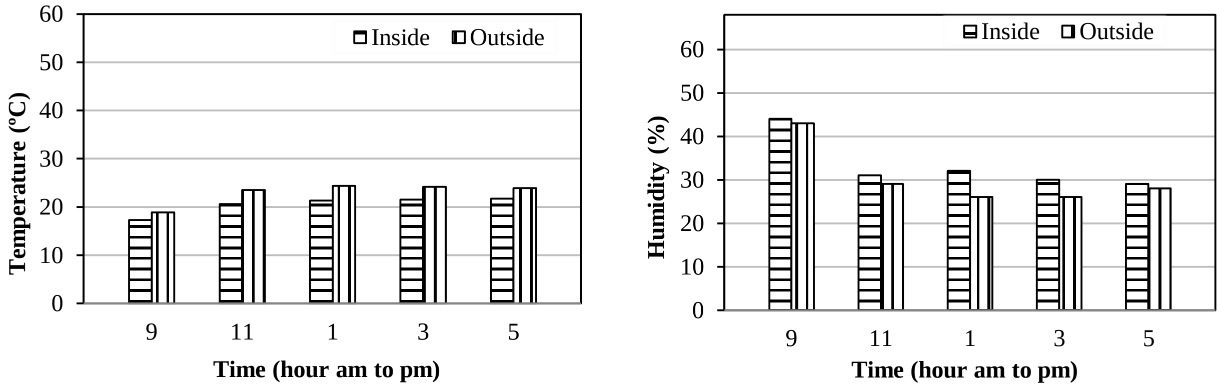


Fig. 4.15 Comparison of indoor and outdoor temperature and humidity values with time at eighth floor of SaudiPak tower.

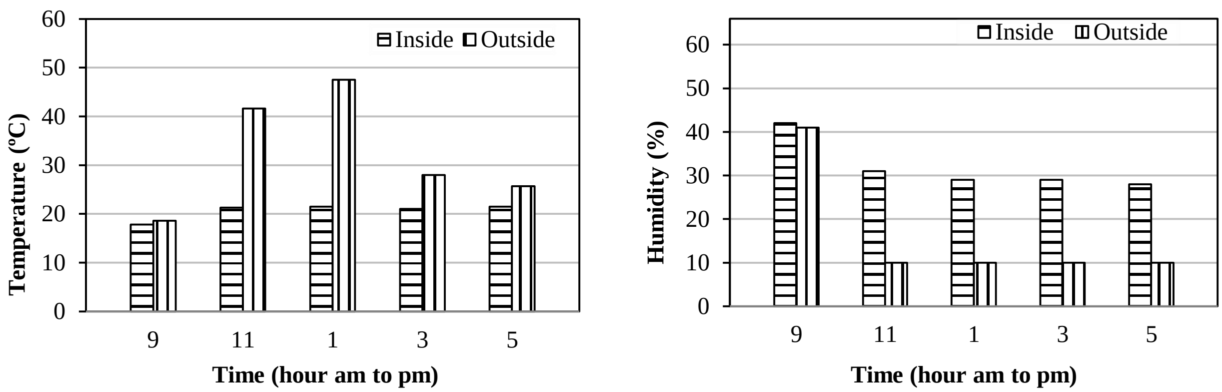


Fig. 4.16 Comparison of indoor and outdoor temperature and humidity values with time at twelfth floor of SaudiPak tower.

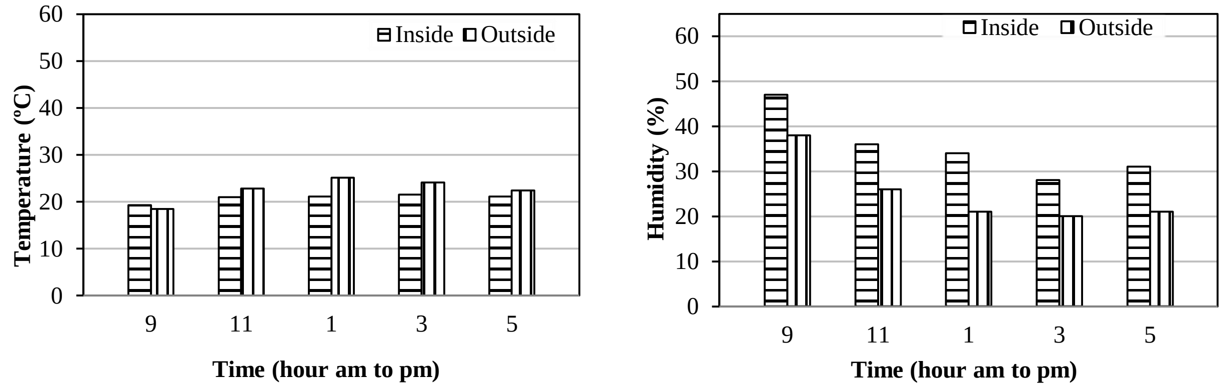


Fig. 4.17 Comparison of indoor and outdoor temperature and humidity values with time at sixteenth floor of SaudiPak tower.

