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Carbon Emissions Due to Construction of Building Using Cement-Stabilized Compressed Earth Bricks and Comparison with Conventional Fired Earth Bricks

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ABSTRACT−Carbon emission from human activities including civil engineering constructions has been a major global environmental issue. The emissions due to the use of conventional fired earth bricks (CFEB) in the construction industry are significantly larger, and a large number of researches have been devoted to developing viable alternatives to the uses of CFEB in the construction industry to achieve a low-carbon society. This research investigated carbon emissions due to the use of cement-stabilized compressed earth blocks (CSCEB) in place of CFEB in the construction of a community building in Bidur Municipality, Nuwakot, using the standard tools and methods by the Intergovernmental Panel on Climate Change (IPCC) guidelines. Also, the Bilan Carbone tool was used. Then the emission results of the two cases (CSCEB and CFEB) were compared from different perspectives. Among the considered major emission sectors, the construction materials sector contributed the highest carbon emissions in both bricks. Results indicate that CSCEB requires lower quantities of cement, sand, and aggregates compared to CFEB. Major construction materials contribute significantly to carbon emissions, with CSCEB showing a 1.7 times lower impact than CFEB. The total carbon emissions for CSCEB and CFEB were 160.97 and 206.42 Tons of CO_2 equivalents in this study. That is, the total carbon emission from CFEB construction was about 1.3 times of the CSCEB. Furthermore, the direct emissions in both cases were almost the same, while the 1.4 times larger emission in the case of CFEB was the sole contribution of indirect emissions. The results of this study once again demonstrated that CSCEB can be an alternative to CFEB in the construction industry to achieve the objective of a low-carbon society.

KEYWORDS– ***Building materials, Bidur Municipality, Environmental impact, Sustainable construction***

1. INTRODUCTION

The problem of greenhouse gas (hereafter GHG) emissions and climate change is a big global concern. Conventional fired earth bricks (hereafter CFEB), which have been widely used in construction globally since ancient times, contribute significantly to greenhouse gas emissions during their manufacturing process. This emission is a major contributor to global warming and climate change. In response to these environmental challenges, alternatives to CFEB, such as cement-stabilized compressed earth brick (hereafter CSCEB), have been explored and researched. The

CSCEB is produced by mixing clay soil with cement generally 5% to 10% at optimum, compressing it with high pressure, curing it with water, and then using it like conventional bricks (AVEI, 2023; Dulal et al., 2023; Waziri & Lawan, 2013). Notably, the manufacture of CSCEB does not involve the environmentally detrimental process of kiln burning (Sapna & Anbalagan, 2023). Although CSCEB has a long history dating back to the early 1900s, it gained prominence only when the issues of greenhouse gas emissions and climate change became significant global threats. In contrast, fired clay bricks have a documented history dating back to about 3,500 BC and have been widely utilized in construction. South Asia has a history of making clay bricks dating back approximately 5,000 years (Kenoyer, 1998). CSCEB emerges as a practical choice for constructing cost-effective, secure, and environmentally friendly buildings. Adopting CSCEB as a construction material sends a favorable message in support of a pollution-free environment, contributing to the protection of the world against the detrimental effects of climate change (Darko et al., 2013; Paudyal et al., 2018).

Production of traditional fired clay bricks requires huge amounts of thermal energy. The entire manufacturing process produces harmful gases like CO_2, SO_2, black carbon, and particulate matter resulting in massive air pollution and global warming (Nepal et al., 2019). Several studies have been conducted to estimate carbon emission from the manufacture of Conventional fired earth bricks and the estimated values vary greatly depending on the types of kilns and fuels used, and geographical regions (Akinshipe & Kornelius, 2018; Dabaieh et al., 2020; Kumbhar et al., 2014). The values vary between 428 and 670 kg CO_2 e per 1,000 fired bricks (AVEI, 2023; Maheshwari & Jain, 2017). However, very high values of up to 6,000 kg CO_2e per 1,000 bricks are also reported for conventional kilns and fuel materials (Dabaieh et al., 2020). Nowadays, construction projects are checked for their GHG emission, and there's a focus on reducing carbon emissions to tackle global warming. Producing conventional fired earth bricks (CFEB) results in substantial greenhouse gas (GHG) emissions, estimated at approximately 335.0 kg CO_2 equivalent per Ton of bricks. In contrast, the manufacture of on-site soil cement bricks, incorporating five percent cement, yields significantly lower GHG emissions, approximately 82 kg CO_2 equivalent per Ton of bricks (AVEI, 2023). Therefore, it is essential to contrast the CO_2 emissions from CSCEB with those from CFEB when applied to construction projects.

