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A REVIEW OF PASSIVE COOLING ARCHITECTURAL DESIGN INTERVENTIONS FOR THERMAL COMFORT IN RESIDENTIAL BUILDINGS

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ABSTRACT

Solar passive design concepts are used in traditional buildings worldwide. This ancient architecture design principles have been used for several years for passive cooling of air in warm humid region. Solar passive design can be referred as a way of designing buildings to achieve a comfortable environment that minimizes the energy use and reliance of mechanical system. But, now-a-days, modern buildings are designed without proper consideration of its form, orientation and other variables. This has lead to a considerable increase in the energy usage. Exhaustive research has been carried out, focusing on the importance of solar passive architecture and passive cooling architectural design interventions for thermal comfort in residential buildings. This paper presents a detailed review on various methods of passive cooling techniques adopted in different traditional buildings and comparison of traditional and modern buildings for thermal comforts. The study reveals that for future construction, the techniques adopted in traditional buildings can be incorporated in modern buildings to achieve thermal comfort in a passive way.

KEYWORDS: Solar Passive Design; Traditional; Modern; Thermal Comfort; Energy

Global crisis confronting mankind is depleting energy reserves. The biggest challenge for an architect is to design a thermally comfortable living environment with minimum or without the usage of electro-mechanical devices - fan, AC, air cooler etc.

Traditional buildings of earlier times had many built-in architectural features for achieving comfort. But now-a-days, while constructing buildings, in the process of modernization, people are not giving importance to climatic design due to lack of awareness. Energy efficiency in modern buildings can be achieved by adopting solar passive architectural principles responsive to the climate of a particular location.

This article presents a detailed review that has been carried out on the various techniques adopted in traditional buildings, modern buildings, comparison of thermal performance between traditional and modern buildings, solar passive architecture cooling design interventions, design of modern solar passive architecture buildings and thermal comfort models in buildings.

THERMAL PERFORMANCE OF TRADITIONAL BUILDINGS

Hatamipour and Abedi (2008) have shared some useful passive cooling systems from ancient Bushehr architecture of Iran for natural cooling of buildings in a Hot and humid region. These technologies are used for several years for protection of people from harsh summer conditions and made the people to live in comfort without the use of any electrical air conditioning systems. The Technologies and controls for solar passive cooling of buildings include: suitable insulation of walls and roofs, reduction of heat gain through walls by light coloured surfaces, small windows and mutual shading restricting heat gain through windows, use of louvers for natural ventilation, orientation of building along wind direction, cooling storage by use of heavy walls as thermal mass, use of overhung for shading using wooden sunshades and shading of buildings using trees. Separation of heat generating spaces, construction of high roofed buildings and providing adequate windows are other solar passive techniques listed out which can be used today for the thermal comfort of modern buildings.

Abdul Manah Dauda (2016) compared the traditional and modern Architecture in Ghana. The temperature measured in traditional indoor varied from 28-35 ˚C and in modern building it ranged from 31-37 ˚C. The maximum MRT is found to be 4-5 ˚C less in traditional building and 3 ˚C higher in modern building than the corresponding indoor air temperature. In traditional building the roof is made of the thatch ensuring well ventilated membrane with pores in between. This offers high insulation and allows hot air to escape. Modern house had corrugated metal sheets allowing heat, increasing air temperature and thermal discomfort. Effective passive and natural central system in traditional building provides a thermal comfort than the modern building.

Susanne Bodach et al. (2014) studied the climate responsive building construction and design strategies of vernacular architecture in Nepal. The design recommendations suitable for Nepal were identified using Olgyay's bioclimatic chart, Givoni's psychometric chart and Mahoney table. From the study of vernacular houses of Nepal. It has been reported that solar passive

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heating for winter, high thermal mass, large roof overhang to keep summer sun away, enhanced air movement and medium sized windows in summer, arrangement of courtyards, shaded semi open spaces like balconies, verandas and courtyards providing cooler spaces in summer used in vernacular houses of Nepal provide thermal comfort and hence these techniques can be followed for modern constructions.

