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INVESTIGATING THE SUSTAINABLE USE OF ENERGY ON CONSTRUCTION SITES IN SRI LANKA

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ABSTRACT

The construction sector can be identified as one of the highest energy-consuming industries in the world. The energy usage of the construction, operation, and maintenance stages is significant due to the complex nature of the industry. However, energy is one of the most undervalued resources in terms of efficiency and conservation in the construction stage. Higher energy usage and energy wastage in construction sites can be identified as significant matters, and various energy efficiency measures have massive potential for saving energy during the construction stage. Accordingly, this paper aims to investigate the sustainable use of energy practices on construction sites in Sri Lanka. A comprehensive literature review was conducted to identify principles and practices of sustainable use of energy, energy-using activities, processes, and the most applicable energy efficiency measures. The research aim was achieved through a qualitative research approach, and four case studies on building construction projects were conducted within the Colombo district. The case boundary of the study is defined as high-rise building sites. Semi-structured interviews, site observation, and document reviews were carried out as data collection techniques within each case. The collected data were analysed using manual content analysis. Key findings revealed how to use energy sustainably, what are the current energy sources and alternative sources available, construction activities and equipment used in the construction process, and reduce energy wastage by using energy efficiency measures. Rework, and workers' behaviour highly affects the energy wastage on the site. Lack of planning, lack of information, limited space, and poor responses from the construction organisation were identified as the most relevant barriers that influence sustainable energy use on construction sites. The proposed recommendations for improving the sustainable use of energy should be adopted at the project level. Measures exceeding the scope of site management, industry-level support, and policy intervention are required.

Keywords: *Construction Sites; Energy Efficiency; Energy Management; Sustainable Energy Use.*

1. INTRODUCTION

Energy is one of the most expensive inputs into the construction industry and the source of the majority of its polluting effects (Der-Petrossian and Johansson, 2000). The built environment accounts for about 40% of the energy consumed worldwide (Devi and Palaniappan, 2017). The world's economic development rapidly increases, consuming a high amount of degraded resources in the environment. Energy and energy-related

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problems are global (Zhang, Nizam and Tian, 2018), and energy consumption and greenhouse gas emissions are critical concerns across the world. A reduction target for greenhouse gas emissions and energy consumption has been recommended in the construction sector, which consumes the most energy (Hong, et al., 2014). Energy consumption in construction projects is not well recognised because of the fragmented nature of the construction industry (Shrivastava and Chini, 2011). The construction industry has several stages, such as construction, operation, and building maintenance (Gottsche, Kelly and Taggart, 2016). According to Devi and Palaniappan (2017), the energy usage during the construction phase presents a significant component of energy usage during the building life cycle. Most studies on the buildings' life cycle were incomplete because they only focused on the energy usage of the building operation and maintenance stages (Gottsche, Kelly and Taggart, 2016). Bilec, Ries and Matthews (2010) mentioned that this was largely due to the highest energy usage and significant impact on the environment during the operation and maintenance stages. Obviously, the time duration of the construction stage is less compared to the maintenance and operation stages. However, the possible environmental impact during the construction stage was significant. Hong, et al. (2014) stated that a detailed analysis is necessary for a more reliable assessment for investigating the energy usage and environmental impact during the construction stage. Buildings generate greenhouse gases due to the energy used in building operation and maintenance stages and also due to energy consumption of onsite construction works and the usage of significant construction materials (Dong, et al., 2015). Korol and Korol (2018) stated that high-rise buildings require more construction energy than low-rise buildings due to the complexity and vertical travelling.

Nowadays, most national estimates referred operational energy and embedded energy studies, which focus on energy consumption in the pre-construction stage (Gottsche, Kelly and Taggart, 2016). Few research works have investigated energy consumption in the construction stage of buildings worldwide. Some researchers have focused on energy usage only for a specific activity in the construction phase. For example, Devi and Palaniappan (2017) studied energy use for excavation and soil transport in construction. Some researchers have focused on the energy usage of specific construction materials in the construction phase; e.g. Heravi, Nafisi and Mousavi (2016) investigated energy consumption during the production and construction of concrete and steel frames in their research.