This study addresses the utilization of CSCEB as an alternative to traditional brick construction at the local level. The investigation focuses on quantifying the carbon emission associated with CSCEB and aims to compare it with CFEB in terms of CO_2 emission. This comparative analysis differentiates the environmental impact of construction activities and the utilization of such materials in construction, contributing to the promotion of eco-friendly construction technologies.

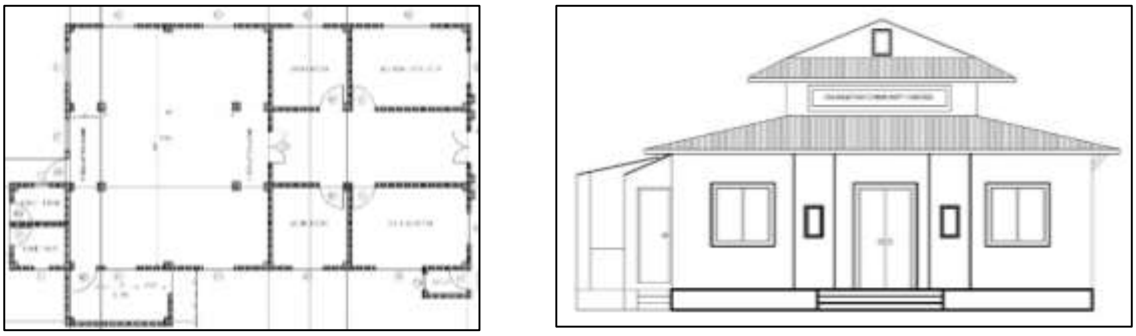
2. STUDY AREA

This investigation focuses on the construction of a community hall located in the rural area of Bidur, situated within the Bidur Municipality of the Nuwakot district in Nepal. The exact coordinates are latitude: 27° 53' 14" N, longitude: 85° 06' 33" E, with an altitude of 2,152 feet above mean sea level. The project encompasses a small settlement covering 50 hectares in total, and Bidur is positioned approximately 50 km Northwest of Kathmandu. The closest town to the Bidur project area is Battar, situated 7 km away as shown in Figure 1. Figure 2 illustrates the interlocking CSCEB community building with a plinth area of 168.24 square meters. The structure comprises a single story, and the roofing utilizes steel members with a corrugated galvanized iron (hereafter CGI) sheet cover.

(a)

(b)

Figure 1. (a) Location map of the study area *(Source: Google Earth Pro)*, (b) Side view of the community building at Bidur, Nuwakot.



(a) **(b)**

Figure 2. (a) Ground floor plan, (b) Front elevation of the community building at Bidur, Nuwakot.

2.1 Research Objectives

The specific objectives are outlined as follows:

- Identify carbon emission sources specific to the construction of the community hall in the Bidur project area.
- Estimate carbon emissions resulting from the construction of the interlocking CSCEB community hall in Bidur
- Conduct a comparative analysis of carbon emissions between the CSCEB community hall and CFEB construction methods.

3. MATERIALS AND METHODS

3.1 Carbon Emission Estimation Tools

Accurately measuring carbon emissions is crucial for understanding climate change impact and implementing effective mitigation strategies. Various tools, following the guidelines of the Intergovernmental Panel on Climate Change (hereafter IPCC), are now available. The IPCC, a United Nations body, offers scientific guidance for governments to formulate climate policies. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories, including recommended emission factors, serve as the foundation for carbon estimation tools (Eggleston et al., 2006).

The "Life Cycle Assessment" and "Bilan Carbone" are prominent tools for estimating carbon emission, providing methodologies, emission factors, and documentation options (Adalberth et al., 2001; ADEME, 2009; Singh et al., 2011; Wibowo & Uda, 2018).

3.2 Methodology

The steps/methods adopted in this study to achieve the objectives mentioned in the earlier section are briefly discussed in the following sections.