Megha Jain and Singh SP (2013) studied the solar passive architecture concepts and techniques incorporated in the design of a heritage building - Gohar Mahal in Bhopal. The building was built in 1820 with passive design concepts applied by our ancestors. Various solar passive design considerations and elements incorporated in the design of Gohar Mahal includes landscaping, water bodies, orientation, site features, open spaces, built form and envelope design. Field measurements taken at strategic locations within the building are compared with outdoor conditions. The parameters measured include temperature, humidity and air movement. During summer, it is found that the indoor temperature is below 26 ºC. The study inferred that the thermal mass and the envelope design in the building contribute to the indoor microclimate, stabilizing the indoor temperatures and giving thermal comfort.

Manoj Kumar Singh et al. (2014) reported on design optimization of vernacular buildings using solar energy modular simulation tool TRNSYS 17 using 3D models with three types of construction and eight possible orientations in warm and humid climate of North-East India. Parametric simulation for different types of scenario such as orientation, wall thickness, thermo-physical properties, window glazing type, window to wall ratio, shading, infiltration, ventilation, internal heat load and false ceiling types are carried out for design optimization. In the recent years, the energy consumption has increased in vernacular buildings though they are naturally ventilated due to the quest for better thermal comfort. Hence, the simulation objective of improving indoor thermal comfort or reducing the number of discomfort hours. The results suggest that for large openings in windows and ventilators promote cross ventilation. It is also found that the heat gain is more during summer due to infiltration. Hence operating windows and ventilators and promoting night ventilation is recommended. Window replacement with double glazing and proper shading elements has shown improvement in indoor thermal conditions. Further analysis revealed that the vernacular building is more comfortable in pre-summer and pre-winter season.

Usha Bajpai and Sachin Gupta (2015) highlighted the solar passive concepts used in Avadh Architectural buildings in Lucknow, India. The passive concepts incorporated in the tomb such as high roof, curved roof, natural ventilation, massive thick wall and openings: light coloured exterior to reduce heat gain into the buildings are widely found. The height of the building is around 10m. This type of construction allowed warm air to collect at top and such stratification of warm air at top maintained cool place crating a comfortable zone. It is observed that U-Value of the wall is low due to very thick wall, It is also observed that usage of water and landscaping has created micro climate inside and around the building.

Manojkumar singh et al. (2010) reported the thermal performance evaluation of comfort temperatures in vernacular buildings of North-East India. 50 vernacular dwellings with 100 inhabitants was taken for the study during winter, pre-summer, summer/monsoon and pre-winter in the months of January, April, July and October. The time lag for the heat transfer in the house is 5-6 hour which show high insulation value. Window to Wall ratio is found to be 0.216. Sufficient number of doors, windows and ventilators are provided for adequate ventilation which accounts for about 50% of the floor area (openings). Maximum temperature swing inside the house is 10 ˚C which is quite good for naturally ventilated traditional buildings. It is also concluded that the day lighting inside the building is insufficient.

Praseeda et al. (2014) have assessed the impact of material transition during retrofitting of a naturally ventilated traditional building of Sugganahalli near Bangalore for thermal comfort models on Embodied Energy (EE) and Operational Energy (OE). ASHRAE comfort standards and TSI model by Sharma and Ali are used. Results show that traditional buildings consume less operational energy even in extreme climatic variations as they use passive techniques or non-mechanical methods for space conditioning. It is reported that by changing material, will increase EE.

Kranti Kumar Mynani (2013) reported on courtyards in traditional residences in Athangudi village, Tamilnadu, India. The central courtyard in the house taken for study is surrounded by a corridor which provides access to the rooms. It has been reported that the courtyard can provide a cool indoor during daytime. Courtyards could also be part of the modern residences creating better living conditions.