As depicted in the literature, energy is a crucial and mandatory need for the total life cycle of buildings. In the Sri Lankan context, many researchers have studied embodied energy and operational energy in buildings during the design stage (Tennakoon, et al., 2019) and operational and maintenance stages (Pathirana and Yarime, 2018). However, limited studies are available in Sri Lanka on energy consumption during the construction phase. Hence, this paper focuses on the sustainable use of energy consumption in Sri Lanka during the construction stage of building projects. The next section provides concepts of sustainable development, energy consumption, and energy efficiency measures related to the construction industry.

2. LITERATURE REVIEW

2.1 SUSTAINABLE DEVELOPMENT IN CONSTRUCTION

According to the WCED (1987, p. 43), sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The construction sector is making a significant contribution to unsustainable development and its environmental and economic effects. The construction sector consumes 40% of the total output of energy, 40% of all raw materials, and 25% of all timber globally while also accounting for 16% of the total consumption of water and 35% of CO_2 emission (Son, et al., 2011). The construction sector will incorporate the improvement of sustainable design procedures, efficient and sustainable construction equipment in the industry, changes in material sustainability practices, the use of high-performance materials, and public and government policy actions for sustainable design and construction practices (Majdalani, Ajam and Mezher, 2006). Moreover, appropriate buildings may accomplish sustainable development by utilising fewer materials with minimal environmental consequences, energy-efficient construction techniques, and employing renewable energies to minimise environmental burdens and energy and water consumption (Ortiz, Castells and Sonnemann, 2009).

2.2 ENERGY CONSUMPTION IN THE CONSTRUCTION SECTOR

The construction industry utilises a large amount of energy and resources because of the current population growth. Building construction only requires approximately 40% of the energy consumed globally (United Nations Environment Programme, 2020). Furthermore, the primary energy resources used in construction include fossil fuels, coal, gas, and secondary sources such as electricity. Supplies of some of these resources might last only a few more decades. Figure 1 illustrates the contribution of energy use activities in the construction sector based on the study of Panagiotakopoulos (2005).

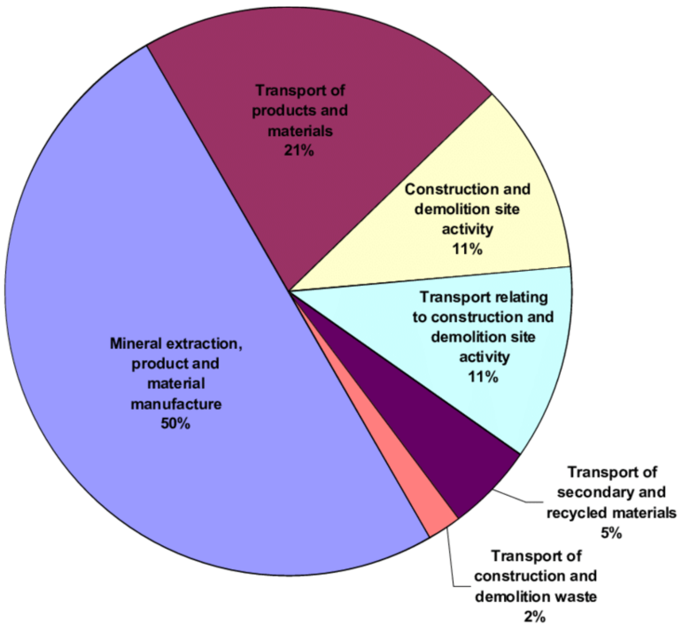

Figure 1: Energy use in the construction sector (%)

(Source: Panagiotakopoulos, 2005)

The industry's energy consumption is not well recognised during construction because of its fragmented structure and involvement of various parties throughout the building phase (Gottsche, Kelly and Taggart, 2016). Therefore, contractors have to estimate energy consumption during the construction phase of a project. Identifying high energy-intensive construction activities during construction and seeking energy-efficient alternatives are more important before investigating the sustainable practices of energy in construction (Shrivastava and Chini, 2011). Energy efficiency is moving near the top of many national agendas for many compelling reasons that are economic, environmental, and intergovernmental in character (Peck and Chipman, 2007). Hence, sustainable use of energy does not harm the environment and protects the resources for future demand.

2.3 ENERGY EFFICIENCY MEASURES RELATED TO CONSTRUCTION

The discovery of energy efficiency methods to minimise energy usage in the building industry can be useful. Relatively few studies have identified energy efficiency techniques used in the construction phase. Having an idea about energy efficiency before beginning the construction process may assist contractors in focusing on energy management means and procedures, such as energy-efficient lighting systems and purchasing renewable energy for managerial set-up to minimise the carbon emission of the building (Shrivastava and Chini, 2011).

