Impact of Climate Change on Energy Demand of a Mid-Rise Office Building

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Abstract:
Globally climate change driven thermal severity has resulted in increased demand for comfort conditioning. Buildings which are designed to the present day scenarios are subject to performance variations in such contexts. It is essential to establish the impact of climate change severity on building energy demand not only in terms of its amplitude but also the periodicity. This study investigates the impact of climate severity on a mid-size office building located in a composite climate of India (New Delhi). The study has the following objectives (a) to map the impact of climate change based on the magnitude and temporal variations of climate variables (b) to establish the effect of climate change on the energy use of a mid-size office building and (c) to delineate design strategies for climate change resilient building envelope. The weather data used in the simulations is made available by ISHRAE for the year 1990 and is morphed for the years 2020 and 2050 using the climate change world weather file generator. This tool uses IPCC TAR model summary data of the HadCM3 A2 experiment ensemble. A statistical analysis of climate variables is carried out to map the magnitude and temporal variation between the years 1990, 2020 and 2050. An energy model of the building was developed for simulations and the results are validated with the actual energy data of the building. The building was found to experience reduction in heating load and increased cooling load in a climate change scenario. Further analysis of periodicity reveals that there is significant increase in cooling demand in the pre-summer and post-summer durations. The study concludes with a set of interventions so as to maintain the current-day energy demand in the future scenario.

Keywords: Climate change, energy demand, Thermal severity, Energy efficiency

1. Introduction

There is a growing concern worldwide about energy use and its implications towards the environment. The fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC) clearly states that since the mid-19th century, the average increase in the temperature of the Earth's surface is 0.85 degrees centigrade (°C). It has also stated that the world temperatures could rise by 1.1 to 6.4 °C during 21st century[1]. Thus, providing a lot of scope for uncertainty in the indoor thermal environment. As the energy consumption and thermal comfort in the building is majorly dependent on outside weather conditions [2]. It is fair to state that climate change plays a vital role in the change of space cooling and heating energy demands globally. Various studies conducted for existing buildings has shown that there is a nearly linear correlation between the increase of average air temperature and the increase of building cooling load. To study the implication of climate change on the building energy consumption three methods are used namely, observation based regression/prediction, global/regional energy modelling and individual building energy simulation [3][4]. The objectives of this paper are (a) to map the impact of climate change based on the magnitude and temporal variations of climate variables (b) to establish the effect of climate change on the energy use of a mid-size office building and (c) to delineate design strategies for climate change resilient building envelope.
The scope of this project is limited to a typical mid-size office building, which comes under the commercial building type as per Indian energy conservation building code (ECBC) [5].

2. Research methodology

The research methodology is divided into three main stages 1) To study the impact of thermal severity of climate change on current and future scenario, 2) to evaluate the actual and simulated building model energy demands, 3) to identify the mitigation and design strategies for built envelope.
Stage 1: Impacts of thermal severity of climate change for current and future scenario are quantified using present-day climate data and A2b emission scenario for future weather files. The selection of A2b scenario for future weather file generation is done based on IPCC third assessment report model summary data of the HadCM3A2 experiment ensemble. Climate change world weather file generator tool based on 'morphing' methodology for climate change transformation of weather data is used in the production of weather data files for 2020, 2050 and 2080 [6]. Analysis of all these years including the current weather data is performed on parameters namely, Dry Bulb Temperature (T), Relative Humidity (RH), Diffuse Horizontal Irradiation (DHI) and Direct Normal Irradiation (DNI).
Stage 2: Changes are established in thermal performance and overall energy demand of a medium-sized office building in New Delhi, for current and future climates. Building simulation model on the basis of various parameters including building materials, architectural details through Plan/Elevation/sections/HVAC system is modelled. These simulations are performed to assess the thermal performance and energy demand of the building model for the current and future climate scenarios.

Following a comparative analysis between simulated and actual energy consumption data.

Stage 3: Identifying the mitigation and design strategies for the built envelope to improve the thermal comfort conditions and building energy demands. Thermal properties of the building envelope includes the U- value and solar heat gain coefficient (SHGC).