3.2.1 Categorization of Emission Sources

This study categorized emission sources into two groups. Direct emissions result from the CSCEB construction project within the Bidur project boundary. Examples include onsite food cooking using fuel wood (CO_2), onsite electricity generation with fuel generators (CO_2), private vehicles for on-site transportation (CO_2), and private vehicles for goods transportation (CO_2). Indirect emission arises from third-party or CSCEB construction activities outside the Bidur boundary. These include air travel by visitors (CO_2), visitor transportation to and from Bidur by buses or cars (CO_2), Major construction materials used in construction (CO_2), electricity consumption in the field office (CO_2), food consumption by workers during construction (CO_2), materials for manufacturing vehicles and CSCEB compressor machines (CO_2), hired vehicles for goods transportation (CO_2), and waste and wastewater generation within the Bidur project premises (CH_4). Comparable sources were categorized for the CFEB construction project to make a comparison with the CSCEB project. These sources and details are presented in Table 2.

3.2.2 Data Collection

A thorough field survey was carried out to obtain comprehensive data on the construction of the interlocking CSCEB community building in Bidur. Primary data, acquired through field observations and questionnaires, covered electricity and fuel consumption, energy used for food production, materials consumed, worker travel specifics, fuel combustion for goods transport, and waste generation. Additional primary data on the building's design and materials were sourced from the project office.

Secondary data, obtained from site records and literature surveys, included information on staff, equipment, vehicle details, and emission factors for activities like electricity use, food production, and material consumption. This comprehensive approach aims to capture a detailed picture of the carbon emissions associated with the community hall construction.

3.2.3 Material Quantity Estimation

The quantities of Major construction materials (such as cement, sand, aggregates, metals, plastics, interlocking CSCEB, glass, etc.) used in constructing interlocking CSCEB building in Bidur were determined based on designs drawings from the field verification. Standard unit weights were sourced from the Indian Standard Code (IS 875 (Part 1), 1987). Design adherence was validated against the Nepal Building Code (NBC, 2003) and the Nepal Design Catalogue for Construction of Earthquake-Resistant Building in this study (DUDBC, 2017).

For certain items/activities, such as fuel wood for cooking, food consumption, and waste and wastewater generation by workers, precise quantities couldn't be directly estimated from the collected primary and secondary information/data. Assumptions were made for these items/activities, as detailed in the following section.

3.2.4 Assumptions

Table 1 shows the points that were assumed to estimate carbon emission for interlocking CSCEB and CFEB buildings in Bidur, Nuwakot.

Table 1. Assumptions made for carbon emission analysis.

Item/Activity	Assumption
Fuelwood	1.5 kg of dry fuel wood per person per day for cooking
Food consumption	Non-vegetarian meals for two days, vegetarian meals for five days
Waste generation	Leftover food: 100 grams per worker per day
Wastewater generation	Wastewater BOD from common toilets: 30 grams per person per day
Number of workers	Assumed based on "Engineering Labor Norms" by the Department of Urban Development and Building Construction, Nepal

Item/Activity	Assumption
Workers' travel	Carbon emission is assumed insignificant due to most workers being local
Conventional fired earth brick production	Transportation distance for conventional bricks: 7 km to the nearest production and selling point in Battar
Foreign visitors travel	Carbon emission assumed proportionate to total travel distance to Bidur, individual contributions based on travel schedules
Freight	Vehicle capacity: 4.5 cu.m. per trip, axle load: 6.1-10.9 Tons. Assumed empty journey: 19%, assumed maximum payload: 35%.

3.2.5 Emission Calculation

An "Emission factor" represents the average GHG emission rate per unit activity/item, varying by location. Defined as the total amount/quantity, "Activity data" for the item/activity, when multiplied by the corresponding "Emission factor," yields the carbon emission (Olaguer, 2016).

$$C_e = E_f \times Q \qquad (1)$$

Where,

C_e= Carbon Emissions
E_f = Emission Factors
Q=Activity Data

Emission factors, derived from representative measurements, were used to calculate the carbon emission of interlocking CSCEB building in Bidur, measured in "Tons of CO_2 equivalent." The emissions from reconstructed buildings and facilities, if built with CFEB, were also calculated and compared sector-wise (Major construction materials, Misc. construction materials energy generation, food consumption, freight, travel, waste & and wastewater, and property).

