COMPARATIVE PERFORMANCE ASSESSMENT OF COMPRESSED STABILIZED EARTH BLOCKS FOR SCHOOL BUILDING CONSTRUCTION IN SRI LANKA

Govinnage Sachitra Priyashan
(228457P)

Degree of Master of Science

Department of Mechanical Engineering

University of Moratuwa
Sri Lanka

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ABSTRACT

This study investigates the potential of Compressed Stabilized Earth Blocks (CSEBs) as a sustainable and cost-effective alternative to conventional construction materials for school buildings in Sri Lanka. CSEBs, made from locally available soil mixed with a small percentage of stabilizers such as cement or lime, offer numerous environmental and economic advantages. The research focuses on assessing the performance of CSEBs in terms of structural integrity, thermal comfort, and life cycle cost analysis, comparing them with traditional materials like cement blocks and fired bricks.

Laboratory analyses were conducted to evaluate the compressive strength of CSEBs. Additionally, a life cycle cost analysis & environmental impact analysis were performed to determine the economic feasibility & sustainability of using CSEBs in school construction. The results indicate that CSEBs, when properly manufactured and stabilized, meet the required standards for school building construction in terms of strength and durability. Moreover, CSEBs provide superior thermal comfort, reducing the need for artificial cooling and thus lowering operational energy costs.

The study concludes that CSEBs represent a viable and sustainable building material for school construction in Sri Lanka, offering both economic and environmental benefits. The adoption of CSEB technology could significantly contribute to the country’s efforts to promote sustainable development and reduce the environmental impact of the construction sector. Further research is recommended to explore long-term performance under varying climatic conditions and to develop guidelines for the widespread adoption of CSEB construction in Sri Lanka.

Keywords: Compressed Stabilized Earth Blocks, Compressive Strength, Thermal Conductivity, Cost-effectiveness, Sustainability, Energy Efficiency, Durability

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LIST OF NOMENCLATURE

Abbreviation	Description
CSEB	Compressed Stabilized Earth Block
NBC	National Building Code
HVAC	Heating Ventilation & Air conditioning
CSB	Cement Sand Block
HCFB	Hollow Core Fired Brick
CFB	Country Fire Bricks
ECB	Earth Concrete blocks
LSEB	Lime Stabilized Earth Block
PSEB	Polymer Stabilized Earth Block
BSEB	Bitumen Stabilized Earth Block
FASEB	Fly-ash Stabilized Earth Block
NPV	Net Present value
LCC	Life Cycle cost
LCCA	Life Cycle cost Analysis
UV	Ultra Violet
HAP	Hourly Analysis Program
HVAC	Heat, Ventilation and Air Conditioning
OM	Operation & Maintenance
CON	Construction
LKR	Sri Lankan Rupee
ICTAD	Institute for Construction Training and Development
BSR	Building Schedule of Rates

CHAPTER 1

1. INTRODUCTION

Sri Lanka is an Island located near the equator & receives uniform sunlight throughout the year. Therefore, compared to other countries, Sri Lanka has a very high amount of energy available from sunlight. In Sri Lanka, we find that most of the schools conduct their daily education activities using natural ventilation (Passive cooling) and natural sunlight (Day light). Especially schools located in the coastal region have a high chance of getting natural ventilation and wind behavior effects, and it changes to some extent as you move inland into the country.

Additionally, the majority of the raw materials needed for building are accessible worldwide. However, there is a global shortage of raw materials used in the construction sector, such as river sand, cement, and clay. As a result, the cost of the materials that are readily available has significantly skyrocketed. Because of this, engineers, researchers, and academics interested in the topic are concentrating on alternative materials and doing various degrees of research. And this may result in its enormous advantages. These studies led to the development of compressed stabilized earth block. Compressed Stabilized Earth Blocks (CSEB) is made of dirt that has been compressed with a stabilizing chemical using either manual or motor-driven press machines. Typically, cement or lime is used to stabilize them.

Compared to traditional brick and cement block stone use, the use of Compressed Stabilized Earth Block can offer a number of distinct advantages. The raw material can be easily found in every part in the country and hence the cost of transportation is reduced. And the production of this Compressed Stabilized Earth Block can be done at any place. No special training personnel are required for the production of these blocks. Also, the cost of products made using imported raw materials can be completely eliminated. Moreover, fast and easy construction methods, good strength and low carbon emissions during production and requiring very little energy during the production phase are also considered major advantages. All the waste generated in the production of Compressed Stabilized Earth Blocks is environmentally friendly. Therefore, the damage to the environment is very minimal. As well as Compressed Stabilized Earth Block have the ability to absorb atmospheric moisture, and a healthy & comfortable environment is created for the occupants of a building.

The main elements necessary for the learning and teaching process are good ventilation, as well as a good amount of sunlight or light and maintaining an **optimal temperature in the classroom.** Today, a school building is not a just building. It is concerned with durability, flexibility, functionality, short construction processes, cost-effectiveness, aesthetics, and thermal comfort and in many cases comfort. The comfort of the student and the teacher has become a major priority, and a number of different environmental tests have been carried out to achieve this.