THERMAL PERFORMANCE OF MODERN BUILDINGS

Fahimeh Foudazi and Mugendi M Rithaa (2013) stated sustainable solutions for cooling systems in residential buildings in Western Cape, South Africa. By incorporating with modified strategies according to local weather conditions of South Africa, people were able to live in comfort and with less consumption of electricity and air conditioning. Basic designs found in such solar passive structures are inward orientation, self shading courts, summer living spaces with higher ceiling, large mass wall & roof, domed roof with vents, light colored roof, earth sheltered buildings, East-west axis orientation with North light roof, north south facades elongated to receive daylight & natural ventilation, natural air flow, heat exhaust systems, wind catchers or wind scoop for fresh air, landscaping and geothermal cooling.

AMR Sayed et al. (2013) analysed thermal comfort and indoor environments inside new assist housing in Egypt. The psychometric charts for ASHRAE standard 55 and Adaptive Comfort Standard (ACS) were used for study during hot summer. During the study period the maximum outdoor temperature is 43˚C with lower humidity level of 4% and minimum outdoor temperature is around 27˚C with a humidity level of 40%. The results showed that the indoor temperature is high, ranging between 31-40 ˚C in different natural ventilation strategies. Using bioclimatic chart it is found that the data measured during summer season is well within the boundaries of natural ventilation and evaporative cooling.

Tofigh Tabesh and Begum Sertyesilisik (2015 & 2016) investigated the performance of building with the objective of the effect of glazing type, the effect of window-to-wall ratio and the usage of courtyard and atrium. Design builder interface and Energy plus analytical software have been used. The investigations revealed that integrated usage of courtyard and atrium space contributes for energy saving in all three climates. Since large openings for courtyards are used it is best suited for summer and an atrium made is used in cold months.

Vincent Jayaseelan V and Ganapathy C (2007) analysed the thermal performance of modern low-cost housing units in three different locations - Kanyakumari, Thirunelveli and Madurai Districts. Tropical summer index (TSI by Sharma and Ali 1986) was calculated and it is compared with comfort temperature (By Nicol F et. al. 1994). Study confirms all the three houses are thermally discomfort. Further various solar passive measures are suggested to improve thermal comfort.

COMPARISON OF TRADITIONAL AND MODERN BUILDINGS

Sangkertadi et al. (2008) compared the thermal comfort of traditional architecture and modern style housing in North Sulawesi – Indonesia. Ten traditional houses and ten modern style houses have been taken as samples for study. Thermal sensation responses were collected from 60 adults living in those houses as subject samples. Results show that the respondents feel thermally comfortable in the indoor environment with maximum temperature of 29 ºC and 60% humidity with a low air velocity.

Paruj Antarikananda et al. (2006) compared the thermal performance of traditional and contemporary house in Thailand using ECOTECT simulation model. The contemporary structures are constructed with concrete structures, brick walls and plasterboard ceiling with 3cm of insulation and concrete tiles over roof with single glazed windows whereas the traditional Thai houses are constructed with open high pitched roof, windows and walls along with large central terrace. Contemporary houses are not designed in consideration to cooling without mechanical devices and air conditioning. Hence use of artificial microclimates to provide comfortable thermal conditions is unavailable in areas of extreme conditions. This results in high energy consumption contributing towards environmental deterioration. The study has concluded that the traditional houses of Thailand provide useful indicators of architectural design responses to climate, particularly in the context of purely passive environmental control.

Tinker JA et al. (2004) reported that most of the modern low income housing built in Sarawak, East Malaysia is totally unsuitable for a hot and humid climate and the houses are thermally uncomfortable for most part of the day. But the traditional Malay houses are designed according to climatic condition and hence provide a comfortable indoor condition. Thermal comfort parameters are measured both in traditionally built house and typical modern low income houses in East Malaysia. Computational Fluid Dynamics (CFD) code is used to evaluate data and the Corrected Effective Temperature (CET) index method is used to assess comfort levels. The research study confirmed that traditional Malay house provided high levels of thermal comfort; whereas the modern houses did not. It is found that thermal comfort could not be achieved when doors and windows are partially open or closed. Though the thermal comfort is attained when doors and windows are completely open in spite of high indoor temperature, security risk does not permit it. Hence the study concludes to provide sufficient secure ventilation with grills for permanent air movement and comfort.

