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Design Strategies for Future Residential Buildings in Delhi, India

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Abstract: This study aims to understand that the houses designed today will be comfortable to live in in the next 100 years and proposes appropriate passive strategies that will be suitable for residential buildings in Delhi, India. To achieve the aim the present and future climate of the region is analyzed using the climate data provided by IPCC. The IPCC medium to high emission scenario is considered for the study. A residential building in Delhi is modeled in DesignBuilder software and the internal conditions are recorded for the building for the present climate, 2050, and 2080. The results show that mechanical cooling will be required for the majority of the time by 2080. Without cooling the building will not be comfortable to live in even with recommended strategies. The study also proposes renewable systems suitable for Delhi which can help in achieving net-zero.
Keywords: Climate Change, Thermal Comfort, Net-Zero

1. Introduction

One of the major contributors to greenhouse gas emissions is the built environment. About 25–40% of anthropogenic greenhouse emissions are associated with buildings in typically developed countries; 40–95% of these emissions are generated by operational energy usage, with the rest caused by construction and demolition (De Wilde and Coley 2012). One of the major factors that influence the performance of the buildings is the climate they are exposed to. According to IPCC the earth's climate is changing and is set to become warmer by the end of the century. The lifespan of buildings is expected to be 100 plus years due to advanced building materials and technologies. Thus they must be designed to work efficiently in the present and future climatic conditions and reduce greenhouse emissions. The changing climate will inevitably cause a rise in energy demand and overheated days in the future.

Given the inherent uncertainty in global climate projections, India's future climate is expected to alter in numerous ways. Wildfires caused by excessive heat and moisture loss, disastrous floods caused by intense rain events, and tropical cyclones caused by temperature differences between the sea and land surface are just a few examples (IPCC, 2021). The buildings should be equipped to deal with the consequences of these events to some extent in the future.

1.1 Impact of Climate Change on Buildings

Buildings act as a partition between the outdoor environment and the indoor environment. The outdoor conditions will change as the climate changes, however, the indoor conditions should be maintained to keep the occupants safe and the activities going inside the building should not be disturbed. In a study (De Wilde and Coley 2012) on climate change and buildings the relationship between climate change, buildings, and occupants is conveyed. De Wilde & Coley (2012) analysed the relationship of greenhouse gas emissions leading to climate change and affecting the environment, which in turn impacts the building, then the occupants. The aim of this study was to minimise the impact on the occupants as far as possible, even considering the climate change likely by 2050 and 2080 in Delhi.

1.2 Adaptive Thermal Comfort Range for Delhi

Thermal comfort is defined as "the state of mind that expresses satisfaction within the thermal environment" according to ASHRAE, 2004.

According to the National Building Code of India (NBC, 2005), the thermal comfort range is between 25ºC to 30ºC with the ideal condition at 27.5ºC. However, this range is suitable for active building systems, this standard does not consider the passive principles and natural ventilation that calls for a wider range of comfort. The thermal range mentioned in NBC is based on ASHRAE-55 and EN15251 models and studies have shown that these models are not suitable for the Indian climate (Manu et al. 2016).

A study (Moossavi 2015) on adaptive comfort standards concludes that it is hard to have a thermal comfort model for Delhi due to the composite climate (very hot summer, cold winter, and wet monsoon). However, the ability of humans to adapt to their surroundings can result in having an adaptive thermal comfort model. The results of the study were –

Table 1 -Thermal Comfort for Delhi

Extremely Minimum Thermal Comfort	19.4 ^{o}C
Extremely Maximum Thermal Comfort	31.5 ^{o}C
Minimum Average of Thermal Comfort	22.2 ^{o}C
Maximum Average of Thermal Comfort	28.1 ^{o}C
Adaptive Thermal Comfort Model	22 ^{o}C to 28 ^{o}C

Source - (Moossavi 2015)

2. Methodology

For the study of future climate years, 2050 and 2080 are considered. The base weather data file (EPW) used in the analysis is obtained from the Meteonorm program (www.meteonorm.com). The weather data for Delhi was obtained from the Safdarjung weather station, latitude 28.58 ^{o}N, and longitude 77.2^{o}E. The study uses the data for the period of 2000 to 2019 to generate the weather data file. The future weather data file are generated using the climate change world weather file generator (CCWorldWeatherGen) program developed by the University of Southampton. This program uses the current EPW file and produces a 'morphed' EPW file for the years 2050 and 2080. The program uses the IPCC TAR model summary data of the HadCM3 A2 experiment (Jentsch et al. 2013). IPCC A2 (medium-high emissions) scenario is considered in this study which describes "a very heterogeneous world with continuously increasing global population and regionally oriented economic growth" (IPCC, 2021).