But it is seen that Sri Lanka has failed to make proper use of these valuable natural resources. Classrooms that are maintained in very dark environments, places such as classrooms or laboratories that do not have proper ventilation and dining halls or cafeterias that lack natural ventilation are some examples. Moreover, **overheated classrooms** greatly hinder the learning and teaching process.

The main purpose of this research is to introduce the use of Compressed Stabilized Earth Block for the construction of school buildings in the coastal areas in Sri Lanka by paying more attention to the benefits mentioned above in the introduction with a comparative performance assessment of the properties of compressed stabilized earth blocks.

CHAPTER 2

2. TYPES OF BUILDINGS & THEIR ENERGY USAGE

2.1 Types of buildings

There are several types of buildings, each with its unique energy usage. Here are some common building types and their energy usage:

- Residential buildings: In the world, residential buildings use more than one-third of the electricity produced. These consist of single-family residences, condominiums, and apartments. In residential buildings, heating, cooling, water heating, lighting, and appliances use the majority of the energy.
- Commercial buildings: About 25% of the total energy used in commercial buildings was for space heating. Offices, schools, hospitals, and shopping malls are some of these. Lighting, heating, cooling, ventilation, and office equipment account for the majority of energy consumption in commercial buildings.
- Industrial buildings: These consist of manufacturing facilities, warehouses, and factories. Energy is used in industrial buildings to run lighting, heating, cooling, and large machinery.
- Government buildings: These consist of government buildings, police stations, and courthouses. In public buildings, energy is used for lighting, heating, cooling, and office equipment.
- Institutional buildings: These include museums, libraries, and religious buildings. Energy usage in institutional buildings is for lighting, heating, cooling, and equipment.

Depending on the size, location, age, and system and equipment efficiency of the building, each building type may use more or less energy than another. To cut down on energy use and expenditures, energy-efficient modifications and practices can be applied to all types of buildings.

2.2 School buildings

In Sri Lanka, the common school building types include:

- Pre-schools: these are for kids ages 3 to 5. Pre-school, or play school or is an educational facility or learning environment giving early childhood education.
- Primary schools: These are schools that provide education for children from ages 5 to 11 (Grade 1 to 5). They are typically small and serve a local community.
- Secondary schools: These schools, which can be either public or private, offer education to students between the ages of 11 and 16 or 18. They offer a greater range of curriculum and facilities than primary schools and are often wider.
- National schools: They may offer specialized programs or facilities, including scientific labs or sports fields, and are often greater in size than ordinary schools.
- International schools: These are private schools that offer an international curriculum and often cater to expatriate families. They may offer facilities such as swimming pools, tennis courts, and music rooms.
- Vocational schools: These institutions offer specialized instruction in a particular trade or talent, such as cosmetology, welding, or carpentry. They may offer more opportunity for experiential learning because they are often smaller than other institutions.

Based on elements including building size, location, age, and the effectiveness of systems and equipment, each type of school building in Sri Lanka can use a different amount of energy. To cut down on energy use and expenditures, however, all schools can profit from energy-efficient renovations and procedures. These could include HVAC and lighting system modifications as well as staff and student energy literacy initiatives.

2.3 Specific requirements for school building construction in Sri Lanka

The National Building Code (NBC), which establishes the standards for building design, construction, and maintenance, specifies the particular requirements for school building construction in Sri Lanka. The Ministry of Education is in charge of making sure that all school structures adhere to the NBC.

Some of the key requirements for school building construction in Sri Lanka include:

1. Site selection:

The site for the school building should be selected based on factors such as accessibility, safety, and suitability for the intended use.

2. Building design:

The building should be designed to withstand natural disasters such as earthquakes and cyclones. It should also provide adequate space for classrooms, administrative offices, restrooms, and other facility and construction: The materials used in the construction of the building should be of high quality and meet the standards set out in the NBC. The construction should be carried out by qualified professionals and supervised by an engineer.

3. Electrical and plumbing systems:

The building should have a safe and efficient electrical and plumbing system that meets the NBC standards. This includes proper wiring, grounding, and fire protection systems.

4. Accessibility:

The building should be designed to be accessible to students and staff with disabilities. This includes providing ramps, elevators, and accessible restrooms.

5. Environmental considerations:

The building should be designed to minimize energy consumption and reduce environmental impact. This includes the use of energy-efficient lighting, HVAC systems, and water-saving fixtures.

2.4 Expected properties & characteristics of building materials

There are several environmental considerations that should be taken into account when constructing school buildings in Sri Lanka. One of the main considerations is the use of sustainable materials and energy-efficient design to minimize the impact on the environment.

Sri Lanka has a tropical climate, which means that buildings need to be designed to stay cool in hot and humid weather. To reduce energy consumption, school buildings should be designed with appropriate insulation, shading, and natural ventilation.