Table 2. Emission Sources and Respective Emission Factors

Sectors	Sources	Emission Factor* kg CO_2 equivalent/Ton
Energy Sources	Fuel from organic origin	1,606.48
	Petrol	2.834
	Diesel	2.943
	Electricity	0.004
Metal	Reinforcement (Iron Rods)	2,599.67
	Steel (Square Hollow Pipe)	3,190.00
	CGI Sheet (0.45 mm)	2,999.99
	GI Sheet (0.45 mm)	2,999.99
	Door/Window Aluminum Frame	26,000.00
	Aluminum	9,826.67
Major Construction Materials	CSCEB	104.11
	CFEB/ Burnt Bricks	334.83
	Ordinary Portland Cement (OPC)	909.99

Sectors	Sources	Emission Factor* kg CO_2 equivalent/Ton
Misc. Construction Materials	Pozzolana Portland Cement (PPC)	990.00
	Sand	8.98
	Aggregate	8.98
	Door/Window Timber frame	2,400.00
	Flat Glass	1,519.00
	Ceramics	680.00
	PVC	1,888.33
	Polypropylene	1,250.00
	Cement fiber Board	410.00
	Gypsum Panel	260.00
Fright	Stone, Bricks, Cement, Sand, Aggregate, and others	0.704
Travel	**Travel Home to Work**	
	Diesel Vehicle - 11 HP & above	0.36
	Home to Work (2 Stroke)	0.12
	Travel During office time	
	Travel by employees by Car	0.36
	Travel by employees by Bus	0.04
	2-wheeler travel by employees	0.12
	Travel by Visitors	
	Cars	0.26
	Bike	0.12
	Plane Long Haul	0.27
	Plane Short Haul	0.26
Labors food consumption	No. of plates of Veg Item	0.44
	No. of Plates of Non-Veg Item	0.587
Waste	Household	975.32
	Sewage	7.5
Properties (Amortization Period one Year)	Vehicle	5,500.00
	Machines	3,666.67
	Furniture	1,833.33
	Printers	110.00
	PC Flat Screen	1,283.33
	Photocopiers	3,300.00
	Printing Papers	1320.00

*Emission Factor sources- ADEME, 2009; Akagi et al., 2011; Doorn et al., 2006; IFC, 2017

4. RESULTS AND DISCUSSION

4.1 Major construction materials

Figure 3 shows the calculated quantities of Major construction materials required for CSCEB and CFEB buildings. The primary Major construction materials; bricks, cement, sand, and stone aggregates played a pivotal role in shaping the structure of both CSCEB and CFEB buildings. Notably, the demand for bricks is nearly identical for both structures, standing at 120.15 Tons for CSCEB and 118.95 Tons for CFEB. However, a significant difference emerges in the quantities of cement, sand, and stone aggregates. For CSCEB buildings, there is a reduction of 27%, 33%, and 13% in OPC, sand, and aggregate, respectively, when compared to their CFEB counterparts. This difference arises as CSCEB has a volume 3.2 times larger than CFEB. The smaller size of CFEB necessitates more mortar beds and head joints. Conversely, in CSCEB construction, mortar is only required in areas where vertical reinforcement is added. Additionally, the smaller wall size of CSCEB results in the need for smaller horizontal concrete bands compared to CFEB walls.(DUDBC, 2017). Consequently, the larger volume of CSCEB contributed to a remarkable reduction in the quantities of mortar materials required for construction, representing the efficiency and resource optimization inherent in utilizing CSCEB in the Bidur project.

