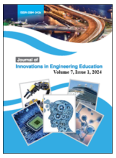

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Energy intensity improvement potential of the commercial buildings in developing countries: A case study of Nepal

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Abstract

The need for building-related energy is increasing, mostly in developing countries where urbanization is taking place rapidly with ever-increasing demand in commercial and public services. Globally, energy efficiency is emphasized as a key strategy for addressing rising energy demand and decoupling energy from economic growth. In order to assess the existing status and potential for energy savings in developing nations like Nepal, we compared the energy intensity with and without biomass among Nepal, India, China, and Germany during 2000–2020. This study uses the typical service sector building, as case study, to examine the potential for building energy savings using various passive and active solutions. It explores the various energy efficient measures by simulating the building's energy system with OpenStudio-EnergyPlus. The bioclimatic chart was used to analyze climate factors and passive design strategies. This study has identified energy-saving opportunities and their economic viability. Finally, the energy use intensity (EUI) of the project site was evaluated. The study's findings and methodologies used can be emulated during development of national standards for commercial buildings for Nepal and other countries promoting building energy efficiency.

1. Introduction

Commercial buildings are one of the major energy consuming sectors with the fastest rise over the past few decades, which can be attributed to population growth, urbanization, commercialization, industrialization, as well as transitioning to higher living standards. The energy is mostly used in lighting, cooking, water heating, and utilizing other appliances in the commercial and service sectors. In recent years, scientists and environmental activists have become increasingly concerned about the effects of climate change and degradation of local and global environments attributed to the present trend of unsustainable fossil fuel consumption. As per European Green Deal, in comparison to 2015 levels, greenhouse gas (GHG) emissions from buildings in the EU should be reduced by 60% by 2030, final energy consumption by at least 14%, and energy consumption for heating and cooling by 18% [1]. Study has found that commercial building-related GHG emission can be reduced by as high as 45.8% through energy efficiency and fuel-switching measures by 2030 for Kathmandu city [2]. Building energy management has become a necessity and norm for conserving energy and optimizing the use of unsustainable energy resources. It helps to increase building energy consumption efficiency while preserving user comfort at a low cost and minimizing carbon footprints.

Though energy audits become more common worldwide, they are only done for a few enterprises and in-

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stitutions as pilot projects with external funding or for research studies in Nepal. There are no national energy standards implemented for the buildings in the country at present excepts some passive building guidelines recently introduced by some local governments. There is a lack of acceptance and awareness of energy audits among most of the consumers. Besides, as the country is yet to be 100% electrified, the energy access factors may have some effects on the energy intensity transition in the country [3]. The Government of Nepal is in the process of introducing the Renewable Energy and Energy Efficiency Bill which will pave the way for mandating the energy efficiency standards and practices in the country.

Energy intensity, which is the quantity of energy used to produce one unit of gross domestic product (GDP) in a country or region, can be used to describe the current level and evolution of energy efficiency in a country or region [4]. There is a lack of holistic studies on the evolution of the energy intensity in the commercial sector and energy performance of commercial building using building model simulation with active and passive energy consuming measures in the context of Nepal. This study examined the evolution of the energy intensity of commercial sector in Nepal and other selected countries between 2000 to 2020. It evaluated existing energy performance and energy efficiency improvement potential through various passive and active measures by using a whole building energy model of the case study building and simulation tool. The Information and Communication Technology Center (ICTC) building of Institute of Engineering, Tribhuvan University located at Lalitpur of Kathmandu Valley, Nepal has been taken as typical commercial building for energy performance and improvement potential analysis.

1.1. Commercial buildings and their energy system

In order to compare the annual per-square-meter energy usage of various buildings, energy use intensity (EUI) can be a useful measure. Operation schedules, occupancy, and density of equipment and their energy performance etc. will affect the value of EUI. The energy-floor area linkage has been proven to be the main predictor of variation in energy use between buildings, making EUI a crucial starting point for development of more sophisticated comparison methodologies. The overall consumption is driven mainly by internal loads in the structures, and cooling and/or heating frequently contribute relatively equivalent additional loads, therefore EUI measurements are less susceptible to climatic variations than expected [5]. According to studies, an annual average energy use index of office buildings in western countries is 251.57 kWh/m^2 [6].

Because of its financial benefits and capacity to reduce demand for some generation capacity, energy efficiency is essential to all economies. Some countries also view it as the primary fuel, ranking it above both the supply and the production of energy [7]. The effect of implementing various low-carbon development strategy options can reduce 35.2% of total GHG emissions from energy use in Kathmandu, Nepal, as compared to the base-case scenario in 2030 [2]. The energy consumption of the buildings can be reduced by implementing various active and passive strategies. Alternatives for improving energy efficiency in the commercial sector might reduce Nepal's overall final energy consumption by up to 57.3% by 2030 [8]. Future nearly zero-energy buildings would prioritize energy-saving techniques to lessen cooling requirements and overheating (such as roof insulation, window type, solar shading, and envelope finishes), demonstrating how improving energy efficiency will become increasingly important under climate change scenarios [9].

Windows positioned well can increase natural light, reducing the need for artificial lighting and saving electricity. Passive solar heating is another application for fenestration. This is also reinforced because of the growing trend to use quite large glass areas in buildings [10]. According to the US Department of Energy, about 30% of the energy used to heat and cool buildings comes from heat that enters or leaves windows; nevertheless, fenestration systems are now thought to be potential platforms for energy savings [11]. By investigating the impact of retrofit glazing in existing housing apartments, it was found that replacing a single clear glass with a double grey low-e glazing reduced cooling loads by 14%, and by using a triple low-e glazing, cooling loads can be reduced by up to 31% [12].

