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Evaluation of energy performance of residential building in a hot and humid region: A Case of Siddharthanagar, Nepal

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Abstract

This paper presents the results of a recent study of the energy performance of residential buildings in one of the hot and humid climatic regions of Nepal, Siddharthanagar, Rupandehi, Nepal. A building's energy performance typically correlates with its energy efficiency, as energy performance is used to determine its annual energy consumption. The energy demand increases when more discomfort is experienced in a building which results in higher consumption of cooling and heating loads. The intention of this study was to observe the thermal comfort of a residential building in the hot and humid region throughout the year and its performance after passive design strategies. The study was performed by analyzing the climatic data collected from the Department of Hydrology and Meteorology, studying the building envelope followed by simulation of a residential building located in Siddharthanagar municipality, Rupandehi, using an energy modelling software named Ecotect. The existing scenario was modified through orientation and the addition of insulation, which could reduce energy demand by 29 percent.

Keywords

Energy consumption, Energy efficiency, Hot and Humid climate, Passive design, Thermal comfort

1. Introduction

Energy efficiency and conservation have always been important topics in the discussion of energy policy.Their significance has increased as worries about the global environment and energy security have grown. Many advocates and decision-makers believe that reducing energy demand is crucial for overcoming these obstacles, and studies typically show that doing so can be an affordable way to solve these issues [1]. A third of the globe's final energy consumption and greenhouse gas emissions are attributable to energy services used in and related to buildings. Additionally, they contribute to the other major energy-related global sustainability issues such as dependence on energy, access to modern energy services, climate change, indoor and outdoor air pollution, and related and additional health hazards [2]. Through increased efficiency and lower energy intensities in both the global and regional economies, the growth of the energy demand and carbon emissions will be significantly slowed [3]. The residential sector in Nepal can be broken down into two categories: rural and urban. According to Water and Energy Commission Secretariat (WECS), urban housing consumes 29 per cent more fuel wood than rural dwellings. LPG is currently the fuel of choice for cooking in urban areas with an annual consumption growth rate of about 23 per cent, with electricity coming in second [4]. The objective of this paper is to find the thermal comfort of residential building in hot and humid climate.

2. Literature review

2.1 History of Energy efficiency

The most noteworthy examples of how man has used and altered natural systems to better living conditions go back to ancient times are dwellings and the construction methods used to build them. Although the phrase "energy efficiency" was not widely used before the 20th century, people still created and passed down good practice standards [5]. After the 1973 Energy Crisis, architects, engineers, and building owners started to take a greater interest in energy-efficient design [6].

2.2 Global energy pattern

Energy consumption in the residential and commercial sectors is expected to increase significantly by 2040, with electricity serving as the main energy source for the building sector. The majority of the growth will be powered by electricity [7]. According to IEA, the share of the total energy consumption in two years; 1973 and 2019 AD is near twice the increase from the consumption rate in 1973, the overall world final consumption by source in 2019 was 418 Ej [8].

2.3 Energy consumption of a residential building

The Heating and cooling demand predominantly depends on the climate in which the building is situated, the building characteristics, such as the external walls of a building (building envelope), and the occupants' behavioral factors, such as occupancy patterns [9].Building efficiency must be viewed as enhancing the functionality of a sophisticated system created to give inhabitants a cozy, secure, and lovely place to live and work. Heaters, ventilation, and air conditioning (HVAC) account for 35% of all building energy use, followed by lighting (11%), major appliances (water heating, refrigerators and freezers, and dryers) (18%), and other uses (36%), including electronics. In each scenario, there are opportunities to enhance both the functionality of system components (such as lighting fixtures) and the manner in which they are controlled as a part of integrated building systems (such as lighting controls) [10].

2.4 Ensuring energy efficiency in buildings

Globally, governments are devoted to accomplishing sustainable development objectives (SDGs). Energy-efficient buildings can significantly help to achieve SDGs 11 and 13 in a scenario where urban agglomerates consume about 80% of the global energy, of which buildings account for 40%. At the moment, socioeconomic and technical constraints prevent the use of energy efficiency measures (EEMs) in buildings [11]. Numerous applications exist that aim to lower building energy use. The analysis of the building life cycle makes it possible to take into account the amount of energy used at each stage of construction. To use less energy, we must comprehend the life cycle of construction. The three main stages of the building life cycle are pre-construction, construction, and post-construction [12].