The house chosen for the analysis is new construction, all the terrace houses built in the last few years and those that will be built in the coming years will be constructed in the same style. Therefore the house represents the terraced house owned by the middle class in Delhi and the results from this study can be applied to any house in the region.

A simplified version of the building is modeled using the DesignBuilder software version 6.1.7.007 and the thermal simulation was carried out in EnergyPlus 8.9 simulation tool. The thermal simulation is carried out using present-day climate data and future climate data that was generated. It is to be noted that during the analysis in DesignBuilder no mechanical cooling, heating, and mechanical ventilation was considered only natural ventilation was taken into account. The indoor air temperature is recorded for the present climate, 2050 and 2080.

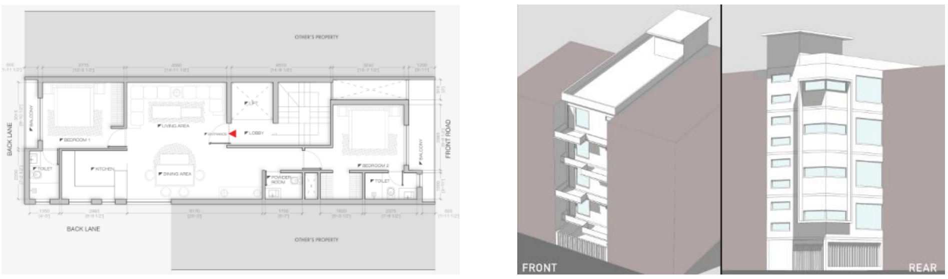

Figure 2. First Floor Plan and 3D view of Residential Building *Source – Authors*

The residential building with recommended strategies in table 2 is modelled in DesignBuilder software and the indoor temperature was noted for present climate, 2050 and 2080. According to psychrometric chart analysis solar shading and thermal mass are the best passive strategies that can help in improving the internal conditions of a building in Delhi. The techniques selected for the residential building are the ones that are cost-effective and can be afforded by most people. Factors such as space constrain, availability, and affordability are also considered. The residential building without any changes is considered as Base Case, the analysis is done for the first floor of the building, the ground floor is parking.

Table 2. Passive Strategies

	Previous	**Now**
Window	Single clear glazing	Double clear glazing, SHGC – 0.5 U Value – 1.2 W/m^{2}K Moveable shutters
Walls	Burnt clay brick Walls U-value : 2 W/m^{2}K	AAC block walls with light color paint on the exterior and 0.23 thick insulation on the inside U Value of wall – 0.5 W/m^{2}K
Roof	Mud Phuska roof insulation	Heat insulation tiles with a layer of PV panels that provide shade to the roof
Airtightness	0.7 ac/h	0.35 ac/h

3. Results

All the results for the residential building are before and after implementing the strategies in table 2. Table 3 represents the monthly average temperature for the present, 2050, and 2080 for the residential building after the changes. The red box shows the months which are out of comfort zone, the thermal comfort zone for Delhi is considered 22 - 28 ^{o}C as discussed.

Table 4 shows indoor air temperature for a whole day 21st June (summer solstice) for present climate, 2050 and 2080 for the residential building after changes. The red box indicates the hours out of comfort zone, the thermal comfort considered for table 4 is extreme maximum thermal comfort 31.5 ^{o}C as mentioned in table 1. Hours during the day when temperature is 35 ^{o}C or above is indicated with bright red.

Figure 3,4 and 5 represents the indoor air temperature for the residential building before and after the implementation of strategies for summer week, monsoon week and winter week for present climate, 2050 and 2080. It is observed that in summer and monsoon week (Figure 3 and 4) there is a decrease in indoor air temperature as compared to the base case.

Whereas in winter week (figure 5) there is an increase in indoor air temperature after the changes.