Most of today's buildings rely on electricity as a source of energy. So, then, the concern is the process of electricity generation. A building's main electrical source is power connected to the National Grid. But in most of the developing countries, like Nepal, people are still dependent on non-renewable energy sources like fuel wood, petroleum products, etc. that contribute to carbon emissions. Reaching climate protection goals depends on reducing CO$_2$ emissions from space heating and hot water preparation in buildings by deploying energy efficient technologies and cleaner fuel switching [13].

The energy consumption pattern of the buildings varies throughout the year. Massive data centers, power data storage, and online information interchange, which used 1%–1.5% of world electricity consumption in 2010 and expected to reach 3%–13% by 2030, depending on energy efficiency interventions [14]. To reduce the energy consumption of buildings over their entire life cycle, two approaches can be taken: one is to reduce energy consumption related to building ontology, and the other is to reduce energy consumption during the building construction process [15]. Among building services, the HVAC systems account for significant share of the building energy (50% of building consumption and 20% of total consumption in the USA) [16]. Multi-VRF systems are adaptable heating and cooling devices that may be made to accommodate any size of space conditioning operations [17]. The direct heating through double-glazed windows saves maximum conventional fuel for thermal heating during winter months and evaporative cooling is one of the best cooling concepts which is economical too in the summer period [18]. HVAC loads of buildings suited for cooling in summer and heating in winter must be estimated for accurate design and equipment selection to fulfil thermal space requirements [19].

1.2. Energy intensity comparison in a global context

Traditional biomass still accounts for a considerable portion of the total energy consumption in developing nations, despite its poor technical and financial efficiency. In most of the developed nations, they are shifting to 100% electrification that contribute positive impact on the nation's energy efficiency indicator. Additionally, the wealth level of the population has an impact on energy consumption, which can either rise due to the usage of more energy-intensive end-use services or fall due to the use of end-use products that consume less energy [3]. In the global energy efficiency scorecard, which can be used to assess countries' energy efficiency, Germany comes in first place [20]. Energy substitution in activities, changes in GDP structures, changes in living standards, and other structural changes are some of the factors that have an impact on energy efficiency and energy intensity values [21].

The energy intensity of GDP as a measure of a country's energy efficiency for four countries (Nepal, India, China, and Germany) representing developing, emerging and developed countries has been shown in Fig. 1. Germany has been considered as the leading country in term of energy efficiency scorecard. The energy consumption data has been used from International Energy Agency's publications and databases and the information on the gross domestic product (GDP) was sourced from the World Bank [22]. The GDP in this study is expressed in 2015 US dollars unless otherwise stated.

The final energy consumed by the countries per unit of GDP was evaluated in order to analyze the energy saving potential. The energy intensity using biomass for the four nations (Nepal, India, China, and Germany) from 2000 to 2020 is shown in Fig. 1.The energy intensity of India was high in 2000, and it decreased by 34.4% up to 2020. The largest decrease in energy intensity among these four nations was found to be in China, at 47%. In case of Germany, it was found be the lowest among other nations. The energy intensity of Nepal is found to be drastically high when compared to other nations. However, it was found to be decreasing by 15.3% between 2000 and 2020 for Nepal. Compared to the average world value in 2020, Nepal consumes almost 4.2 times as much energy to generate per unit of GDP.

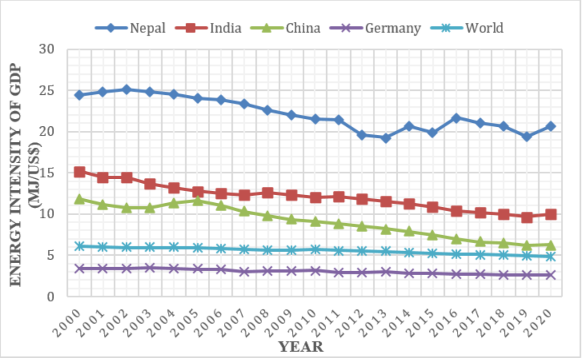


Figure 1: Energy intensity of the GDP for final energy consumption of four countries during 2000-2020 (with biomass)

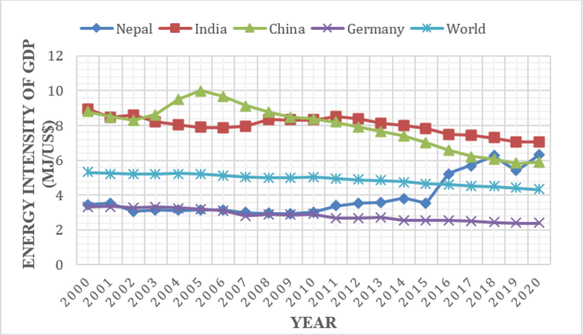


Figure 2: Energy intensity of the GDP for final energy consumption of four countries during 2000-2020 (without biomass)

Fig. 2 shows the energy intensity of the GDP of four countries (Nepal, India, China, and Germany) from 2000 to 2020, excluding biomass. Across India, the energy intensity was found to have decreased by 20.9%. Despite the peak in 2005, China has experienced the biggest drop in energy intensity without biomass, by over 33%. The energy intensity without biomass was found to be lowest in Germany when compared to other nations. While the average world energy intensity without biomass is found to be declining by 18.5%, the situation in Nepal is found to be the exact reverse. In comparison to the other three countries in 2000, Nepal had a low energy intensity without biomass because it relied heavily on biomass (85.8% of total primary energy supply) at that time. The energy intensity of Nepal remained almost constant up until 2009 without biomass but climbed significantly thereafter, with an overall increment of 83% up to 2020. This is because of rapid urbanization, access to electricity, transportation, commercialization, etc.