3. Case study

Development Alternatives World Headquarters (DA HQ) building is considered for the study. It is recognized for its energy conservation measures which reduce the overall energy consumption by 25-30% when compared with similar typology. It is located in New Delhi, India which represents a humid sub-tropical as per Köppen-Geiger climate classification. Delhi experiences hot summers starting from April to May with an average temperature of approximately 32°C with occasional heat waves, followed by monsoon from June to September and then short winters starting from late November with an average temperature 6-7°C till January.The building is modeled as per the actual specifications. Its total built-up area is 4500 sqm. with a six storey construction. It is modeled with density of 0.11 people/sqm, with scheduled occupancy as per actuals.

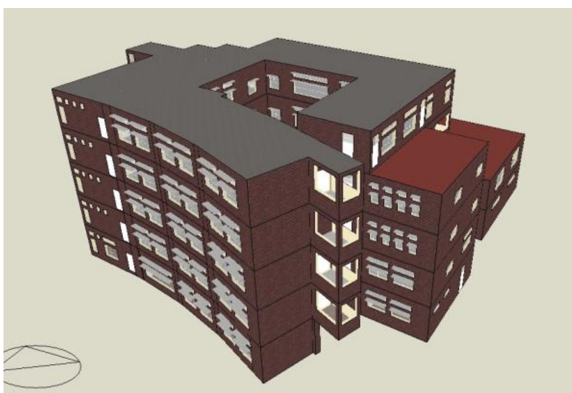

Figure 1: DA headquarters building simulation model.

The building simulation model for DA HQ building shows 91.37% similarity between simulated vs actual energy consumption data. Further analysis on monthly energy data comparison shows that the simulated model performed similar with the summer and monsoon months (May to Oct) with 102.31% similarity, while winter months (Nov to Apr) works with 74.06% efficiency.

Simulations are performed to quantify the impact of energy consumption for 1990, 2020 and 2050. The comparison between heating energy demand, cooling energy demand and total HVAC energy is shown in Figure 2,3 and 4. To validate the energy performance of the simulated model of DA Building (New Delhi), a collective mean monthly energy consumption for 2016 to 2018 is calculated. This monthly mean and annual average data is further used to validate the energy consumption of 2020 for DA building.