The ideal classroom temperature can change depending on a number of factors, including air movement, humidity levels, and personal preferences. The majority of teachers and students, according to academics, believe that a temperature range of 20 to 22 degrees Celsius is appropriate. If the temperature is outside of this range, students' learning and academic performance may decrease. For instance, hot weather might make students sleepy and make it difficult for them to concentrate, while cold weather can be uncomfortable and make it difficult for pupils to focus.

Construction of school buildings can have a lesser adverse effect on the environment if sustainable materials are used. Materials like recycled steel, low VOC protective coatings, compressed stabilized earth bricks, etc.

These requirements are aimed at ensuring that school buildings in Sri Lanka are safe, functional, and conducive to learning.

CHAPTER 3

3. MATERIAL USED IN BUILDING CONSTRUCTION

The first attempts at compressed earth blocks were made in Europe in the 19th century. In the 1950s, the Cinvaram steel manual press was developed to improve the hand molded & sun-dried brick (adobe). Since then, many types of machines have been designed and laboratories have been specialized to identify the soils for buildings. Compressed earth blocks can be stabilized with cement or lime, and can be used like common bricks with a soil cement stabilized mortar [1].

3.1 Deferent types of wall construction materials & blocks

3.1.1 Cement sand block (CSB)

A specific combination of cement, sand, and water are combined to create cement sand blocks, which are then compressed into solid blocks. To construct walls, foundations, and other buildings, these blocks are frequently used in construction. Depending on the intended application and strength requirements for the blocks, the ratio of cement to sand in the mixture can change. In general, blocks with sufficient strength are often made using a ratio of 1:6 (one part cement to six parts sand). A device known as a block-making machine, which can create blocks of different sizes and forms, is commonly used to create the blocks. Before using the mixture, the mixture is compacted into a block shape and allowed to dry and harden.

Figure 1 : Cement Sand Block (CSB)

3.1.2 Hollow core fired brick (HCFB)

The same materials as solid bricks are used to create hollow-core bricks, commonly referred to as "hollow blocks," but they have voids or hollow cores in the middle. These blocks are lightweight because of their hollow cores, which makes them easier to handle and move around. As air trapped within the cores can serve as a thermal barrier, they can act as insulation. HCFB is an industrial brick and masonry system that is not available in every area in Sri Lanka but can be seen in Kilinochchi and Mullaitivu [2].

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Figure 2 : Hollow Core Fired Brick (HCFB)

3.1.3 Country fired brick (CFB)

Clay is often used to make bricks, which are then fired in a kiln to give them strength and durability. They are utilized in a variety of construction applications, such as walls, chimneys, and fireplaces, and available in a variety of colors, textures, and sizes due to soil properties.

Figure 3 : Country Fired Bricks (CFB)

3.1.4 Earth concrete block (ECB)

Dr. Rangika Halwatura of the University of Moratuwa created the Earth Concrete Block (ECB), a mixture of soil, gravel, cement, and water with the consistency of concrete. In order to prevent shrinking, there must be at least 50% gravel that is evenly distributed. Although Sri Lankan specialists do not support ECB as a regular building product, this method has the potential to be adopted and scaled up in regions with acceptable soils and concrete-based construction methods. However, community centers in Batticaloa, where the soils are unsuitable, use solely MCB (mud concrete blocks) [2].

Figure 4 : Earth Concrete Blocks (ECB)

Figure 5 : Compressed Stabilized Earth Blocks (CSEB)

3.1.5 Compressed stabilized earth block (CSEB)

A modern, stabilized improvement over conventional building techniques created in the 1950s for structural, load-bearing strength, and climatic resilience is CSEB technology. It can be applied to plain walls, walls that interlock to resist disasters, composite technologies for columns and beams, etc. It uses mostly inexpensive and widely accessible local resources and is a practical, low-carbon, low-embodied energy solution for sustainable development. With an average cost breakdown of 60% local labor and 40% materials, it is a labor-intensive building technology. It can be put into practice with the intention of mobilizing local actors with the necessary abilities for the creation of locally based businesses. In Sri Lanka, there are building regulations for CSEB.

Four things make up soil: gravel, sand, silt, and clay. To provide silt and clay with long-lasting qualities that require little upkeep, stabilization is required. Organic soils and topsoil are not acceptable. To produce products of high quality, it is crucial to understand soil characteristics. Not all soils can be used to build on the earth.