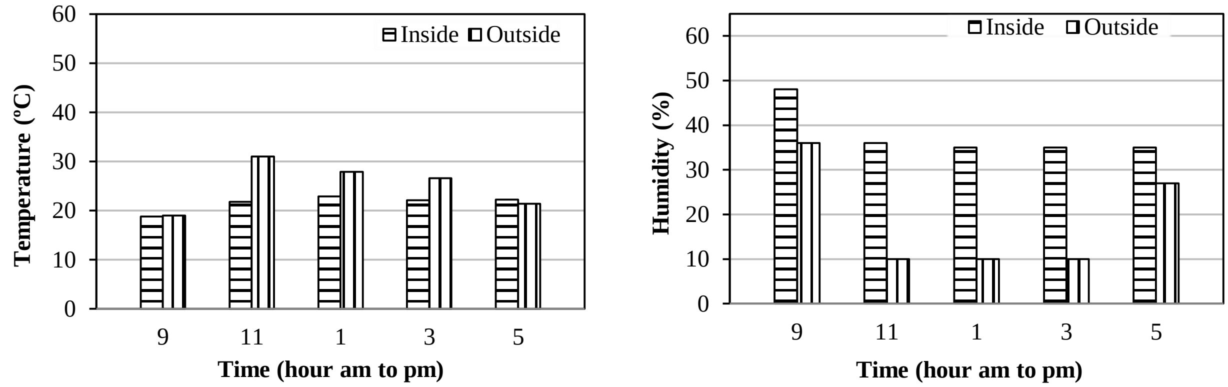


Fig. 4.18 Comparison of indoor and outdoor temperature and humidity values with time at twentieth floor of SaudiPak tower.

4.2.4 Temperature and humidity (inside-outside) graphs for Telecom tower:

Recently constructed state-of-the art provision of architectural components, Telecom tower is classified as energy-efficient construction. This high rise building is totally covered with Alpolic cladding and double layered glass. The orientation is set in such way that building faces the sunlight for a few hours only. In addition to humidity and temperature control of this building, external cladding contributes to reflect sunlight. The double layered glass casing used with an air cavity allows minimum heat to enter inside building. The building is fully insulated as a result of the combined effect of both the materials used. Graphical results had shown low values of both parameters and comfortable environment for occupants.

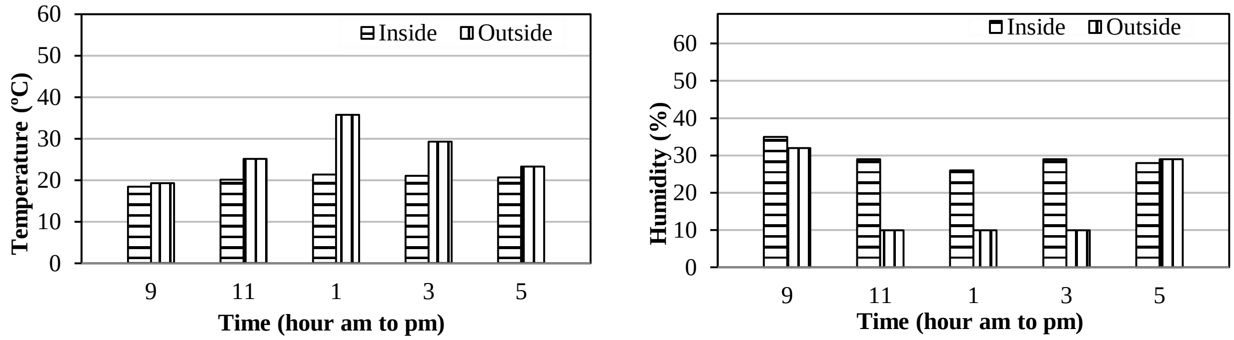


Fig. 4.19 Comparison of indoor and outdoor temperature and humidity values with time at first floor of Telecom tower.

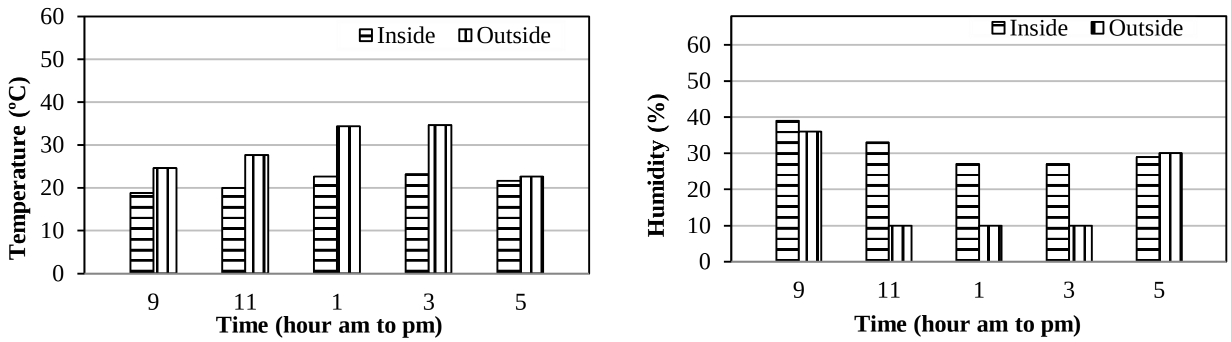


Fig. 4.20 Comparison of indoor and outdoor temperature and humidity values with time at fourth floor of Telecom tower.

