



Enhancing indoor thermal comfort and energy efficiency in residential buildings of hot humid region of Nepal – A case of Biratnagar Metropolitan City

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Abstract

Essence of indoor thermal comfort and reduction of active power consumption to meet indoor thermal needs has been a keen interest of academia around the globe which has resulted into formulation of strict guidelines for indoor environment requirements in developed countries. Nepal on the other hand lacks the basic provisions when it comes to assuring indoor comfort. Studies shows that unscientific building construction has caused people to depend on changing food and clothing habits to accommodate to the present scenario of indoor environment. The main aim of this study is to address this underlying issue through passive interventions such that both indoor thermal comfort and energy efficiency can be achieved. The study is based on evaluating the effects of various passive and energy efficient building technologies on indoor thermal environment through building energy modeling using EnergyPlus computational engine. Present scenario of indoor thermal environment of residential buildings at Biratnagar and retrofitting measures including insulation, glazing variants, shading, air tightness and others that can enhance indoor thermal comfort whilst enhancing energy efficiency is presented in this paper. In present context, the indoor thermal comfort as indicated by ASHRAE (American Society of Heating Refrigeration and Air Conditioning Engineers) 55 Adaptive Model 80% Acceptability limits is only 32% of total hours in a year, i.e. indoor comfort is compromised for above 5800 hours (equivalent to 8 months) with 'hot' to 'sweltering' indoor environment. Effects of 8 passive design interventions on residential building was analyzed based on the thermal load reduction potential and increase in acceptable limits of indoor comfort hours. It was found that combination of various design changes would help achieve up to 86% indoor thermal comfort hours and reduce annual thermal load by 68% relative to the base case scenario. The study shows that incorporating passive techniques on Nepalese residential buildings can assure indoor comfort and reduce active heating/cooling demand.

Keywords: Residential building; Thermal comfort; BEM; Passive design; Energy efficiency

1. Introduction

Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment [1]. Right from the start of human civilization, as humans became more civilized, more health conscious they became. In addition to basic needs of food and shelter, thermal comfort in accommodation got added to the list. Advances in the sector of thermal comfort led to development of varieties of air conditioning equipment which however is not within the reach of every living individual in the planet due to economical hindrances and energy crisis reasons. In the meantime, researchers around the globe came with the solution, i.e. passive design which basically is the application of design techniques that works with the local climate to ensure indoor thermal comfort and eliminate wastage or redundant use of energy i.e. achieve energy efficiency [2].

Numerous studies has been performed in Nepal in the sector of passive building design with the sole motive of increasing energy efficiency. Yadav et.al has conducted BEM study as energy saving assessment for supermarket (Bhatbhateni) building being based on EnergyPlus solver. The study investigated the energy saving opportunity with adding wall insulation and using double glazed window in the existing building and went on to conclude that approximately 1.3 % - 4.0 % energy saving can be achieved by adding 25 mm of wall insulation and double glazed window[3].

Bodach et.al [4] has conducted BEM based study to improve en-

ergy efficiency of hotels of warm temperate and cool temperate regions in Nepal. The study found that 20 % -30 % WWR (Window to Wall Ratio) for hotels located at altitude below 1000 m [4]. Similarly WWR of 40 % was recommended for locations above 1000 m altitude to enhance passive solar heating. High and medium thermal mass was found as effective passive design strategy for locations above 500 m altitude. The study further concluded that nearly 37 % energy saving would be achieved by following the design recommendation as suggested in the study[4].

Borgkvist in her graduate thesis presented at Lund University has conducted BEM study using IDA ICE at selected study building of Dhulikhel and Ghorepani. The study mainly focused on analyzing the effects of passive design strategies including orientation, WWR, insulation materials and others on indoor thermal comfort [5]. She went on to conclude that, using passive solar heating and insulating the roof and walls at Ghorepani can increase the mean indoor temperature from 0.8°C to 11.1°C in the coldest winter days[5]. The study also found that, in summer days, a well ventilated attic space would increase the indoor comfort hours and added insulation would unnecessarily lower the indoor temperature. For case study at Dhulikhel, adding roof and wall insulation, change in orientation, change in placement of windows jointly would increase the indoor temperature from 7.9°C to 18.1°C [5].

