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Life Cycle Energy Analysis of The Academic Building: A Case Study of Shree Balpremi School in Kathmandu Valley, Nepal

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Abstract:
A comprehensive life cycle energy analysis of a 648.12 m^2, three-story building with a projected 60-year life span was conducted. An inventory of all installed materials, material replacements for building structure, envelope, interior structure, and finishes is prepared. The embodied energy calculated for construction phase showed that the foundation, structural frames, masonry work and finishing work represent 22%, 32%, 14% and 13% of the total embodied energy, respectively. The concreting work represents 59% of the total embodied energy. The masonry work represents 16% of the total embodied energy. The material footprint during construction is 1448.77 kg/m^2. Computer modeling is used to determine primary energy consumption for cooling and lighting of the building. The primary energy intensity over the building's life cycle was 2.9 x 10^4 GJ. The production of building materials, their transportation to the site, and the construction of the building accounts for 12.11% of life cycle primary energy consumption. The remaining 87.89% was the operational energy of the building. It clearly showed that lifecycle distribution of energy consumption was concentrated in the operation of the building. This study shows that the life cycle energy analysis of a building can successfully lead to sustainable and energy-efficient building construction. In a broader sense, building life cycle energy analysis will assist in understanding the energy consumption pattern of a building, which can be used to maintain energy efficiency in the design and construction of the building.

Keywords: Academic building, Embodied energy, Energy consumption, Life cycle assessment

1.Introduction

To meet the Paris Agreement and the Sustainable Development Goals (SDGs) of the United Nations, it is essential to decarbonize the buildings and construction sector, which accounts for almost 40% of energy and process-related emissions[1]. But according to the Global Status Report on Buildings and Construction 2019, this sector is not taking the necessary climate action. The year 2018 saw a 1% increase over 2017 and a 7% increase over 2010 in the final energy demand for buildings[1].
According to the 2019 Emissions Gap Report, it is necessary to cut emissions by almost 8% a year starting in 2020[1].The International Energy Agency's (IEA)World Energy Outlook 2019 also found that energy intensity improved at a slower pace (1.2%) in 2018 than it had in the past five years[2]. Both reports stress the necessity for policymakers and investors to take immediate steps. IEA's sustainable development scenario calls for a 3 % annual decarbonization and energy efficiency increase in buildings to meet the SDGs and the IEA's sustainable development scenario[2].
Under the Paris Agreement, Nationally Determined Contributions (NDCs) are required. So, it is an opportunity to increase ambition in buildings and construction. A total of 136 countries have

mentioned buildings in their Nationally Determined Contributions (NDCs), but few have specified the actions they will take to reduce emissions[3,4]. As a result, nations must make decarbonization of this essential sector a priority in their new NDCs. This requires a switch to sustainable energy sources, such as solar and tidal. It entails improving the design of the buildings in terms of heating, cooling, ventilation, appliances, and equipment.

Since the 1970s oil crises, a key problem in building design and performance has been the reduction of operational energy [1]. Increasing regulatory requirements for building energy performance have driven building construction to ever more complicated levels, requiring the use of additional materials and technologies to decrease energy consumption during the operation phase. Life cycle assessment (LCA) is an obvious component of building evaluation due to the evolution of buildings toward highly complex products, combined with the feature of significantly longer product life[3].

There are very limited studies in Nepal on the subject of renewable energy and energy-efficient building construction. Moreover, almost all building construction in Nepal happens without considering energy efficiency, making buildings vulnerable in the case of an energy crisis. Large numbers of buildings are constructed or are currently under construction in Nepal. The life cycle energy analysis (LCEA) helps to determine sustainability in the building and construction sector. Besides supporting policy formulation, implementation, and regulation, lifecycle-based approaches also help evaluate policies and their effectiveness. So, the objective of this study focuses on identifying how building design affects its energy performance through a life cycle analysis of a whole building. The previous LCEAs are based on generalized building information or only on certain aspects of the building. The LCEAs' studies on modern buildings are limited in the case of Nepal. Therefore, a complete LCEA of a modern academic building is completed. Additionally, an inventory of all installed building materials, as well as their operational characteristics are prepared. Also, the effects of climate change on the energy performance of the building are analyzed using computer modeling.