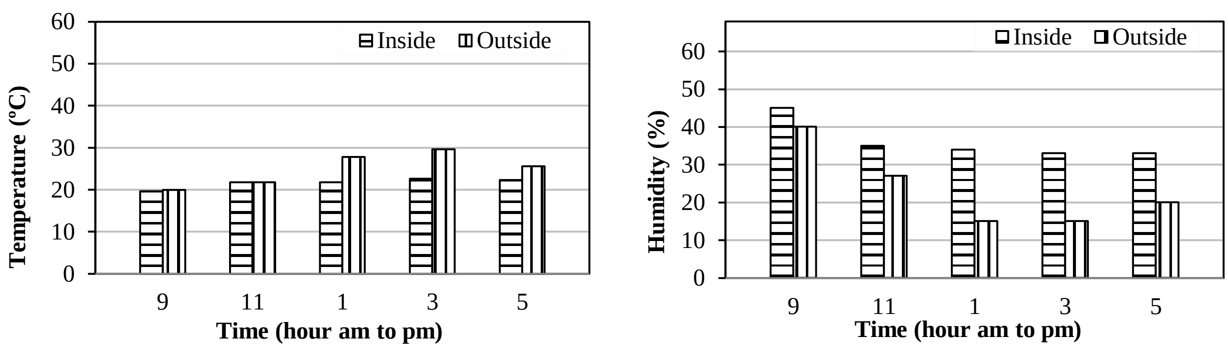


Fig. 4.21 Comparison of indoor and outdoor temperature and humidity values with time at eighth floor of Telecom tower.

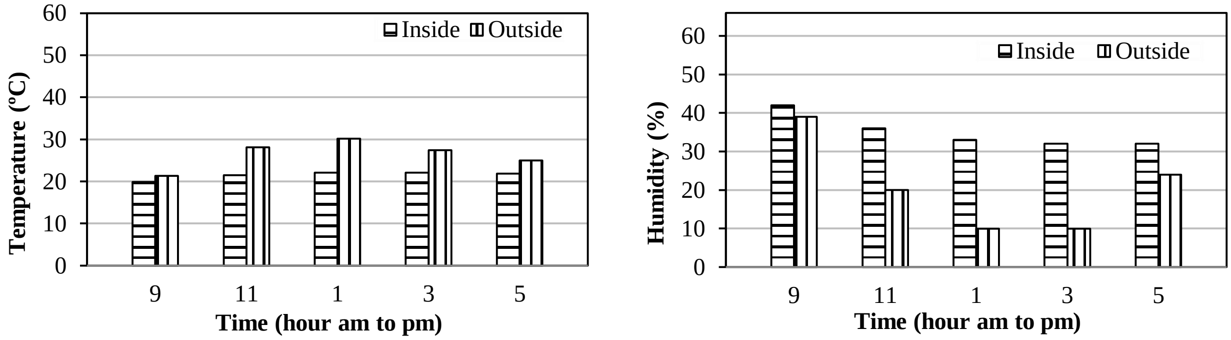


Fig. 4.22 Comparison of indoor and outdoor temperature and humidity values with time at twelfth floor of Telecom tower.

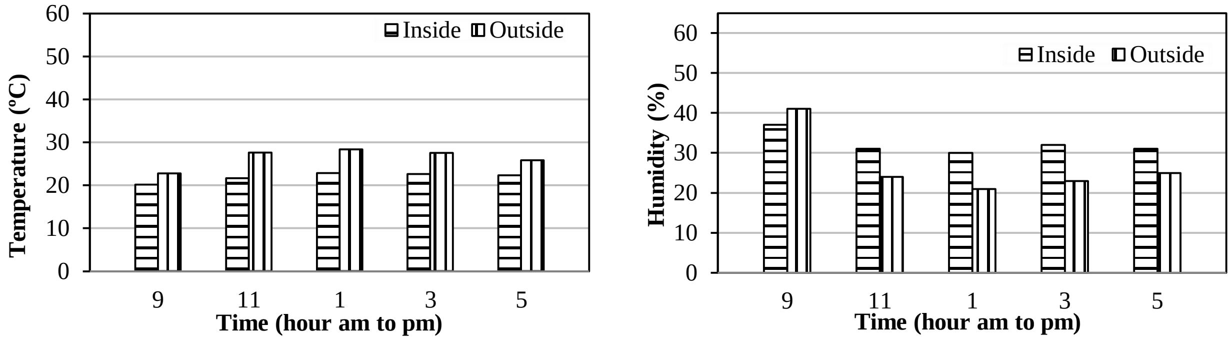


Fig. 4.23 Comparison of indoor and outdoor temperature and humidity values with time at sixteenth floor of Telecom tower.