Table 3. Monthly Average Indoor Temperature (After Changes)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Present	18.62	21.5	24.8	29.7	32.2	32.7	30.7	30.3	30	27.4	23.5	20.3
2050	20.92	23.28	26.83	31.65	34.19	34.27	31.83	31.22	31.61	28.93	24.87	22.21
2080	22	24.83	28.4	33	35.39	35.24	32.29	32	33	30.17	25.9	23.26

Table 4. Indoor Air Temperature for whole day 21st June (After Changes)

Time	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 AM
Present	31.7	31.3	31.2	31	30.8	30.6	30.7	31.2	31.6	31.8	32.6	33.1
2050	33.16	32.87	32.7	32.6	32.47	32.36	32.5	32.95	33.3	33.83	34.4	34.87
2080	34	33.73	33.63	33.52	33.42	33.35	33.52	33.9	34.34	34.89	35.44	35.91
Time	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM	12:00 AM
Present	33.47	33.88	34.27	34.4	34.3	34.1	34.2	34.2	33.98	32.9	32.87	32.2
2050	35.23	35.66	36	36.2	36	35.7	35.76	35.45	35	34.75	34.38	33.62
2080	36.28	36.71	37.1	37.27	37	36.75	36.7	36.38	35.99	35.63	35.22	34.45

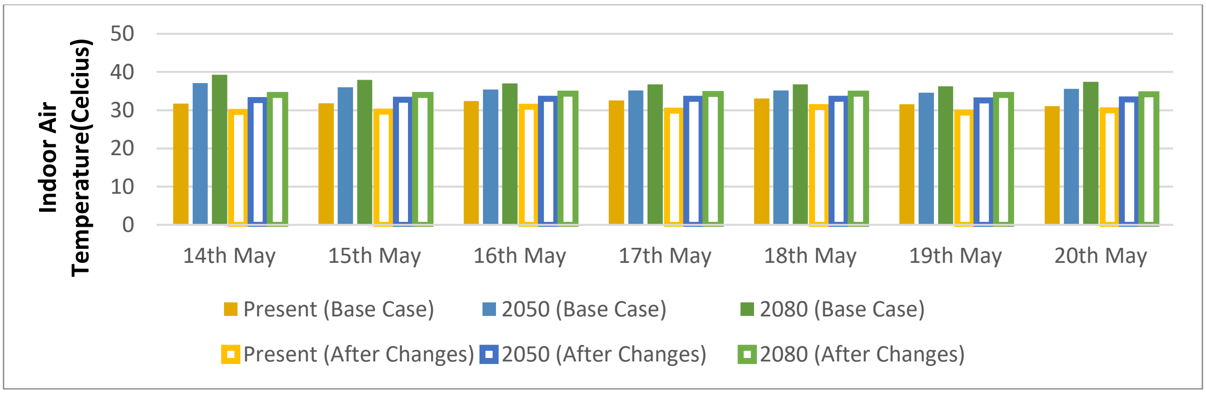

Figure 3. Indoor Air Temperature for Present year, 2050 and 2080 (Summer Week)

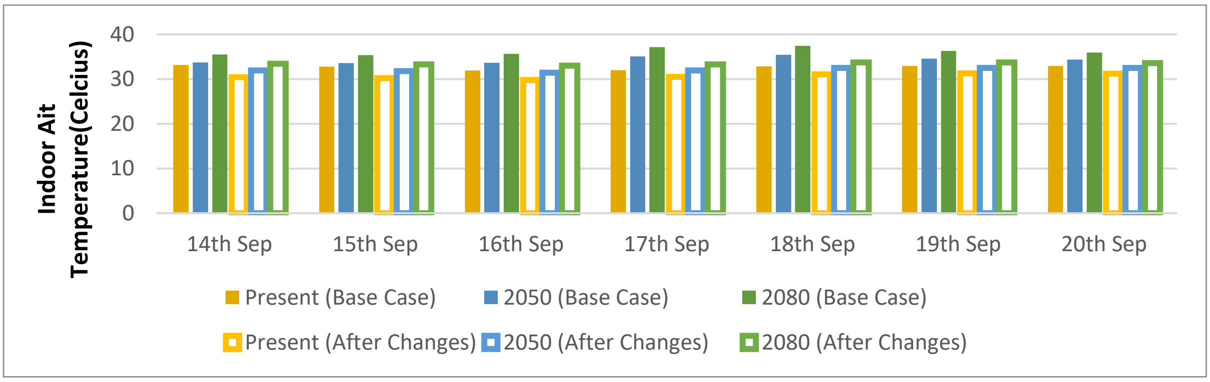

Figure 4. Indoor Air Temperature for Present year, 2050 and 2080 (Monsoon Week)