This paper presents the study of effects of various passive design changes to the existing building located at one of the most populated city of Nepal, Biratnagar based on BEM (Building Energy

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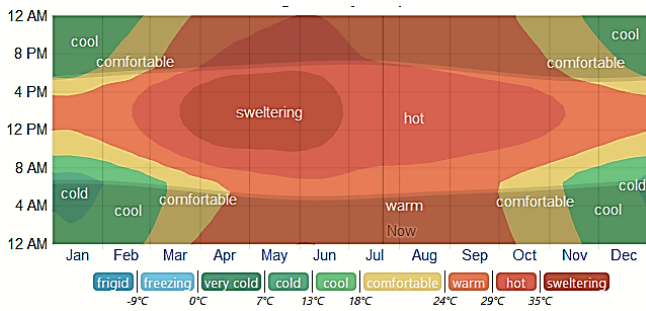


Figure 1: Year round outdoor dry bulb temperature profile of Biratnagar [9].

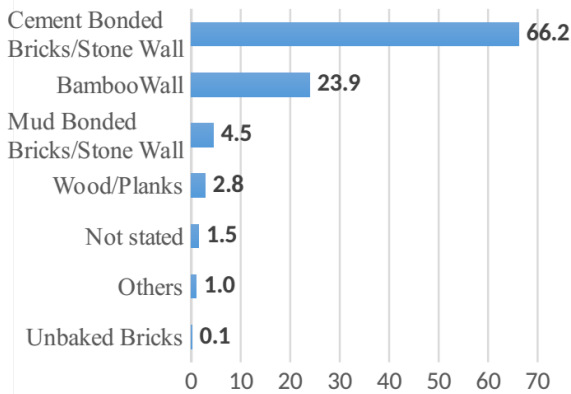


Figure 2: Household percent distribution by wall type for Biratnagar [10].

Modelling) which is the process of replicating various aspects of building in the form of computer models and analysing the energy systems of the building.

The study location Biratnagar is one of the largest (area) and densely populated city of Nepal with population density of 3100/km²[6]. Biratnagar is situated at an altitude of 72 m above sea level, lies in the south-eastern region of Nepal around 400 km east of the nation's capital Kathmandu. With 47,798 households the city houses around 214,663 people [6].

Biratnagar has warm and temperate type of climate with annual average temperature of 24.5°C and 1898 mm rainfall per year and is categorized under 'Cwa' (humid subtropical) [7] by the Köppen-Geiger climate classification system. Year round outdoor dry bulb temperature coded into bands of thermal sensation index for Biratnagar is shown in Fig. 1 which shows hot to sweltering outdoor condition for most periods of the year from May to October.

Households categorized under wall and roof type in Fig. 2 and 3 shows BMC (Brick Masonry in Cement Mortar) structure with RCC (Reinforced Cement Concrete) roof and pillar are widely practiced housing type in this area. Bamboo and mud based structures are also found abundantly used for residential purpose. However, post 2015 earthquake, GoN (Government of Nepal) issued revised building codes which has resulted into increase in RCC based BMC type buildings in the region[8].

2. Methodology

Based on the household distribution statistics of Biratnagar, one typical BMC type residential building with RCC roof was selected for study, shown in Fig. 4. Questionnaire survey was conducted to identify the occupancy status, occupancy schedule, indoor heat sources and use pattern. Building geometrical and constructional properties including building layout, window size and opening pattern, constructional material and others were noted during field

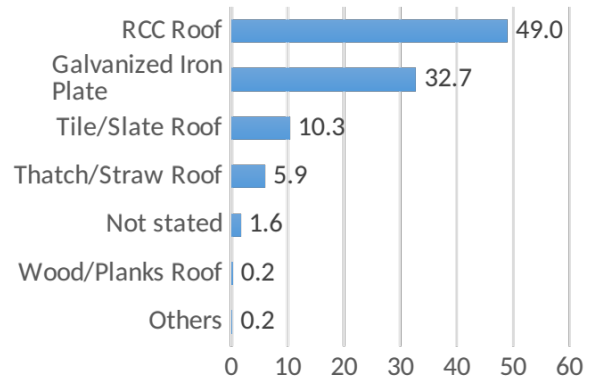


Figure 3: Household percent distribution by roof type for Biratnagar [10].



