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Building envelope as insulating barrier for adaptable building with response to climate change

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Abstract

Due to climate change, much greater temperature increases, change in precipitation pattern, extreme weather events are expected in the coming decades. These changes in weather patterns affect both energy demand, especially with increased peak electricity use for air conditioning, and energy supply, with reduced reliability and efficiency.

The built environment generally has a design life of 40–100 years. This makes climate change a current, rather than a future issue. Accordingly, this research aims to find out the potential of reducing energy consumption of buildings through proper selection of building envelope to adapt present as well as future climate. For this purpose, the research examined the effect of thermal properties of various building envelope elements on energy required.The future forecast of climatic data was performed using least square method. In order to validate temperature calculated by least square method, the forecasted temperatures were compared with the expected increment in temperature of 2050 and 2080 provided by IPCC 5th Assessment Report. The research focused on finding out the comparative evaluation in the energy performance of commercial building in Kathmandu valley with future weather files modifying the building envelope. Ecotect program was used to carry out simulation and to calculate the amount of energy required in all three years. The study and analysis of energy performance of building in different timeframes were done in order to find the impact of climate change in indoor comfort in future by ensuring long-lived characteristics such as orientation, insulation, and windows for expected climate conditions. Energy efficiency being one of the ways for adaptation of building for climate change, this research looked briefly at the current and expected impacts of climate change, and focused ways on how building envelope as insulating barrier can be applied in creating adaptable buildings to tackle the impacts of climate change.

Keywords

Building envelope, adaptable building, climate change, thermal insulation

1. Introduction

Weather shifts resulting from climate change pose serious risks to the energy sector. The Earth's average temperature has risen by 1.5°F over the past century, and is projected to rise another 0.5°F to 8.6°F over the next hundred years [1]. Climate change is a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer [2].

Climate change has a significant impact on the design of buildings, how they are kept cool and how they are weathered against more extreme climatic conditions [3]. Buildings by themselves can contribute to thermal discomfort and if this is not addressed while choosing materials for its construction and applying them appropriately in the design stage, the issue of thermal comfort could be costly to handle at a later stage.

Adaptation is fundamental to life, survival, and sustainability. As postulated in Darwin's theory, building adaptability determines the ability to respond and survive within the prevalent environment [4]. In order to help communities adapt, planners, urban designers, architects, and developers should take into account predicted climates over this century at the design stage of any new development, refurbishment, or regeneration program. This research paper is an attempt to discern the adaptive response in buildings attributed to ongoing and imminent climate change. Almost every analysis of how we can reduce greenhouse gas emissions and building adaptation to climate change finds energy efficiency as a key part of the solution. Energy efficiency is one of the ways for adaptation of building in response to climate change so most of the energy efficiency measures help deal with the climate change consequences.

Nepal is one of the least developed countries in the world and was ranked as the 4th most vulnerable country due to the impacts of climate change by Maplecroft in 2010, but, in contrary, it is one of the least contributors to global GHGs emissions, emitting 0.027 percent of the global total [1]. Hence this research focuses to explore the building envelope insulation as one of the energy efficiency measures for adaptable building with response to change in climate to make design and construction better so that the building can withstand the change in climate with the flow of time.

In the context of Nepal, there appears to be a gap in the area of assessment of buildings in particular measuring their vulnerability and aiding in creating climate-adaptable buildings. The study done before is only related to climate responsive design and climate change but this research is based on how adaptation can be done with respect to energy perspective. Thermally efficient building envelope as energy efficiency measure being one of the ways for adaptation of building for climate change, it should be incorporated in buildings to achieve sustainable goals. Adaptation to climate change is a functional (adaptation) requirement expected from a building. The best way to insulate a building is to have a well-defined thermal boundary.

2. Research Objectives

To study the effectiveness of building envelope as an insulating barrier for adapting climate change in commercial building (Bhatbhateni Supermarket and Departmental Store at Pulchowk) of Kathmandu

-To analyze the effects of climate change in the energy performance of building and identify critical thresholds.

-To study the methods of adaptation concerning energy in response to climate change into the existing commercial building of Kathmandu.

-To find out the comparative evaluation in the energy performance of building (commercial) with future weather files creating different scenarios modifying building envelope for recognizing the best option for design.

