International Journal of Engineering Research
Volume No.7, Issue Special 2, pp : 156-159

ISSN:2319-6890 (online),2347-5013(print)
11-12 Jan. 2018

Potential of Mixed Mode Buildings in Hot-Dry Climate, Ahmedabad

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Abstract: The Mixed-Mode buildings are designed to make maximum use of natural ventilation but incorporate supplementary mechanical cooling systems for use in the most extreme conditions. Energy can be potentially minimized by adopting this method while maintaining satisfactory comfort. Considerable amount of research has been carried by International Energy Agency IEA-Annex 35 and University of California, Berkeley but this has been limited to temperate climate of Europe. There is a lack of information about the application of Mixed-Mode buildings in India specifically for hot and dry climate. The investigation is carried out by analyzing the climate of Ahmedabad on basis of providing comfortable hours in which natural ventilation can be used. The Psychormetric and bioclimatic chart are analysied. The research prime focus is to find out the potential of Mixed-Mode office buildings in hot and dry climate, Ahmedabad.

Key Words
Energy Efficiency, Mixed-Mode, Thermal Comfort, Sustainable Strategies

Introduction:

The hot and dry regions do not receive great attention in low energy office building research due to the severity of climate (Ezzeldin, Sherif; Rees, Simon and Cook, Malcolm.). The effective cooling of office buildings in hot and dry climate requires designer's particular attention. The research done by Brager and Dear demonstrates that the occupants of buildings with centralized HVAC become finely adapted to very narrow range of indoor temperatures due to the current HVAC practice. The same study also mentions that, *"occupants of such buildings develop high expectation for homogeneity and cool temperatures, and soon become critical if thermal conditions do not match these expectations"* (De Dear, Richard and Gail S.

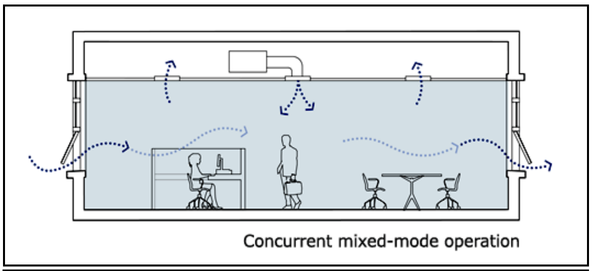
Brager). These buildings in most cases, ensure comfort conditions can be maintained but at the expense of relatively high carbon emissions. In contrast, occupants of naturally ventilated buildings appear tolerant to a wider range of temperatures, which may extend beyond the comfort zones described by standards and more closely reflect the local patterns of outdoor climate change (Demirbilek, Nur, and Depczynski, Fabrice.).

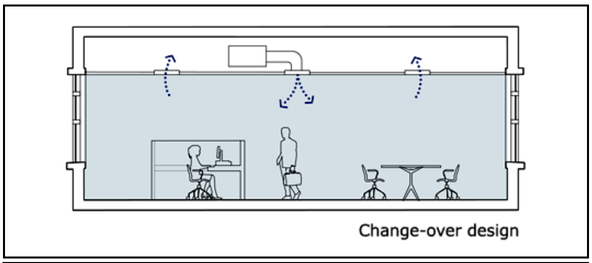
Efforts towards decreasing the dependency of buildings on HVAC systems without compromising on thermal comfort, has shifted the focus of researchers and designers towards Mixed-Mode Buildings. Due to their operational flexibility that combines operable windows with mechanical cooling; the Mixed-Mode Buildings often get high marks from occupants on satisfaction with their thermal environment (Brager, Gail, and Baker, Lindsay.). However, due to the lack of information and no standard protocol available the designers of Mixed-Mode buildings face challenges. Thus, this has resulted in fewer examples of Mixed-Mode buildings in practice. This study is concerned with examining the performance of Mixed-Mode Office Building and their potential to reduce energy consumption in hot and dry climate, Ahmedabad.

Mixed-Mode Buildings

The basic concept of Mixed-Mode buildings is that, whenever the outside climatic conditions are conducive no mechanical processes are used, but when the conditions are non-conducive, mechanical processes are used to achieve thermal comfort for the users. Hence, Mixed-Mode buildings maximize the use of natural energy sources and use a supplementary mechanical process only when strictly required.