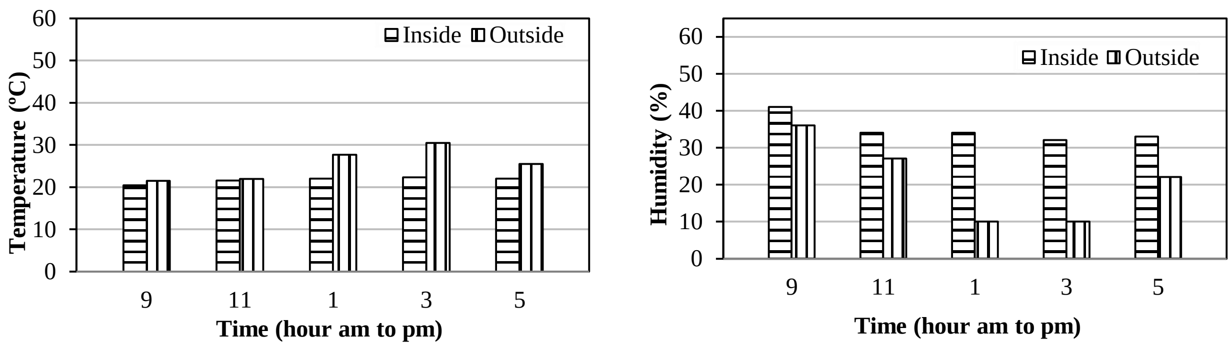


Fig. 4.24 Comparison of indoor and outdoor temperature and humidity values with time at twentieth floor of Telecom tower.

The formula devised to calculate the temperature efficiency in buildings under investigation is given by equation 1.

$$E = \frac{\left| T_o - T_i \right|}{T_o} \times 100 \qquad (1)$$

where,

E = Efficiency of the system (taken average of values from 8 am to 5 pm) in percentage

T_o = Outside temperature in Celsius

T_i = Inside temperature in Celsius

This will give the value of temperature efficiency for a system. For calculating the humidity efficiency the formula is given by equation 2.

$$\overline{H} = \frac{\sum H_1 + H_2 + H_3 + \ldots . H_n}{n} \quad (2)$$

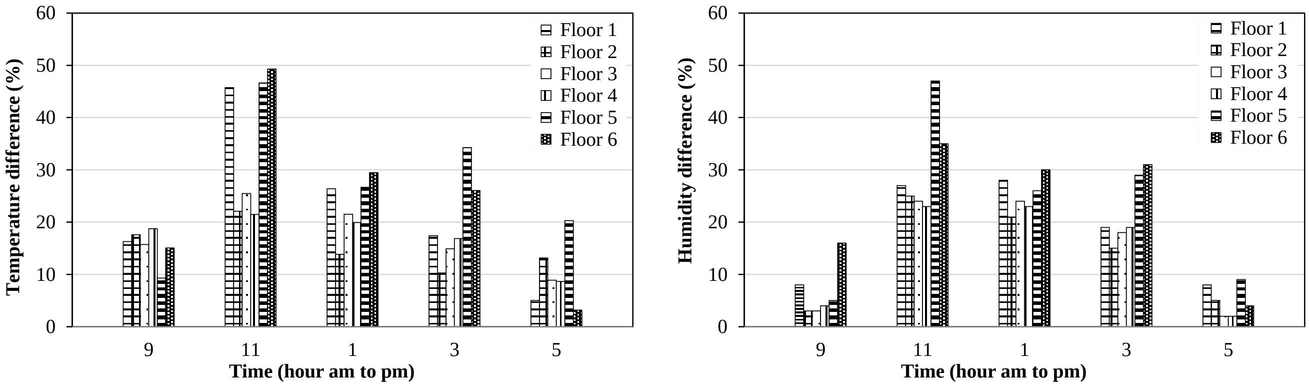
where,

$\overline{H}$ = Average Humidity in percentage

H_1, H_2, ..., H_n = Humidity value measured in percentage

n = no of reading taken (i.e. 10 in case of 8 am to 5 pm)

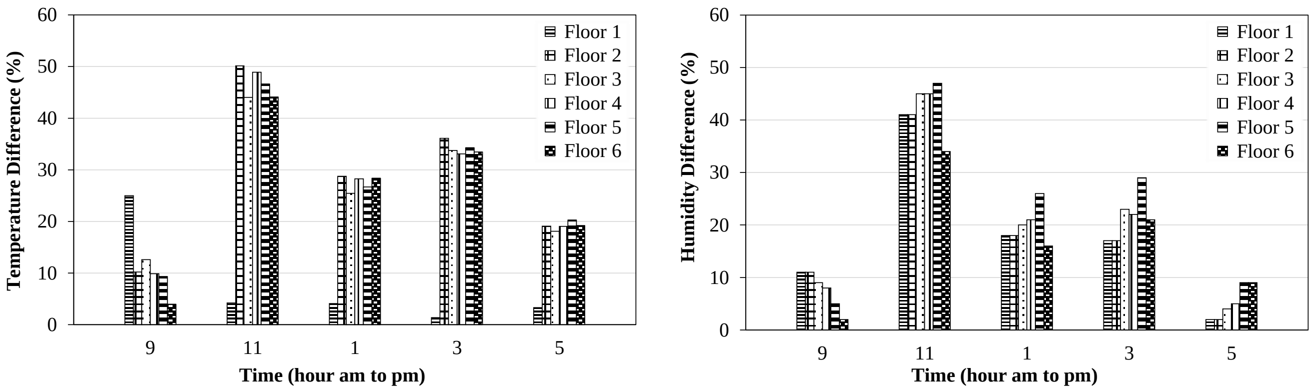
The data collected from Nespak house shows that its performance was enhanced due to heat insulation with the provision of cavity walls around the building. Also the insulation materials used in the roof are responsible for high values of percentage difference. This building is installed with HVAC system, which have become necessary accounting for almost half the energy consumed in buildings (Pérez-Lombard et al., 2008). As HVAC systems were intestinally turned off, the high value of humidity inside the building can be attributed to low temperature and heat resistant properties of the panels used in the external walls. Temperature and humidity difference plotted for different floors are shown in Fig. 4.25 (a) and (b). The high value of temperature difference (inside to outside of building) reflects the efficient performance of the building as inside temperatures tend to remain uniform without being effected from changes in outside temperatures. When observed, most of the values fall in 20% to 30% range. While for Judicial complex as shown in Fig. 4.26 (a) and (b), the values fall between 15-25%, which shows that efficiency of this system is comparatively low.