2.3.1 Energy Management Policies

The government promotes investments related to energy-efficient construction equipment or increases the purchase of energy costs via tax and fiscal policies (Peck and Chipman, 2007). Dimitriev (2013) introduced two principles of energy consumption in construction: (1) only renewable energy sources should be used, and (2) the amount of consumed energy should not exceed the amount of energy received by the Earth.

2.3.2 Energy Audit

An *Energy audit* is a visual inspection, survey, and analysis of energy flow to reduce the amount of energy input while maintaining the system's output. Therefore, it is considered a systematic and reliable strategy in the construction industry (Moya, Torres and Stegen, 2016). An energy audit assists an institution in analysing its energy consumption and identifying areas where energy waste can occur, planning and implementing feasible energy efficiency methods that will improve their energy efficiency, identifying all energy flows in a facility, and quantifying energy consumption in an attempt to mitigate the overall energy inputs with its consumption (Abdelaziz, Saidur and Mekhilef, 2011). Figure 2 presents the energy audit process.

The energy audit report includes a detailed analysis of energy usage in each activity, which helps investigate larger energy-demanding activities and equipment in the construction process.

As stated by Shrivastava and Chini (2011), the project manager can use the energy audit report to identify site energy-related issues, find solutions, prepare energy reduction plans, and investigate alternative energy-efficient methods and techniques for identified energy-intensive activities.

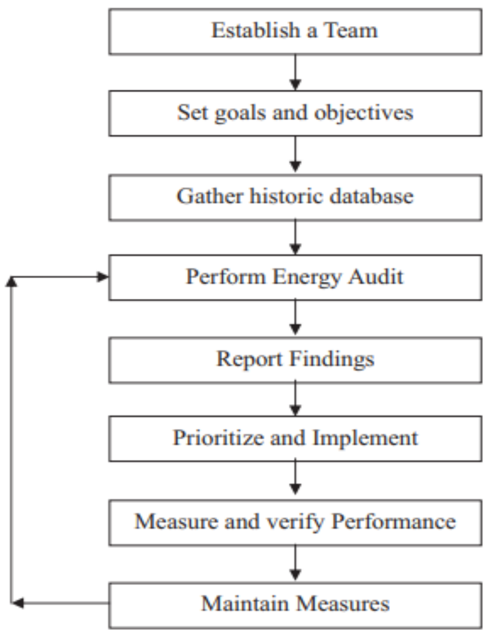

Figure 2: Energy audit process

Source: Abdelaziz, Saidur and Mekhilef (2011)

2.3.3 Site Management

Site management is the most important energy-efficient tactic on a construction site. Site planning helps minimise double handling materials and equipment and avoids reworks in building construction supplies (Sharrard, Matthews and Roth, 2007). Further, site delivery and onsite processing of supplies account for a significant portion of the energy used on construction sites. Selecting resources that are easily accessible may reduce transportation to the site, and effective site layout planning may reduce transportation on site. Inefficiency is caused by inefficient deliveries, such as materials being late or having too many items on the construction site. Therefore, scheduling material orders are a must (Der-Petrossian and Johansson, 2000).

As mentioned above, the contractor may minimise the transportation distances for materials. When the distance of transport is raised by three times, energy demand for facilitating the transport of workers, construction inputs, and transporting equipment grow by 26%, 22%, and 9%, respectively (Der-Petrossian and Johansson, 2000). This indicates that the increased transportation distance significantly influences the energy usage by employees and materials than construction equipment (Shrivastava and Chini, 2011). Moreover, project managers who want to save energy should focus on reducing labour and material transportation distances but may acquire equipment from a faraway location if it is more energy efficient.

2.3.4 Efficient Use of Machinery and Labour

The efficient use of machines and manpower has the potential to save a significant amount of energy. The contractor might insist that energy-saving lighting systems be used and energy-efficient electrical items and equipment be purchased and properly maintained to avoid energy losses (Majdalani, Ajam and Mezher, 2006). According to the financial cost perspective, machines with new technologies are the best (Repin and Evtjukov, 2015) because of their energy efficiency and less maintenance. According to Der-Petrossian and Johansson (2000), when manpower is inexpensive, the replacement of machinery with employees can save energy while boosting employment. Nonetheless, some activities must be performed by machinery.