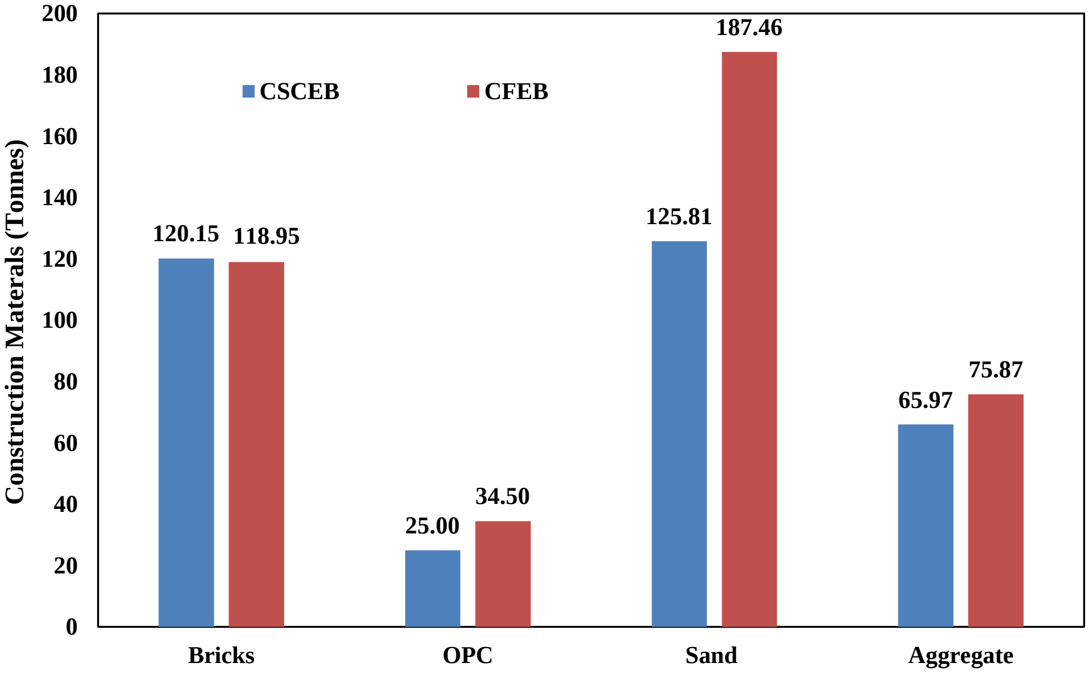


Figure 3. Calculated quantities of Major construction materials

4.2 Sector-wise Carbon Emission

The assessment of carbon emission highlighted the significant contributions of key sectors: "Major construction materials," "Misc. construction materials," "Metals," "Energy Generation," and "Food Consumption.", along with "Freight" and "Sewage & Household Waste," collectively shaped the carbon emission of the project over the two years, as illustrated in Figure 4. The "Major construction materials" sector emerged as the primary contributor to carbon emission in both CSCEB and CFEB cases, aligning with the findings presented in the study. The carbon emissions from this sector were notably higher for CFEB, reaching 97.97 Tonnes of CO_2 equivalent, compared to 57.13 Tonnes of CO_2 equivalent for CSCEB. Furthermore, the contributions from the "Misc construction materials," "Metals," "Energy Generation," and "Food Consumption" sectors were relatively lower, ranging from 2.47 to 47.52 Tonnes of CO_2 equivalent for both CSCEB and CFEB.

Remarkably, the cumulative total emissions for the CFEB building were greater than those for the CSCEB building. Specifically, in the context of the most impactful sector, "Major construction materials," the total emissions from CFEB buildings were approximately 1.7 times higher than the corresponding emissions from CSCEB buildings. This reinforces the observation that the choice of Major construction materials significantly influences carbon emissions and emphasizes the potential environmental advantages associated with adopting CSCEB in the construction of community buildings in Bidur.