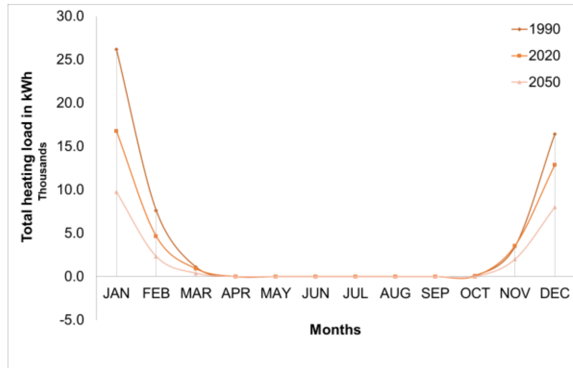

Figure 2: Heating load in kWh for DA HQ building

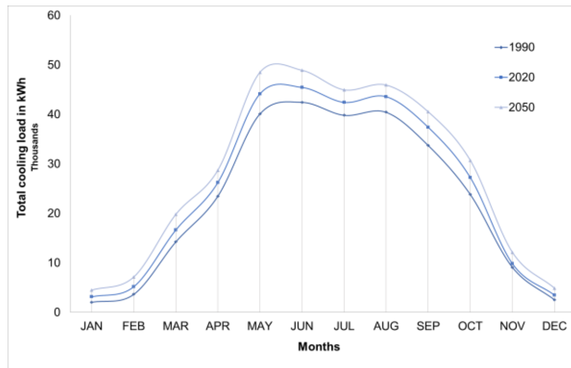

Figure 3: Cooling load in kWh for DA HQ building

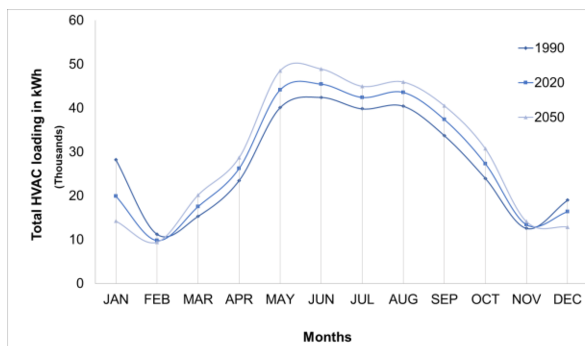

Figure 4: Total HVAC in kWh for DA building

The heating energy load decreased by 16032.6 kWh (-29.93%) from year 1990 to 2020 and 16256.3 kWh (-41.97%) from year 2020 to 2050 (Fig 2). Whereas, cooling energy load increased by 29271 kWh (11%) from year 1990 to 2020 and 31873 kWh (10%) from year 2020 to 2050 (Fig 3). The total HVAC energy demand increased by 13162 kWh (4%) from year 1990 to 2020 and by 15574 kWh (5%) from year 2020 to 2050.

4. Result and discussions

In order to quantify the impact of climate change on building energy consumption. Climate clustering for base year (1990) and 2050 (A2b) future scenario is done.

4.1 Impact of climate change based on the magnitude and temporal variations of climate variables

In the context of present study, a two-step cluster analysis yielded nine climate clusters based on their homogeneity. Data in a specific cluster has attributes namely, daily maximum temperature (T_max), daily minimum temperature (T_min), daily average relative humidity (RH_avg) and daily average global horizontal irradiation (GHI_avg). Table 1 presents the summary of the clustering for summer, winter and monsoon seasons.

	SEVERE		MODERATE		LOW	
	1990	2050	1990	2050	1990	2050
Summer	3(25)	1(16)	2(37)	2(41)	4(24)	4(32)
Tmax	40.4	43.5	38.6	40.2	33.3	36.9
Tmin	25.9	31.2	27.2	29.7	20.0	23.3
GHIavg	610	608	520	503	560	553
RHavg	38	38	52	53	40	39
Winter	7(76)	9(56)	5(19)	8(41)	8(70)	5(63)
Tmax	22.6	25.3	18.2	23	29.3	30.9
Tmin	9.9	11.7	10.9	13.9	14.8	17.3
GHIavg	373	384	261	296	443	436
RHavg	69	65	84	80	58	61
Monsoon	6(45)	7(31)	9(1)	6(1)	1(68)	3(84)
Tmax	31.8	32.6	31.6	33.7	34.8	35.3
Tmin	24.6	27.6	18	20.9	26	28
GHIavg	368	333	280	310	455	411
RHavg	77	85	51	55	65	71

Table 1 Cluster days Comparison
() denotes number of days

These clusters are further identified into three seasons- summer, monsoon and winter. Clusters with highest daily T_max and T_min are classified into summer and winter clusters while high RH_avg and low GHI_avg are classified into monsoon clusters. Every season is assigned three clusters severe, moderate and low. From the climate clustering analysis, it is clear that the number of days shifting from winter clusters (5) are compensated into summer (3) and monsoon (2).

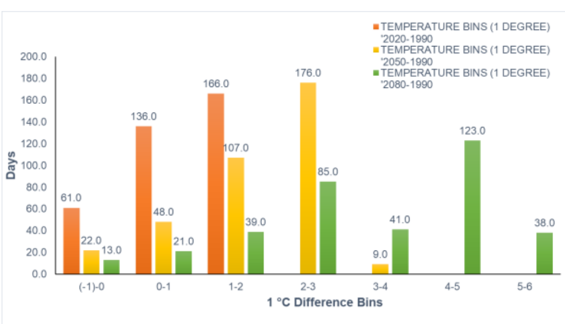

Figure5 : Frequency difference between 2020, 2050 and 2080 to 1990 (T_max)

Compared to the base year (1990) a significant increase in the number of days with higher temperature difference is observed, 4-6°C for 2080, 2-4°C for 2050 and 1-2°C for 2020 as shown in Figure 5 and 6. Comparison of GHI_avg shows a similar trend to temperature.

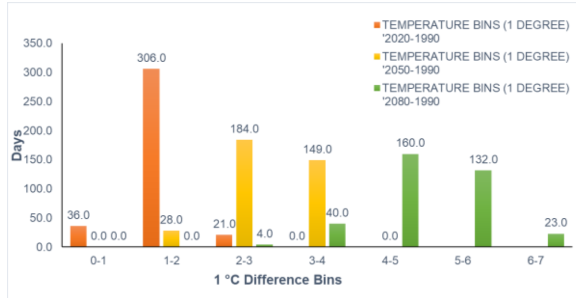

Figure6 : Frequency difference between 2020, 2050 and 2080 to 1990 (T_min)

Comparison of RH_avg for the three years 2020, 2050 and 2080 with base year shows a significant increase in extreme category of 10%-20% and 90%-100% .Refer Table 2 to infer the frequency differences in RH_avg.