2. Literature Review

Life cycle assessments in the building application area are primarily used to compare different choices of shape, design, or material at a single building level [6,7]. The possible effects of innovative design options are compared to the standard performance of the specific type of building and use. Over the last decade, there has been an increased attention on life cycle thinking, the improvement of building sustainability certification systems (e.g., BREEAM, DGNB), and the parallel development of standards and LCA methodology in general. For example, the ISO/TC 59 SC 17 and European CEN/TC 350 standards series on building and construction sustainability assessment provide harmonized methods for configuring and assessing environmental impacts of a building's life cycle [4]. But it is hard to compare the environmental impacts of one specific building to another as each building’s service life is unique and has different range of specific requirements as:

- Type or purpose of building (e.g., office, hospital)
- Location specific requirements (e.g., related to built environment)
- Technical necessities (e.g., thermal transmittance of building envelope)
- User specific requirements

Life cycle energy analysis is a method of accounting for all energy inputs to a building throughout its life cycle[5]. This analysis process includes the energy during manufacturing, operation and demolition phases. Materials used during construction and renovations are produced and transported during the manufacturing phase. While the operation phase comprises, all activities associated with the building's usage during its age. These activities include thermal comfort, water usage, and powering appliances. Dismantling and transport of the materials to landfills or salvaging plants are final steps in the demolition process. Life cycle energy includes [5]:

- Embodied energy: The energy content of all building materials and technical installations, as well as the energy expended during construction and renovation of the building, are included.

- Operating energy: Energy required to maintain comfort levels and perform routine maintenance of building for example, heating, ventilation, and air conditioning (HVAC), domestic hot water, lighting, and appliance operation.
- Demolition energy: The amount of energy required to demolish a building at the end of its useful life and transport the materials to landfills or recycling facilities.

There are many studies that use LCA to assess the energy consumption of buildings. Some of these studies focus on the environmental impact of different building materials, while others look at the energy efficiency of different building systems, such as heating, ventilation, and air conditioning (HVAC) systems.For example, a study published in the journal "Building Research & Information" in 2010 used LCA to find the energy consumption in a residential building(128m^2) in Australia. The study found that energy use for construction phase of a residential building is 1803 GJ while the energy during operational phase is 38.2 GJ/year[6]. The total life cycle energy of the residence with service life of 50 years is 76 GJ/m^2[6].

Another study, published in the journal "Energy and Buildings" in 1995, used LCA to find that the cement (44%), brick (18%) and rebar (23%) represent major portion of embodied energy in four storied RCC building [7]. In a similar type of study published in the journal "International Journal of Construction Education and Research" in 2018 found that the cement, brick and rebar represent 30%,49% and 14% respectively in a single storied residential building in India using LCA tool [8]. Other studies on life cycle energy analysis and their comparisons are shown in the Table 1.

Table 1: Comparisons of Previous Studies

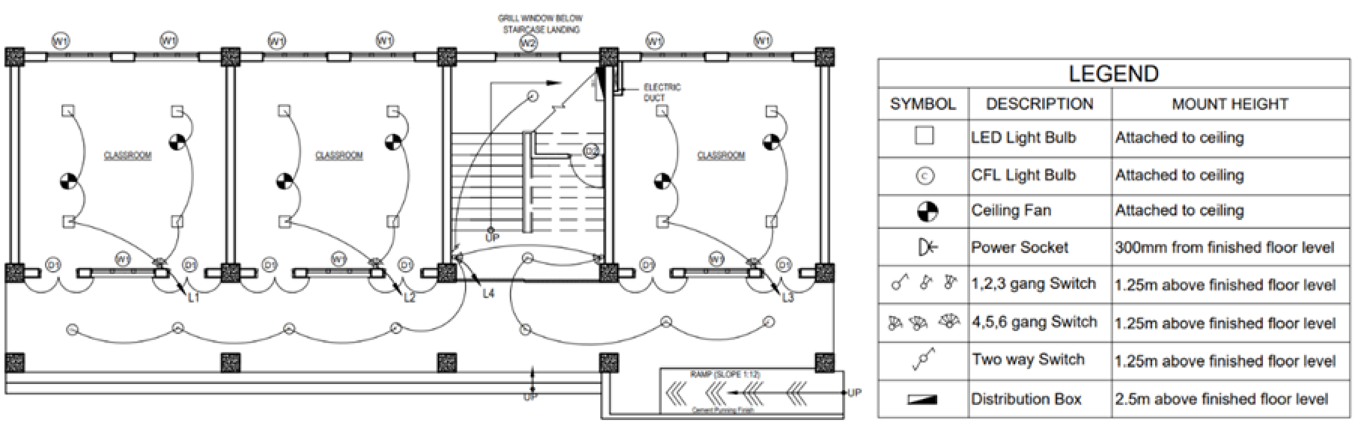
Reference	Study Type	Country	Area	Service Life (years)	Embodied energy	Operation Energy	Lifecycle Energy
Scheuer, C., Keoleian, G. A., & Reppe, P. (2003)[9]	University Building	USA	7300 m^2	75	51 x 10^6 MJ	2260 x 10^6 MJ	2.3×10^6 GJ or 316 GJ/m^2
Sharma, A., Shree, V., & Nautiyal, H. (2012)[10]	School Building	North India	3960 m^2	50	10 X 10^6 MJ	15 X 10^6 MJ	2.6 X 10^4 GJ
Ding, G. K. (2007)[11]	Secondary Schools	Australia	1300-16 000 m^2	60	72 025 GJ or 7.83 GJ/m^2	237110 GJ or 0.55 GJ/m^2 /year	3.84 X 10^{5}GJ or 48.95 GJ/m^2
Muñoz, P., Morales, P., Letelier, V., Muñoz, L., &Mora, D. (2017)[12]	School Building	Spain	222.51 m^2	75	16.56 GJ/m^2 or 0.22GJ/m^2/year	0.33GJ /m^2/year	0.58GJ/m^2 /year
Pinky Devi, L., & Palaniappan, S. (2019)[8]	Residential Building	South India	32.5 m^2	50	217,897 MJ	541,987 MJ or 0.3335 GJ/m^2 /year.	0.467 GJ/m^2 /year

