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# Impact of Climate Change on Heating and Cooling Load Demand for Sustaining Thermal Comfort in a Residential Building – A Case Study of Kathmandu Valley

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**Abstract**

Climate change is considered as one of the main challenges facing humankind in the 21th century, with serious and global consequences for the environment, human health and the economy. At the same time, the performance of buildings depends on the climate they are exposed to. Their long lifetime (in the range of 50–100 plus years) corresponds to the timescale over which the climate is expected to show substantial change. This implies that buildings built today need to be designed to work successfully in both the current and future climate. Thus, a measure for remodeling building envelopes in response to climate change has attracted much attention. This study presents an analysis of the impacts of climate change on thermal comfort and energy performance of residential buildings in Kathmandu Valley. It explores mitigation as well as adaptation strategies to improve buildings' performance under climate change conditions. The results suggest that climate change influences energy performance and indoor comfort conditions of buildings. However, effective building design strategies could significantly improve buildings' energy and indoor climate performances under both current and future climate conditions.

**Keywords**

Climate Change, Housing, Thermal Comfort, Building Envelope, Building Energy Simulation–Heating and Cooling Load

## 1. Introduction

The buildings and buildings construction sectors combined are responsible for 36% of global final energy consumption and nearly 40% of total direct and indirect CO2 emissions [1]. Climate change is expected to have an impact on many aspects of building performance and energy use. Throughout the world, scientists are using the projections of future climate to estimate the impacts on the local scale [2]. Similarly, the use of future climatic data is also important to study thermal comfort and energy demand in the building sector. As the replacement rate of buildings is low, and the lifetime of buildings long, much of the existing and future building stock will be affected by any long-term (30- 70 years) changes in climate. There is a need to identify what impacts climate change may have on buildings, how serious they are, and what action (if any) could be taken to ensure that future building performance is not compromised [3].

In Nepal, building thermal comfort for traditional and modern buildings has been explored before in [4], [5], [6], [7] etc. However, the relation between energy use for thermal comfort and future climate change has yet to be explored. The impact of future climate change patterns has been studied mostly for agriculture, water resources, urban flooding, etc. [8], [9]. Nonetheless, research addressing thermal comfort, climate change,heating, and cooling demand collectively have been conducted in different climatic zones of Argentina, Sweden, Turkey, Hong Kong, United States, Taiwan etc. Multiple studies have been conducted to explore the effects of changes in climate on the projected future performance of buildings [10], [11], [12].Likewise, previous studies have addressed the impact of the surface characteristics of exterior building components on the thermal performance of buildings [12].

Energy consumption levels for cooling and heating are expected to increase and decrease respectively, as a result of global warming [13]. However, the impact of climate change on heating and cooling energy use in different locations will vary because of their different climates [14], [15]. Thus, analysis of heating and cooling energy use in the future is needed to better understand the impact of climate change on building energy consumption

Thermal comfort conditions are as important as energy demand in buildings because the level of of thermal comfort is mostly concerned with energy consumption [16]. The building envelope essentially works as a mitigation shelter to moderate the outdoor natural environment for creating optimum conditions of livability [17]. In this research, with the constructed future weather data of Taiwan, it was possible to analyze future building energy use and the thermal performance under the influences of climate change.Annual increases in cooling energy of 31%, 59%, and 82% over current levels were observed for the 2020s, 2050s, and 2080s, suggesting an urgent need to regulate the excessive use of cooling energy by remodeling existing building with passive design means.Similarly, alternative building designs (specifically, various surface design options) were studied in view of their mitigation effectiveness vis-à-vis climate change projections in Vienna, Austria. The results thusfar suggested that – in case of buildings with highly insulated envelopes – surface reflectance and longwave emissivity of envolope elements do not significantly affect buildings' heating and cooling loads. Currently, active cooling was not required in Austria for residential buildings. However, should this change due to the projected warming trend, a dramatic increase in energy demand has to be expected [12].