2.5 Thermal Adaptability

Through acclimatization, the human body intelligently adjusts to a variety of environmental circumstances. Clearly, the design strategy for a building must be in accordance with the locality of the building given the varying thermal comfort needs of people in various climatic conditions and for various seasons. A building will start to experience thermal discomfort in a hot, humid atmosphere. [13].

2.6 Climate Responsive Design

Using climate-responsive architecture design concepts makes it simpler to adapt to difficult conditions.. Based on how occupants adjust to heat, the functional building diagram is created. Spaces can be used dynamically to make the best use of climate resources during different seasons. For dry-hot and dry-cold environments, heavy constructions with great thermal storage capacity are preferable. In the summer, semi-basement rooms can maintain comfortable temperatures all day long [14]. Through the application of passive design techniques that are appropriate to the local environment, such as air tightness, ventilation, building envelope insulation, surface color, sun shading, and building form, energy efficiency can be improved.

3. Methodology

The study is based on both qualitative and quantitative research. The climate data of two variables; temperature and humidity recorded by the station no. 729 located in Mayadevi complex, Lumbini Sanskritik Municipality, Rupandehi was collected from the Department of Hydrology and Meteorology (DHM) for the past 10 years. Through random sampling, 18 households were surveyed and simulation was performed on Ecotect software. The input parameters; operating schedule, no. of occupants, operating hours, and clothing behavior were provided as the inputs to the software.

4. Research setting

The Lumbini Province's Siddharthanagar Municipality, which serves as the district's administrative center, is located in Rupandehi District's southern portion. The municipality is found geographically at 83º26' east longitude and 27º31' north latitude. The municipality has a total size of

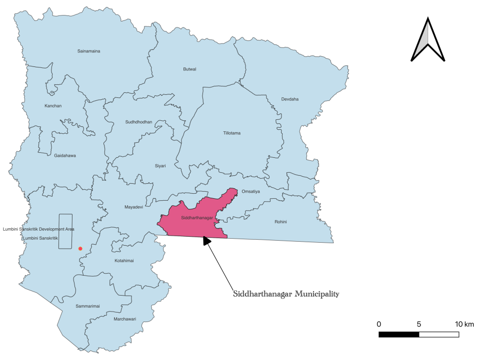

Figure 1: Map of Rupandehi District

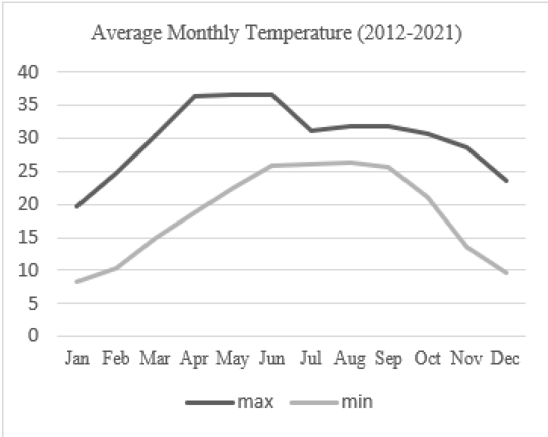

Figure 2: Monthly average temperature for the past 10 years

36.03 square kilometers, is 110 meters above sea level, and experiences tropical weather. The maximum and lowest temperatures recorded were 45.20°C and 2.40°C, respectively, with an average rainfall of 1436.5 mm. Gautam Buddha International Airport, the second international airport in the nation, is located in this municipality [15]. According to the Municipality, the major population in the settings is composed of Brahmin, Chhetri, Muslim, Madhesi, Magar, Gurung, Newar, etc. Major religions practiced by the population are Hinduism, Muslim, Buddhism, etc. The population density is 2118 per sq. km. There are 12329 households and 16,011 family members according to Census 2078 Initial Report.