(a) Temperature difference (b) Humidity difference

Fig. 4.25 Variation in indoor environmental efficiency with time at various floors of Nespak House

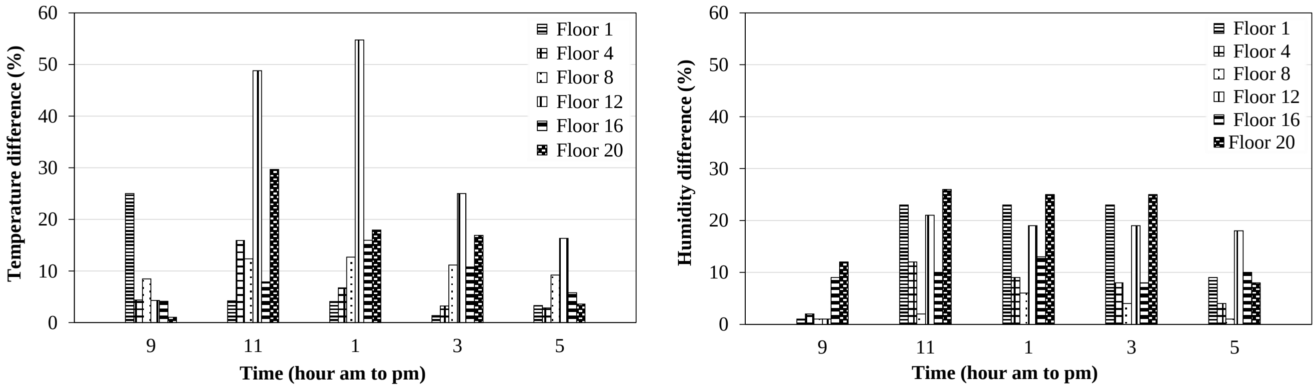
The lower efficiency of Judicial complex is attributed to simple frame structure construction with standard block masonry without any enhanced qualities of heat insulation. Simple mortar plaster is applied at both inside and outside faces of the whole building. No change in architecture and construction methodology is adopted to make energy efficient construction. The design of such buildings without using any insulation are considered designed through ambient energy conditions design approach (Spence and Mulligan, 1995). Orientation of this building is such that, sun faces the building at the second half of the day due to which the heat entering the building from 8 am to 10 am is not making much temperature difference as shown in Fig. 4.26 (a). Also humidity level of the building stays high at the first half of the day. Whereas, in the second half of the day the percentage difference shows significant increase in the value of temperatures (outside to inside) which leads to change of comfort level during the passing time of the day. This shows that the orientation of the building is a significant contributing factor while finalizing architectural design. The internal layout of the building must also be decided keeping building direction consideration with respect to sun. Orientation of the building is considered the foremost objective to analyze the thermal performance including the evaluation of heating and cooling loads (Andersson et al., 1985).



(a) Temperature difference (b) Humidity difference

Fig. 4.26 Variation in indoor environmental efficiency with time at various floors of Judicial complex

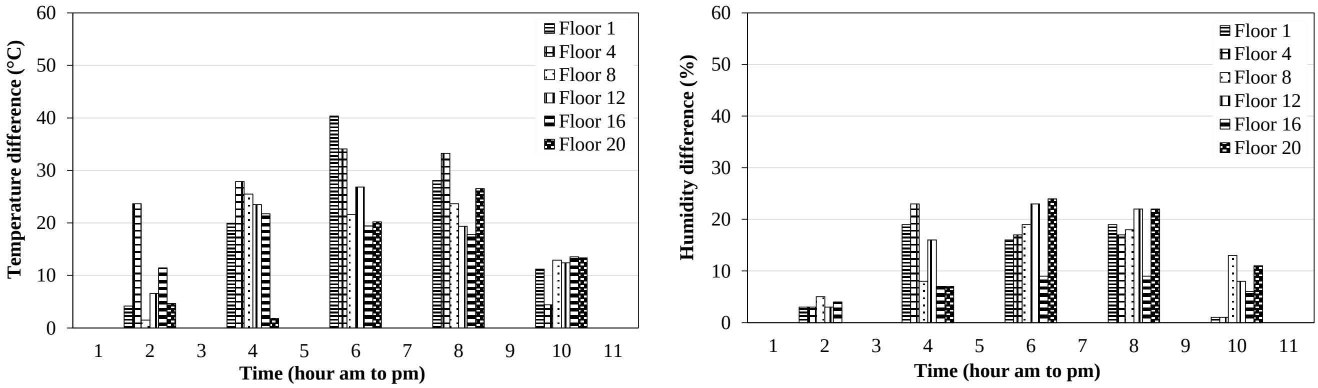
When considering the high rise buildings same experiments were performed at Saudi Pak tower which comprises 20 floors. Being designed as energy efficient structure, sheets of polystyrene in roof, terrazzo panels composed of chips at external walls and thick glass were used all over this building for heat insulation. The exterior single glazed windows, the type used in this building, has typical heat transfer coefficient of 6.40 $w/m^2.K$ and 23.7% heat loss (Lang, 2004). The orientation of tower is such that it faces the sunlight for more than 6 hours and after 2 pm the sun fully covers only one side of the building. This results in the shaded areas being comparatively comfortable to areas which are fully exposed to sun. This shows that owing to summer weather conditions, interactive shading of a building contributes in providing comfortable environment and improving indoor conditions (Zhu and Lin, 2004). The temperature and humidity graphs for Saudi Pak tower are shown in Fig. 4.27 (a) and (b). High valve of temperature difference observed at 11 am and 1 pm is due to direct exposure of the sunlight at 12^{th} floor. The temperature difference values (inside to outside) seen from both these graphs are low signifying that Saudi Pak tower in not as energy efficient construction as envisaged.