Figure 4: Study building at Biratnagar as viewed from South-East face.

study. Blower door test was performed on the building to identify the present status of building airtightness using calibrated TEC (The Energy Conservatory) Minneapolis Blower door test setup. Real-time indoor temperature and relative humidity was recorded for a year using standard calibrated HOBO MX series data loggers.

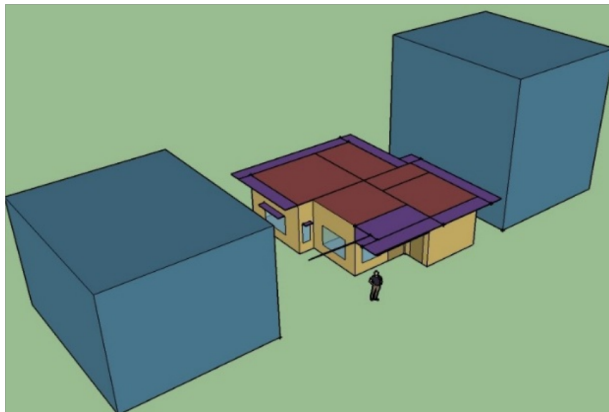
All the above mentioned building information as shown in Table 1 were put into building energy model, modeled using SketchUp and OpenStudio GUI (Graphical User Interface). The simulation ready computer model for which is shown in Fig. 5. The building energy model thus prepared was calibrated by comparing the simulated hourly indoor temperature with measured temperature data. The calibrated model as such has NMBE (Normalized Mean Bias Error) of 18.8 % and CVRMSE (Coefficient of Variation of Root Mean Square Error) of 8.6 % on hourly temperature values (ASHRAE guideline requires computer models to have NMBE ± 30 % and CVRMSE ± 15 % [11] for hourly values) with root mean square temperature deviation of 2.2°C and maximum temperature deviation of 6°C between the simulated and measured operative temperature.

BEM was conducted first to identify the present status of indoor thermal comfort and second series of BEM was conducted to study the effect of various passive design changes / retrofitting measures on indoor thermal comfort and energy efficiency.

In order to quantify the effect of each design change, ideal thermal load to maintain indoor temperature in the range of 19°C - 27°C and number of comfort hours in a year was studied. Different sets of passive design changes were then combined to define a new 'Design Alternative'.

Table 1: Constructional and non-constructional properties of study building.

Assembly	Material	Overall thickness (mm)	U-value	Non-constructional properties
Wall	Cement Plaster	254	1.893	<ul style="list-style-type: none"> – Front facade oriented to S-E – 40 watts ceiling fan operated at occupied hours – 6 people defined for the building at scheduled hours
	BMC Cement Plaster			
Floor	PCC	100	4.014	– Activity level set to 65 W/person during occupied hours
Roof	Plaster	112	4.45	<ul style="list-style-type: none"> – Constant infiltration of 3 ACH@ normal pressure – 1 ACH ventilation
	RCC			
Window	Clear glass	6	5.78	– Fixed concrete shadings over windows
Door	Wood plank	25.4	3.24	

**Figure 5:** BEM ready computer model of study building.

3. Results and discussion

3.1. Initial building performance

Fig. 6 shows that the indoor operative temperature lies between 15°C - 38°C. ASHRAE Adaptive comfort temperature for the running outdoor dry bulb temperature of Biratnagar city lies within the range of 23°C - 28°C for which only 32.4 % hour in a year indoor thermal comfort is achieved which is equivalent to 118 days in a year. This in turn also implies that indoor comfort is compromised for more than 65% period of year with 'hot' to 'sweltering' indoor scenario for most hours of day for the period of Mid-March to Early November.

Simulation results from the calibrated computer model shows high radiant surface temperatures as the main reason for indoor discomfort resulting due to high ceiling and wall temperatures as shown in Fig. 7 and Fig. 8. Annual heat gain from various sources summarized in Fig. 9 shows massive heat gain from exposed roof surfaces comprising 62 % of total heat gain. For a typical summer day (May 20), the ceiling temperature reaches a maximum of 50°C on the indoor face (10°C less than that of the outside face with 3 hour time lag resulting due to thermal storage effect of concrete). Wall temperatures on the other hand remains almost stagnant at 33°C over 24 hour period. The temperature difference between the outside face and inside face is notably low (10°C in case of ceiling of 7°C in case exposed wall surfaces) which indicates that these surfaces are not thermally massive enough to prevent outdoor weather influence the indoor environment.