A comprehensive training programme without excluding any specific group of experts (with varied backgrounds and qualifications) involved during the inception is necessary for the construction stages and afterwards in monitoring and maintenance (Gottsche, Kelly and Taggart, 2016).

Enhanced education and training will ensure the development of energy-efficient design and practices as the standard. Permanent ties and exchanges may be formed with all professional partners by including them in the process of establishing the energy efficiency targets, setting the funding and assessing the related actions for their advantages (ESCAP, 2004). Some research identifies training initiatives and their mediums. The contractor can sustainably use energy by implementing these energy-efficient practices effectively. Table 1 provides some onsite training initiatives as highlighted by Gottsche, Kelly and Taggart (2016).

Table 1: Training initiatives used onsite

Medium	Topic
Pocket meetings	Energy efficiency onsite, Eco-driving techniques, Fuel efficiency, Lighting onsite
Posters	Idling machinery onsite, Night-time lighting, Lighting onsite, Fuel efficiency/usage, Energy-saving tips at the accommodation, Energy savings at the site office
E-mails	Office equipment, Transport

(Source: Gottsche, Kelly and Taggart, 2016)

3. RESEARCH METHODOLOGY

A qualitative research approach was conducted to achieve the study aim. Yin (2011) described that a qualitative approach is suitable if the researcher investigates existing phenomena, current situations, opinions, aspects, and in-depth study on topics. First, a comprehensive literature review is carried out to identify and understand the research gap and practices of sustainable use of energy, construction activities and equipment that have higher energy consumption during the construction stage, and current energy sources used for the activities discussed in the above alternative sources. Data were collected through qualitative data collection techniques. A case study research strategy was chosen as a research strategy. This research required an in-depth study of the sustainable use of energy rather than a sweeping statistical survey. Yin (2011) introduced fundamental types of case study designs, such as single and multiple case studies. Four high-rise building construction projects were reviewed under the case study. The underlying principle of a case study is to get a clear idea of a problem, and thus, several data collection methods should evaluate the real-life situation from many aspects and perspectives (Yin, 2009). The interviews, document reviews, and observations were selected as data collection methods. They identified variables specific to the Sri Lankan context and investigated the most applicable energy efficiency measures and strategies for enhancing the sustainable use of energy practices in construction projects. Each of the four cases conducted individual, semi-structured interviews with construction professionals. The interview questions were prepared based on the literature. Table 2 provides a profile of selected cases and interviewees.

Table 2: Profiles of interviewees in case studies

Interviewer	Case 1	Case 2	Case 3	Case 4
Project Manager (PM)	PM-C1	PM-C2	PM-C3	PM-C4
Site Engineer (SE)	-	SE-C2	SE-C3	-
Project Quantity Surveyor (QS)	QS-C1	QS-C2	QS-C3	QS-C4
Planning Engineer (PE)	PE-C1	-	-	PE-C4
Site Supervisor (SS)	SS-C1	SS-C2	SS-C3	SS-C4
Storekeeper (SK)	SK-C1	-	SK-C3	-

Multiple sources of evidence such as project documents (Bill of Quantities, specifications, labour records, Environmental Management System, energy bills, and Building Schedule of Rates-BSR) and site observations contributed to gathering extra data for the case analysis. Both individual case analysis and cross-case analysis were employed to analyse data.

4. RESEARCH FINDINGS

A detailed description of the cross-case analysis of Cases A, B, C, and D are presented in the following subsections: Section 4.1 describes the "onsite energy efficiency measures", Section 4.2 describes "barriers that affect the efficient use of energy during the construction stage", and Section 4.3 describes "recommendations for the sustainable use of energy during construction".

4.1 ONSITE ENERGY EFFICIENCY MEASURES

This section presents the most applicable energy-efficient measures based on case study findings. The objective of energy efficiency measures in construction is to reduce energy consumption while maintaining or enhancing the quality of works provided on the construction site. Nine energy efficiency measures were identified based on case study findings.