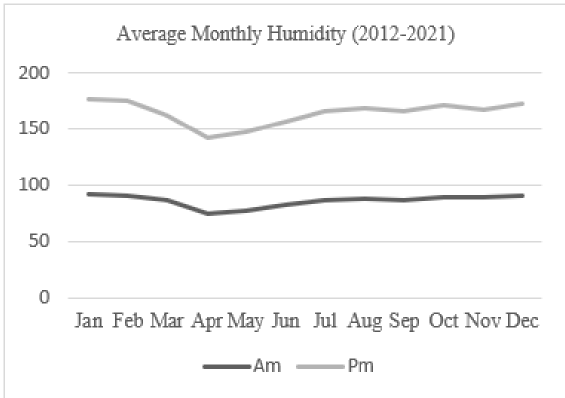

Figure 3: Monthly average temperature for the past 10 years

5. Analysis and finding

5.1 Climate analysis

The data collected shows that the temperature reaches maximum during May and the minimum temperature is during January. The hottest month is mainly April to May while the coldest month is December to January as shown in Figure 2. According to the Department of Hydrology and Metereology, humidity is highest during January which can be seen in Figure 3.

5.2 Questionnaire survey

18 households were chosen for survey through random sampling. Random sampling is one of the most simple methods for gathering information from the entire population where each member of the subset has an equal chance of being chosen as part of the sample process when using random sampling.[16]

5.2.1 Type of structure

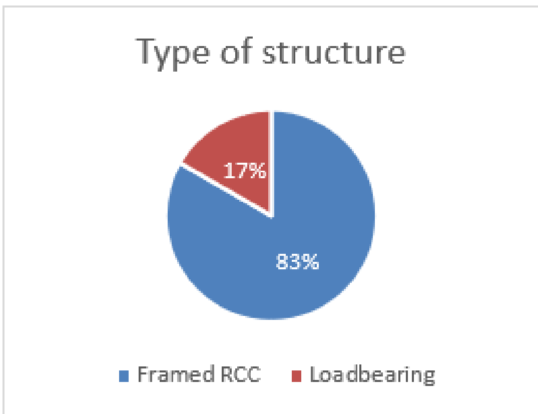

Figure 4: Monthly average temperature for the past 10 years

Among the houses surveyed, 83 percentage of the houses were RCC Framed structured where as 17 percentage were load bearing.

5.2.2 Source of electricity

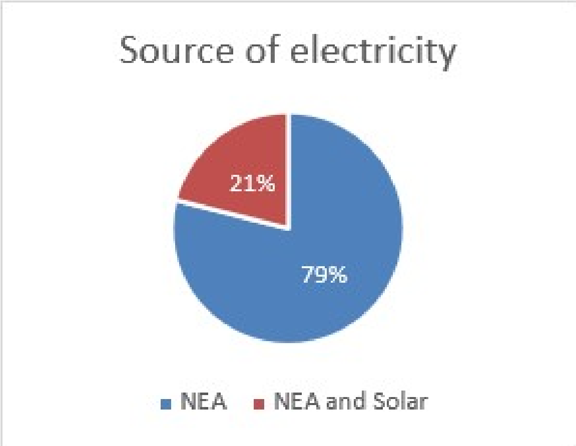

Figure 5: Monthly average temperature for the past 10 years

All the households were electrified by NEA. Four out of eighteen houses also had solar panels installed as a source of alternate energy for lighting.

5.2.3 Source of cooking

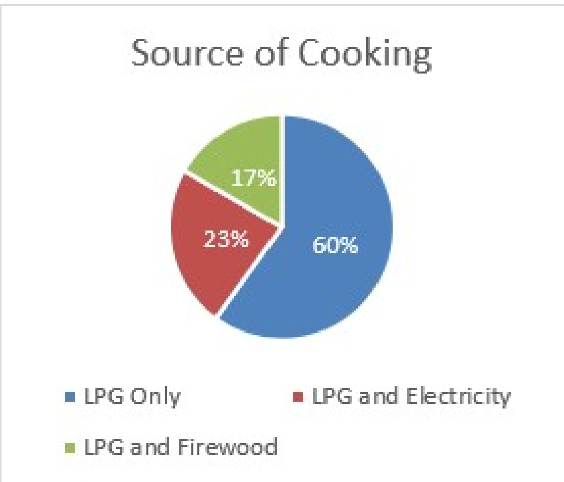

Figure 6: Monthly average temperature for the past 10 years

All the households relied on LP Gas for cooking.60 percent households were also dependent on electricity for cooking where as seventeen households used firewood as alternate source for cooking.