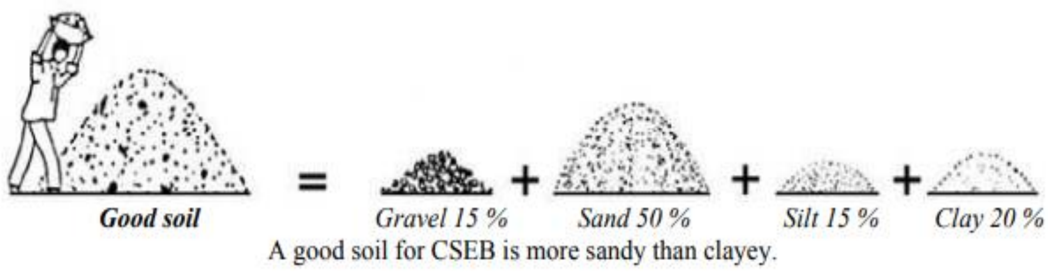

Figure 6 : Content of good soil for CSEB

Anyone with sensitive analyses can identify soil, and anyone can learn how to do so after a few trainings. The primary elements to look at are;

- Grain size distribution, which lets you know how many grains come in each size.
- Quality and properties of the binders
- Optimum moisture content
- Cohesion, to understand how binders hold the inert grains together.

The average stabilizer proportion is rather low:

Cement stabilization = 5% average.

The minimum is 3% and the maximum is 8%

Lime stabilization = 6% average. The minimum is 2% and the maximum is 10%

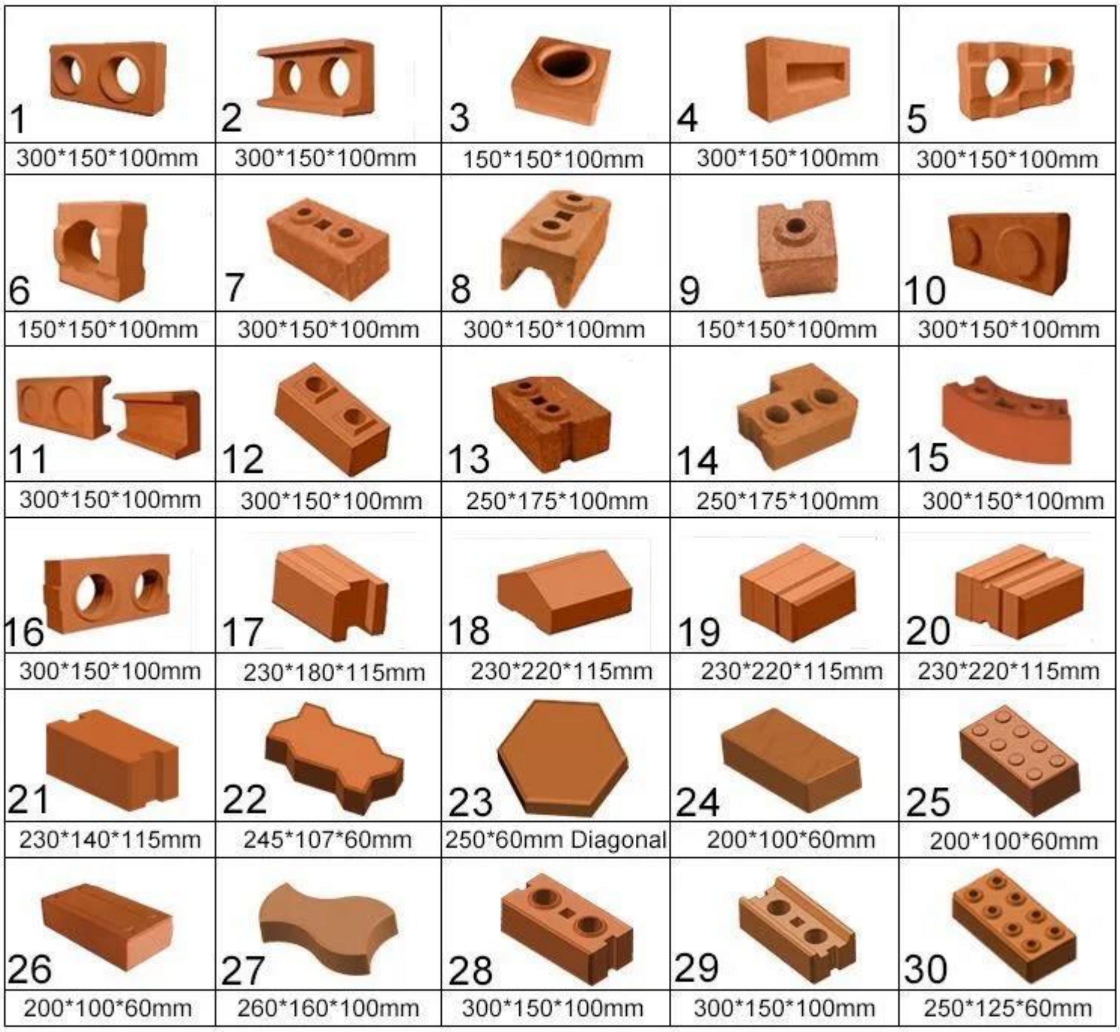

Figure 7: Types of CSEB

3.2 Comparison of properties between different conventional wall materials

Table 1: Properties of different conventional wall materials [3]