4.1.1 Energy-Efficient Lights and Equipment

The interviewees highlighted that there are many onsite energy-efficient lights and equipment. According to QS-C1, the site operated on mercury bulbs and filament lamps before the use of Light-Emitting Diode (LED) lighting, and it consumed much energy. The use of LED lights has now reduced electricity usage up to 20%. Besides, it has increased the lifetime, instant lighting ability and lumen per square meter, voltage operation, cost, heat, and UV emissions.

PM-C4 mentioned that LED lights with motion sensors and the switch are activated when the sensor detects movement. Due to safety purposes, unnecessary locations were lit up frequently and LED lights with motion sensors helped reduce the mass quantity of electricity. Case 2 used solar-powered motion sensor wireless light as security lighting, with no connection to any electricity line. In addition to lights, high-efficiency grinders, sanders, putty mixtures, and breakers are used in most cases. This was also emphasised by many other respondents.

According to PE-C1 and SE-C2, there is a dusk-to-dawn feature in some LED lamps. These bulbs have built-in sensors that turn them *on* when dark and turn them *off* at dawn. This eliminates the need to turn the light on and off manually. The study revealed that most energy-efficient and cost-effective machines had been purchased for construction activities as a site policy. PE-C4 stated, *"we can minimise the energy usage, and it can be reduced up to 80% to 60% by using energy efficiency machines"*.

4.1.2 Site Planning

Site planning is the best way to manage energy. It is noted that energy consumption is calculated approximately before beginning the project. The site arrangement, selection of heavy equipment such as tower cranes, hoists, concrete pumps, placing booms, generators, project programme, and project duration significantly impact energy consumption. Several interviewees highlighted that storage facilities, loading bays, hoists, concrete pumps, and tower cranes were allocated in a planned manner in the site layout to reduce unnecessary movements. SE-C3 mentions, *"the storage, hoist, loading bay, and tower cranes are better placed in the same location"*. This facilitates unloading materials and lifting reinforcements and concretes using tower cranes without wasting energy.

It is also important to choose heavy equipment with a suitable capacity. Selecting a low capacity hoist may save energy, but it may require more cycles to fulfil site requirements. This will consume more energy than the high-capacity hoist.

The same will happen when choosing a suitable tower crane. As highlighted by many respondents, it is essential to plan how many heavy machineries are needed to optimise the construction works. In Case 3, the management has planned early procurement for the passenger lift contract during the planning stage, and the lift was placed after finishing the structure. It resulted in significant energy savings.

4.1.3 Energy Management Plans

Construction management plans and method statements include energy management plans. Those documents include how to use equipment efficiently without wasting energy. It also includes suitable equipment for a particular work since using appropriate tools and equipment help to reduce energy usage. PE-C4 mentioned that their site has an energy plan for the construction period, and the Mechanical, Electrical, and Plumbing (MEP) section checked whether the actual energy consumption tallied with the plan. If there is a discrepancy between plans and actual consumption, the MEP division makes appropriate adjustments. Construction management plans help maintain the required project performance quality standards, as highlighted by several respondents.

4.1.4 Monitoring and Supervision

PM-C2 pointed out the uselessness of having energy plans or method statements without monitoring workers. Even without an energy management plan, energy can be optimised by monitoring. The site management has assigned staff to monitor and supervise construction activities, including preventing energy waste by site workers while performing all direct and indirect site activities.

SS-C2 mentioned that supervisors behaving like responsible persons are sufficient to reduce energy waste. However, it was noted that some supervisors are not performing their job roles suitably. In Case 2, senior engineers monitored the supervisor's actions at the site. The study revealed that site meetings should be held to discuss the work progress and problems at the site. During the meetings, energy-related matters such as energy usage, energy wastage, and energy management actions can be discussed. PE-C1 stated, *"We never do night work without proper planning and supervision. Because in night works, a large amount of energy is used for lighting and there may be an energy waste if productivity is low"*.

4.1.5 Increasing Employee Awareness

Many respondents highlighted that energy usage is often based on employees' behaviour, and employees are one category of the main influencers in a construction site. Proper site meetings are required to discuss daily work plans, safety aspects, instructions about machines, equipment, and awareness of electricity and water consumption. Workers, as well as staff members, should be instructed about energy management. Signboards are an effective method to increase the workers' awareness because the instructions given in the meetings can be forgotten due to various reasons. Signboards and posters can display in areas with a high chance of energy waste. The site office, canteen, washrooms, and electrical distribution panels in a site are identified as the best places to display posters. The SS-C2 stated, *"According to my experience, this method is more effective than other methods because workers may recall what the supervisor said during the meeting"*.