5.2.4 Heating,Ventilation, and Air Conditioning system

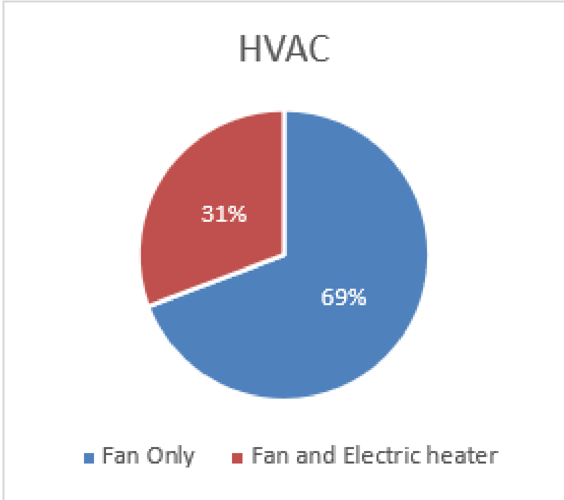

Figure 7: Monthly average temperature for the past 10 years

Siddharthanagar, being a very hot and humid from April to September, all the households were equipped with ceiling fans. However, only six households were equipped with electric heaters.

5.2.5 Thermal sensitivity

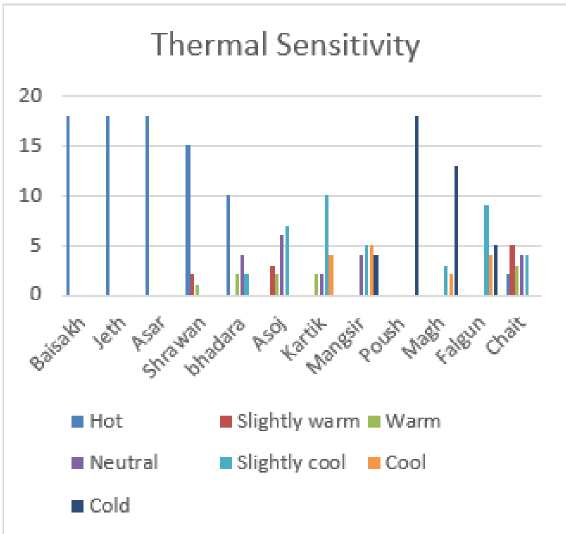

Figure 8: Monthly average temperature for the past 10 years

The month of Baisakh to Asar was felt the hottest where as Poush and Magh was the coldes by the residents surveyed.