3. Methodology

For the study, Shree Balpremi Secondary School is selected. It is in Madhyapur Thimi Municipality-4. This school has one 3-C-9 block, which can accommodate about 180 students. The building is extended towards East-West along the axis with main entry towards the South.

The 3-C-9 is three storied-building blocks with three rooms on each floor and has a 648.12 square meter area. It has rectangular floor plans with similar floor plans at every level. The classroom layout is designed for 20 students (1 square meter per student). It is a frame- structured building and has wall made up of brick masonry with thickness of 230mm. Both outside wall and partition wall are of a same thickness. Likewise, the doors and windows are of powder -coated metal. The front and back side of the building has nine windows and six doors in each floor, while two side faces have no windows and doors as shown in figure 1. Based on the school design guidelines published by government[14], every classroom is provided two doors of 1.1m width opening towards the passage for earthquake safety purpose. The passage is 2m wide with stainless pipe for railings.

Figure 1: 3D views of 3-C-9(Source: Central Level Project Implementation Unit (Education))



The framed structure is of M20 (1:1.5:3) concrete mix. The floor finish is of 38 mm PCC with cement punning. The painting works are of two coats of distemper paints and two coats of weather coat paints. All the rooms of this block are used as classroom and are naturally ventilated. The figure 2 shows the electrical layout of 3-C-9. Each classroom has 24 W 4 LED light bulbs and two ceiling fans attached to ceiling. The corridors and staircase are provided with total 8 CFL bulbs each of 12W in each floor. Power consumption for lighting and each equipment's electrical power requirement are calculated based on government school running hours and government holidays.

Construction and operation are the two main phases in the life cycle energy analysis of the building. The annual operating energy of the building is assumed to remain constant throughout its life span in the business-as-usual scenario However, it may change in the future due to changes in climate conditions. Therefore, three different scenarios are built to assess energy consumption using the design builder software. Climate Change World Weather Gen Tool is used to predict future weather data [18,19,20]. The present study does not consider demolition because it consumes a small amount of energy (1%) compared to the building's entire life cycle energy[15]. The building's operation phase is expected to last for 60 years according to the life span of material[9] and further assumption is made that no extensions and re-construction are made during the 60-year life cycle. The energy consumption of this phase is used to evaluate its impact. The recurring embodied energy is negligible in comparison to the initial embodied energy. So, the recurring embodied energy is not considered in this research. Itis necessary to calculate the material inventory data to perform the life cycle energy analysis during the construction phase. The building floor plans and a visual inspection of the building have provided information on the construction material inventory used in the building. For each material, the embodied energy is calculated. The embodied energy coefficients of the building materials are extracted from ICE (The Inventory of Carbon and Energy)[16], as a starting point for our calculations. Multiplying the quantity of each item with its respective embodied energy coefficients and adding up the embodied energy of all materials in construction yields the total embodied energy of the building. The energy consumption during operation phase is calculated using computer modelling (design builder software).