4.1.6 Assign Responsibilities for Works

The majority of respondents believed that a particular person should monitor temporary electricity at the site. His job role is to supply and maintain electricity connections, monitor and effectively control the energy use, and always be responsible for temporary lighting. As revealed, a separate person has been assigned in each case. SE-C3 mentioned that the MEP section is responsible for the supply and control of temporary electricity on the site, and each floor has a particular technical officer as the in-charge of the floor. The electrical crew should have a separate red colour uniform for easy identification, and they are always responsible for temporary lighting.

In addition, the construction manager, project engineer, quality assurance and quality control engineer, mechanical, electrical, and plumbing engineers, site supervisor, and every worker have equal responsibility for energy usage on construction sites. The site supervisor of Case 2 (SS-C2) stated that signboards and monitoring systems are more effective but maintaining notices throughout the construction period is difficult.

4.1.7 Energy Audit

The energy audit is an inspection survey and analysis of energy flows for energy conservation in the site. It could involve a technique or system that reduces the amount of energy input while maintaining the work output.

Energy audit has major steps, which include several sub-activities. The Mechanical, Electrical, and Plumbing (MEP) section publish energy audit reports to the project manager and contractor's head office. The project manager should review the report and take necessary actions to enhance energy efficiency. Case 2 and Case 3 have proper energy audit processes.

The main steps in the energy audit used in Case 2 were as follows:

- Step 1: Investigation of energy inlets and outlets
- Step 2: Data collection and measurements
- Step 3: Economic evaluation of energy consumption in the site
- Step 4: Examine energy-consuming sub-processes
- Step 5: Propose energy conservation methods and alternatives
- Step 6: Propose strategies for reducing energy consumption without losing productivity

4.1.8 Submetering

Installing power meters that can detect energy usage after it reaches the primary utility meter is known as *electrical submetering*. It can be used on the site, floor-wise, or based on organisations that involve construction works. For example, PM-C2 and PM C4 mentioned that the sub-contractor office has a separate meter connection for electricity, and it can help to manage electricity consumption efficiently. Case 2 and Case 4 had 4 and 15 submeters, respectively. PM-C4 stated, *"We get energy usage reports from submeter connections, and those are analysed every month".*

However, sub-contractors did not pay separately for meter readings, and those costs were claimed under the attendance fee. The case study findings revealed that the sub-metering concept easily identifies which section consumes more energy and which section has sudden deviation within the meter section.

4.1.9 Fuel Monitoring System

Fuel is used for most site activities. Hence, a proper fuel monitoring system is necessary to manage fuel purchases, fuel storage, and fuel issuing. Typically, the storekeeper is the responsible person for fuel purchasing, issuing, and maintaining proper records. The responsibility of the assistant quantity surveyor is to collect the fuel usage details and check machine hours or meter readings. Then machine report is prepared, and fuel usage per unit is calculated. Most sites have pre-calculated fuel rates in the site. QS-C2 stated, *"Every month, actual unit rates should be compared with pre-calculated rates, and if there is a major deviation, the particular supervisor should find the reasons for the deviation".*

Several reasons were identified for deviations: serviceability issues, economic lifetime expired, not being properly maintained, and fraudulent labour acts. All four cases reported fuel use, but fuel analysis was subjective.

4.2 BARRIERS THAT AFFECT SUSTAINABLE AND EFFICIENT USE OF ENERGY DURING CONSTRUCTION

Based on cross-case analysis findings, this section examines key barriers that affect the sustainable and efficient use of energy during the construction stage.

4.2.1 Lack of Knowledge

Information is the main input of any kind of analysis. Lack of knowledge is the main barrier to implementing energy efficiency practices. PM-C1 stated, *"Without proper information, we cannot make correct decisions".* Sometimes, site supervisors attempt to reduce energy consumption in a particular activity, but that work may have a minor impact on total energy. Thus, using resources to reduce energy in such activities is useless.

The management should be aware of energy management and energy efficiency. Several professionals with proper knowledge of energy should be at the site. SE-C2 stated, *"Before thinking about energy-reducing, it is necessary to identify energy usage trends on the site"*. Most professionals were not aware of the stage which used more and which stage used less energy.