## 2. Research Methodology

Both qualitative and quantitative methods are employed in this research.The first half of the research which includes literature review, relevant case study, problem identification was based on qualitative approach where as climate projection, Givoni's bioclimatic chart preparation and energy modelling were quantitative. Energy modeling and simulation was carried out in Ecotect with the base case and variable properties as alternative scenarios. This method is quantitative that uses the virtual lab for experimentation. The results were analyzed and compared to energy performance evaluation.The methods applied are discussed below.

### 2.1 Building Description

Brihat Community living is a housing project developed by Brihat Developers, which is in Ramkot, 2.4 km from Sitapila Chowk. It is was selected as the case study because this community has adopted passive measures along with the attempt to use aerated concrete block for building construction. This community includes sixty-one standalone units and among them, Type C building is taken as a base model for energy modeling.


**Figure 1:** Floor plan of case study building

It is a two and a half storey building. It consists of 3 bedrooms and 3 bathrooms built on the plot of 5 Anna (1711.25 sq.ft). The built-up area of this building is 1730 sq.ft. It is developed in Ecotect to analyze energy use for heating and cooling load to maintain the thermal comfort of the building in future climatic conditions. The table below shows the basic information of the selected building.

**Table 1:** General description of base case building

| Parameters | Details |
|---|---|
| Housing type | Detached |
| Construction Materials | RCC with Brick and Cement |
| Floor Finish | Tile Finish in kitchen and bathroom |
| Ceiling | RCC slab |
| Area | 1730 sq.ft |
| Orientation | South |
| Openings | In all three directions except for west |
| Floor height | 9'5" |
| Storey | Two storey with the top floor for staircase cover and puja room |

## 2.2 Climatic Analysis

The present climatic data of Kathmandu valley was collected from the Department of Hydrology and Meteorology. Weather generating tool weather shift was used for generating the data necessary for consecutive years 2035, 2050 and 2090. Once the data was generated bio-climatic chart was created. A format for bio-climatic charts was proposed and boundaries of direct passive evaporative cooling with and without night-time ventilation were determined by using these charts.

The future climatic data was projected using the weather shift tool. Based on two of the RCP emission scenarios (4.5 and 8.5), Arup and Argos Analytics has developed a tool named WeatherShift™‘ (WeatherShift, n.d.) that applies the morphing procedure on the outcomes of 14 GCMs (out of approximately 40 models) available under AR5. The tool provides future projection weather data for three time periods – 2026-2045 (referred as 2035s‘), 2056-2075 (referred as 2065s‘), 2081-2100 (referred as 2090s‘) relative to the baseline period 1976-2005 – and two emission scenarios – RCP8.5 and RCP4.5 – of the IPCC‘s AR5. Based on the tool maximum and minimum temperature, monthly maximum heat index, diurnal temperature variation, relative humidity were generated for the year 2035,2065,2090 [18].

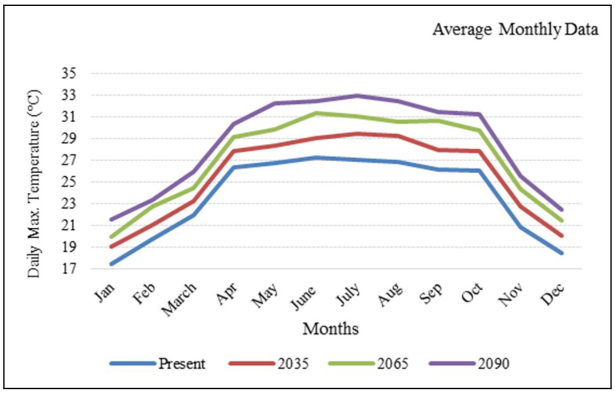


**Figure 2:** Daily max temperature data for RCP 8.5

Figure 2 shows the gradual increase in the surface temperature over the year reaching the average monthly maximum of 33 degrees for the hottest month in 2090. Similarly, figure 3 shows the total number of days for a certain temperature frame. Data binning is a data pre-processing technique used to reduce the effects of minor observation errors. The original data values which fall into a given small interval, a bin, are replaced by a value representative of that interval, often the central value. It is a form of quantization.