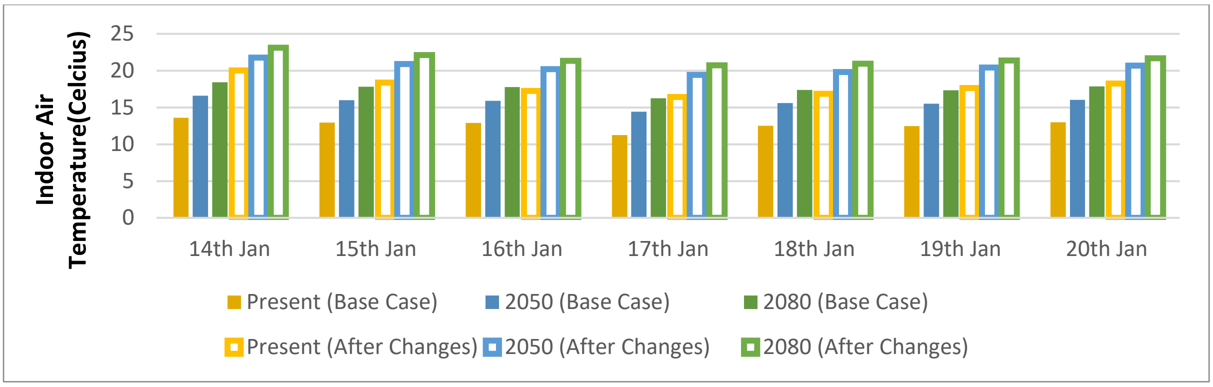

Figure 5. Indoor Air Temperature for Present year, 2050 and 2080 (Winter Week)

The renewable energy sources that will be suitable for buildings in Delhi are – Solar energy and geothermal systems. Solar panels generate electricity that is used to operate appliances in the house however the use of air conditioners still contributes to global warming no matter how clean the electricity is. Geothermal systems use the earth's surface temperature to cool or heat buildings, they are a brilliant low carbon cooling or heating solution. However geothermal systems need electricity to run, thus using electricity generated by solar panels to run the geothermal system. The combination of solar panels and geothermal systems in buildings can help in achieving Net-Zero and the dependence on the power grid for electricity will reduce (GreenMatch, 2015).

1. Discussion and Conclusion

The combination of techniques mentioned in the table 2 can bring down the indoor air temperature up to 2-4 ^{o}C in summer and monsoon season. Whereas in Winter season these strategies can increase the indoor air temperature by 2-4 ^{o}C. For the present scenario, the indoor air temperature according to the figure 3 and 4 before the passive techniques were implemented was out of comfort zone, and to achieve comfort cooling was required however same building with the above-mentioned techniques will be almost in the comfort zone on some days in summers and if not mechanical fans or coolers will be enough to provide comfort as ceiling fan are present in every room in residential houses in Delhi. According to EN ISO 7730:2005 opening of windows and the use of fans (which will increase air velocity) can help to reduce the sensation of warmth caused by the rise in temperature. On days when the temperature is extreme or at peak times during the day (afternoon) mechanical cooling will be required. While looking at the years 2050 and 2080 the temperature is lower as compared to the base case building, still it is too high cooling will be required otherwise the indoor conditions will be uncomfortable and during peak hours (afternoon) it will not be possible to live in the house.

While considering Figure 5 (winter week) the situation is opposite. The indoor air temperature for the base case is 2-4 ^{o}C less as compared to the indoor air temperature for building after implementation of strategies. This indicates that in winters the need for heating will reduce and, on some days, the indoor air temperature will be in comfort zone. For the years 2050 and 2080 there will be an impressive decrease in mechanical heating and increase in number of days in comfort zone. By 2080 winter season will be in comfort zone as indicated in Table 3 with suggested strategies.

Limitations – There might be more than a 2-4 ^{o}C decrease in indoor temperature due to limitations of the software and modeling and the surrounding buildings are also not considered. Most residential areas such as the one in the case study have compact planning.

All the houses share at least one wall with other buildings which reduces the area of building directly exposed to the sun. The residential building in this study shares 1.5 walls (the longer walls) with the adjacent building. Therefore, the actual difference in temperature might be more than 2-4 °C.

The main aim of the research was to understand that the buildings designed today will be livable in the coming 100 years as the changing climate will affect the indoor conditions of the house. It can be concluded that with all the suggested strategies also the residential buildings that are designed today will not be hundred percent comfortable. In the coming years the number of hours in a day out of comfort zone will increase which will lead to increased use of mechanical cooling. Whereas in the winters the need for mechanical heating will decrease due to increase in external air temperature in the coming years. The changing climate will also impact the performance of the renewable energy systems, which will ultimately impact the performance of the building's HVAC system which will be the main lifeline for comfort in buildings in the future. However, in the future, there are possibilities for the invention of better technologies that are sustainable and efficient that can help in making buildings comfortable.

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