3.2. Passive design changes and energy efficiency

Eight passive strategies / design changes were identified for the climate type of Biratnagar and BEM simulation was performed for a total of 42 variant of 9 strategies (Table 2). In Fig. 10 annual thermal load under ideal condition to maintain the indoor space with

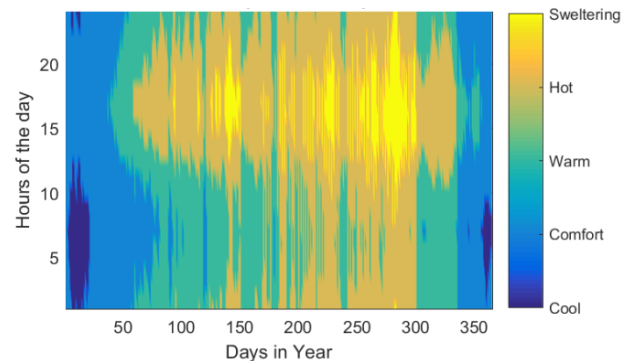
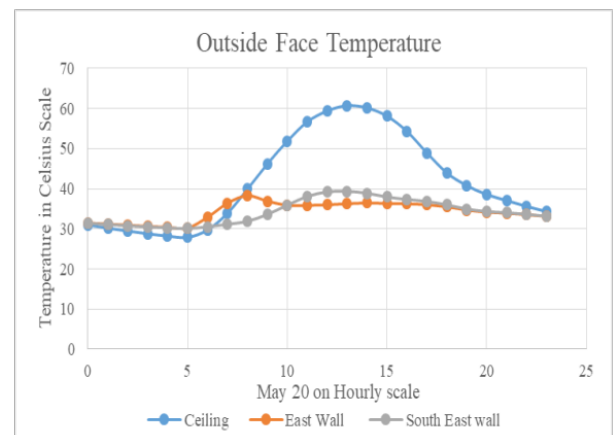
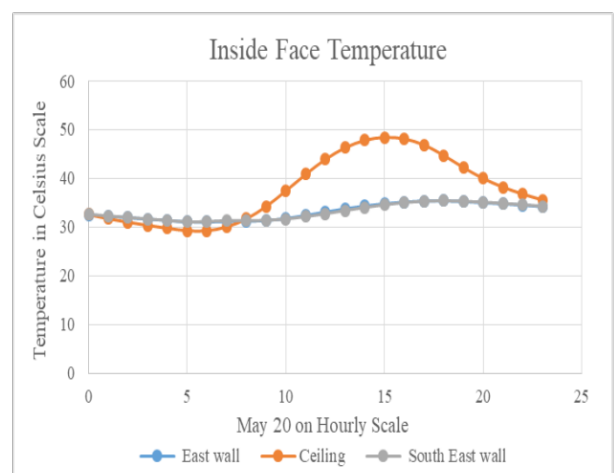
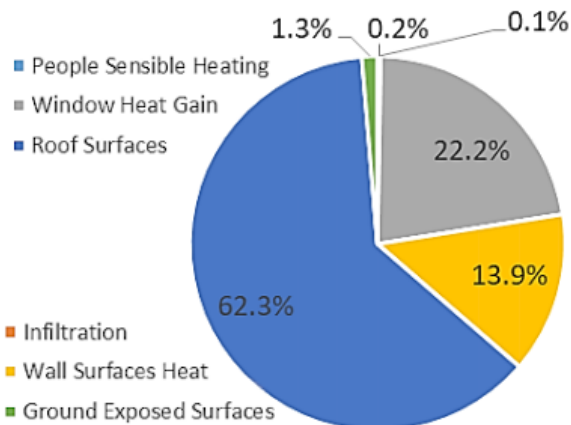
**Figure 6:** Year Round indoor operative temperature profile of study space.**Figure 7:** Exposed wall and ceiling temperature - outside face.**Figure 8:** Exposed face wall and ceiling temperature - inside face.