From figure 3, we can see that most of the design days that need to be considered in the future year correspond to 22 to 29.4 degrees Celsius. The graph shows that’ in the years to come to the max temperature will gradually increase. Similarly, the daily minimum temperature was also generated which is shown in Figures 4 and 5.

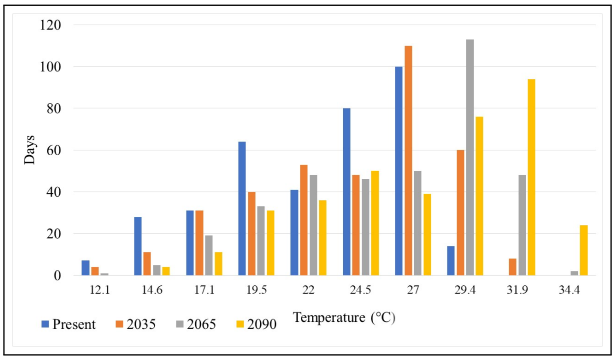


**Figure 3:** Binned daily max temperature data for RCP 8.5

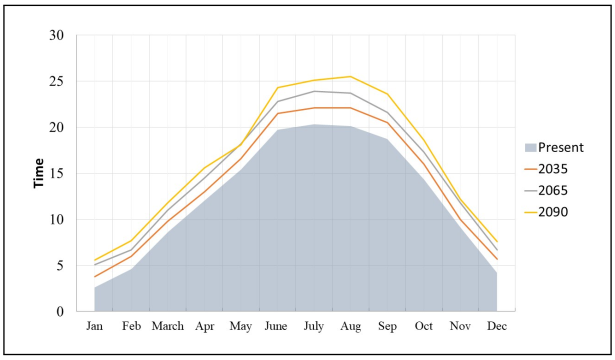


**Figure 4:** Daily min temperature data for RCP 4.5

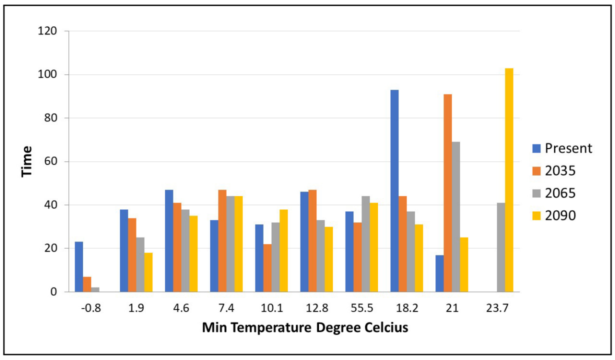


**Figure 5:** Binned daily min temperature data for RCP 4.5

Based on the data that was generated from the weather shift tool the bio-climatic chart for each year was generated along with the present year. Table 2, depicts the comfort zone for winter and summer under the future scenarios of Representation Concentration Path 4.5 and 8.5 for the median probability of 50%.

**Table 2:** Comfort range for various years under a different future scenario in degree celius generated using Givoni's Bioclimatic chart

| - | Winter (RCP 4.5) | Winter (RCP 4.5) | Summer (RCP 8.5) | Summer (RCP 8.5) |
|---|---|---|---|---|
| Year | Lower limit | Upper limit | Lower limit | Upper limit |
| 2035 | 18.5 | 23.5 | 23 | 28 |
| 2065 | 18.3 | 23.3 | 23.3 | 28.3 |
| 2090 | 18.9 | 23.3 | 23.9 | 28.3 |
| - | Winter (RCP 8.5) | Winter (RCP 8.5) | Summer (RCP 8.5) | Summer (RCP 8.5) |
| Year | Lower limit | Upper limit | Lower limit | Upper limit |
| 2035 | 18.6 | 23.6 | 23.6 | 28.1 |
| 2065 | 19 | 23.6 | 24 | 28.6 |
| 2090 | 19.3 | 24.3 | 24.1 | 29.1 |
| Present | 18.6 | 23.6 | 22.8 | 27.8 |

### 2.3 Energy Modelling

Before analysis using the Ecotect process, rooms known as zones were produced to separate operational spaces of the building required for energy simulation in Ecotect.