Dilli AS et al. (2010 & 2011) carried out questionnaire survey among the residents of traditional and modern buildings in Kerala. Around 70% of the residents of traditional houses voted for very comfortable condition in all seasons; while no one feels that they are uncomfortable or very uncomfortable. Less than 20% of the residents of modern houses voted for very comfortable in summer season. The evaluation using PMV-PPD analysis and with bioclimatic chart proves the indoor thermal comfort of traditional buildings are better compared to modern buildings.

SOLAR PASSIVE ARCHITECTURE COOLING DESIGN INTERVENTIONS

David J. Sailor et al. (2012) explored the performance of the building with green roof surface designs in USA. Building energy simulations were carried out for black roof and white membrane roofs along with different types of green roofs. The investigations carried out in eight buildings in four cities representing different climatic conditions. Six out of eight buildings proved that white roof resulted in lower annual energy consumption cost than green roof and black roof. It is also found that high vegetation green roof found to outperform the white roof.

Guimares et al. (2013) found the influence of ceiling height in thermal comfort of buildings at Brazil. Varying ceiling height of 3m, 2.8m and 2.4m are constructed. In each one thermocouple is installed at different heights to record temperature. Thermal inertia of indoor environments is directly proportional to the volume of that environment. In hot weather locations, the reduction of ceiling height causes a small increase in indoor temperature. Upper and lower layers of the indoor environment can reach up to 4 ºC. Results indicate that temperature increases 1 ºC for each 20 cm. A range of human comfort varies; it may cause thermal comfort to occupants.

Ogali et al. (2001) prompted research on passive cooling and heating systems in Kenya and many developing countries. Four houses with different thermal properties were analyzed in Kenya. Dry bulb temperature, mean radiant temperature, floor surface temperature and wet bulb temperature were observed in the selected samples. The maximum dry bulb temperature in a high mass building was 24.5 ºC which is well within the comfort zone, when the outdoor temperature was 31.4 ºC. Thermal mass has capacity of reducing both peak and total energy required. Even when outdoor temperature goes too high, architectural design solutions like location, building, orientation, form and shape, envelope design, fenestrations and day lighting, landscaping can control effects of solar radiation.

Tobi Eniolu Morakinyo et al. (2014) reported the study of thermal comfort conditions due to the effect of vegetation on urban buildings in Nigeria. Temperature Humidity Index (THI) and Relative Strain Index (RSI) are the indices used to assess the thermal comfort. The study assessed two typical buildings in Nigeria, one building was shaded with trees and the other building was not shaded. Air temperature and relative humidity was measured simultaneously inside and outside both the buildings for a period of six months. Results of the analysis revealed that unshaded building is less comfortable when compared to shaded building. Recommendations are given on strategic tree planting and vegetation to improve thermal comfort.

Nishita Baderia (2014) reported on the role of thermal mass in humid subtropical climate located on the eastern coast of China at Ningbo. 300mm thick high thermal mass concrete walls and 400mm thick high thermal concrete slab was used. Thermal Analysis Simulation (TAS) software was used to carry out parametric analysis. Out of four cases experimented, result indicated that building with high thermal mass and night ventilation performed best comfort and efficiency.

Nahar et al. (2003) carried out experiment on eight different passive techniques used over roof for cooling of buildings in arid climate regions and analysed its performance at Jodhpur, India. Eight identical structures had all the four sides covered with galvanized steel sheet and mild steel angle. RCC roof of 100 mm thickness was coated over the test structures. Ventilation is totally avoided as all the sides are closed by galvanized steel. Heat load in building through the roof is the maximum. After analysis during the hot summer it was found that different passive cooling techniques in increasing order with respect to Sania covering over the concrete roof, 50 mm cement vermiculate insulation over the roof, white painting by cement, roof provided with air void insulation using earthen pots, roof pond with movable thermal insulation, white glazed tiles over roof and evaporative cooling. Though evaporative cooling was found best, it requires about 50 l/m2 water per day. Hence white glazed tiles struck over the concrete roof can be used to reduce heat load from the roof.