(a) Temperature difference (b) Humidity difference

Fig. 4.27 Variation in indoor environmental efficiency with time at various floors of Saudi Pak tower

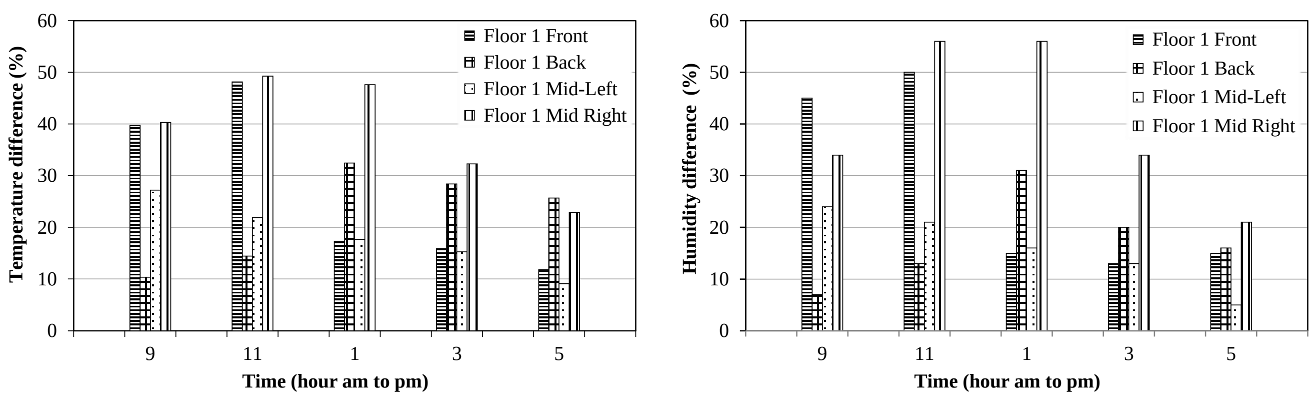
Telecom yower is also designed as an energy efficient structure using state of the art materials and architectural techniques. In this tower, alpolic cladding at facade enhances the heat insulation and contributes towards the building architectural aesthetics. Windows used are double layered glass with air cavity in between which significantly blocks the sunlight and internal/external temperature (heat) exchange in the building. The design and orientation of the tower is such that it gets sunlight on its faces all day long, however with the use of cladding and double layered glass windows the inside temperature remains uniform at a comfortable level and enhances the performance of the building. Graphs for temperature and humidity monitoring for Telecom tower are given in Fig. 4.28 (a) and (b). These plots show slightly high values of both thermal and humidity percentage difference (inside/outside) than that of Saudi Pak yower, indicating that Telecom tower is more energy efficient owing to its insulation properties.



(a) Temperature difference (b) Humidity difference

Fig. 4.28 Variation in indoor environmental efficiency with time at various floors of Telecom tower

Conversely, the model structure when monitored for selected criteria, exhibited significantly efficient results for controlled temperatures and humidity. The dense thermopore used in the SCIP performed efficiently with high values of percentage difference of temperature and humidity values. The temperature and humidity performance of model is shown in the Fig. 4.29 (a) and (b).