5.3 Energy modelling

5.3.1 Base case scenario

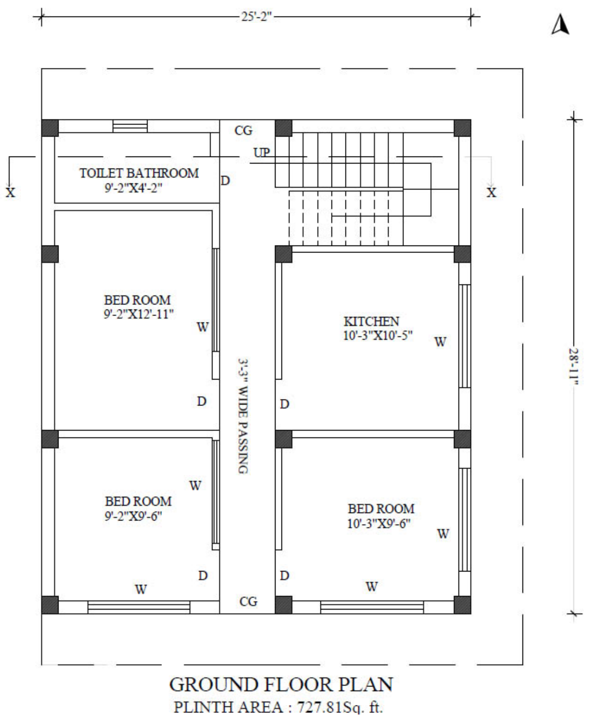

Figure 9: Ground Floor Plan of Simulated building

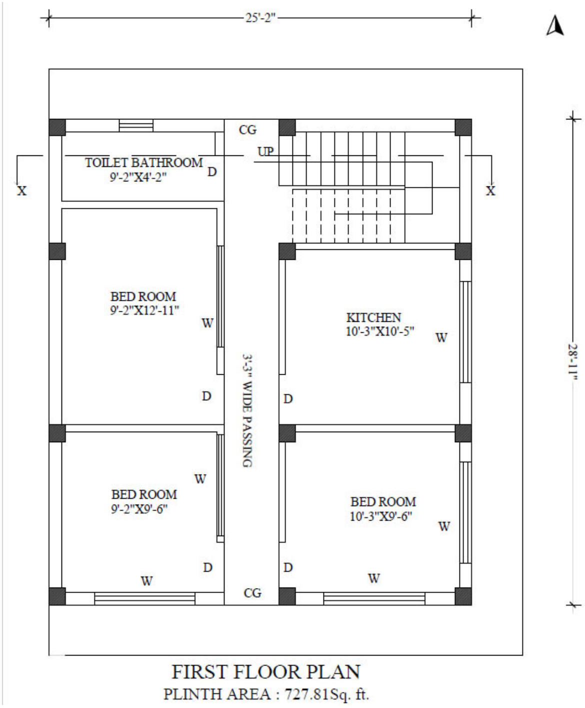

Figure 10: First Floor Plan of Simulated building

Table 1: Building details given in the software

Description	Value
No. of occupants	12
Humidity	70%
Infiltration rate	1 ACH (Average)
Type of system	Natural ventilation
Comfort band	18 deg C – 26 deg C

The base case was simulated by modeling the existing scenario using the energy modelling software Ecotect.In order to divide the operational sections of the building needed for simulation, rooms known as zones were created prior to analysis. The building is RCC Framed, two storeyed with brick envelope having U-Value 2.57 W/m²K oriented on South direction. The energy consumption of the two storeyed building with Brick envelope has been simulated using Ecotect Software.The floor plans are represented by Figure 9 and Figure 10. The program, which is fully compatible with Autodesk REVIT and is primarily used by architects and building engineers to advance their designs, is integrated into the core Autodesk CAD architecture [17]. The area and the height of the building was specified and the materials of the building walls, windows, plinth, slab, ceiling were assigned. Inputs such as activities done in the rooms, number of occupants, humidity, infiltration rate, type of system and comfort band were assigned which is tabulated in Table 1.

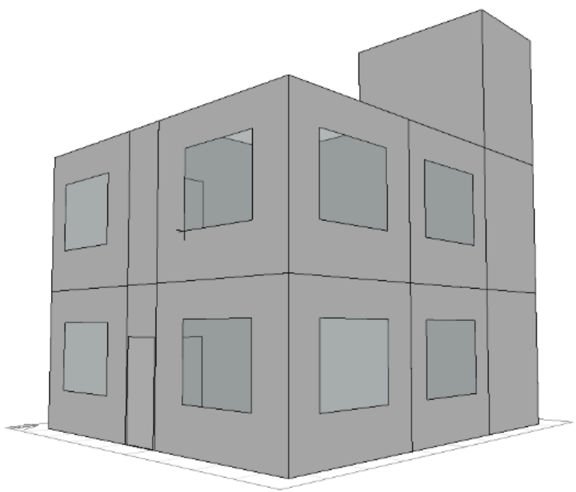

Figure 11: Model of the simulated residential building

Table 2: Discomfort degree hours of the base case scenario

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	409.77	409.77
Feb	1.85	90.08	91.92
Mar	133.54	0	133.54
Apr	411.38	0	411.38
May	433.92	0	433.92
Jun	419.85	0	419.85
Jul	433.46	0	433.46
Aug	433.92	0	433.92
Sep	407.85	0	407.85
Oct	368.15	0	368.15
Nov	10.08	0.8	10.15
Dec	0.31	219.77	220.08
TOTAL	3054.3	719.7	3774.0