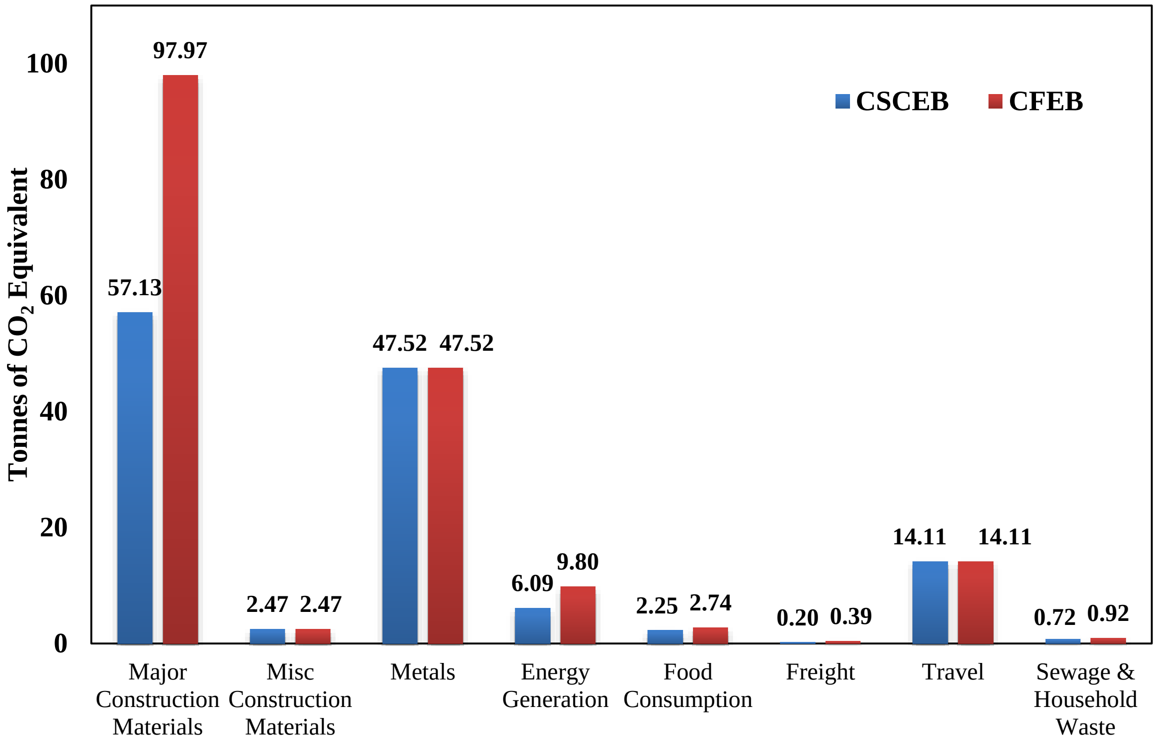


Figure 4. Sector-wise emissions

4.3 Indirect and Direct Emission

The indirect emissions for CSCEB and CFEB are detailed in the data, encompassing various sources such as electricity, food production, air and vehicle travel, Major construction materials, and equipment. The total indirect emission for CSCEB amounts to 138.87 Tonnes of CO_2 equivalent, while CFEB shows a higher total of 195.20 Tonnes of CO_2 equivalent. This aligns with the observation that the indirect emissions of CFEB are about 1.4-fold higher than those for CSCEB, reinforcing the sector-wise emission results outlined in Figure 5.

Direct emission for both construction methods involves factors like fuel wood consumption, generator usage, brick production, material transport, vehicle travel, and household waste. Surprisingly, the direct emission for CSCEB is quite similar to that for CFEB. A key factor that CFEB direct emission does not surpass CSCEB is the production process. CSCEBs were manufactured locally within the project area, contributing to higher direct emissions, whereas CFEBs were produced externally and transported to the community building site, resulting in lower direct emissions for CFEB.

This distinction emphasizes the importance of considering the entire life cycle of Major construction materials, including their production and transportation, in assessing environmental impacts (Eštoková et al., 2023; Rebitzer et al., 2004). While CFEBs demonstrated higher indirect emissions due to external production, their lower direct emission, attributed to reduced on-site manufacturing, contribute to a more comprehensive understanding of the carbon emission associated with different construction methods in the Community Building Project.