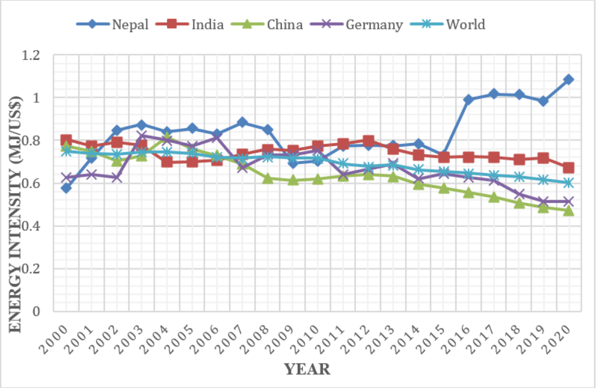


Figure 3: Energy intensity of the commercial and public services GDP value addition of four countries during 2000-2020 (with biomass)

The amount of energy used by the commercial and public service sectors (CPSS) per unit of GDP value added is referred to as the energy intensity of the related sectors. The CPSS energy intensity using biomass for the four nations (Nepal, India, China, and Germany) from 2000 to 2020 is shown in Fig. 3. India's energy intensity was high in 2000, and it eventually decreased by 16.4% during 2000-2020. China has had the largest decrease in energy intensity among the four nations, by around 39%. Germany's CPSS energy intensity was low and steadily declining, however a jump upward was visible in 2004. While the world's CPSS energy intensity is found to be dropping generally by 19.6%, Nepal's energy intensity is found to be increasing. In contrast to other nations in 2000, Nepal's energy intensity CPSS was relatively low in 2000 but later it grew steadily as the commercial and public service sectors expanded. It has increased by an aggregate 88.7% between 2000 and 2020. This is a result of Nepal's fast growing service economy, particularly the energy-intensive tourism industry. Gradually, there are more schools, hospitals, five-star hotels, etc.

Furthermore, while comparing Fig. 1 and Fig. 3, it is clear that the overall energy intensity of Nepal is found to be decreasing, but exact reverse trend was found in the case of CPSS. The outcome demonstrates Nepal's enormous potential for energy consumption reductions in CPSS. If this trend persist in Nepal, this might have a significant effect on the GDP of the nation and eventually lead to an energy crisis.

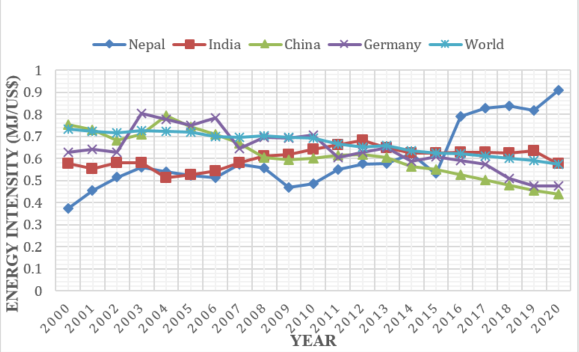


Figure 4: Energy intensity of the commercial and public services GDP value addition of four countries during 2000-2020 (without biomass)

Fig. 4 shows the energy intensity of the commercial and public services provided by the four nations (Nepal, India, China, and Germany) from 2000 to 2020, excluding biomass. Without biomass, Nepal's service sector intensity differs significantly from Germany's and the world average. Across India, the energy intensity varies across the years but is essentially the same in 2000 and 2020. Despite the reduction in biomass consumption, even an economically strong country like India is not able to bring about a significant decrease in energy intensity without biomass. Despite the peak in 2004, China has experienced the biggest drop in energy intensity without biomass, by over 41%. In the case of Germany, the energy intensity with and without biomass is nearly equal due to the absence of traditional biomass use. Although the energy intensity is low and steadily declining, the 2003 upward surge was visible.

While the global CPSS energy intensity without biomass is found to be declining by 21.6%, the situation in Nepal is found to be the exact reverse. In comparison to the other three countries in 2000, Nepal had the lowest energy intensity without biomass. It illustrates how heavily reliant on biomass the CPSS were at the time. But as the commercial and public service sectors expanded, the energy intensity gradually increased. Due to the devastating earthquakes that happened in 2015, there was a significant increase in energy intensity without biomass. The energy intensity of Nepal's service sector without biomass climbed significantly between 2000 and 2003, fluctuated until a sudden surge in 2015, and increased by a total of 144.4% between 2000 and 2020. This is a result of Nepal's fast growing service industry, which includes energy-intensive industries like tourism, education, healthcare, and hospitality. The covid pandemic in 2019 poses a significant threat to economic expansion. This shows that Nepal hasn't been able to advance in the field of energy efficiency. The country is unable to make use of possible energy efficiency enhancement through the use of non-biomass based renewable energy sources such as hydroelectricity, solar and wind etc. in CPSS thus raising question regarding sustainability and security of energy supply.