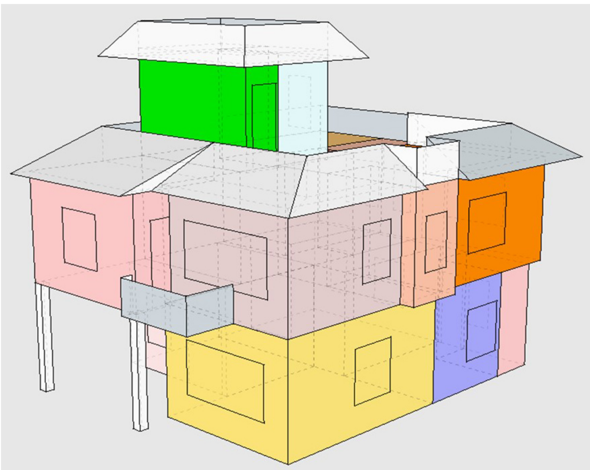

**Figure 6:** Various zones created for building simulation

The other application of the room element was to specify the area and volume of the spaces. In addition to room setting before exporting the energy model, the location and types of the building were also defined. Figure 6, shows the perspective of the building and the colors displayed in the model identifies different rooms also known as zones. The base residential building was divided into different zones and the building activity was chosen as per the zone.The general setting used in Ecotect are as follows: 1.Clothing: Shorts and t-shirts, 2.Humidity : 60%, 3.AirSpeed : Pleasant Breeze ($0.5m/s^2$), 4.No. of people : Dependent upon the room, 5.Activity : Sleeping, reading, cooking, sedentary, etc, 6.Air change rate : Average 1 air change per hour, 7.Wind Sensitivity : Reasonably protected 0.25 air change per hour.

## 3. Data set and Analysis

### 3.1 Scenario 1: Base Case

The base scenario was modeled as the existing scenario. All specifications were as per actual site measurements and conditions. Each room was assigned with different hours of operation and occupancy numbers. The results are mainly represented through monthly loads and passive heat breakdown for a better understanding of the performance of building materials and its subsequent energy requirements.

**Table 3:** Monthly Heating and Cooling Load for Base Case

| Month | Heating (Wh) | Cooling (Wh) | Total (Wh) |
|---|---|---|---|
| Jan | 2595766 | 0 | 2595766 |
| Feb | 1610612 | 0 | 1610612 |
| Mar | 744565 | 14085 | 758650 |
| Apr | 93031 | 242168 | 335199 |
| May | 12002 | 509644 | 521646 |
| Jun | 0 | 864366 | 864366 |
| Jul | 0 | 850268 | 850268 |
| Aug | 0 | 749687 | 749687 |
| Sep | 0 | 468150 | 468150 |
| Oct | 94016 | 249484 | 343500 |
| Nov | 933809 | 1102 | 934911 |
| Dec | 2099722 | 0 | 2099722 |
| TOTAL | 8183522 | 3948954 | 12132476 |
| KWh | 8183.52 | 3948.954 | 12132.4 |

Table 3 shows the monthly heating and cooling load to maintain the thermal comfort of the building. According to the calculation made by Ecotect

Analysis, the total annual heating load is 8183.52 KWh and the total annual cooling load is 3948.95 KWh. The maximum heating load is 10.4 Kw at 8 pm on 6th January and the maximum cooling load is 5.9 Kw at 8 pm on 19th June. According to the result, the heating and cooling load is maximum and minimum in January and June respectively. The total annual heating-cooling load of the building is 12132.47 KWh.The total floor area is 302.292$m^2$.