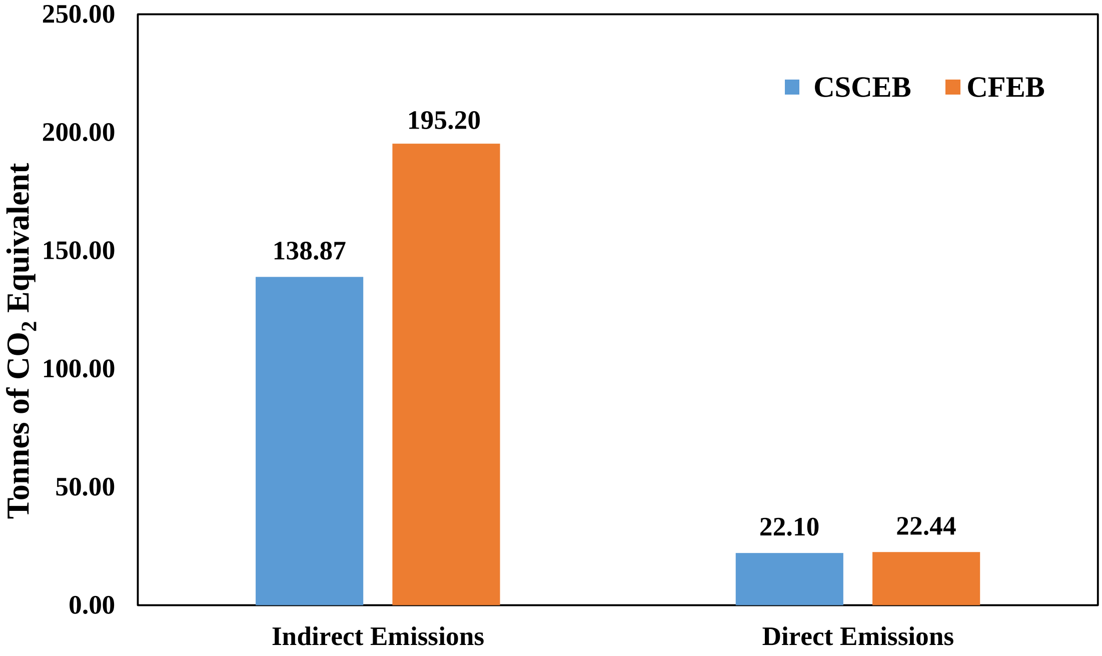


Figure 5. Direct and indirect emissions

4.4 Total Emission

The data presented in Figure 6 reveals that the total emission for the Community Building constructed with Compressed Stabilized Earth Blocks (CSCEB) is 160.97 Tonnes of CO_2 equivalent. In contrast, the Community Building constructed with CFEB has a higher total emission, amounting to 206.42 Tonnes of CO_2 equivalent. These results can be correlated to the study done for three-room single-storied building by Built Up Nepal (Built Up Nepal, 2018). Also, it can be compared with results from different authors (Morton, 2008; Riza et al., 2010).

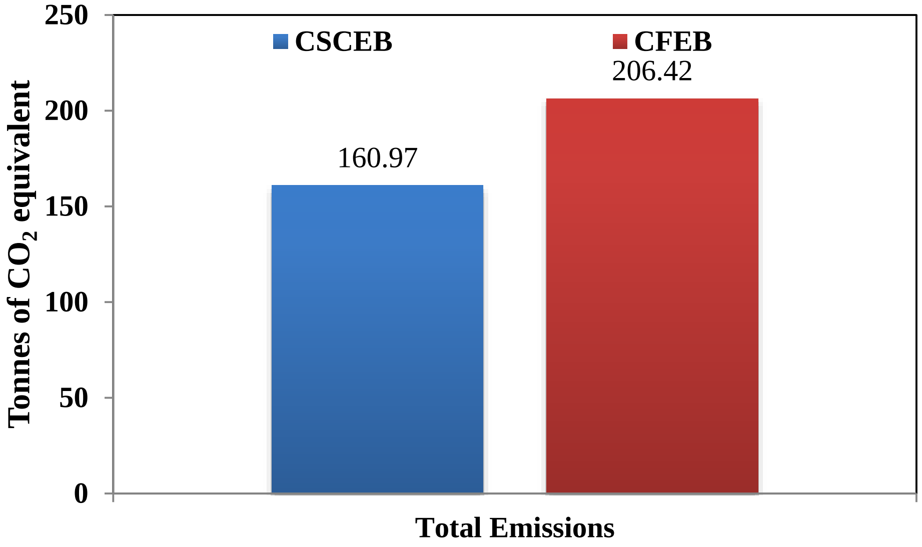


Figure 6. Total Emission

5. CONCLUSIONS

This study presents a comparative analysis of the carbon emissions associated with the construction of a community hall in Bidur with carbon emission of CSCEB) and CFEB buildings.

Results indicate that CSCEB construction, when compared to CFEB, demonstrates a notable reduction in the consumption of major construction materials such as cement, sand, and aggregates. This translates into a 27% decrease in Ordinary Portland Cement (OPC), a 33% reduction in sand, and a 13% decrease in aggregate, showcasing the efficiency and resource optimization inherent in CSCEB construction. “Major construction materials” was found to be the single sector contributing to most of the carbon emissions from both types of buildings.

The hall building analyzed with CFEB resulted in a higher overall carbon emission compared to the one constructed with CSCEB. Emissions from the CFEB building were about 1.3 folds higher than those of the CSCEB building in terms of total emission.

The indirect emissions for CFEB were about 1.4 folds than CSCEB buildings. The lower value of total direct emissions of the CFEB building than those of the CSCEB building was attributed to the manufacturing of CFEB outside the project area.

The study also sheds light on the environmental consequences of construction material choices and notes that the total direct emissions from CSCEB buildings surpass those of CFEB buildings. This is attributed to the on-site manufacturing of CSCEBs, in contrast to the external production of CFEBs. The comprehensive estimation of carbon emission for both building types underscores the relationship of various factors, emphasizing the need to consider the entire lifecycle of construction materials for informed environmental decision-making.

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