Table 2: Nomenclature for passive design interventions used in computer model.

SN	Design designation	Model	Design description (In order from outdoor face to indoor face)
1	Wall Design (WD)	Base	12 mm Cement mortar plaster + 230 mm Brick layer + 12 mm Cement mortar plaster
		WD1	25 mm EPS (Expanded Polystyrene) insulation + Base Model
		WD2	50 mm EPS insulation + Base Model
		WD3	100 mm EPS insulation + Base Model
		WD4	150 mm EPS insulation + Base Model
2	Wall Design (WD#)	Base	12 mm Cement mortar plaster + 230 mm Brick layer + 12 mm Cement mortar plaster
		WD#1	Base Model + 25 mm EPS insulation
		WD#2	Base Model + 50 mm EPS insulation
		WD#3	Base Model + 100 mm EPS insulation
		WD#4	Base Model + 150 mm EPS insulation
3	Roof Design (RD)	Base	100 mm RCC + 12 mm Cement mortar plaster
		RD1	Base Model + 25 mm EPS insulation
		RD2	Base Model + 50 mm EPS insulation
		RD3	Base Model + 100 mm EPS insulation
		RD4	Base Model + 150 mm EPS insulation
		RD5	Base Model + 200 mm EPS insulation
4	Radiant Barrier (RB)	Base	100 mm RCC + 12 mm Cement mortar plaster
		RB1	Base model + Reflective Insulation (TA 0.2 , SA 0.3 , VA 0.3)
		RB2	Base model + Reflective Insulation (TA 0.1, SA 0.2, VA 0.2)
		RB3	Reflective Insulation (TA 0.1, SA 0.2, VA 0.2) + Base Model
5	Glazing Design (GD)	Base	6 mm clear glass, Single Pane
		GD1	Double glazing of 6mm clear glass with air in between
		GD2	Double glazing of 6mm blue glass with air in between
		GD3	Double glazing of 6mm clear glass with air in between with low e-coating
		GD4	Triple glazing (3-6-6)mm clear glass with air in between
		GD5	Triple glazing with low e-coating
6	Shading Design(SD)	SD1	0.5 m horizontal concrete shading over windows
		SD2	0.5 m horizontal and vertical concrete shading on windows
		SD3	0.5 m vertical concrete shadings on windows
7	Thermal Mass (TM)	TM1	12 mm Cement mortar plaster + 508 mm Brick layer + 12 mm Cement mortar plaster
		TM2	508 mm Brick masonry Mud mortar Construction
		TM3	25.4 mm Wood plank wall, floor, ceiling construction
8	Roof shading (RS)	RS1	open space 7 feet height Metal Truss with GI sheet roof shading
		RS2	Closed attic space with GI sheet roofing over base model

**Figure 9:** Annual heat gain summary for study space from various sources.

19°C -27°C for different design changes are shown. Results shows that, building airtightness, wall insulation, roof insulation, radiant barrier/ reflective coating on roof surface, window shading and roof shading has considerable load reduction capacity and ensure increased indoor comfort hours. While, glazing design changes has negative effect on load reduction and decrease the total indoor comfort hours.

As seen in Fig. 10, wall insulation (WD in Fig. 10) on the outer

exposed face has more load reduction potential that that placed on the inner face (WD #). Similarly, it was found that, adding roof insulation of 25 mm reduced thermal load by 23 % in comparison to base model. Roof insulation up to 150 mm has load reduction of 28 % however, adding further insulation by 50 mm has increased load reduction of only 0.4 %. i.e. no considerable load reduction can be achieved on roof insulation above 150 mm.

It was found that, up-to 11 % load reduction can be achieved just by using reflective coating/ radiant barriers on the outer face of roof surface. Three variants of window shading study showed 0.5-meter horizontal shading over window more efficient with load reduction potential 11.3 %.

Results showed building airtightness has considerable energy saving potential with load reduction of 33.4 % if the building was completely airtight in comparison to base model infiltration of 3 ACH at normal pressure. Similarly, it was found that open space roof shading (metal truss with GI roof sheeting, 7' vertical height) has more energy saving potential than traditional type closed attic space with indoor comfort hours of 73 % and 61 % respectively over the year.