2. Methodology

There are five subsections in the methodology. The location and climate of the area around the structure under study are covered in Section 2.1. The geometry, construction materials, and maintenance schedules of the modeled building are all described in Section 2.2. A few specifics regarding Sketchup design and Open Studio simulations are covered in Section 2.3. The energy-saving tactics that must be demonstrated in the case study are defined in Section 2.4. Finally, the payback period calculation is covered in section 2.5. An energy audit is often a systematic and repetitive procedure of collecting data from numerous devices located within a building. So, different devices were used to finish the task. The most commonly used instruments were measuring tape, infrared thermal camera, luxmeter, and vernier caliper.

2.1. Location and climatic conditions

The Kathmandu Valley is 1340 meters above sea level between 27°36 and 27°50’ north latitude and 85°7’and 85°37’ east longitude. The Valley experiences monthly maximum temperatures averaging 29.30°C, monthly minimum temperatures averaging 0.90°C, annual mean temperatures averaging roughly 16.50 °C, and daily temperature variations around 10°C and also the relative humidity is a little high, although it decreases over the day and ranges from 36% to 100% [23].

As passive design strategies can save a significant amount of energy, it is quite crucial to study the bioclimatic chart. It is a psychrometric chart that illustrates, evaluates, and simplifies climate data for a region from the standpoint of human comfort [24]. It also provides data on how much energy can be saved by implementing various passive tactics. The bioclimatic chart was created using the Climate Consultant software, version 6.0. For the Kathmandu Valley, the EnergyPlus weather file was utilized. It creates a bioclimatic chart after receiving location and climate information. Following the creation of the chart, the data necessary to ascertain the appropriate passive design techniques for the structure and the surrounding climate was examined. The chart commonly depicts temperature, humidity, and solar radiation to choose the best passive design strategies for the construction.

2.2. Building description

The ICTC building is the structure being studied (27° 40’ 55.1994" North Latitude, 85° 19’ 8.4" East Longitude). It is a five-story structure made of typical regional building materials (Fig. 5). Brick walls, a built-up roof with roof tiles for insulation above the deck, and concrete slab-on-grade floors with building heights of 3.5 m floor to the floor made up the majority of opaque constructions. Here, the Table 1 represents the thermal properties of the envelope of the building.

Table 1: Thermal properties of the envelope of building

S.N.	**Description**	**Thermal Resistance ($K\text{-}m^2/W$)**
1	0.5” Plaster	0.0176
2	9” Brick	0.5835
3	0.5” Plaster	0.0176
4	4” Face Brick	0.2593
Total Resistance		0.8781
Overall Heat Transfer Coefficient		0.0352

Figure 5: ICTC building, Pulchowk campus (Project site)

2.3. Building design and simulation

The energy model of the project site was designed in SketchUp Pro 2022 and the building simulation was done in Openstudio-Energyplus version 3.4.0 (Fig. 6). The electrical and lighting loads intensity of all the rooms were calculated. At first, the current existing conditions were taken to depict the current scenario. Then after, various energy conservation opportunities were used to make the site more efficient. The schedule, and human occupancy was used as per existing conditions.

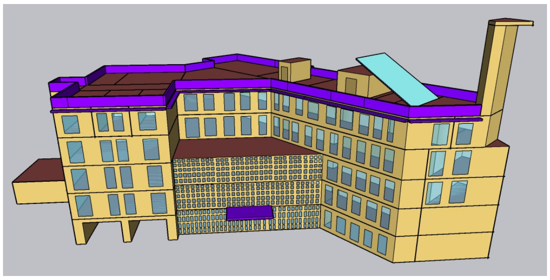


Figure 6: ICTC building energy model in Sketchup

2.4. Energy efficient case scenarios

In this study, four energy efficiency improvement measures were considered for energy efficient building. In the energy model, all the measures were tested independently to find the individual's contribution in the energy savings. The efficient case used a cavity wall with 0.15 m^2K/W wall air space resistance. Despite having the same window area, the revised model had better U-factor window structures. The upgraded model case included a model of double-pane low-emissivity glass. Double-glazing with a U value of 0.46 replaced single-glazing. In the project site, all the rooms were facilitated by CFLs. A lux meter can quantify room illumination based on sunlight entering [25].

For the normal case, the lighting intensity of each room was measured using a lux meter (HTC LX-101) to determine the lighting illumination. Efficient lighting devices were chosen to replicate the same illumination. The luminous efficacy was considered as 60 lm/W for CFL and 120 lm/W for LED [`https://united4efficiency.org/`].

It was found that not all rooms were illuminated appropriately. In the energy model, all the CFLs were replaced by the LED for more energy efficiency in an efficient case scenario. Here, the Table 2 presents the normal and efficient case light intensity of each space type.

During building energy audit, it was found the building uses 371 numbers of old outdated computer desktops that consume a significant amount of energy. For the efficient case, all the outdated computers were replaced by the modern ones in the modeling. This causes huge investment costs as well as huge amounts of energy savings. The Table 3 represents the normal and efficient case electrical intensity of each space type.

2.5. Payback period calculation

Prioritizing energy saving measures requires calculating their payback periods. The simple payback period was calculated by using the formula:

$$\text{Payback Period} = \frac{\text{Investment Cost}}{\text{Annual Energy Saving (kWh)} \times \text{Tariff (USD/kWh)}} \quad \text{(i)}$$

3. Result and Discussion

This section discusses the annual energy consumption of the building for the Normal Case and Efficient Case scenarios, comparative analysis and payback period calculation, evaluation of passive design strategies using a bioclimatic chart, and finally model validation using the building's energy use intensity (EUI).