Table 3: Discomfort degree hours of the optimized case scenario

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0.00	391.08	391.08
Feb	0.77	76.54	77.31
Mar	148.69	0.00	148.69
Apr	411.31	0.00	411.31
May	433.85	0.00	433.85
Jun	419.77	0.00	419.77
Jul	433.54	0.00	433.54
Aug	433.85	0.00	433.85
Sep	411.54	0.00	411.54
Oct	376.46	0.00	376.46
Nov	18.15	0.00	18.15
Dec	0.00	203.62	203.62
TOTAL	3087.9	671.2	3759.2

5.4 Optimized scenario

The building was then modeled by intervening the orientation and wall envelope. The wall was insulated with EPS insulation with low thermal resistance having U-Value 0.32 W/m²K. Similarly, the energy consumption was examined with mixed-mode system. The reduced degree hours is shown in Table 3 and the energy consumption demand is shown in Table 5.

5.5 Findings

The building was analyzed to offer discomfort degree hours after the relevant input parameters were provided and settings were adjusted. The analysis shows that the building experiences most discomfort during the month of May and August, which according to the observed data collected from DHM is the month with high temperature. The highest discomfort degree hours induced due to hot temperature is recorded to be 433.92 hours during May and August. Similarly, the most discomfort induced due to cold temperature was during January which is the month with minimum temperature as per the DHM data. The discomfort recorded in the month of January was 409.77 hours. The analysis also shows that during November, the building experiences most comfort in comparison to the other months. The detailed monthly discomfort degree hours through the year are tabulated in the Table 2.With the introduction of EPS insulation and changing the orientation of the building to North, the discomfort hours was reduced to 3759.2 hours from 3774.0 hours. The simulation when performed in mixed-mode system, with the help of insulation and changing the orientation to North, the consumption was reduced to 15859.961 kWh from 22,343.717 kWh. The energy consumption could be reduced by 29 percentage.

Table 4: Energy consumption of base case scenario

MONTH	HEATING (kWh)	COOLING (kWh)	TOTAL (kWh)
Jan	165.677	0.000	165.677
Feb	4.487	22.748	27.234
Mar	0.000	1646.518	1646.518
Apr	0.000	3297.795	3297.795
May	0.000	3738.610	3738.610
Jun	0.000	3263.814	3263.814
Jul	0.000	2754.997	2754.997
Aug	0.000	2821.319	2821.319
Sep	0.000	2438.937	2438.937
Oct	0.000	1926.605	1926.605
Nov	0.000	217.108	217.108
Dec	45.099	0.000	45.099
TOTAL	215.263	22128.449	22343.713

6. Conclusion

The observed data collected from the DHM shows that the region is hottest during May and June where the average highest temperature reaches up to 36.5 Degree Celsius during June. While the coldest month is December to January, the average lowest temperature recorded is 8.33 degree Celsius. The simulation performed in the Ecotect software shows that the building experienced the most discomfort

Table 5: Energy consumption of optimized case scenario

MONTH	HEATING (kWh)	COOLING (kWh)	TOTAL (kWh)
Jan	75.134	0.000	75.134
Feb	0.613	32.891	33.504
Mar	0.000	1133.285	1133.285
Apr	0.000	2315.814	2315.814
May	0.000	2667.019	2667.019
Jun	0.000	2352.559	2352.559
Jul	0.000	2017.043	2017.043
Aug	0.000	2038.152	2038.152
Sep	0.000	1732.308	1732.308
Oct	0.000	1331.400	1331.400
Nov	0.000	145.507	145.507
Dec	18.235	0.000	18.235
TOTAL	93.983	15765.978	15859.961

induced by hot temperature during May and August and the discomfort induced by cold is experienced during December and January. The thermal discomfort enables an increase in energy consumption within the building, the more discomfort, the more energy is demanded by the building to maintain thermal comfort resulting in energy inefficiency. By intervening the building orientation from South to the North and introducing 80 mm EPS insulation in the external wall the energy consumption demanded by the building could be reduced by 29 percentage. The paper shows results for only one type of residential building; an RCC building with a brick envelope which might not represent discomfort hours for other types of residential buildings.

7. Recommendation

Applying passive design strategies like changing the orientation and building the envelope with materials with lesser U-Value during the design phase can enhance the thermal comfort of the building, combating the discomfort hours decreasing the energy demand in a hot and humid climate.

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