No	Parameter	Red Bricks	Solid Cement Blocks
1.0	Raw Materials	Sand, Iron Oxide, Magnesium, Lime Clay or Alumina, and are the raw materials used to make red bricks. The majority of the sand needed to make red bricks comes from local areas.	The following raw materials are used to make solid cement blocks: regular Portland cement, sand, gravel, and water. Fly ash may be used in place of fine sand in some circumstances.
2.0	Properties	The modular sizes for red bricks are 190 x 90 x 90mm and 190 x 90 x 40mm. 230 x 110 x 70 mm and 230 x 110 x 30 mm non-modular versions are also available.	Solid cement blocks often come in lengths of 300, 350, or 400 mm, heights of 200, 175 mm, and widths ranging from 50, 75, 100, 150 or 200 mm. The dimensions vary from one manufacturer to another.
3.0	Compressive Strength	Accordingly, the compressive strength ranges from 3.5 to 35 N/mm2, depending on the class.	Depending on the type of cement used, solid concrete blocks have varying compressive strengths. The range of its compressive strength is 4 to 5 N/mm2.
4.0	Dry Density	The dry density also varies depending on the class of brick. It normally ranges from 1600 to 1920 kg/m3	The dry density of the solid cement block is depended on the grade of block. This ranges from 1800 to 2500 kg/m3
5.0	Water Absorption	Red bricks should absorb water at a rate of no more than 20% of their weight.	Solid cement blocks must not have a water absorption value not greater than 10% of it their Weight
6.0	Thermal Conductivity	It is advised that red bricks have thermal conductivities between 0.6 and 1 W/mK.	Thermal conductivity for solid cement blocks typically falls between 0.7 and 1.28 W/mK.

7.0	Environmental Impact	Clay, which is naturally available, is used to make red bricks. Thus, the top rich soil is depleted by this production. Carbon dioxide emissions from the production of red bricks are also higher.	The amount of carbon dioxide emitted during the manufacture of solid cement blocks is less.
8.0	Water Usage	Curing requires more water	Solid cement blocks require 7 to 14 days of curing which demand high amount of water compared to red bricks.
9.0	Cost	Just red bricks are inexpensive. However, because it requires more mortar, the overall cost, which includes the cost of building, is expensive.	The price of the solid cement blocks as separate pieces is considerable. Less mortar is needed for it. It has the advantage that less solid cement blocks than red bricks are needed to build the same amount of wall space.

CHAPTER 4

4. COMPRESSED STABILIZED EARTH BLOCKS & THEIR PROPERTIES

Compressed Stabilized Earth Blocks (CSEB) are construction materials created by compressing soil, sand, cement, and water in a hydraulic press to create a solid block. Due to their great thermal characteristics, low carbon footprint, and high durability, these blocks are frequently utilized in environmentally friendly construction. Among the essential characteristics of CSEBs are:

4.1 Compressive strength

Figure 8: Compressive strength testing for CSEB

Expending on the kind of soil, the quantity of cement used, and the compaction technique, the compressive strength of CSEBs can range from 2.0 MPa to 10 MPa. They can therefore be utilized in load-bearing walls.

Since Portland cement considerably increases the compressive strength of CSEB, it is frequently utilized as a stabilizer in rammed-earth combinations. It was demonstrated that the compressive strength range of 2.68 MPa to 9.30 MPa by adding 9% cement.

By the mass of the remaining dry materials, cement was added to the mixes in the amounts of 6% and 9%, respectively [4].

The most widely used metric for assessing the quality of bricks is compressive strength. However, it has a close relationship with the soil types and stabilizer content. Compressive strength measurement under moist conditions typically yields the poorest strength value. The growth of pore water pressures and the liquefaction of unsterilized clay minerals in the brick matrix are the two factors that contribute to the reduction in compressive strength under saturation conditions [5].

4.1.1 Soil properties

The strength of CSEB can be considerably impacted by the quality of the soil used to produce it. It is best to choose soil that has a lot of clay because it has good cohesion and compaction qualities.

Compressive strength is an essential element of soil blocks and according to SLS 1382, grade 1 soil cement blocks should have a 28-day dry compressive strength of 6 MPa or above. The relationship between compressive strength and reduced clay & silt content, with the block with 20% clay & silt having the highest value of 8.95 MPa and the block with 10% clay & silt having the lowest value of 5.54 MPa [6].

4.1.2 Stabilized agent

stabilizers may also be utilized; cement or limes are generally used to stabilize CSEB. The CSEB's compressive strength, durability, and weather resistance can all be impacted by the kind and quantity of stabilizer used. The ideal cement level for stabilization is between 5% and 10%, with an addition of more than 10% hurting the bricks' strength [4]. [5]

4.1.3 Curing time

The process of allowing the blocks to dry and strengthen after they have been created is known as curing. The type of stabilizer used, the size and shape of the blocks, as well as the ambient conditions, all affect how long CSEB takes to cure. Before being utilized in construction, CSEB blocks typically need to be cured for a minimum of 21 to 28 days. To avoid damage or cracking, the blocks should be shielded from excessive moisture and sunshine while they are curing. Maximum strengths at 28 days' strength are within the range of the minimum strength needed for low-rise building construction [7].