3.1. Normal case scenario

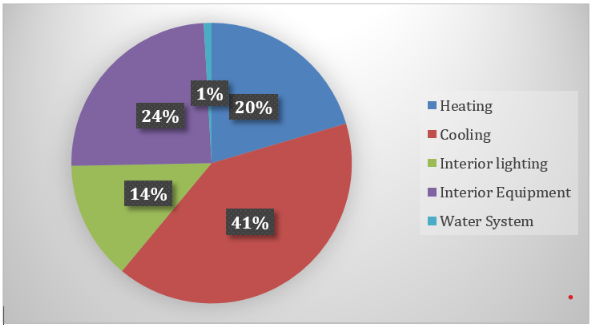


Figure 7: Annual energy consumption for Normal Case Scenario

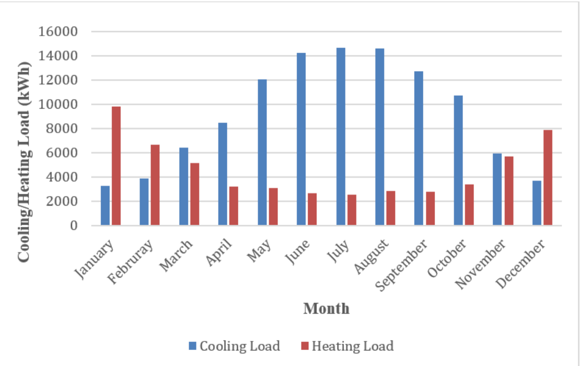


Figure 8: HVAC Load Profile for Normal Case Scenario

Heating, cooling, lighting, interior equipment, and the water system consumed 20.45%, 40.58%, 13.66%, 24.42%, and 0.89% of energy annually in the Normal Case Scenario. (Fig. 7).

The cooling load exceeds the heating load due to climate, building design, occupancy, equipment, and appliances. The Kathmandu Valley is warm and humid in summer. This requires additional cooling to maintain reasonable inside temperatures, increasing the cooling load (Fig. 8). Overhang projections are not as commonly used. The ICTC facility features several computers, printers, and lighting devices that generate heat and increase cooling demand. The server room always remains in operation throughout the year, and a huge amount of cooling is required to maintain the temperature at 16 °C for efficient

Table 2: Normal and Efficient case light intensity of each space type

Zone/Standard Space Type	Normal Lights Intensity (W/m^2)	Efficient Lights Intensity (W/m^2)
MDF server room	8.18	3.93
Administration room	8.08	3.88
Stair	4.29	2.06
Toilet	3.31	1.59
Meeting room	4.26	2.04
Conference room	3.90	1.87
Storage room	6.29	3.02
Corridor	2.65	1.27
Cafeteria	5.10	2.45
Lecture room	5.04	2.41
Computer lab	5.08	2.43
Seminar	5.10	2.45
Language lab	5.08	2.44
Generator room	8.18	3.93
Machine room	15.15	7.27
Battery room	5.10	2.45

Table 3: Normal and Efficient case electrical intensity of each space type

Zone/Standard Space Type	Normal Case Electrical Intensity (W/m^2)	Efficient Case Electrical Intensity (W/m^2)
MDF server room	28.30	12.17
Administration room	17.52	7.53
Stair	-	-
Toilet	0.75	0.75
Meeting room	37.23	16.00
Conference room	17.07	7.34
Storage room	-	-
Corridor	0.75	0.75
Cafeteria	5.00	5.00
Lecture room	44.08	28.68
Computer lab	66.70	26.68
Seminar	33.48	14.40
Language lab	44.47	19.12
Generator room	13.50	13.50
Machine room	2.91	2.91
Battery room	122.45	122.45

working. During computer-based exams, the building is heavily occupied, which increases body heat and other heat-generating activities and cooling demand. Many computers, printers, servers, etc. are concentrated in a small area. These are typically older types that produce more heat. These add to the overall warmth of the structure.

3.2. Efficient case scenario

The water system, interior equipment, heating, cooling, and lighting all had yearly energy usage of 1.43%, 22.68%, 14.74%, 50.69%, and 10.46%, respectively, for the Efficient Case Scenario (Fig. 9).

When used effectively, hollow walls and double-glazing windows lessen thermal load by enhancing a building's thermal insulation, which may result in less need for heating and cooling. Significant energy savings can be achieved by replacing outdated desktop computers and implementing efficient lighting systems. These actions contribute to a considerable energy reduction. However, due to the cold weather in the extreme months and the hot climate in the middle of the seasons, there is a substantial heating load and cooling burden, respectively (Fig. 10).