Mixed-Mode buildings are classified in terms of their operation strategies, which describe whether the natural ventilation and mechanical cooling are operating in the same or different spaces, or at the same or different times. As per CBE Berkeley, classifications done on the basis of operation strategies are-(Fig. 1)





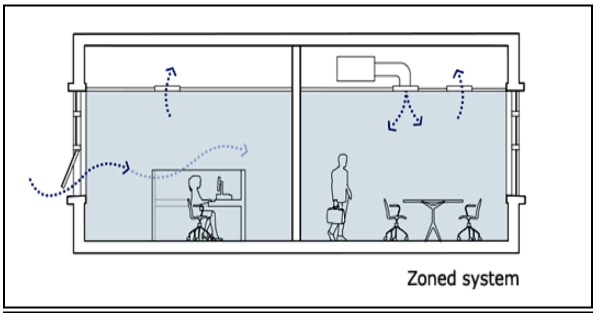


Figure 1 Classification of Mixed-Mode Buildings on basis of operational strategies, as per CBE Berkeley

- Concurrent - mechanical cooling and natural ventilation can operate in the same space at the same time.
- Changeover - the building switches between mechanical cooling and natural ventilation on a seasonal or daily basis
- Zoned - mechanical cooling and natural ventilation operates in different areas of the building.

The Mixed-Mode buildings have three major advantages over conventional Air-Conditioned (AC) buildings, mainly which are:

- Reduction in HVAC energy consumption
- Increased occupant satisfaction
- Reduction in problems associated with indoor air quality

However, there is a lack of knowledge and information available for its application, in Indian context. This research attempts to fill this gap in knowledge. Thus, using an energy efficient approach like Mixed-Mode building in Indian context will prove beneficial in energy saving when to conventional HVAC buildings.

Energy Saving Potential

According to various studies done, the Mixed-Mode buildings show a great potential in minimizing energy consumption while maintaining satisfactory comfort. The research carried out by the International Energy Agency IEA-Annex 35 and the University of California, Berkeley has mostly been limited to its applications in temperate climates such as that of Europe. There is a lack of information and standard protocols available for the designers to follow due to which lesser number of Mixed-Mode buildings are seen in practices in Indian context. Mixed-Mode Buildings Simulations using Energy Plus demonstrated that energy savings associated with various forms of Mixed-Mode operation ranged from 13% (medium-sized office building with a VAV system in Miami) to 29% (small office building with a CAV system in Atlanta) to 79% (similar building in Los Angeles) (Brager, Gail; Borgeson,Sam and Lee, Yoon Soo.) According to field studies conducted by CMU's BIDS identifies 47-79% HVAC energy saving, 0.8-1.3% health cost savings and 3-18% productivity gains by replacing or supplementing mechanical ventilation with natural ventilation or Mixed-Mode conditioning.

Hot and Dry Climate, Ahmedabad

Ahmedabad falls in the hot and dry climatic zone of India as per Indian Metrological Department and is located at latitude 23°07' North and longitude 72°63' East, with 55m height above sea level. There are three main seasons: summer, monsoon & winter. Apart from the monsoon season, the climate is extremely dry. The weather is hot through the months of March to June; May is the hottest month with Mean maximum temperature of 41.4°C, and the Mean minimum of 26.3°C. On the other hand, the months of November to February are cold; January is the coldest month with Mean maximum temperature of 28.7°C the Mean minimum is 13.1°C. The climate has high diurnal variation, i.e. more than 10ºC, due to which nights are pleasant.

As shown in studies of Ezzeldin, Rees and Cook, the severity of the climate in hot and dry regions means that mechanical cooling systems are often adopted in modern office building designs (Ezzeldin, Sherif; Rees, Simon and Cook, Malcolm.). The same holds for Ahmedabad. The dependency on such mechanical cooling systems is expected to grow as the development increases, thus increasing the cooling energy demand. On the other hand, in such extreme conditions the natural ventilation solely cannot provide comfort to the users and thus, is not a reliable source of providing comfort to the users in hot and dry climate, Ahmedabad. The Mixed-Mode System plays a vital role in such situation, which maximizes the use of natural ventilation and reduces or minimizes the use of mechanical means without sacrificing the thermal comfort of the users.

Mean Max	Mean Min	
33.2	17.5	November
29.9	14.1	December
28.7	13.1	January
31.0	14.8	February
35.9	19.4	March
39.5	23.5	April
41.4	26.3	May
38.5	27.2	June
33.5	25.7	July
32.0	24.9	August
33.5	24.4	September
35.8	21.9	October

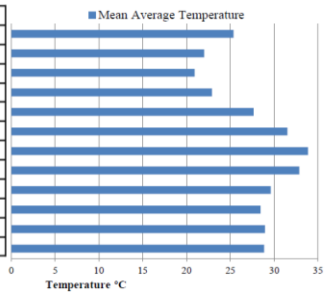


Figure 2 Showing Average Monthly & Mean Maximum & Minimum temperature of Ahmedabad based upon 1971-2000-Meteorological Centre, Ahmedabad

Methodology

This section focuses on analysis of the climate of Ahmedabad using natural ventilation through bioclimatic analysis. Bioclimatic analysis methods are designed to assess climatic data in relation to comfort conditions at the early stages of building design using hourly annual climate data (Ezzeldin, Sherif; Rees, Simon and Cook, Malcolm.). These methods have been widely used for hot and dry region (Attia). Hence, these methods are very useful in the evaluation of Mixed-Mode buildings, where the percentage of hours using natural ventilation or mechanical cooling to maintain comfort can be quantified. Thus, in this study the graphical methods utilized to analyze the climate of Ahmedabad for providing comfort are as follows.