4. Results

4.1 The Construction Phase

Inventory analysis is performed by studying the building structure. The key components are expressed as volumes of constitutive materials; as a result, the 19 most important materials are examined and shown in table 2 with their respective quantities.

Table 2: Bills of Material

S. No	Material	Unit	Quantity
1	Aggregate	m^3	433
2	Diesel	ltr	1579
3	Petrol	ltr	44
4	Water	ltr	108253
5	Sand	m^3	445
6	Brick	No	72265
7	Stone	m^3	38
8	Polyethene Sheet	m^2	238
9	Cement	MT	229
10	Reinforcement bar (Fe 500)	kg	75869
11	19mm board	m^2	327
12	Local wood	m^3	5
13	Iron pipes (NMB50-M)	No.	87
14	Iron	kg	686
15	Kota stone	m^2	339
16	Steel	m^2	391
17	Paint	ltr	607
18	Glass	m^2	24
19	Steel Pipe	rm	838

Table 3: Embodied Energy Coefficients of Building Materials

S. No	Material	Embodied Energy Coefficients (MJ/Kg)[16]
1	Aggregate	0.08
2	Diesel	38.39
3	Petrol	32.07
4	Water	0.01
5	Sand	0.08
6	Brick	3.00
7	Stone	0.30
8	Polyethene Sheet	83.10
9	Cement	4.50
10	Reinforcement bar (Fe 500)	17.44
11	19mm board	15.00
12	Local wood	10.00
13	Iron pipes	25.00
14	Iron	25.00
15	Kota stone	1.50

16	Steel	20.10
17	Paint	70.00
18	Glass	15.00
19	Steel Pipe	25.00

The embodied energy of each construction materials for 3-C-9 building is summarized in Table 4 of which reinforcement bars have maximum amount of energy. The relative contribution of each material is also shown through Figure 3. Cement, brick, and steel rebar represent 81% of the total embodied energy of materials. It is comparable with the findings of an earlier study by Pinky Devi, L., & Palaniappan, S. (2019) [8]. The energy use of sand and gravel is 5% of total embodied energy, although these materials represent a vital portion of the total weight of all materials used. The energy use of stone, timber and glass is found to be less than or equal to 1%. The energy intensity of polythene sheet is significantly high compared to cement, rebar and brick. However, the relative contribution of polythene sheet on total embodied energy is less because its quantity is small. The total embodied energy thus calculated for construction phase is 3541.35 GJ. The embodied energy of materials is 2.36 GJ/m^2.

Table 4: Total Embodied Energy of Building Materials

S. No	Material	Embodied Energy (GJ)
1	Aggregate	52328
2	Diesel	18432
3	Petrol	256
4	Water	234
5	Sand	42264
6	Brick	85289
7	Stone	18
8	Polyethene Sheet	9
9	Cement	195731
10	Reinforcement bar (Fe 500)	1311244
11	Plywood	20
12	Local wood	37
13	Iron pipes	73
14	Iron	12386
15	Kota stone	33
16	Steel	103238
17	Paint	41776
18	Glass	4
19	Steel Pipe	92080

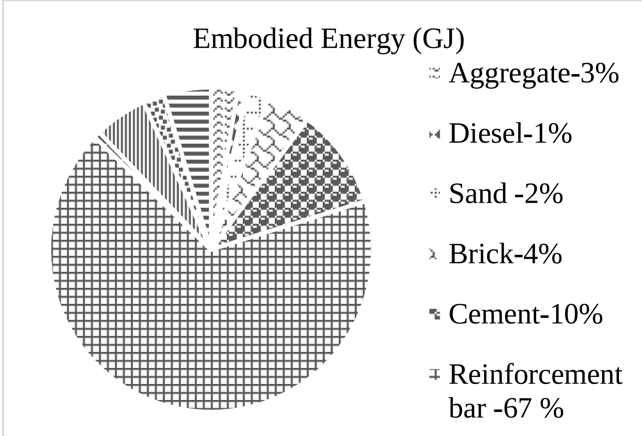


Figure 3: Relative contribution of building materials

Table 5 below presents the bill of quantities of 3-C-9 block. The embodied energy of building components is determined using the quantity and the energy intensity of building materials.