3. Literature Review

Climate Change Adaptation by Design is necessary to communicate to some degree of inevitable climate change, and to show how adaptation can be integrated into the planning, design and development of new and existing buildings.

Nepal is considered as one of the top ten countries most likely to be impacted by global climate change [1]. Data on trends of Nepal from 1975 to 2005 showed that temperature rise by 0.06°C annually whereas mean rainfall has significantly decreased on an average of 3.7 mm (-3.2%) per month per decade. Under various climate change scenarios, mean annual temperatures are projected to increase between 1.3-3.8°C by the 2060s and 1.8-5.8°C by the 2090s [1].

Building envelop plays vital role to tackle the change in climate pattern. In case study, the simulation result of one office building in Shanghai which belongs to hot summer and cold winter climate zone shows that the warm weather data has minor impact on the cooling energy consumption when good performance envelope is adopted in building. With energy efficiency as a driving force for future building design, the building envelope is the first line of defense for reducing whole building energy use, encouraging the building designer to design the envelope to meet as many energy loads and comfort requirements as possible, and allowing any unmet loads to be handled by a smaller sized HVAC system. The potential for energy savings is 40 – 50% in commercial buildings, if energy efficiency measures are incorporated.

4. Methodology

Qualitative and exploratory research were adapted to understand and explore the current scenario. The research was done to focus on understanding emerging themes and various definitions on adaptability of buildings form. The study helped to compare and analyze the variation trends of temperature, solar radiation, humidity, etc. of the different kinds of weather data files.

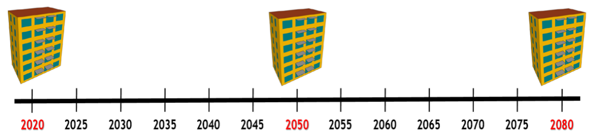


Figure 1: Research Frame work of the Study

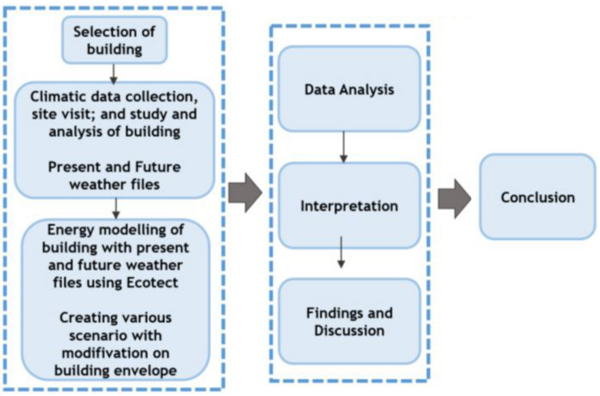


Figure 2: Research Methodology

Here the building in which detail research was performed was BBSM at Pulchowk. However, for studies, four branches of Bhatbhateni buildings, at Pulchowk, Kalanki, Naxal and Anamnagar were taken. A questionnaire survey and observatory survey were carried out in each location. The participants of the survey were of different age groups and include both staffs and customers. Autodesk Ecotect Analysis software was used to simulate the energy consumption of BBSM building at Pulchowk with different modified scenarios. The future forecast of weather was done using least square method which was then validated using the 5th IPCC Assessment Report [5].

Firstly, literature review was done to validate the need for research and develop research questions. This research studied the impact and consequences of climate change and the need for buildings to adapt such climate. The research focused on finding out the comparative evaluation in the energy performance of BBSM building at Pulchowk with future weather files modifying the building envelope.

The study and analysis of energy performance of the building in different timeframes with present and future weather files helped to find the impact of climate change in indoor comfort in future and find climate adaptive pathways.