Climate Consultant - 5.4

1. Software design by Department of Architecture & Urban Design, University of California using IWEC-EPW weather file of Ahmedabad from EnergyPlus as well as PMV and Adaptive comfort model ASHRAE Standard 55-2004.
2. Calculation done in Excel spreadsheet using IWEC-EPW weather file from EnergyPlus as well as PMV and Adaptive comfort ranges derived for Ahmedabad.

Comparison of both the methods is analyzed for number of comfortable hours on annual, seasonal and monthly basis. Since the software Climate Consultant - 5.4 limits to only graphical representation of data, there is a lack of numerical values available for Adaptive comfort ranges. Due to which the Adaptive comfort ranges for each month is approximately assumed using the graphs generated by software Climate Consultant - 5.4. On the other hand, the calculations done in Excel spreadsheet are more accurate using the formula proposed by Brager and Gail in 2001 for deriving the Adaptive comfort range. Thus, only calculation using Excel spreadsheet is further analyzed in detail for the Climate of Ahmedabad.

Comfort Temperature Range for Ahmedabad

PMV Comfort Range –

With the aid of software Climate Consultant 5.4 the comfort range of ASHRAE 55 PMV Model is calculated for Ahmedabad. For 90% predicted percent of people satisfied and activity 1.1Met, the comfort range for clothing indoors 1.0 Clo and 0.5 Clo for winter & summer respectively is calculated. The Comfort lowest and highest winter temperature is 20.3ºC and 24.3ºC respectively and Comfort highest summer temperature is 26.7ºC. The Maximum Humidity calculated is 84.6%.

Table 1 Comfort temperature ranges for winter and summer specified by NBC of India based on ASHRAE Standard

	Operative Temperature	Acceptable
Winter	22ºC	21 - 23ºC
Summer	24ºC	23–26ºC

The range shown in Table 1 suggested by NBC is used for Excel spreadsheet analysis in this study. Other method for calculating comfort temperature range using PMV ±1 & ±0.5 (20% and 20% PPD) is not considered in this study.

Adaptive Comfort Range

Brager and Dear in 2001 proposed for an Adaptive comfort standard (ACS) that would serve as an alternative to the PMV-based method in ASHRAE Standard 55. The outdoor climatic environment for each building was characterized in terms of mean outdoor dry bulb temperature ($T_{a,out}$). Optimum comfort temperature (T_{comf}) is calculated on basis of mean $T_{a,out}$:

$$\mathbf{T_{comf} = (0.31 \times T_{a,out}) + 17.8\ (^{o}C)\ ----(eqn.\ 1)}$$

A total of 90% and 80% of people satisfied are assumed to fall at T_{comf} ±2.5 °C and ±3.5ºC, respectively. As per the Climate Consultant 5.4 software the comfort range of Adaptive comfort model for Ahmedabad is calculated and shown in Table 4 and Graph 2. And for Excel spreadsheet analysis in this study the comfort range for the climate of Ahmedabad is calculated using equation 1 and IWEC-EPW weather file for Ahmedabad from EnergyPlus.

Table 2 Adaptive Comfort Range for Ahmedabad derived with Climate Consultant 5.4 software.

Climate Consultant 5.4 with IWEC-EPW data			Adaptive Comfort Range (ºC)			
Seasons	Month	Mean DB temp(ºC)	80 %	90 %	90 %	80 %
Winter	November	23	21.0	22.0	28.2	29.2
	December	20	20.3	21.3	27.2	28.2
	January	19	20.8	21.3	26.8	27.8
	February	22	20.8	21.8	27.8	28.8
Summer	March	28	21.8	22.8	29.7	30.7
	April	31	23.7	24.7	30.3	31.3
	May	33	24.5	25.5	30.7	31.7
	June	33	24.0	25.0	30.7	31.7
Monsoon	July	29	23.2	24.2	30.0	31.0
	August	28	23.0	24.0	29.0	30.0
	September	28	23.2	24.2	29.3	30.3
	October	27	22.2	23.2	29.2	30.2
Annual (19ºCmin & 33ºCmax)			20.3	21.3	30.7	31.7