	DIFFRENCE AS TO 2020	DIFFRENCE AS TO 2050	DIFFRENCE AS TO 2080
RH (10-0)	0	0	1
RH (20-10)	-3	-4	61
RH (30-20)	-115	-102	-147
RH (40-30)	-131	-128	-207
RH (50-40)	-198	-179	-184
RH (60-50)	-268	-249	-346
RH (70-60)	-167	-141	-170
RH (80-70)	-205	-159	-263
RH (90-80)	-1	1	10
RH (100-90)	229	102	386

Table2 :Frequency difference between 2020, 2050 and 2080 to 1990 (RH_avg)

4.2 Effect of climate change on the energy use

To understand the energy consumption of DA HQ building an ECBC prescribed base case of the same is modelled and simulated to compare the seasonal clusters energy consumption of year 1990 and 2050.

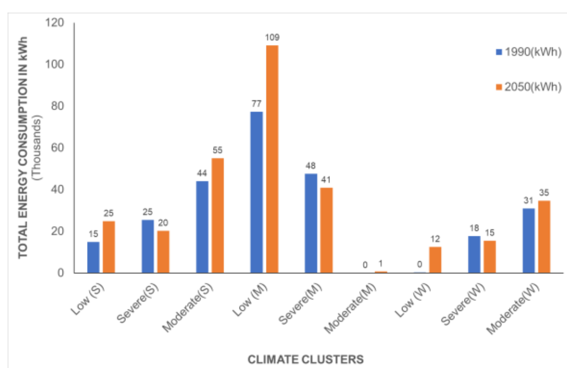

Figure7 : Total energy consumption of DA HQ building (ECBC compliant) 1990 and 2050

From Figure 7, it is determined that the total energy consumption for severe summer, monsoon and winter months decreases when the year 1990 is compared to 2050 and increases for all the three seasons for low and moderate clusters.This simultaneous comparison between change in the number of days and change in energy consumption shows a similar pattern. Energy consumption changes as the number of days shift among the clusters.

4.3 Design strategies for climate change resilient building envelope

In this study we focus on the U-Value (External Wall, Window) and Solar Heat Gain Coefficient (SHGC) of the building envelope for energy performance improvement.
Optimization of each property is done to estimate the suitable U-Value, which can bring down the energy consumption of the year 2050 to the same level as that of the base year (1990) for DA HQ building. Through various iterative runs of the building model, the U-value for external wall of 0.14 W/m^{2}K yielded a comparable HVAC energy consumption between the year 2050 and the base year. This meant a 66.82% decrease in heating load and 12.50% increase in cooling energy load. Further for an SHGC of 0.1, the decrease in the heating load is 44.28% and the increase in cooling energy load is 9.02%. Similarly, when the U-value of window is considered as 0.1 W/m^{2}K it yields a comparable HVAC energy consumption between the year 2050 and the base year. This meant a decreased by 70.7% in heating load and 20.51% increase in cooling energy load.

5. Conclusion and outlook

This paper maps the impact of climate change based on the magnitude and temporal variations as well as establishes the effect of climate change on the energy use and delineates the resiliency measures to future proof the building.
A comparative cluster analysis of climate variables T_max, T_min, RH_avg and GHI_avg for base year 1990 and 2050 indicates that the decrease of 5 days from winter cluster are compensated in summer cluster by increase of 3 days and in monsoon cluster by increase of 2 days.
Energy simulations for DA Building indicates a decrease in heating energy demand by 35.6% on average, increase in cooling energy demand by 10.5% and overall increase in HVAC energy demand by 4.5%.
A single mitigative factor is able to limit the energy consumption of future scenario (2050) to the base year scenario (1990). The paper presented a change in envelope U-value for external wall of 0.14 W/m^{2}K, U-value for window of 0.1 W/m^{2}K and glazing SHGC which leads to changing building energy demand as per base case scenario as 0.1.

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