(a) Temperature difference (b) Humidity difference

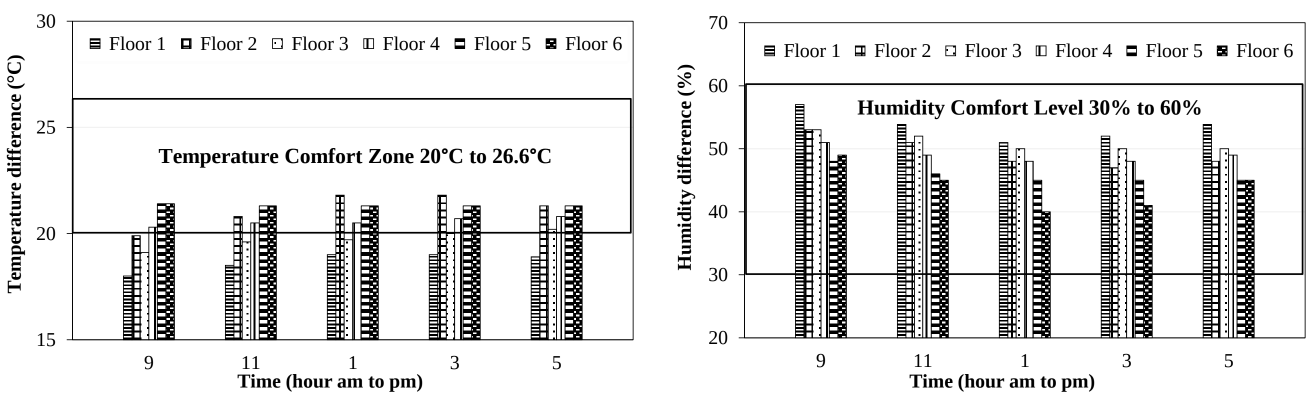
Fig. 4.29 Variation in indoor environmental efficiency with time of model structure

It is noted that with the passage of day the inside temperature rises but decreases when the effect of sunlight is reduced. This trend is more significant in non-energy efficient buildings. The use of energy efficient techniques helps the building to stay warm inside when the outside temperature decreases. As the height of the building increases a slight increase in temperature is observed which is attributed to more exposure of high rise to sunlight and radiations. Humidity decrease was also observed at elevations, but some abnormalities were also noted because humidity suddenly drops to minimum value when building is exposed to direct or indirect sunlight.

4.3 Comfort analysis

It is known that human body experiences greater distress of waste heat burden at a lower temperature with high humidity than at a higher temperature with lower humidity (Conceição, 2003; De Dear et al., 1991). As recommended by the American society of heating, refrigerating, and air conditioning engineers (ASHRAE) standard 55 "Thermal environmental conditions for human occupancy" (ANSI/ASHARE Standard, 2013), the recommended temperature ranges observed to describe the comfort level of at least 80% of individuals are 20°C to 25.5°C in winter and 22.2°C to 26.6°C in summer whereas the comfort range of relative humidity is 30% to 60% (De Dear et al., 1991).

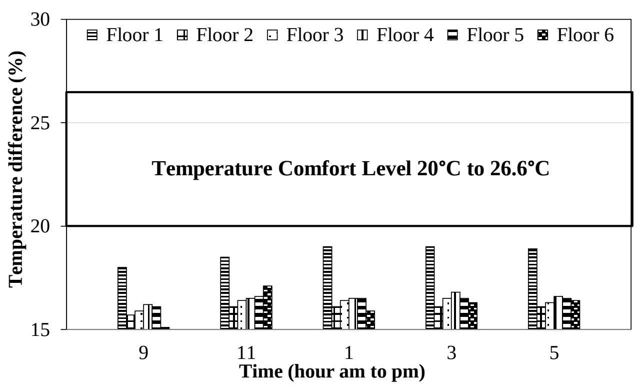
Energy efficient buildings response was studied to consider the comfort level of the occupants as shown in Fig. 4.30 and 4.31. While designing energy efficient systems and operating such buildings, the comfort of the occupants becomes a significant parameter. Due to the climatic change, the seasonal performance of the buildings also effects the inside temperature and humidity. Hence the inside temperature and humidity of the Nespak house building and Telecom tower are analyzed as per the comfort zone defined by ASHRAE (ANSI/ASHARE Standard, 2013).



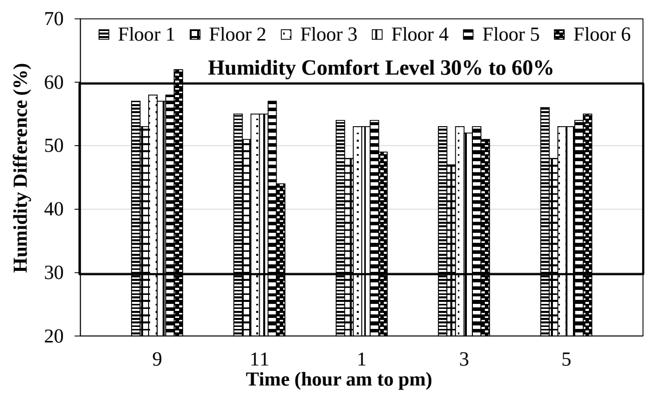
(a) Indoor temperatures (b) Indoor humidity

Fig. 4.30 Comfort zone with time based on indoor environmental efficiency of Nespak house

Fig. 4.30 shows that, in Nespak house building the temperature is lower and the humidity is well in the comfort zone which is attributed to cavity walls and facade insulation panels. At the peak hours of sunlight, the insulation kept the upper floors of the building under controlled environmental conditions. Hence, it can be seen that during much part of the day, the inside environment remains within comfort zone and feasible for the occupants. In Fig. 4.31 a difference is observed from the data achieved for Judicial complex, owing to its conventional construction technique and without any insulation, the humidity level is significantly high. Also the temperature is very low from the comfort zone so the conditions become uncomfortable for the occupants inside (De Dear et al., 1991).