**Table 4:** Passive Gain Breakdown

| Category | Losses (%) | Gain(%) |
|---|---|---|
| Fabric | 75.6 | 16.3 |
| Sol-Air | 0 | 35.3 |
| Solar | 0 | 19.5 |
| Ventilation | 12.7 | 3.4 |
| Internal | 0 | 16.4 |
| Inter-Zonal | 11.7 | 9.2 |

Table 4 shows that the building loses 75%of heat through fabric whereas gain is about 16.3%. This loss results in increased heating loads in the colder months. 35.3 % of heat is gained through the sol-air which refers to heat gain due to the increase in the surface temperature of the building components excluding the windows and opening.Similarly, 19.5% of the heat is gained through direct solar gain which refers to the heat gain through windows.12.7% and 3.4% of heat are respectively lost and gain through ventilation. Internal gain refers to the heat generated within the rooms itself due to the activities that are carried out which is 16.4%. The inter-zonal gain refers to the heat transferred to the adjacent rooms which are 11.7% loss and a 9.2% gain.

### 3.2 Scenario 2: Modification of Wall

In scenario II, the materials used in the reference scenario were modified accordingly to enhance the comfort of the occupant and reduce energy consumption. The main objective of creating this scenario is to analyze the impact of material selection.

**Table 5:** Comparison of alternative wall materials on the amount of annual operational energy

| Building Component | U-value $(w/m^2.k)$ | Energy Consumption annual (KWh) |
|---|---|---|
| 1. Cavity construction: 12mm plaster+ 100m brick+ 50mm cavity + 100 mm brick | 1.43 | 7446.12 |
| 2. Cavity construction: 16mm plaster+ 110m brick+ 50mm cavity + 110 mm brick+ 16mm plaster | 0.77 | 6865.06 |
| 3. 200mm AAC Block with 10mm plaster on both sides | 0.69 | 6865.06 |
| 4. Cavity Brick Wall: 103mm double facing brick +75mm cavity batts +115 mm aerated block any plaster finish | 0.30 | 6462.56 |

### 3.3 Scenario 3: Modification of Window

As mentioned before, the windows component used for the case study was single-glazed glass in aluminum frames. In this step, alternative materials were used to analyze their effect on the overall operational energy use of the building. Here, the existing base scenario is taken, and keeping all the other parameters constant only the windows are changed. Table 6 demonstrates the amount of operational energy consumption based on the alternative materials that can be used as window components.The Solar Heat Gain Coefficient of material 1, 2 and 3 listed below is 0.75, 0.55 and 0.48 respectively. The lower the SHGC solar heat gains coefficient, the less solar heat it transmits and the greater its shading ability. A product with a high SHGC rating is more effective at collecting solar heat during the winter. A product with a low AHGC rating is more effective at reducing cooling loads during the summer by blocking heat gain from sun. Ecotherm is a 1 mm thick thermal insulation coating which is ultra-thin coating and absorbs /reflects the energy back into the room, creating a thermal barrier to heat loss.

The glass type with clear float, air gap and different layer made of ecotherm or ecosol had same u value so only one of the compositions was taken for analysis. The only difference is in its solar heat gain coefficient. A triple glazed window as per the calculation show to have better performance

**Table 6:** Comparison of alternative windoe materials on the amount of annual operational energy

| Building Component | Total Width | U-value $(w/m^2.k)$ | Annual Energy use(KWh) |
|---|---|---|---|
| 1. Clear float , Air gap , Clear float | 4+12+4 | 0.75 | 11379.36 |
| 2. Clear float,Air gap,TRC Ecotherm | 4+12+4 | 0.55 | 11027.38 |
| 3. LowE,Air gap,Clear float,Air gap,LowE | 4+12+4+12 +4 | 0.48 | 10899.41 |

### 3.4 Scenario 4: Modification of Floor

In this study, two alternative components are considered for the floor, i.e., Uninsulated and insulated floor.

1. Uninsulated Floor slab:
   Uninsulated floor with 2cm tiling, 3cm gravel. 0.5 cm waterproof membrane, 5cm screed and 10cm reinforced concrete floor slab is used in first case scenario. The U-value of this composite floor is 1.89 w/m2k. For this simulation, the overall parameters in the building are kept constant with the change only made in floor. 10703.12KWh energy was annually used in this case.

2. Insulated Floor slab:
   The insulated floor with 2cm tiling, 3cm gravel. 0.5 cm waterproof membrane, 5cm extruded polystyrene thermal insulation, 0.5 cm damp proof membrane, 5cm screed and 20cm reinforced concrete floor slab is used in second case scenario. The u value of this composite floor is 0.46 W/m2k.The energy used was reduced from 10703.12 KWh to 9283.17 KWh annually.