Madhumathi et al. (2014) carried out research to select the suitable roof constructions for naturally ventilated residential buildings in warm humid climates of India. Six case studies of residential buildings in Madurai, Tamilnadu, India are selected. 50% of the heat load in the building is from the roof. Various roof treatments have been studied for comparing their effective passive cooling. The average indoor air temperature measured in RCC roof slab was around 33.57 ºC, which does not fall in the comfort zone indoor temperature as per ASHRAE standards. Among the investigated traditional roofs the Madras Terrace roof possesses a high thermal capacity as it stored the absorbed heat for a larger period of time. The average indoor temperature reading of the traditional building with Madras terrace roof was around 30.55 ºC during peak summer. This is nearly equal to the thermal comfort level as per ASHRAE standards. From the study it is concluded that it is desirable for multi-layered roof comprising materials of different thermo physical properties.

Vijaykumar et al. (2006) found a new concept of laying Hollow Clay Tiles (HCT) over RCC roof instead of conventional Weathering Course (WC). It is found that 38-63% of energy savings can be achieved than the conventional WC roof by this method. Heat transmitted through the exposed roof of single or two storey residential buildings is about 50-70%. Thus heat transmission is proved to be reduced by hollow clay tiles and further by air flow through the hollow passages took care of all variations in climate and heat radiations.

Anand et al. (2014) experimented different cool roof techniques. Cool roof technology reduces the heat gain into the building, internal temperature of the building which in turn contributes for reduction in electricity usage and CO_2 emissions into the environment. The cool roof technology evolves as a better clean and green technology because it helps to maintain building envelope at the comfort level.

DESIGN OF MODERN SOLAR PASSIVE ARCHITECTURE BUILDINGS

Hanan M.Taleb (2014) simulated using IES software to assess the building performance by incorporating eight solar passive cooling strategies in UAE. Eight principle passive cooling strategies applied to the case study villa includes louvre shading devices, double glazing, wind catcher and cross ventilation, green roofing, insulation, evaporative cooling via fountain, indirect radiant cooling and light colour coatings with high reflection. In depth analysis revealed the potential of 9% reduction of cooling load on application of these passive cooling strategies. Energy saving of 23.6% was observed.

Thomas et al. (2006) presented the combined results of analytical, computational and experimental investigation of the parameters for choosing affordable materials and thermal comfort design in solar passive buildings. In order to minimize the cost, the quantity of the building material must be minimized which becomes the merit index for cost. At Egypt near Cairo in Inshas Science city project, three rooms of guest house were selected for thermal investigation. One room had high domed ceiling, other room had vaulted ceiling and third room had shallow dome ceiling. All the windows and doors are kept closed in all the three rooms during the study. Air and wall temperatures were taken for all the rooms in both interior and exterior. The results of the investigation revealed that maximum temperature achieved in each room depends on the orientation. The north, north west and southern rooms reached a maximum of 31 ºC, 32 ºC and 33 ºC respectively. It was found that material selection had an influence on thermal comfort. The time lag and decrement factors are only functions of wall thickness and thermal diffusivity.