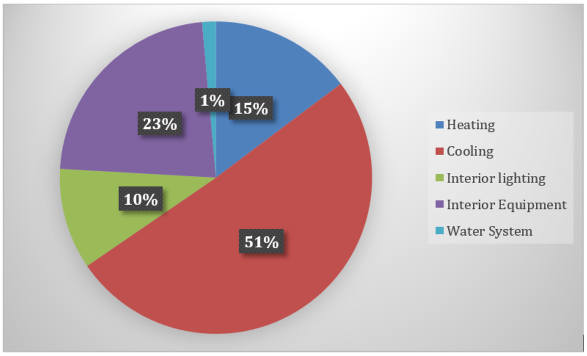


Figure 9: Annual energy consumption for Efficient Case Scenario

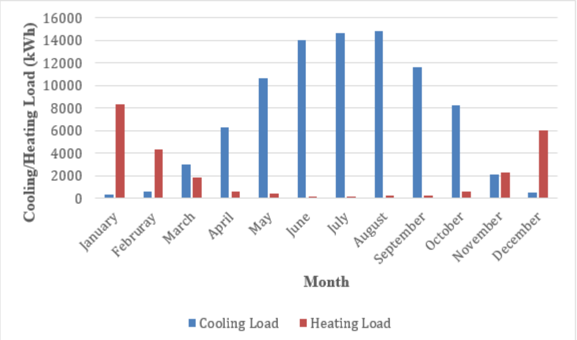


Figure 10: HVAC load profile for efficient case scenario

3.3. Comparative analysis

Here Table 4 shows the comparison of annual energy consumption of both case scenarios. Both the normal and efficient case scenarios of the energy model were simulated for the comparative study. Using energy-saving techniques like hollow walls, double-pane windows, energy-efficient lights, and energy-efficient electric equipment can increase the building's energy efficiency by 37.12%. The findings showed that the percentage improvements for electric equipment, heating, cooling, and interior illumination were 41.6%, 54.66%, 21.45%, and 51.84%, respectively. Similarly, the payback period was found to be 31.5 years, 40 years, 1.87 years, 58.1 years respectively. Except for lighting, payback period for all the energy efficiency measures were found to be high. The high value of payback period can be reduced by considering salvage value of the equipment replaced from Normal Case scenario and prolonging the daily service period of the building. Cavity walls and double-glazed windows help to improve a building's heating and cooling load by minimizing heat transfer through the walls and windows and lowering the energy required to maintain a suitable indoor temperature. Modern desktop computers and LED lamps are made to use less energy than their predecessors, which results in considerable energy savings (Fig. 11).

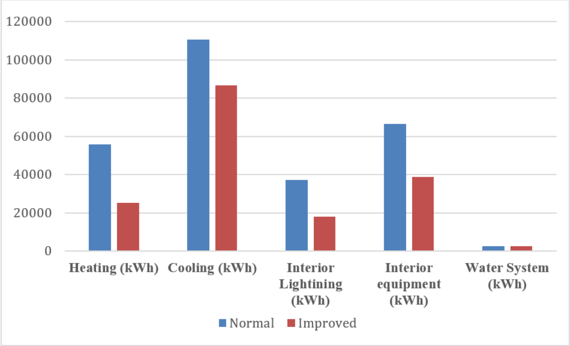


Figure 11: Comparison of Normal and Improved case scenarios

3.4. Energy saving and payback period

The Table 5 shows the payback period calculation and energy saving for various energy saving measures. The cost per unit of electricity was taken as US$ 0.092 as per the normal tariff rate from the electricity bill.

Cavity walls, double-pane windows, light definitions, and electric equipment definitions were found to have improved annual energy usage by 13.11%, 6.78%, 7.08%, and 10.15%, respectively.

The cavity wall was found to have a comparatively long payback period of 48.69 years. The reason for this is that the building's opposite side has walls, and the glasses

Table 4: Comparison of annual energy consumption of both case scenarios

Component	Normal Case Scenario (kWh)	Efficient Case Scenario (kWh)	Payback Period (yrs)	Percentage Improvement
Heating (kWh)	55,681	25,244	31.15	54.66%
Cooling (kWh)	110,495	86,790	40.00	21.45%
Interior lighting (kWh)	37,208	17,918	1.87	51.84%
Interior Equipment (kWh)	66,478	38,821	58.10	41.60%
Water system (kWh)	2,430	2,430	-	0.00%
Total (kWh)	**272,292**	**171,203**	-	**37.12%**

Table 5: Energy saving and payback period calculation of various energy saving measures

Measures	Total Investment (US$)	Annual Energy Saving (kWh)	Payback Period (yrs)	Annual Energy Demand Conservation (%)
Cavity wall	159,919	35,697	48.69	13.11%
Double glazing window	14,568	18,479	8.57	6.78%
Lighting measures	3,325	19,290	1.87	7.08%
Electric equipment measures	147,842	27,657	58.10	10.15%

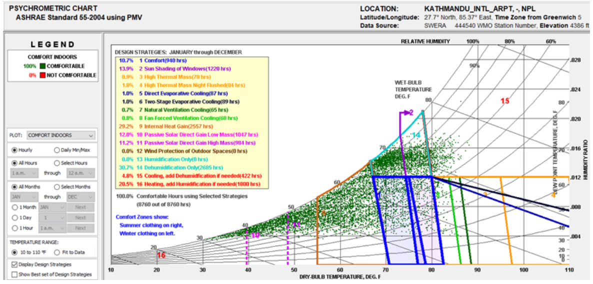
are oriented towards the south. As a result, the wall experiences relatively less solar radiation. The cost of installing cavities is expensive since walls have a sophisticated design and a larger surface area. 8.57 years is the calculated payback period for the double-glazing window. With the majority of the windows facing south, the ICTC building has a high window-to-wall ratio. Because of the sun's rays, windows facing south in Kathmandu can produce a lot of heat. The sun's rays impact south-facing windows at a more direct angle during the winter months when the sun is low in the sky, which can lead to a considerable quantity of solar heat gain. Furthermore, throughout the summer, the sun's rays become more intense in the south.