## 4. Findings and Discussions

From figure7, we can see that the AAC block with one side cavity had better insulation, and less total annual energy was used for heating and cooling load. However, the AAC block of 220 mm could also have a reduction in energy consumption annually when the original brick wall of 230 mm was replaced.

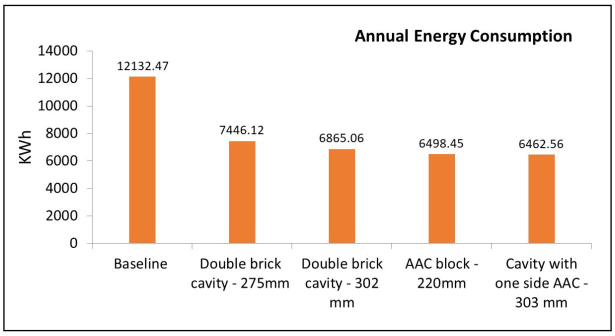


**Figure 7:** Comparison between energy usages for different wall materials

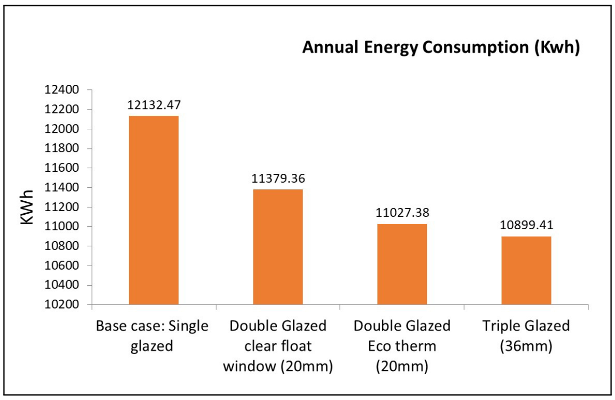


**Figure 8:** Comparison between energy usages for different window materials

Figure 8 shows that the use of triple glazed reduces total energy use. However, based on the availability and construction in Kathmandu double glazed with protective insulation can also have better performance.

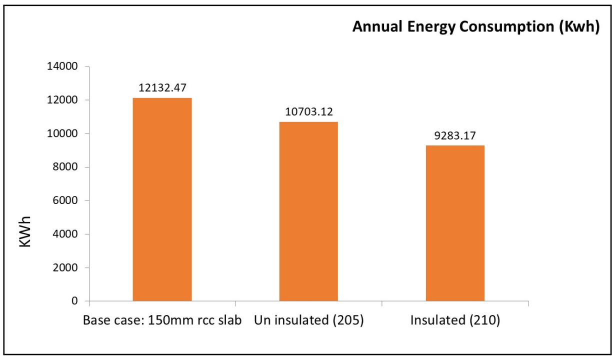


**Figure 9:** Comparison between energy usages for different floor materials

Figure 9 shows the difference in energy consumption between the usages of the insulated and uninsulated floor.

## 4.1 Modifcation of Overall Scenario

Based on findings, the wall, window and floor was replaced by AAC block of 220mm, double glazed window of 20mm and uninsulated floor of 205mm dimension respectively.Figure 10, shows the annual operational energy consumption based on the combination of all of the modifications, i.e., that the combination has the potential for reducing the overall energy consumption.It also shows the difference in need of annual heating and cooling load of the base case and the modified case.

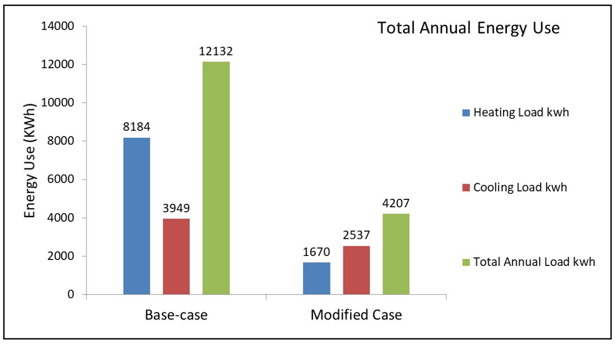


**Figure 10:** Comparison between energy usages for base case scenario and overall modified scenario for the present year 2020

From figure 11 we can see that the heating load is gradually increasing whereas the cooling load is decreasing for the base case scenario. In figure 12, the heating load for the modified case is low compared to the base case scenario.