4.1.4 Production techniques

Hand pressing: The most popular method for creating CSEB is hand pressing. By using a manually operated press, the soil and stabilizer mixture is compressed into the required block shape in this process.

Figure 9: Hand pressed block manufacturing

Machine pressing or motorized pressing: For the production of CSEB, machine pressing provides a quicker and more effective method. This technique involves feeding a hydraulic press with a mixture of soil and stabilizer, which compresses the material into the desired block shape.

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Figure 10 : Machine Pressed Block Manufacturing

4.1.5 Block size & shape

The size and shape of CSEBs can be altered to fit certain building needs and designs. The blocks can be produced in a variety of designs, including interlocking shapes that make it simple to put up and take down walls, using less mortar and specialized labor in the process.

The wall's stability and compressive strength, as well as the structure's thermal characteristics, can all be impacted by the size and shape of the blocks. These elements should be taken into account when choosing the right CSEB size and shape for a certain construction project [8].

4.2 Thermal values

The ability of building materials to conduct, store, and resist heat transmission is referred to as their thermal characteristics. These characteristics are significant because they influence building energy efficiency and thermal comfort. Thermal qualities of building materials are affected by a variety of elements, including composition, density, thickness, and surface features. Thermal qualities of building materials must be considered during the design and construction process to enhance energy efficiency, occupant comfort, and overall building performance.

4.2.1 Thermal conductivity

Thermal comfort in building materials is a crucial factor that receives a lot of attention today due to the growing energy consciousness and ecological awareness, as well as the fact that modern building rules place a greater emphasis on the thermal performance of structures than they did in the past. Brick is a very good heat conductor as a building material.

Compressed stabilized earth bricks showed better thermal conductivity value compare to the fired clay bricks. [5]

- Lime-GGBS based: 0.2545 ± 0.0350 W/mK
- Cement-GGBS based: 0.2612 ± 0.0350 W/mK
- Fired clay bricks: 0.4007 ± 0.0350 W/mK

The conductivity of the brick may somewhat decrease with the addition of cement and sand content. Low thermal conductivity is advantageous since it can increase a building's energy efficiency, lower its summer and winter heating and cooling costs, and make it more environmentally friendly. Clay bricks that have been fired have a greater conductivity rating because heating causes the clay to partially mix to produce a glassy product, giving the product strength and longevity. It is also a result of the original clay mineral's breakdown and the development of new crystalline and glass phases [5].

4.2.2 Thermal mass

The term "thermal mass" describes a substance's capacity to take in, hold, and release thermal energy. Due to their composition and density, Compressed Stabilized Earth Blocks (CSEB) often exhibit significant thermal mass.

The thermal mass of a material is typically measured in terms of its specific heat capacity and density. Specific heat capacity refers to the amount of heat energy required to raise the temperature of a given amount of material by a certain degree. Density, on the other hand, is the mass of the material per unit volume.

CSEB, being composed of soil and stabilizers, generally have higher density and specific heat capacity compared to materials like wood or lightweight construction materials. This higher density contributes to their thermal mass, allowing them to store and release heat slowly, thereby helping to regulate temperature fluctuations.

Because they are mostly composed of stabilizers like cement or lime and soil, CSEB have the ability to trap heat. When the temperature outside rises during the day, CSEB absorbs heat from the environment. By reducing the rate of heat transmission through the walls, this method aids in controlling a building's internal temperature. The heat is then gradually released at cooler times, including at night, assisting in maintaining a more steady and cozy indoor climate [9].

The increased thermal mass of CSEB enhances their thermal performance and energy efficiency. It could perhaps lessen the demand for extra heating or cooling systems while lowering temperature variations and enhancing indoor comfort. It's crucial to remember that other elements like insulation, building orientation, and design can also affect thermal performance [10].

Buildings can take advantage of CSEB's natural ability to store heat by utilizing its thermal mass, which will increase the efficiency of energy and thermal comfort.

4.3 Durability

When produced and maintained appropriately, compressed stabilized earth blocks (CSEB) can have a good level of durability. However, a number of variables, like the caliber of the materials used, the manufacturing process, the environment, and maintenance procedures, might affect how long CSEB will last in a particular application [11].

4.3.1 Quality of material (soil properties)

As pre describes in Compressive Strength (4.1) the soil used in CSEB production should have suitable properties such as adequate clay content, proper particle size distribution, and good compaction characteristics. Moreover, that we have to consider Material contamination of the soil. Stabilizers or pollutants in the soil can have a negative effect on how long CSEB will last. Salts and other contaminants can cause the blocks to corrode, deteriorate, or weaken over time. It is essential to make sure that the components are devoid of any impurities that can damage the longevity of CSEB [12].