For more efficient illumination, all of the CFL bulbs were swapped out with LED ones. It was determined that the LED's payback period was 1.87 years, which is sufficient. This is because LED lamps use less electricity to create the same amount of light as fluorescent lamps. Additionally, LED lighting lasts longer than conventional lighting, which lowers maintenance expenses and the need for frequent bulb replacements. Over time, this may lead to reduced overall expenses.

All of the outdated desktop computers were swapped out for the new models in order to use electrical energy more efficiently. It was determined that the electric equipment would pay for itself in 58.1 years. This is due to the large number of desktop computers and the high cost of replacing them. Additionally, desktop utilization rates are rather low. Exams are the only time it is utilized.

3.5. Passive design strategies

Using passive design techniques provides 6538 hours of indoor comfort out of 8760 hours, meeting 74.6% of comfort hours annually, according to an analysis of the graph result from Fig. 10. The yearly comfort hour is approximately 940 hours, or 10.7% of the 8760 total annual hours needed to maintain comfort indoors. To ensure indoor comfort, the window solar shade is effective for 1220 hours, or 13.9% of the yearly hours. For the purpose of maintaining indoor comfort, internal heat gain, passive solar direct heat gain, and the passive strategy of dehumidification each contribute 29.2%, 23.2%, and 30.7% of the total. The combined use of natural ventilation, thermal mass, direct and two-stage evaporative cooling, fan-forced ventilation, and natural ventilation enhances indoor comfort by 5.4%. In the Kathmandu Valley, there is no need for humidification or wind protection for outdoor areas (Fig. 12). Therefore, it is important to urge them to use passive design principles while creating structures, such as long axis east-west orientation, overhang projections, medium apertures, good building envelopes, window placement, passive solar heating, etc.


PSYCHROMETRIC CHART
ASHRAE Standard 55-2004 using PMV

LOCATION: KATHMANDU_INTL_ARPT, -, NPL
Latitude/Longitude: 27.7° North, 85.37° East, Time Zone from Greenwich 5
Data Source: SWERA 444540 WMO Station Number, Elevation 4386 ft

DESIGN STRATEGIES: JANUARY through DECEMBER
10.7% 1 Comfort(940 hrs)
13.9% 2 Sun Shading of Windows(1220 hrs)
0.9% 3 High Thermal Mass(78 hrs)
1.0% 4 High Thermal Mass Night Flushed(84 hrs)
1.0% 5 Direct Evaporative Cooling(87 hrs)
1.0% 6 Two-Stage Evaporative Cooling(89 hrs)
0.7% 7 Natural Ventilation Cooling(65 hrs)
0.8% 8 Fan-Forced Ventilation Cooling(68 hrs)
29.2% 9 Internal Heat Gain(2557 hrs)
12.0% 10 Passive Solar Direct Gain Low Mass(1047 hrs)
11.2% 11 Passive Solar Direct Gain High Mass(984 hrs)
0.0% 12 Wind Protection of Outdoor Spaces(0 hrs)
0.0% 13 Humidification Only(0 hrs)
30.7% 14 Dehumidification Only(2685 hrs)
4.8% 15 Cooling, add Dehumidification if needed(422 hrs)
20.5% 16 Heating, add Humidification if needed(1800 hrs)

100.0% Comfortable Hours using Selected Strategies (8760 out of 8760 hrs)

Comfort Zones show:
Summer clothing on right,
Winter clothing on left.

PLOT: COMFORT INDOORS
● Hourly ○ Daily Min/Max
● All Hours ○ Select Hours 1 a.m. through 12 a.m.
● All Months ○ Select Months JAN through DEC
○ 1 Month JAN Next
○ 1 Day 1 Next
○ 1 Hour 1 a.m. Next
TEMPERATURE RANGE: ● 10 to 110 °F ○ Fit to Data
☑ Display Design Strategies
☐ Show Best set of Design Strategies

Figure 12: Hourly outdoor temperature and humidity in Kathmandu valley (obtained from Climate Consultant)

3.6. Model validation

The user and the software have a significant impact on the quality of the simulation results. The US Department of Energy (DOE) created the renowned building energy simulation application EnergyPlus. The program has passed various analytical and comparative tests and has been validated by ANSI/ASHRAE Standard 140-2011 [26]. As a result, it is reasonable to assume that the findings are reliable and indicative of actual structures. A comparison with pre-existing data was done to confirm the results' credibility. There aren't any measured statistics from Nepal, though. As a result, studies on energy use from other nations were utilized.

The EUI of the project site building for the normal and efficient case scenarios was found to be 417.87 kWh/m^2/year and 262.74 kWh/m^2/year, respectively. Depending on the location, temperature, standard, facility size, additional services offered, occupancy rate, and equipment efficiency, energy usage in commercial buildings etc. may vary significantly. According to an analysis of numerous surveys carried out all around the world, hotels typically utilize between 69 and 689 kWh/m^2/year of energy [27]. The majority of commercial buildings in India have an EUI of 200 to 400 kWh/m^2/year, as opposed to less than 150 kWh/m^2/year for buildings in North America [28]. The EUI value is fairly comparable to the commercial sector's value in neighbouring India. The value, when compared to North America, demonstrates that Nepal's commercial sector has a significant potential for energy savings.