4.2.2 Lack of Planning

Many respondents emphasised that if the information is available, there should be an appropriate planning procedure to make energy management decisions. Lack of planning affects onsite energy wastage. Planning is the first step of energy management, and it is a set of activities that includes site planning, plant and machinery selection, energy sources selection, selection of construction methods and technologies, and preparation of a detailed working schedule. The study revealed that the project manager should plan the site to minimise unnecessary transportation, get maximum daylight for the site office, store, canteen, and other common areas, and minimise the tower crane movement. Energy management becomes difficult if management fails to make proper planning decisions in the early stage. PM- C3 and Pm-C4 mentioned that sometimes the site office and labour facilities are improperly ventilated and receive inadequate daylight due to poor site planning; hence, reducing lighting and air conditioning becomes an issue.

4.2.3 Lack of Responsibility

The study revealed that lack of responsibility is a serious problem in Sri Lanka. Although the management level collects information and makes decisions to improve energy efficiency practices, people are reluctant to take responsibility for implementing such practices. As many respondents highlighted, everyone on the site is responsible for minimising energy consumption and reducing waste, but frequently, the administrative division is responsible for any major deviations of the site's monthly energy bills. It is noted that one person or one department cannot control it, and burdening one party with the whole responsibility is not a good practice - all parties should share the responsibility.

4.2.4 Poor Responses from the Construction Organisation

The construction organisation may respond poorly to energy management and may not focus on introducing any energy management during the project's design stage. In the tendering stage, proposals should come up to reduce energy in the site with the involvement of the consultant. Also, the contractor can implement policies to increase energy management, which are strong policies to fulfil energy-efficient practices.

4.3 RECOMMENDATIONS FOR THE SUSTAINABLE USE OF ENERGY DURING CONSTRUCTION

Sustainable energy is defined as 'a type of energy that may be used repeatedly without placing a source at risk of becoming depleted, expired, or disappearing'.

As suggested by respondents of each case, the proposed recommendations for improving the sustainable use of energy should be adopted at the project level, and some recommendations exceed the scope of site management. Table 3 summarises the findings.

Table 3: Recommendations for the sustainable use of energy in construction site

The action made within the site	The action made beyond the site level
• Establish a code of conduct for managers and other employees, including labourers. • Explore alternative energy sources for facilities like the site office, labour hut, and security lights. • Implement a supervision and monitoring system for energy management. • Display established targets and energy usage plans for energy usage activities at sites for site workers and staff to reference. • Develop an energy action plan for the site. • Establish detailed guidelines for the construction activities. • Encourage innovations in the site. • Submetering the connection as much as possible. • Establish a computerised fuel monitoring system. • Set goals with equipment operators. • Identify the right equipment for each activity.	• Set up energy management components from the initial stages of the project. • Raising public awareness about the future energy crisis. • Add credit points for using renewable energy sources on a construction site in the green building rating system. • Ensure that appropriate environmental protection legislation is enforced. • Include energy-efficient measures in contract documents. • Establish energy limits for construction projects by CEB. • Encourage the renewable energy offset concept within the industry. • Laws should be enacted by the government and appropriate authorities to increase the sustainable use of energy.

5. CONCLUSIONS

The construction sector consumes more energy than other industries. Construction sites have become one of the largest energy consumers with the highest energy waste. In the Sri Lankan context, there is a lack of research evidence on the sustainable use of energy on construction sites. This study provided a comprehensive overview of sustainable principles of the construction industry, energy consumption during the construction stage, energy-efficient measures related to the construction industry, barriers, and finally, recommendations. The measures related to site staff and workers can influence energy efficiency more than the measures related to machinery and equipment. The strategies were identified in sub-section 4.3. The suggested recommendations for improving the sustainable use of energy should be implemented at the project level, and some suggestions go beyond the scope of site management. The project level strategies established in the pre-contract stage and post-contract stage can directly impact the energy efficiency at the site. Some actions exceed the project level guides to facilitate and govern the development of energy-efficient requirements and measures. The study was limited to examining ongoing high-rise building projects in building construction. It guides construction industry stakeholders to use energy in a sustainable way. Further research can quantify the energy requirement and develop a suitable framework for enhancing the sustainable use of energy practices on construction sites in Sri Lanka.

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