Table 5: Bill of Quantities

S. No	Building Components	Building Materials	Unit	Quantity
1	Foundation	PCC (1:3:6)	m^3	16
		Concrete	m^3	106
		Sand	m^3	9
		Brickwork	m^3	12
		Reinforcement	kg	17510
2	Column	Concrete	m^3	39
		Reinforcement	kg	6451
3	Lintel	Concrete	m^3	12
		Reinforcement	kg	2042
4	Roof Slab & Beam	Concrete	m^3	157
		Reinforcement	kg	25947
5	Staircase	Concrete	m^3	19
		Reinforcement	kg	3104
6	Masonry	Brickwork	m^3	104
7	Plasterwork	Mortar	m^2	1755
8	Painting	Paint	m^2	2416
9	Flooring	PCC	m^2	137
10	Woodwork	Wood	m^2	133
11	Metalwork	Metal	m^2	106

Table 6 presents the total embodied energy of building components such as foundation, structural frames (plinth beam, column, lintel, roof slab, and staircase), masonry work, and finishing work (plastering, painting, flooring). The result shows that the foundation, structural frames, masonry work, and finishing work represent 22%, 32%, 14%, and 13% of the total embodied energy, respectively. The concreting work represents 59% of the total embodied energy. The masonry work represents 16% of the total embodied energy. The contribution of masonry work is comparatively less because the percentage of opening is more in the academic building.

Table 6: Total Embodied Energy of Building Component

Building Elements	Embodied Energy
Foundation	619
Column	116
Lintel	193
Roof Slab & Beam	778
Staircase	93
Masonry	400
Plasterwork	96
Painting	64
Flooring	227
Woodwork	141
Metalwork	103

4.2 The Operation Phase

The building structure, envelope, interior and electrical appliances are only considered in this analysis. For HVAC analysis, only the cooling provided by electrical fan is considered as schools in Nepal lack mechanical heating and cooling systems. It is also assumed that the energy mix for cooling and electrical services, and the composition of material replacements through renovations, remain constant over the building life.

The energy analysis for operation phase is done in separate phases. Firstly, the energy analysis for the year 2020 AD is done by energy modelling in design builder software. The effect of the climatic condition is analyzed based on thermal comfort, internal gain and relative humidity.

Since the life span of building is assumed to be 60 years, the weather data is forecasted for the year 2050 AD and 2080 AD using CCWorldGen tool separately. The weather data thus extracted in epwformat are simulated respectively in design builder, and the climatic effect on the building is analyzed for respective year. The general simulation details obtained from the modelling is presented in the table 7 below.

Table 7 : General Simulation Details

	Value
Program and Version	Energy Plus, Version 8.9.0
Run Period	3C9 (O1-O1:31-12)
Weather File	KATHMANDU_INTL_ ARPT - NPL SWERA
Latitude [deg]	27.7
Longitude [deg]	85.37
Elevation [m]	1337
Time Zone	5.75
North Axis Angle [deg]	0
Hours Simulated [hrs.]	8760

4.2.1 Base Case Scenario for 2020

The year 2020 is considered as the base year. The building is modeled using the 2020 weather data in design builder software. All specifications are as per actual site data collection and conditions. This scenario is modeled with the best possible way to obtain the findings that match the situation on site.

Table 8: Annual Energy Consumption for 2020

	Total Energy [GJ]	Energy Per Total Building Area [GJ/m^2]
Total Site Energy	257.42	0.74
Total Source Energy	323.43	0.94

Table 8 shows the annual energy consumption of the building for the year 2020. The total source energy is 323.43 GJ, while energy consumption per square meter is 0.94 GJ. It is comparable with a similar study conducted in US for a University building by Scheuer, Keoleian, &Reppe, which is 1.5 GJ/m^2/year [17]. Also, the Department of Energy's (DOE) Commercial Buildings Energy Consumption Survey ("Summary Comparison Table") shows 1.0 GJ/m^2 per year for educational buildings [17].

4.2.2 Case Scenario for 2050

The building is modeled with the weather data for 2050 in design builder software. Table9 shows the annual energy consumption of 3-C-9 building for the year 2050. The total source energy is 424.25 GJ, and energy consumption per square meter is 1.23 GJ. It is a 31.19% increase in the annual energy consumption compared to the energy consumption of 2020.