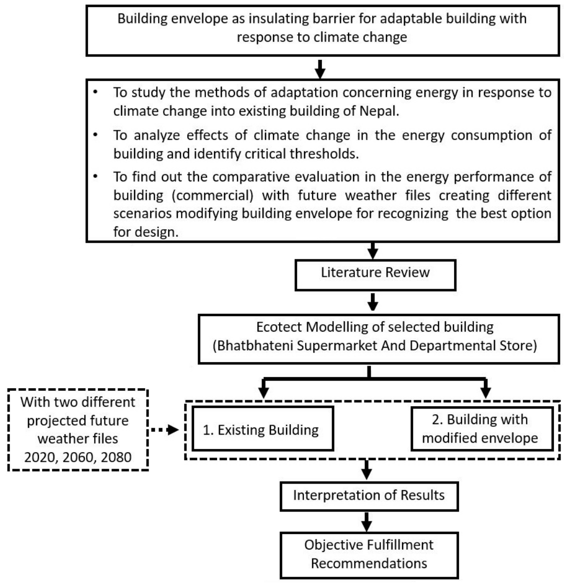


Figure 3: Research Framework of the Study

5. Research Context

The design of Bhatbhateni buildings is identical and architectural uniformity is maintained providing typical façade material, colour, fenestration designs and plane geometry with similar technical facilities. Bhatbhateni supermarket and departmental store depends mainly on electricity, HVAC system and refrigeration system. Modification on building envelope can play vital role in energy optimization.

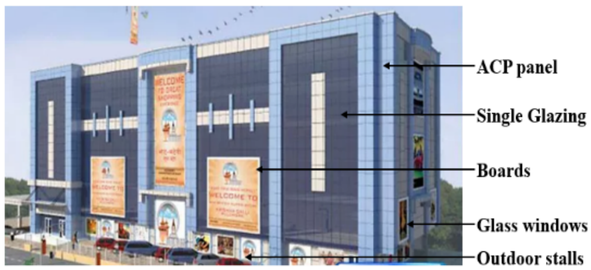


Figure 4: Features of bhatbhateni building at Pulchowk

Every supermarket is strategically stratified horizontally and vertically in terms of commodities. Every floor has typical layout with display area towards west and escalator or vertical circulation towards East. These two zones are separated by the central lobby space. The South portion contains service area i.e. staircase, elevator and toilets. The homogeneous tile is used for flooring with an exposed ceiling so that HVAC ducts and AHUs are easily visible.

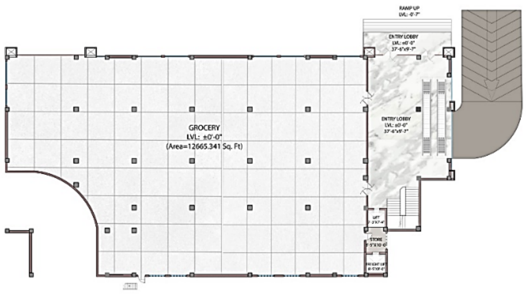


Figure 5: Horizontal zoning

The basement is used for parking. The ground floor is used for basic daily commodities like food. The food stalls outside enliven the space. It is always a good idea to put food stalls outside the market because the shopping tires people down. Inside the store, the most basic commodities are usually kept in the rear end so that people are compelled to wheel their way to it while picking up other products on the way. The first floor displays kitchen wares and other household items which are one of the most frequent purchases. Similarly the second floor displays the fashion and accessories with a myriad of choices. The third floor which is the stationery and toy zone is popular among the parents, children and students. The least frequent purchase but with the highest profit margin are electronic gadgets. It is strategically placed on the fourth floor. The top floor is used as the terrace. A certain portion of terrace area are used as service space for HVAC chillers, motors and water tanks.

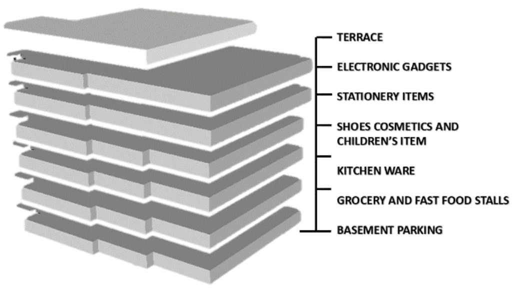


Figure 6: Vertical zoning

5.1 Climatic Analysis

The ten years climatic data of Kathmandu valley is collected from world weather online data. The changing trend of temperature pattern, humidity, rainfall and wind flow are analyzed. To observe the effect of climate change in the building, temperature and humidity are forecasted to 30 and 60 years. The temperature rises by 0.06C annually on a trend of 1975 to 2005. The mean average temperatures are projected to increase between 1.3C to 3.8C by 2060 and 1.8 to 5.8C by 2090.