Petros A. Lapithis (2002) investigated the traditional and contemporary Architecture of Cyprus. Thermal performance of the traditional, contemporary and solar buildings are discussed related to architectural design, materials, methods and occupancy pattern. In the designed solar house 250mm brick work + 70mm expanded polystyrene was used as insulation mass to exclude thermal bridges. Two years of hourly monitoring using computer data loggers was carried out. Computer simulation performed using Energy 10 resulted that the solar house (121 kWh/m2) is most energy efficient, followed by traditional house (243 kWh/m2) and finally the contemporary house (368 kWh/m2). Traditional buildings performed thermally better than contemporary buildings due to various solar passive architecture designs like orientation, natural ventilation, thermal mass, landscaping, fenestrations, solar heat gain, thermal insulation, exploitation of spaces – courtyards, solarium, building envelope, which were incorporated in the building. It was concluded that designed solar passive house in Cyprus climate has 100% energy saving potential.

Bhavana Patil and Sheeba Valsson (2015) have studied on using the building materials and construction techniques towards Thermal comfort. Two types of structures- filler slabs with rat trap bond masonry and mud block masonry are analyzed. The data was recorded from 9am to 5pm for the month of June. The data recorded is compared with that of other researchers. It is found that for rat-trap bond building, the temperature ranges from 31.7-32.8 ˚C and for mud block building it ranges from 33.2-33.8 ˚C. These readings are very close with the previous study carried out by others. Bioclimatic chart was also used for taking decisions during construction. Here it concludes that the use of 1m/s – 0.4m/s air movement can contribute towards thermal comfort for rat trap bond block.

Bhavesh et al. (2016) stated that 3 solar passive techniques are advisable for Mumbai in warm and humid climate - Induced ventilation, desiccant cooling and day lighting. Incorporating energy efficient practices in architectural building design can reduce annual energy needs of building.

Ramesh kumar et al. (2014) reviewed passive cooling practices for residential buildings. It has been reported that the indoor temperature can be reduced 6-10 ºC by incorporating solar passive cooling techniques such as thermal mass, evaporative cooling and natural ventilation. This can further enhance the performance of the building.

Mohammed Arif Kamal (2012) analyzed the design concepts and architectural interventions of various solar passive cooling techniques. In India, the building sector consumes about 33% of total energy consumed, in which commercial sector needs 8% and residential sector requires 25% to maintain comfortable indoor for thermal comfort is achieved by reducing the rate of heat gains into the building and removing excess heat gained from the building. The important cooling concepts reviewed include solar shading by overhang roof shading, shading by trees and vegetation, induced ventilation by solar chimney, air vents, evaporative cooling, passive down draft cooling. Theoretical studies have shown that cooling techniques in the building decrease cooling load for about 50% - 70%. Passive cooling is relatively of low-cost and offers savings in both capital and operating costs.

Induja and Chani (2013) highlighted that solar passive strategies are suitable for indoor thermal comfort in warm and humid climate. The major paths of thermal load penetration into the buildings include direct sun rays, conduction through walls, roofs and infiltration of outside air. Other strategies like providing proper shading devices for various fenestrations, landscaping for microclimate, avoiding undesirable openings, white washing roof to improve its performance by 2.5 times.

Veronica I. Soebarto and Siti Handjarinto (1998) highlighted that standards currently used worldwide are those from northern or mid latitudes. ASHRAE 1992 is based on data from climate chamber experiments conducted in mid latitudes. Actual research studies conducted at different places in tropical region showed people can tolerate warmer than predicted comfort models and ASHRAE standards. The research was carried out to investigate thermal comfort range of occupants, simulation models predicting effect of openings and wall structures and design strategies that could be incorporated. The house had several strategies in the house - few windows on east-west, 2m long overhangs as shading devices for windows, natural / cross ventilation and high ceilings with cavities for warm air to raise and escape. Results showed that indoor temperature was 5 ˚C lower than outdoor ambient temperature during peak summer while at night temperature was 2 ˚C higher. The house was comfortable with passive design strategies. Hence occupants did not use any mechanical air conditioning system. By simulation it was found in the house if all windows are opened (25% of floor area) the house is comfortable at night but less comfortable during day time.