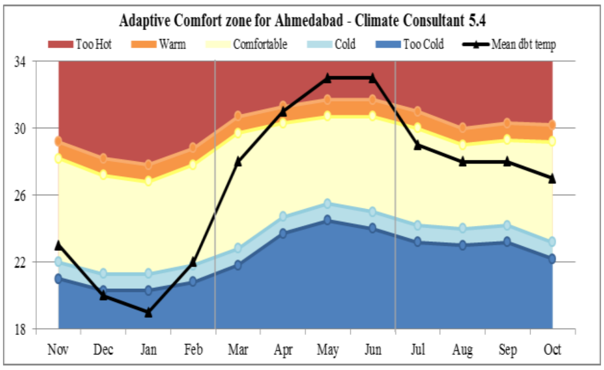


Figure 3 Adaptive Comfort Zone & Mean dry bulb temperature of Ahmedabad derived with Climate Consultant 5.4 software.

Psychrometric chart of Ahmedabad

The climate of Ahmedabad is studied with Psychrometric chart plotted manually (Figure 4) as well as in Climate Consultant 5.4 software (Figure 5), using IWEC-EPW weather file form EnergyPlus. For plotting manually the average monthly maximum and minimum of both dry bulb temperature and relative humidity data is used. The line connecting the two points: first, the average minimum dry bulb temperature by average maximum relative humidity; second, the average

ISSN:2319-6890 (online),2347-5013(print)
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maximum dry bulb temperature by average minimum relative humidity for each month, represents the change in temperature and relative humidity over an average day. Both PMV comfort zones for winter (1.0 Clo) and summer (0.5 Clo) as well as Adaptive comfort zone for annual extent is plotted on Psychrometric chart. Psychrometric chart with Climate Consultant 5.4 software is also plotted on annual hourly basis using daily maximum and minimum of both dry bulb temperature and relative humidity.

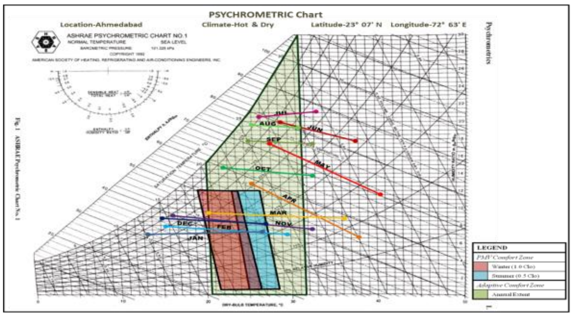

Figure 4 Psychrometric Chart for Ahmedabad plotted manually using mean monthly maximum and minimum of both dry bulb temperature as well as relative humidity.

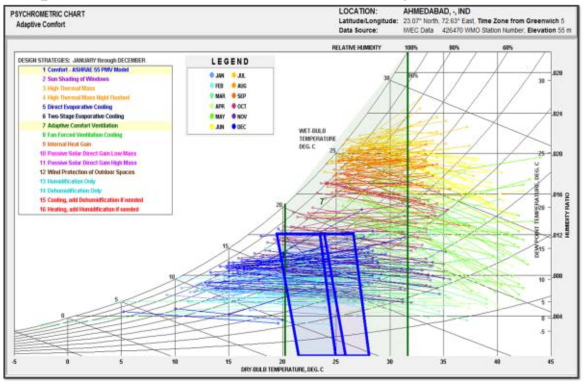

Figure 5 Psychrometric Chart for Ahmedabad plotted in Climate Consultant 5.4 using daily maximum and minimum of both dry bulb temperature as well as relative humidity.

Analysis of Psychrometric Chart

The Psychrometric chart of Ahmedabad (Figure 4 & Figure 5) demonstrates high diurnal temperature range throughout the year, except in the months of July, August and September. The months of June through October have humidity ratio >0.012 which is beyond the PMV comfort range. Daily high variation of relative humidity is shown in the months of April and May.

According to the PMV comfort range for winters (1.0 Clo) the months of November through February show the potential of providing comfort during daytime. In March some hours fall within the limit of PMV comfort zone for summers (0.5 Clo), whereas, other months are way beyond the limits.

On the other hand, as per Adaptive comfort range the months of November through February show good potential during daytime hours. On the contrary, the months of March through July show potential during night time hours. The months of August, September and October show the best potential of providing comfort under Adaptive range, though have high humidity.

Conclusion

The categorization of Mixed-Mode building on basis of operation can be made on basis of observation made from the Graph 4 and Graph 5. The graphs clearly indicate that the number of comfortable hours around the year. As per the observations the winter months shows the potential of comfortable hours during the day time. Whereas, the summer months show the potential of comfortable hours during the night-time, due to the fact that in summers the day temperature is extremely hot and nights are cool. The monsoon season shows the maximum potential of comfortable hours when natural ventilation could be used.

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