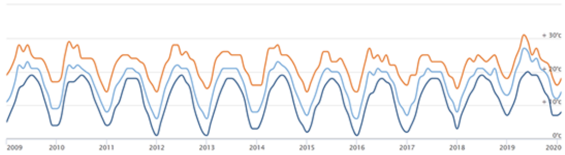


Figure 7: Maximum, minimum and average temperature from 2009 to 2020

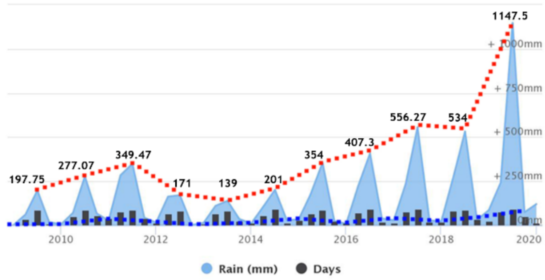


Figure 8: Average Rainfall Amount (mm)

5.2 Future forecast of climatic data using least square method

The "least squares" method is a form of mathematical regression analysis used to determine the line of best fit for a set of data, providing a visual demonstration of the relationship between the data points.

- $\Sigma Y = na + b\Sigma X$..............(i)
- $\Sigma XY = a\Sigma X + b\Sigma X^2$........(ii)
- where Y= Avg. Temp. and X= Deviation from 2014
- Equations (i) and (ii) give the values of a and b
- $Y_c = a + bx$.........(iii)

Putting the values of a and b in equation (iii), we get least square equation.

Table 1: Calculation of expected temperature in 2050 and 2080 using least square method

Months	Expected temp. in 2019	Expected temp. in 2050	Expected temp. in 2080
January	10	11.84	15.11
February	15	15.35	18.89
March	20	20.94	24.73
April	18	19.91	21.27
May	26	26.98	31.89
June	26	26.35	29.89
July	23	22.31	23.40
August	24	24.65	27.93
September	21	21.24	22.87
October	20	21.51	25.87
November	17	17.29	20.56
December	13	14.47	19.11

This method is used to forecast the temperature of 2050 and 2080. To validate the values obtained by least square method, it is compared with the expected increment in temperature of 2050 and 2080.

The bioclimatic chart for Lalitpur shows the winter comfort zone between 18.5C to 23.5C and summer comfort zone between 22.8C to 27.8C. Most of the months need cold and passive solar heat strategies for a comfortable environment. Active solar heating is needed for three coldest months of December, January and February. The months of June, July, August and September are hot and need the provision of air movement.

6. Analysis and Result

The questionnaire survey of four Bhatbhateni buildings located at Pulchowk, Naxal, Kalanki and Anamnagar are performed. Due to the lack of cross ventilation and natural ventilation, discomfort in breathing is caused. Mostly the HVAC is being used which is not always efficient. It is found that this problem is most prevalent in Bhatbhateni supermarket and departmental store at Naxal and Pulchowk. The most complaints on suffocation are reported by the interviewees from the age range of 27-37 and 38-48.

Although technology failure is a rare case, it is observed that the extreme dependency on technology causes energy inefficiency. The building envelope is not used to its full potential.

Although natural light is avoided in department stores like Bhatbhateni, the complete dependence on artificial lighting is not an efficient or sustainable option. The windows are often blocked by the cabinets to avoid the damage that long exposure of sunlight might do to the products. In the BBSM at Kalanki, there is use of clerestory windows. It is noticed that no direct sunlight penetrates through the clerestory windows whilst it admits enough natural light for vision. This indeed would be one of the best options for ventilation and lighting.

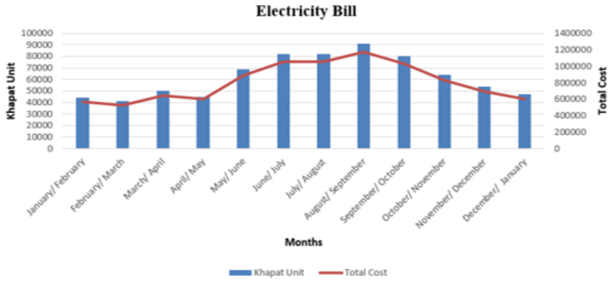


Figure 9: Electricity bill of the year 2075

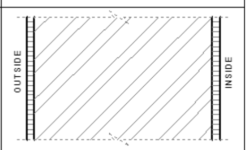
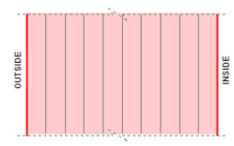
Table 2: Connected load per month (Pulchowk)