(a) Indoor temperatures



(b) Indoor humidity

Fig. 4.31 Comfort zone with time based on indoor environmental efficiency of Judicial complex

Comparing the architectural and construction techniques shows that, the use of alpolic cladding and double layered glass in Telecom tower is 8% more temperature efficient than the terrazzo panels and thick glass used in Saudi Pak tower. Similarly, humidity efficiency comes out to be 5% higher for Telecom tower. The reason for this difference is that alpolic cladding proves to be more temperature resistive. It is composed of skin material of 0.5 mm thick aluminum alloy and core material of non-combustible mineral filled core which best insulates the heat coming from sunlight and conserving energy (Turner, 2012). Also the double layered glazed glass used shown in Fig. 3.1(b) contains a vacuum layer which creates a barrier for heat to travel across. The overall facade of the Telecom tower is applied with glass panels and alpolic cladding, resulting in higher energy efficiency.

Similarly, cavity walls construction and ordinary block masonry construction comparison show that Nespak house behaves 6% more efficient than the Judicial complex in respect of temperature efficiency and 4% in humidity efficiency. This efficiency is attributed to cavity wall construction technique in Nespak house where a 50 mm thick cavity in outer walls of the building is used. The cavities of different sizes inside walls such as the one provided in Nespak house results in thermal resistance of the structures (Aviram et al., 2001). Moreover a 40 mm thick jumbolon sheet is used in roof insulation which is contributing for conserving indoor temperatures. The efficiency of this system is more than that of ordinary construction owing to use of energy efficient materials and techniques. Also the orientation of Nespak house building is such that its side is exposed to direct sun in first few hours of day. The building however stays insulated with controlled temperature and humidity conditions, owing to thick glass and external panels as shown in Fig. 3.1(a).

When model performance was compared with Nespak house, the SCIP technique used in model comes out to be 3% more temperature efficient and 6% more humidity efficient. Same model when compared with Telecom tower comes out to be 6% and 5% more efficient in temperature and humidity respectively. This is attributed to insulation properties of SCIP which includes the dense thermopore all around the walls and roof of the model. The wide use of structural insulated panels (SIP) in commercial, residential and industrial buildings provide structural safety and distributed thermal mass (Medina et al., 2008). Thermopore has low thermal conductivity and high strength properties therefore it can be used in energy efficient building construction. The energy efficiency in model is significant, because the thermopore panels are properly insulated and no outside temperature fluctuations are allowed to effect the system. A controlled environment is said to be generated confirming the behavior to be energy efficient.

4.4 Cost analysis

When the model was constructed using SCIP technique, also provision of different sizes of doors and windows and their position the total cost of the project has increased. Without using energy efficient materials, cost comes out to be **1200-1300 Rs/sq-ft** and with usage it is near **2600-2700 Rs/sq-ft** and recovery period for this cost is **9-12 months** as given by the manufacturers.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 General

The aim of this study is to enhance the architecture and design of buildings which reduces the energy demand of a building and also contributes towards building sustainability. It is done through monitoring of the performance of selected buildings which were different in construction material used, type of construction selected and architectural techniques adopted. Model also demonstrated the usage of energy efficient material and its benefits. Based on the data of each building and graphical results conclusion are drawn.

The energy efficiency in the built infrastructure can be attained using modern insulation materials, architecture and orientation, and modified construction methodology that can conserve energy significantly. Jumbolon sheets, thermopore insulation and alpolic cladding are known to be energy efficient construction materials. The use of these materials during the construction, application of architectural techniques, setting the orientation of the buildings and the most important sustainable operation and maintenance of the system are the basic demands of construction industry in modern time. Building construction with provision of cavity wall is being widely practiced for its important contribution towards energy saving. Also the SCIP technique is considered to be safe as well as energy efficient that enhances the performance of the buildings significantly. As far as the architectural techniques are concerned, setting the orientation of the buildings keeping in view the direction of movement of the sun and wind in the region is of key importance. Hence it can be stated that, it is the collective provisions of the architectural, construction and environmental factors which not only conserve and save energy but also promise the sustainable operation of a building. The combination of both energy efficiency and sustainability concept in buildings would result in a better society for future generations.

5.2 Conclusions

Based on the results achieved during this study following conclusions are drawn:

- The building comprised of cavity wall construction performs thermally 6% more efficient than traditional construction technique owing to air gaps as insulation.
- New construction techniques involving alpolic cladding and double layered windows are 8% more energy efficient than conventional insulation technique used earlier.
- Structural concrete insulated panels (SCIP) construction technique enhances the energy efficiency by 6%.
- Comfort level for occupants can be achieved when building operates within specific temperature and humidity range for all climatic conditions.
- Orientation and layout of buildings are governing criteria to translate comfort level of the occupants

5.3 Recommendations

While this research has provided significant understanding about the existing construction material and architectural technique being adopted. Given below are some of the recommendations for further research in this area.

- There is still a need of further research in order to determine the best suitable energy efficient technique for residential buildings keeping in view the economy.
- A detailed cost analysis is required so that user can easily decide to adopt energy efficient techniques while construction.
- Further study is required for the detailed understanding of sustainable methods keeping in view depletion of resources.
- Alternate resources of energy saving and usage be adopted in our daily life, saving natural resources for future human generations.
- Complete seasonal study must be carried out on energy efficient building to fully understand the effect of material, architectural and construction techniques.

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