4.2.3 Case Scenario for 2080

In this scenario, the building is modeled using the 2080 weather data in the design builder software. Table 10 shows the annual energy consumption of the building in the year 2080. The total source energy is 516.43 GJ, while energy consumption per square meter is 1.49 GJ. The annual energy consumption has increased by 59.67% compared to the base year energy consumption.

Table 9: Annual Energy Consumption For 2080

	Total Energy [GJ]	Energy Per Total Building Area [GJ/m^2]
Total Site Energy	440.25	1.28
Total Source Energy	516.43	1.49

4.3 Total Lifecycle Energy for Operation Phase

The energy consumption for three different years i.e., 2020,2050 and 2080 are calculated using the design builder software. The energy consumption between 2020 to 2080 are forecasted using Microsoft excel. So, the total energy consumption for the life cycle of operating phase is 25692GJ. This result is similar to study done in secondary schools in Australia which estimated operational energy of 237110 GJ for life span of 60 years [11]. The slight difference is due to the fact that energy consumption can change depending on several elements including building design, occupancy patterns, and energy efficiency measures.

4.4 Total Energy Consumption

The total life cycle energy of the 3-C-9 building is 29233.45 GJ (2.9 x 10^4 GJ) which is the sum of total embodied energy during construction and total energy consumption during operational years of 60 years. This data is comparable to study done in Northern India on the educational building published in the journal "Sustainable Cities and Society" in 2012 [10]. The study found that the total life cycle energy for building lifespan of 50 years is estimated to be 26398.33 GJ (2.6×10^4 GJ). Since both building have similar life span and purpose, the results of both studies are comparable. Comparing the total life cycle energy of these two buildings provides useful insights into the factors that contribute to energy consumption in buildings. It highlights the importance of designing and constructing buildings with energy efficiency in mind, as well as ensuring that energy use during the operational years of the building is minimized.

5.Discussion

From the energy analysis result of the building, it is known that the embodied energy during construction stage is 12.11% of the total lifecycle energy while the remaining 87.89% of the total energy is due to operation energy of the building during its lifespan. This clearly demonstrates that energy use is centered in the operating phase of a building throughout its existence. It is also known from the data from different studies which are presented in table 1. Furthermore, it is known from the literature that the particular design of the building, construction materials employed, and local climatic conditions all have a substantial effect on operational energy, which accounts for around 50-80% of overall life cycle energy. This is also known from the result of simulation for year 2020,2050 and 2080.The result shows that theenergy consumption is increasing by 31.19% with comparison to base year for 2050 and by 59.67% with comparison to base year for2080 respectively. From this data it can be clearly stated that the increase in energy consumption is due to increase in cooling load to maintain the thermal comfort inside the building as the electrical appliances (HVAC) play major role in the energy consumption in buildings during operational phase. So, in the future due to climate change, the operational energy will be much higher than present year.

Therefore, the primary focus of design should continue to be on enhance the efficiency of the operations phase. For example, design enhancements to the building envelope can dramatically lower accumulated loads despite rising material production and construction costs. These tradeoffs can be quantified using life cycle modeling. Many pressures are alleviated by the preliminary concept, which also determines effective improvement chances. While designers have little control over the outcome after a structure is finished (for example, how it is restored or operated), the early design of a building will set the tone for the rest of its life [9].

5.Conclusion

Based on the results, it is clear that the construction materials used in the building have a significant impact on its energy consumption, both during construction and operation. This suggests that the choice of materials and construction methods should be carefully considered to ensure that they are as energy-efficient as possible. In addition, the impact of climate change on building energy performance is also a concern, as the energy consumption of the building is likely to increase in the future without improvements to the building envelope. Therefore, it is recommended that more energy-efficient designs be given priority, including high-performance facades, building certification, and planning for future upgrades. It is also worth noting that there is a gap in sustainability and energy conservation in Nepal, so efforts should be made to formulate reduction strategies, with a main focus on energy efficiency design. This will not only help to reduce the energy consumption of buildings in Nepal but also contribute to global efforts to mitigate the effects of climate change.

In conclusion, the findings of the life cycle energy analysis of the educational building in hilly terrain suggest that the choice of construction materials, design, and planning for future upgrades are all important factors in reducing energy consumption and improving sustainability. Therefore, it is important to prioritize energy efficiency design in building construction and to focus on formulating reduction strategies to address the gap in sustainability and energy conservation in Nepal.

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