Numerous studies and findings emphasize Nepal's potential for energy efficiency, offering helpful pointers for other developing nations. Opting for CFL is the most favorable choice due to its short payback period. Similarly, the substitution of single glazed windows with double glazing is of utmost significance as it results in substantial energy savings and has a low payback period. Building owners should prioritize the installation of cavity walls during the construction phase. Additionally, it is necessary to replace electric equipment that consumes a significant amount of energy. It is important to promote the use of bio-climatic tables to identify appropriate passive design strategies.

The study's result indicates that there is huge potential for energy conservation in the commercial and public service sectors of Nepal. While comparing energy intensity with four countries (Nepal, India, China, and Germany), the energy intensity is found to be drastically increasing in Nepal. Electricity is major source of energy consumption in building sector. Despite having a significant hydropower potential, Nepal imports 1543 GWh of electricity from India out of 8,823 GWh of total electricity consumption, as per the NEA report for fiscal year 2021-2022 [29]. This mostly due to the dominance of the Run of the River (ROR) type of hydropower plants in the country whose plant factor is as low as 30% during dry season. Moreover, as per the Central Electricity Authority of India, they still generate 56.8% of their electricity from fossil fuels in 2023 [30]. Reducing the electricity consumption can also results in the reduction of the imported electricity generated from coal dominated power plants thus helping the national and international initiatives for reducing GHG emission and ambient air pollution.

The comparison of the energy intensities shows that while the overall energy intensity of Nepal was found to be decreasing by 15.3%, it was found to be increasing by 88.7% in the commercial and public service sectors during 2000–2020. Under further evaluation, it shows that while the world's CPSS energy intensity with and without biomass is found to be dropping by 19.6% and 21.6%, respectively, Nepal's CPSS energy intensity is found to be increasing. The CPSS energy intensity of Nepal during 2000–2020 with and without biomass was found to have increased by 88.7% and 114.4%, respectively. The analysis found that the defined electric equipment, cavity wall, double glazing window, and light definition improved annual energy usage by 10.15%, 13.11%, 6.78%, and 7.08%, respectively. The payback period for the cavity wall, double glazing window, efficient lighting, and efficient electric equipment were found to be 48.69 years, 8.57 years, 1.87 years, and 58.1 years respectively. In overall, the building can be made 37.12% more efficient by using these energy conservation measures. Additionally, indoor comfort can be increased by up to 74.6% throughout the year by implementing passive design principles. These strategies are also relevant to future energy-efficient buildings.

This study presents energy intensity as a key factor to compare the energy levels globally and identifying the gaps. As the majority of developing nations, like Nepal, still lack building codes and rules for energy and emission footprints, it also illustrates the importance in reduction of energy intensity and environmental emissions, which ultimately enhances the energy security and lowers emissions of ambient air pollutants. The country needs to get out of its restrictive reliance on just active possibilities. Building in Nepal can save a lot of energy, enhance indoor comfort, and support a healthier environment by moving the attention from just active solutions to holistic approaches. Also, it is crucial to take into account a number of aspects when comparing building energy efficiency measures with those of other nations like India, China, the EU, and the US. It is necessary to investigate how to use new technologies, intelligent building systems, and automation to maximize energy use, monitoring, and management. The lack of proactive measures by the government in the energy sector can lead to increased energy use, bigger carbon emissions, and a potential energy crisis. This study can be used to design specialized strategies and activities that draw on global best practices while taking Nepal's particular situation and challenges into account. However, geographical and meteorological constraints limit the study's scope. Furthermore, simulation results may vary slightly depending on the number of iterations and program version.

The ICTC building was chosen for this case study in order to reflect Nepal's commercial and public service building sectors. The rising energy intensity trend in this sector is contrary to the declining tendencies evidenced in developed and emerging economies. Using simulation and bioclimatic analysis of a typical facility, this study determined energy-saving opportunities from passive and active measures and showed that efficient heating can save up to 54.66%. These results highlight Nepal's overall potential for energy intensity reduction and GHG emissions reduction in the commercial sector. Despite the design's concentration on a particular site, the technique and conclusions can be applied to other large-scale comparable buildings, providing a reference for evaluating energy footprints related to national building regulations. This method can assist Nepal and other comparable developing countries in improving energy efficiency, reducing emissions, and implementing sustainable development practices in line with UN SDG Goal 11: Sustainable cities and communities.

4. Conclusion

In order to depict the condition of Nepal in a global context, the energy intensity with and without biomass was calculated for four countries (Nepal, India, China, and Germany) during 2000–2020. Though the energy intensity of commercial sector seems to have decreased in the developed and emerging countries during 2000–2020, it is in fact increasing (by more than 140%) in the context of developing countries like Nepal. The possibility for several energy-saving techniques to be used in the commercial building is examined in this study. Active and passive energy efficiency measures can save the existing energy consumption in the range of 6.78% from double glazing windows to 54.66% for efficient heating system in the typical case study commercial building of the country.

The findings of the study suggest the following;

1. Nepal shows the increasing trend in the energy intensity against the trends observed in the developed countries and global average, thus indicating existence of the huge potential for the improvement in energy efficiency in commercial and public sector.
2. There are various active and passive energy efficiency measures that can be implemented for reducing the energy intensity of the commercial and public sector buildings.
3. The policy intervention in the building sector can results multiple co-benefits related to the mitigation of GHG emissions and ambient air pollution, health benefits, energy security etc. ultimately leading to the sustainable development path for the country.

This study is limited to the case study of the commercial building providing IT services, further studies can be done for other types of the commercial building with different end-use activities and service requirements in the country.

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