Description	Source	Connected load per month (kwh)
Lightings	1-Φ, 220V, 50Hz	4205.60
Equipments	1-Φ, 220V, 50Hz	41754.67
Security system and IT equipment	1-Φ, 220V, 50Hz	720.00
HVAC system	3-Φ, 4000V, 50Hz	280980.53

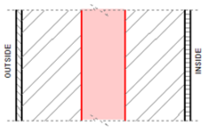
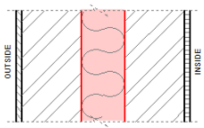
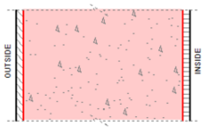
Major load present can be summarized as HVAC load, equipment loads, lightings and electricity loads.

6.1 Scenario Cases

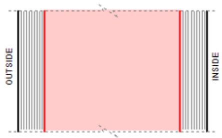
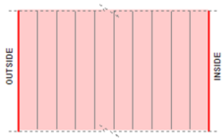
Scenario 1: Basecase Scenario

Cases	Description	U- value	Section
Scenario 1	**Brick wall:** ACP cladding at outer face + 230 mm brick wall + 10mm plaster in internal face **Single glazed window**	1.830 5.44	 

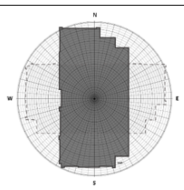
Scenario 2: Intervention on wall

Cases	Description	U- value	Section
Scenario 2a	**Cavity wall**: ACP cladding at outer face + 110 mm brick wall + 50 mm cavity + 110 mm brick wall + 10mm plaster in internal face)	1.5	
Scenario 2b	**Cavity filled**: ACP cladding at outer face + 110 mm brick wall + 50 mm fibrous wool + 110 mm brick wall + 10mm plaster in internal face	0.45	
Scenario 2c	**AAC block**: ACP cladding at outer face + 200 mm AAC + 10mm plaster in internal face	1.24	

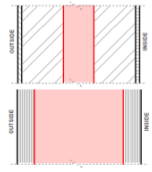
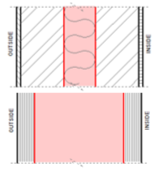
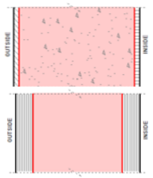
Scenario 3: Intervention on window

Cases	Description	U- value	Section
Scenario 3a	**Double glazed window:** 8mm glass+ 22mm air cavity + 8mm glass	2.710	
Scenario 3b	**Northern glazing reduced** Reduction of size of fenestrations at northern face of the wall and clerestory windows were added for provision of natural light	Win=5.4	

Scenario 4: Change in orientation

Cases	Description	U- value	Section
Scenario 4a	**North-south longitudinal axis** (Rotation of building towards 90 degree from North direction)	-	

Scenario 5: Intervention on wall and window

Cases	Description	U- value	Section
Scenario 5a	**Cavity wall+ double glazed window** (ACP cladding at outer face + 110 mm brick wall + 50 mm cavity + 110 mm brick wall + 10mm plaster in internal face)	Wall=1.5 Win.=2.710	
Scenario 5b	**Cavity filled+ double glazed** (ACP cladding at outer face + 110 mm brick wall + 50 mm fibrous wool + 110 mm brick wall + 10mm plaster in internal face)	Wall= 0.45 Win.=2.710	
Scenario 5c	**AAC+ double glazed** (ACP cladding at outer face + 200 mm AAC + 10mm plaster in internal face with 8mm glass+ 22mm air cavity + 8mm glass)	Wall= 1.24 Win.=2.710	

Scenario 6: Change in furniture layout

Cases	Description	Plan
Scenario 6a	**Change in furniture layout:** Modification in furniture layout so that natural light can be gained through existing fenestrations	

A total of ten scenario cases are developed regarding alternation on building envelope in order to analyze better option for energy optimization and occupancy comfort.