4.3.2 Design of building

A building's ability to endure different loads, such as vertical loads (such as gravity) and horizontal loads (such as wind and seismic forces), depends on its structural design. It is more durable for CSEB walls and components to withstand the appropriate loads without experiencing undue strain or deformation. Therefore, the structural design plays a vital role in CSEB walls.

Effective moisture management is necessary for CSEB buildings to last a long time. Designing a structure with appropriate moisture control features including right roof overhangs, efficient drainage systems, moisture barriers, and sufficient ventilation is essential. Infiltration and accumulation of too much moisture can harm CSEB and cause swelling, cracking, or erosion.

Insulation and weatherproofing are also important in CSEB wall construction. The design of the building envelope, which incorporates insulation and weatherproofing materials, is essential for preserving a cozy and long-lasting interior environment. Insulation aids in temperature control, keeps condensation from forming, and lessens the thermal strain on CSEB walls. The CSEB is guarded against water infiltration and associated damage by utilizing appropriate weatherproofing techniques, such as using the right sealants, flashing, and protective coatings.

It is very important that the design should take into account the regional climate, including the temperature, humidity, rainfall, wind loads, and seismic activity. The ability of CSEB structures to withstand environmental stressors and preserve their durability over time is ensured by designing in accordance with regional climate parameters [13].

4.3.3 Maintenance

The long-term durability of Compressed Stabilized Earth Blocks (CSEB) buildings depends heavily on maintenance. Practices for routine and adequate maintenance might aid in preventing and resolving problems that might jeopardize the longevity of CSEB.

- Moisture Control: Maintaining effective moisture control is crucial for keeping CSEB durable. Water penetration and moisture-related damage to CSEB walls can be avoided with routine roof system, gutter, downspout, and drainage system inspections and repair. To avoid prolonged moisture exposure, leaks, cracks, or damaged waterproofing layers must be fixed as away.
- Surface Protection: Surface treatments or protective coatings that increase CSEB walls' resilience to weathering, moisture, and UV degradation may be beneficial. The durability of CSEB can be maintained through routine examination and upkeep of such coatings or surface treatments, including recoating or reapplication as necessary.
- Repair & Rehabilitation: In order to stop future degradation, it is crucial to promptly identify and fix any faults, cracks, or erosion in CSEB walls. The longevity and integrity of CSEB constructions can be restored with the use of proper repair methods, such as patching cracks with the right materials.
- Pest control: To prevent damage from pests, such as termites or rats, which might jeopardize the structural integrity and longevity of CSEB, regular inspections and the right pest control techniques are required. Implementing measures like termite barriers, baiting systems or soil treatment will help safeguard CSEB from pest-related problems.

- Structural Integrity: Regular structural inspections by trained experts can aid in spotting any indications of distress, settling, or instability in CSEB structures. Early detection and repair of structural problems can stop additional harm and guarantee the building's long-term stability.
- Cleaning and Upkeep of Surrounding Areas: Keeping the surrounding areas clean and in good shapes, such as by ensuring adequate drainage, clearing away trash, and managing vegetation, will assist avoid moisture buildup and shield the CSEB walls from potential harm [14].

Figure 11 : Improper maintenance of CSEB buildings

4.4 Environmental factors

As describe in earlier compressed stabilized earth blocks are created by combining soil, sand, and a stabilizer like cement or lime. Environmental conditions can have an impact on CSEB performance. It's important to keep in mind those local conditions, soil types, and construction methods can all affect the individual environmental elements and how they affect CSEBs. In order to ensure the long-term performance and longevity of CSEB structures, it is crucial to take these elements into account and alter construction approaches accordingly.

Soil composition: The strength and durability of CSEBs are substantially influenced by the kind and content of the soil used to create them. While sandy soils may need additional stabilizers, soils with a high clay concentration typically have greater binding qualities & investigates how design parameters affect the thermal resistance and conductivity of unfired clay bricks. When conducting the test, two distinct kinds of unfired clay bricks are used. In order to forecast the design thermal values of unfired clay masonry bricks, the measured thermal properties of the unfired clay bricks were compared to the design thermal properties of fired bricks. The findings show that unfired clay bricks can meet the design thermal specifications for clay masonry units, indicating that they can be utilized to build masonry structures that are energy efficient and affordable.

Moisture content: During the manufacturing and curing processes, the soil's moisture content is crucial. While insufficient moisture might prevent appropriate compaction and bonding, excessive moisture can cause shrinkage and breaking. Moisture content and thermal characteristics are correlated, with higher effective thermal conductivity and diffusivity being found. Thermal inertia is measured through phase shift and thermal damping, while theoretical analysis shows specific heat and thermal diffusivity [15].

Climate & weather condition: The current weather and climate have a big impact on how well CSEB performs and produces. The blocks' overall stability and the curing process can be impacted by extremes in temperature, humidity, and rainfall.