THERMAL COMFORT MODELS IN BUILDINGS

Arash Beizaee and Steven K. Firth (2011) investigated the accuracy of predicted mean vote (PMV) model in residential buildings in UK. It resulted that PMV can only partially predict thermal sensation in naturally ventilated offices and houses in UK. Sixteen participants consisting of six females and ten males from diverse ethnic origins and age groups participated in the field study. Actual Mean Vote (AMV) and predicted mean vote (PMV) was compared and linear regression equations that best fit the survey data was arrived for the houses. It was found that the existence of context effects affecting thermal sensation of occupants. The investigation suggests further large scale study in order to confirm the applicability of these findings. It will help the organizations like ASHRAE to provide a larger database of field studies in order to validate the accuracy of PMV model.

David Mwale Ogoli (2007) reported the comprehensive study of thermal comfort in a naturally ventilated education building in Chicago with 120 student's sample. Field study and climate chamber laboratory study are the two research methods followed. Physical parameters (air temperature, mean radiant temperature, air movement and humidity), personal factors (activity and clothing), classifications (gender, age, education, etc.,) and psychological factors are considered. ASHRAE thermal comfort scale was used for thermal sensation. The observed temperature was compared with various thermal comfort models proposed for solar passive free running buildings proposed by Humphreys, Auliciems de dear and Nicol & Roaf. The temperature is found to be well within the comfort value. It was also concluded that there is a need to establish localized thermal comfort standards.

Olanipekun Emmannuel Abiodun (2014) reported the thermal comfort quality assessment in Naturally Ventilated (NV) hostel buildings in Obafemi Awolowo University, Nigeria. The measured data shows the indoor air temperature of 28.1-34 ºC and relative humidity of 30.8-75.5%. 80% of the respondents felt comfortable while the PPD index predicted that 58% of the occupants are not comfortable. The calculated average PMV index was +1.63. The PMV-PPD models used in standards are the most accepted and widely applied thermal comfort model. But, its applicability in NV buildings has been doubted as it is based on climate chamber experiments and thermal adaptation occurring in real buildings is totally ignored in it. The results of the study confirmed the suggestions recommended by previous researchers on the limitations of the PMV-PPD model for predicting thermal comfort in NV buildings.

Oluwafemi and Michael (2010) stated the importance of indoor thermal comfort for occupants well being and efficiency in productivity. Field survey on comfort study was carried out in Bauchi, Northern Nigeria. As per ASHRAE standard 55 (2004) acceptable thermal environment should be 80%. But it is found that 68% and 51% of occupants voted during summer and rainy season respectively in the central three categories. The people are also not comfortable with reference to humidity and air movement. It is also suggested that by increasing the size and number of window openings the hindrances can be reduced.

Harini Djamila et al. (2014) carried out a cross sectional questionnaire survey among 890 individuals in Kota Kinabalu City in East Malaysia. Major concern exists on validating the PMV in air conditioned spaces and adaptive model for thermal comfort in naturally conditioned spaces. It was widely accepted that air movement is the preferred strategy for improving the indoor thermal comfort in the humid tropics due to the presence of high humidity. The acceptable comfort zone refers to the optimum votes percentage within the central three categories (-1,0,1) on the ASHRAE thermal sensation scale. The mean relative humidity for the corresponding neutral temperature of 30 ºC is 73%. For the indoor thermal comfort ranges from 27.5 ºC to 33.5 ºC, the corresponding mean relative humidity ranges from 82% to 63% respectively as per the predicted regression model. It is found that air temperature and relative humidity are highly correlated. The result shows the occupants tolerance level to higher humidity. Thus humidity may not affect occupant thermal comfort.

Sushil B Bajracharya compared the thermal performance of traditional and modern residential buildings in Kathmandu valley in two different seasons. The traditional buildings are 1 to 2 ºC cooler than modern buildings in summer and 1 to 2 ºC warmer in winter. New equations to predict the indoor temperature of the residential buildings are developed using regression analysis with the help of SPSS software. This study concludes that traditional buildings can save a lot of energy compared to modern buildings. The linear regression equation proposed is useful to predict indoor air temperature by knowing outdoor air temperature from weather forecast of meteorological department. The readings measured proved that traditional building temperature lies well within comfort zone and support the Nicol theory of adaptive thermal comfort.