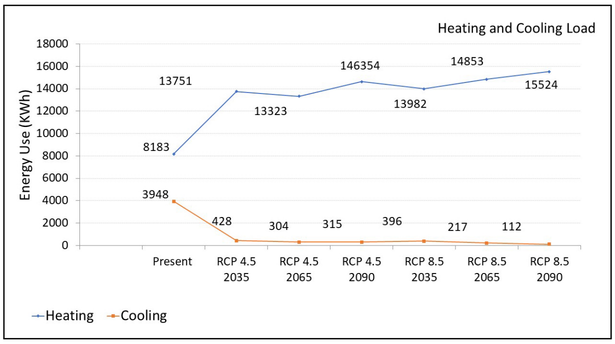


**Figure 11:** Change in heating and cooling load of the base case scenario for different years

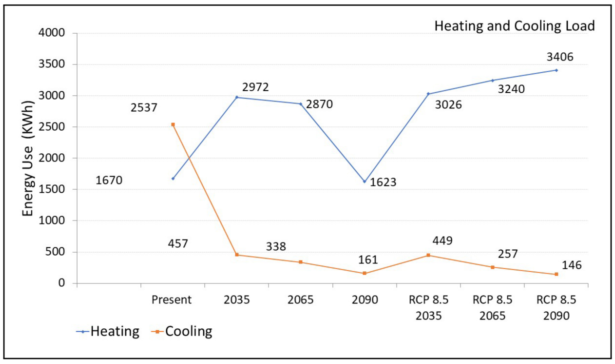


**Figure 12:** Change in heating and cooling load of modified case scenario for different years

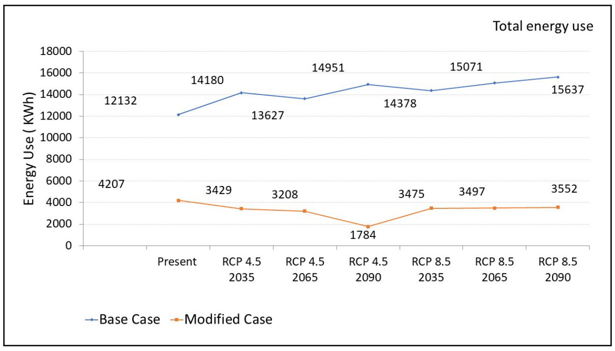


**Figure 13:** Comparison between the total energy load between the base case and modified case scenario for different years

By the end of 2090 for RCP 4.5 the difference between the total energy use for the base case building is increased from 12,132 KWh to 14951 KWh and for RCP 8.5 it is increased up to 15,637 KWh.Whereas, for the modified case the total energy use is decreased form 4207 KWh to 1784 KWh and 3352 KWh for RCP 4.5 and RCP8.5 respectively.

## 5. Conclusions

With rapid building stock development and rising living standards, the building sector will continue to be a main energy user The primary objective of this study is to analyse the level of thermal comfort and changing energy use under climate change in Kathmandu The bioclimatic chart developed by Givoni was used in this paper. And the rise in surface temperature was established from weathershift tool Based on the results presented in this study, following conclusions can be drawn.

1. The impactof climate change on cooling and heating energy use of Kathmandu valley was found to be decreasing and increasing respectively.

2. The total energy use in base case scenario was approx.increased by 18.85% and 22.4% respectively for RCP 4.5 and RCP 8.5.

3. With the adaptaion of alternative materials with less U-value in building envelope the total energy was reduced from 12132 KWh to 4207 KWh. This indicates that the building uses approx. 65.32% less use of active energy for maintaining thermal comfort.

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