6.2 Result and comparison of scenario cases

Monthly loads/discomfort: The monthly heating and cooling load required by above all ten scenarios are compared with the base case scenario. The result concluded that the required loads increase gradually with increasing the corresponding U-value of material, i.e. decreasing the thermal resistance of the materials. This confirms the overall agreed on the tendency that the lower the U-value of envelope material is, the lower will be the loads required to maintain comfortable conditions in the building. In the above cases, scenario 5 i.e. intervention on wall and window showed better result. Also, the reduction of Northern glazing and addition of clerestory window can decrease energy load by 16.8% and 25% in the years 2019 and 2080 respectively.

Scenario	Description	2019	Reduction	2080	Reduction
1	Base case	15837			
2	**Intervention on wall**				
2a	Cavity wall	15600	1.5%	15498	8.21%
2b	Cavity filled	15348	3.09%	15208	9.93%
2c	AAC	15623	1.35%	15483	8.3%
3	**Intervention on window**				
3a	Double glazed window	13681	13.6%	13295	21.2%
3b	Reduction of Northern glazing and addition of clerestory	13169	16.8%	12666	25%
4	**Change on orientation**				
4	N-S longitudinal axis	18040	-13.91%	15543	7.95%
5	**Intervention on both wall and window**				
5a	Cavity wall+ double glazed	13800	12.86%	13350	20.94%
5b	Cavity filled+ double glazed	13365	15.6%	12957	23.2%
5c	AAC+ double glazed	13697	13.5%	13254	21.5%
6	**Change in furniture layout**				

Figure 10: Reduction percent of total load compared to base case

Hence, the result shows that the change in orientation of the building only has negative impact. Hence, the existing orientation i.e. elongation through E-W longitudinal axis is considered better.

Case I: Monthly loads/discomfort in different years with same scenario: The comparative graph below shows the monthly heating and cooling load in basecase in 2019 and 2080. The total annual heating-cooling load of the building is 15837 Wh/m2 and 16885 Wh/m2 in the year 2019 and 2080 respectively. Although there is decrease in heating load in the preceding year, the cooling load gains its number and ultimately there is increase in total heating and cooling load. This shows that the total energy load increases in 2080 due to climate change which affects in the energy performance of the building. The increase in energy load demands adaptation of building for future change in climate.

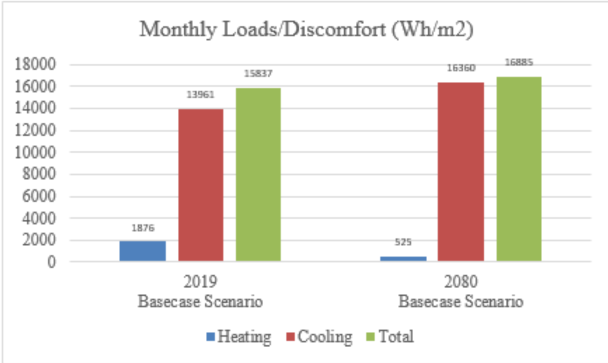


Figure 11: Case I- Comparison of Monthly loads/discomfort in 2019 and 2080 demands for adaptation for future change in climate

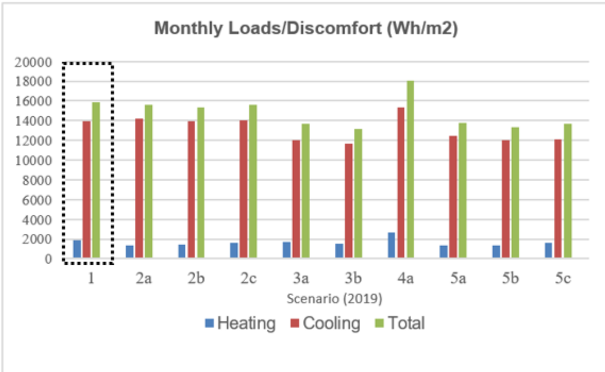


Figure 12: Figure: Case IIa-Comparison of Monthly loads/discomfort in same year (2019) with different scenarios (Reduction of total required load in comparison to basecase except in scenario 4a)

Case II: Monthly loads/discomfort in different years with different scenarios: The graph below shows an effect on monthly heating and cooling load in changing both time and scenario. Without changing scenario i.e. with existing building envelope in all years, the load increases in preceding years (case-I). However modifying building envelope can optimize the total energy load in the same as well as in preceding years (case-IIa). The graph hence concludes that the optimization in building envelope can decrease the load in same as well as in preceding years. Hence building with energy efficient envelope has a comparatively minimum effect due to change in climate and has more tendency to tolerate future climate.