Glazing variants of double pane and triple pane with low e-coating windows were used in BEM which further increases indoor temperature resulting into increased thermal load and decrease in number of comfort hours and thus was not used as a design alternative.

Design changes with maximum load reduction capability from

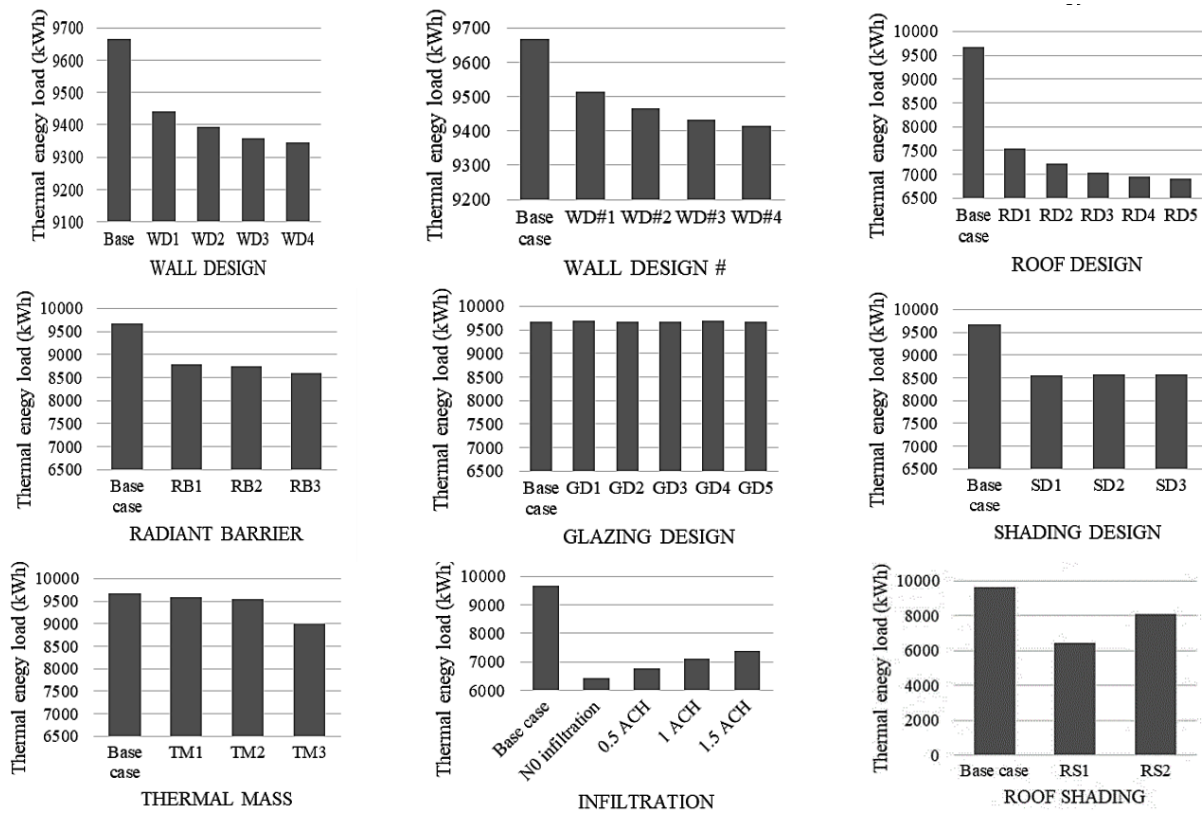


Figure 10: Ideal thermal load of the space after incorporating various design changes to the base model.

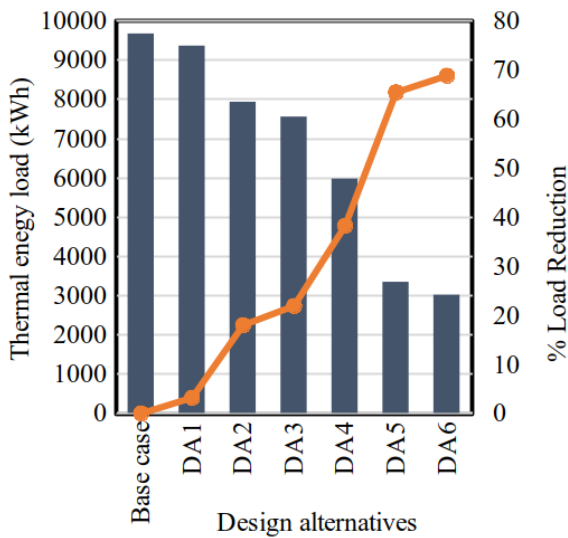


Figure 11: Annual energy demand and load reduction potential plot for different design alternatives.