Nicol and Humphreys (2004) have stated the origin on development of adaptive thermal comfort and sustainable thermal standards for buildings. Pakistani buildings were found comfortable with temperatures ranging from 20-30 ºC with no cooling devices other than usage of fans. ASHRAE 55 (ASHRAE 1992) may save energy in air conditioned buildings with single constant temperature throughout the year. But it is hard to achieve in a free-running building.

Amitava Sarkar and Shivashish Bose (2015) carried out field survey on traditional and modern buildings in Mandi, Himachal Pradesh. 100 occupants from traditional and modern houses were used to assess their subjective responses in ASHRAE's 7 -point thermal sensation scale along with thermal performance in ASHRAE’s 3 point scale and thermal acceptance in ASHRAE’s 2 point scale. Thermal comfort standards suggest the temperature range of 18-30 ºC, with air velocity 0-2 m/s and relative humidity between 30-70% as comfortable range on the psychometric charts. The NBC 2005 standards are based on TSI. During comparative study it is found 80% occupants of modern houses preferred for higher indoor temperature while only 25% occupants of traditional houses have preferred for comfortable indoor. The results obtained from regression analysis confirms that the relation between indoor and outdoor temperature is in close agreement with the Humphrey Model. In order to support the continuity of tradition in building design and traditional construction techniques, Himachal Pradesh Government has amended Building Bye-laws in 2009 making it mandatory to incorporate solar passive architecture features in building designs suitable for local geo-climatic locations.

Kate E. Charles (2003) assessed the validity of two commonly used thermal comfort models. Fanger's Predicted Mean Vote (PMV) model and Fanger's draught model predicting percentage of occupants dissatisfied (PPD). PMV combines four physical variables (air temperature, air velocity, mean radiant temperature and relative humidity) and two personal variables (clothing insulation and activity level). Fanger's draught model combines three physical variables (air temperature, mean air velocity and turbulence intensity). It is suggested that PMV model would be a better predictor in air conditioned buildings than naturally ventilated buildings because of the influence of outdoor temperature and opportunities for adaptation.

Madhavi Indraganti et al. (2012) conducted Thermal comfort research in warm-humid (Chennai) and composite (Hyderabad) climates of India. Indian designers invariably follow strict ASHRAE standard when designing the indoor environments. This is inappropriate to the local climate conditions, leading to overdesign or energy wastage. Their previous study also highlighted the gap between the field measurements and that specified in National Building Code 2005. Hence thermal comfort studies and new standards are exigent in India. The hot humid climate experienced in Chennai and the composite climate of Hyderabad represents about 80% of the geographic area in India. Authors have conducted the study in 20 buildings and arrived a comfort equation $TS=0.31Tg - 9.06$ for thermal sensation. The study focused on the significance of air movement for thermal comfort in warm climates at elevated indoor temperatures and humidity. Comfort temperatures were achieved at 31.5˚ C with or without use of fans in their Hyderabad study contradictory to standard comfort zone of 23-26˚ C. Hence revisions of standards are recommended as per the study. It was also concluded that residents displayed tendency to choose for higher air movement indoors. Their preference for air movement varied with temperature, with humidity having little effect on air movement. Higher comfort temperatures are achieved with air movement. Several adaptive controls were used to achieve higher indoor air velocities when humidity was high.

CONCLUSION

From the review of various research papers, it can be concluded that in traditional buildings an effective passive and natural cooling system provides a comfortable thermal comfort in all seasons, which is not found in modern building. Such solar passive techniques should be re engineered and re examined to incorporate within modern building forms and materials. By incorporating with modified strategies according to local weather conditions, people can live in comfort with less consumption of electricity and air conditioning. This can provide a sustainable solution towards Energy efficient green buildings of future.

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