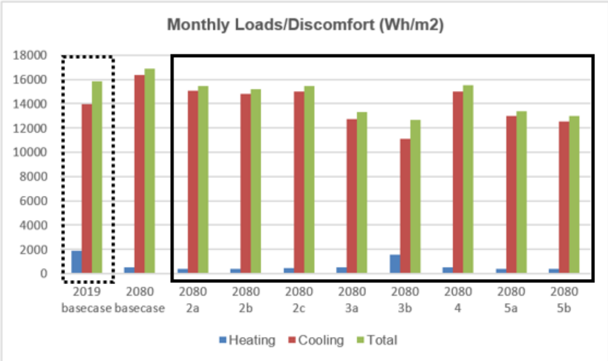


Figure 13: Figure: Figure: Case IIb-Comparison of Monthly loads/discomfort in different years with different scenarios (Reduction of total required load in same as well as in preceding years)

2. Passive gain breakdowns: The passive gain breakdowns have a positive impact with the change in scenario. The values of fabric gain and loss are lesser on all alternative cases in comparison with base case. The total heat gain through external surfaces i.e. sol-air gain is also reduced in scenario cases. Due to climate change, there is a rise in ambient temperature. The higher value of solar gain on preceding years is corrected by intervention on walls and windows. The rise in the value of internal gain can be balanced by using small clerestory windows as in scenario 3b.

7. Findings and Discussion

This research was conducted with the aim to provide an appropriate building envelope to Bhatbhateni building at Pulchowk so that it can tackle future climatic conditions or climate change. The energy consumption pattern of the building was studied and energy modeling was performed to visualize parameters.

The building walls are constructed with 9” thick brick wall. The outer facade is cladded with ACP panel and the inner facade has cement plaster finishing.There is no provision of any wall insulation in the north, east and west facade of the building. In the south facade, the building has 3” air gap in between 4” inner and outer brick wall to reduce AC load to some extent. The internal layout of the building is not managed as cabinets are placed towards glazing obstructing natural lights and ventilation for internal space. The energy consumption charges for the summer season is double than that of the winter season. The building is dependent fully upon mechanical and artificial systems for operation. Building envelope plays a predominant role in attaining building energy efficiency and thermal comfort [6]. Particularly the energy consumption related to building walls is 25%, followed by the windows for 23%, roofs for 22%, and others for 30% [7]. Modification in building envelope to adapt and tackle change in climate can, therefore, be the better solution.

The findings suggest that with the use of energy performance enhancement initiatives like the use of cavity wall, less energy consumption pattern was found in Scenario 2a when compared to the existing building scenario during simulation process. Also reduction of glazing towards north facade (which are not utilized in interior of the building) and addition of clerestory windows have improved energy consumption pattern as there is minimization of artificial lighting. Similarly intervention on the wall and window in various scenarios has a positive impact in the energy performance of the building. Hence, energy performance in commercial buildings can be improvised with the intervention of building materials and energy efficient guidelines. The building should be designed with respect to the current as well as future climatic conditions throughout the building service life.

8. Conclusion and recommendation

The main objective of this research is to find out the effectiveness of building envelope as an insulating barrier for adapting climate change in commercial building of Kathmandu which has been fulfilled by the simulation results of different scenario cases according to which the modified building envelope provided better results with both present and future weather files. The energy used by buildings is mainly dictated by energy gain and/or loss through building envelopes. Fundamentally, properties of building envelope materials are responsible for the total energy consumption of the building, such as material conduction, solar reflectivity, solar energy transmitted through the window, shading characteristics, etc. The secondary objectives are to analyze the effects of climate change in energy performance of building which has been clearly shown by developing charts comparing the required energy loads in 2019, 2050 and 2080. The comparison chart concluded that the load is increased in preceding years with existing building envelope. However modifying building envelope can optimize the total energy load in the same as well as in preceding years by 16.8% and 25% respectively as compared to basecase scenario. Hence building with energy efficient envelope has a comparatively minimum effect due to change in climate and has more tendency to tolerate future climate. This justified all secondary objectives. Hence, energy efficiency is one of the major ways for adaptation of building with response to climate change.

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