among the above mentioned strategies were used in combination to define new design alternatives. Fig. 11 and 12 show the cumulative effects of different design changes when used in combination. Result shows, annual thermal loads can be reduced by 68 % when different passive design changes are opted in combination to the existing building. Similarly, indoor comfort hours up to 86 % based on ASHARE 55 Adaptive model 80 % acceptability limits and up to 99 % based on more heat tolerant CEN 15251 Adaptive model Category III standards can be achieved when design alternatives are opted.

Table 3 shows the model description for 6 variants of Design Al-

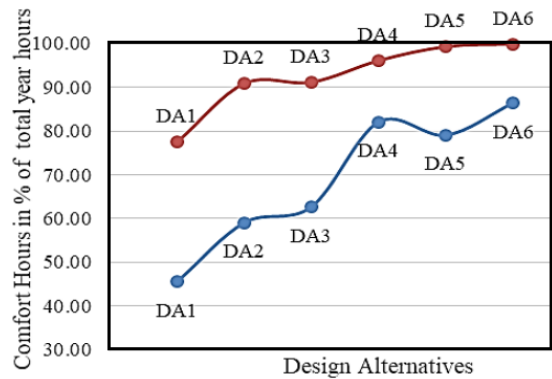


Figure 12: Year round comfort hours for various design alternatives.

ternatives (DA) prepared from among the best sets of 9 passive design changes listed above.

4. Conclusion

The study shows residential buildings at Biratnagar at present context has poor indoor thermal comfort with indoor comfort no more than 33 % hours of the year. Sophisticated air conditioning equipment can address this issue of poor thermal comfort however, considering energy consumption and its consequent environmental effect, it cannot be suggested for long run.

Passive design strategies and simplest retrofitting measures including wall and roof insulation, reflective coating on exposed wall and roof surfaces, window and roof shading, building airtightness when adopted in combination in the building construction can help reduce up to 68 % of indoor thermal loads under ideal condition and increase indoor comfort hours to 86 %.

The study building type (BMC) was the abundantly found build-

Table 3: Design alternatives and model description.

	Base Case	DA1	DA2	DA3	DA4	DA5	DA6	Passive intervention to base model
Base Model	✓	✓	✓	✓	✓	✓	✓	
WD3		✓	✓	✓	✓	✓	✓	100mm EPS wall insulation
RB3			✓	✓	✓	✓	✓	Reflective coating on roof
SD1				✓	✓	✓	✓	0.5m horizontal window shading
INFIL1					✓	✓	✓	0 ACH infiltration
RD4						✓	✓	150mm EPS roof insulation
RS1							✓	Roof shading; Metal truss with GI sheeting, 7' vertical height

ing practice in the study region. It is evident from other studies that apart from the use pattern of indoor space, building envelope and the materials used for construction are the major parameters that influence the thermal interaction in the building. The author thus strongly believe that the results from the study building can be used to generalize the indoor environment of similar building types in the region.

5. Recommendation

The passive design strategies are not limited to the above mentioned studied strategies. Effect of passive strategies including vegetation around the building premises to shade exposed wall surfaces and ensure fresh air distribution, night flush ventilation, porch design, evaporative cooling and other can be studied as probable design alternative.

This research was based on the evaluating the indoor environment based on thermal comfort definition of ASHRAE which is a well experimented and widely accepted standard. The author however also believes that the comfort range based on indoor operative temperature defined by ASHRAE may not outright address the adaptive behavior of Nepalese people, thus a study to identify the neutral/comfort temperature for Nepalese people for wide range of indoor operative conditions is necessary.

This study shows the added benefits of incorporating passive and energy efficient building technology on indoor thermal comfort and load reduction. The author thus strongly recommends that GoN and academia should work hand in hand to explore the applicability of passive and energy efficient building technology in traditional and modern residential buildings in Nepal.

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