Temperature & humidity: Temperature and humidity changes might cause CSEBs to expand and shrink, which could cause cracking or disintegration. Both during manufacture and throughout building, it is crucial to take these elements into account.

Exposure to water: CSEBs need to be safeguarded against excessive moisture, such as prolonged water contact or submersion. The blocks can decay over time if they are exposed to water without the required waterproofing precautions [16].

Wind & seismic loads: Wind and seismic activity are two examples of environmental conditions that might put additional stress on CSEB buildings. To guarantee that the buildings can bear such loads, proper design considerations, including reinforcement and structural detailing, are required.

Vegetation & organic matters: Organic debris and plants can contribute to problems like decomposition, differential movement, and settlement in the soil used for CSEBs. It is crucial to get rid of organic matter or take the necessary precautions to stop it from decomposing.

UV exposure: UV radiation's impacts can cause CSEBs exposed to direct sunlight for lengthy periods of time to degrade. This problem can be reduced with the use of protective coatings or suitable finishes.

4.5 Cost effectiveness

Compressed Stabilized Earth Blocks are renowned for being more affordable than conventional building supplies. It's vital to remember that the cost-effectiveness of CSEBs might vary depending on elements including regional market conditions, raw material availability, manufacturing volume, and building methods used. However, CSEBs frequently provide a more affordable option to conventional building materials, especially in regions with a plentiful supply of raw resources and few expensive alternatives [1].

4.5.1 Raw material availability

Soil, sand, and a stabilizer like cement or lime are the main raw materials for CSEBs. These resources are frequently accessible close to home, which lowers costs for shipping and reliance on pricey imported parts.

The main component of CSEBs is soil, which should have suitable particle size distribution, clay content, and cohesion. Sand is added to the soil mixture to improve workability and reduce shrinkage. A stabilizer is added to the soil-sand mixture to enhance the strength and durability of CSEBs. Common stabilizers include cement, lime, or a combination of both. These stabilizers help bind the soil particles together, provide resistance to water damage, and improve the overall structural integrity of the blocks [1].

4.5.2 Low material cost

Materials used for CSEBs are often less expensive than more common building materials like bricks or concrete blocks. Sand and soil are widely available and reasonably priced, and the amount of stabilizer needed is minimal as compared to the volume of blocks that will be produced.

Other than the raw material (soil, sand & stabilizer) structural stability can be achieved with CSEBs without the requirement for significant reinforcing. Because the blocks themselves can support loads, there is no longer a need for extra reinforcement materials like steel, which further reduces the cost of the raw materials.

Because CSEBs can be dry-stacked, mortar is not usually necessary for installation. The ability to interlock or join the blocks with less mortar results in cost and mortar consumption reductions.

It is important to note that the actual material costs of CSEBs can vary depending on factors such as local market conditions, availability of raw materials, and the scale of production. However, overall, CSEBs are known for their cost-effectiveness due to the utilization of locally available materials and reduced reliance on expensive imported materials [17].

4.5.3 Labor efficiency

Depending on the volume of production, CSEBs can be made manually or with relatively simple technology. The dirt, sand, and stabilizer are mixed, the mixture is compacted into molds or presses, and the blocks are then cured. There is less need for highly skilled or trained labor due to how easily a variety of employees can participate in the production process. Manual manufacturing uses a workforce that is easily trainable in the procedure and doesn't demand a high level of technical knowledge. CSEBs are frequently larger than regular bricks, enabling faster manufacturing rates and higher worker productivity.

The possibility for skill development offered by CSEB manufacturing increases the labor force's construction knowledge and employability over time. CSEB scan be produced on-site, minimizing transportation requirements and associated costs.

4.5.4 Energy efficiency

Compression and stabilization of soil, sand, and a stabilizer like cement or lime are steps in the production of CSEBs. Compared to the manufacturing of materials like burned bricks or concrete blocks, which involves high-temperature firing or energy-intensive procedures, this approach uses substantially less energy. In the production process, CSEBs' lower embodied energy results in less energy use and a less environmental effect.

Because of the soil and air gaps inside the blocks, CSEBs naturally insulate heat. By effectively resisting heat flow, they can lessen the need for additional insulation materials. The insulating qualities of CSEBs help buildings use less energy by limiting heat transmission through the walls, which lowers the need for heating and cooling. This leads to reduced energy use and cost savings for heating and cooling systems

Because of their thermal bulk, CSEBs can absorb and release heat slowly. This can help with passive cooling in hot areas by absorbing heat during the day and gradually releasing it during cooler evenings, decreasing the demand for mechanical cooling systems. In colder areas, the thermal mass of CSEBs can aid in heat retention and reduce the demand for heating systems [17].

4.5.5 Construction speed

It is crucial to note that the actual building speed of CSEBs might vary based on factors such as project scale, availability of experienced labor, and the effectiveness of construction techniques used. However, as compared to traditional methods, the intrinsic qualities of CSEBs, such as greater block size, interlocking design, and simplified construction processes, contribute to speedier construction.

CSEBs are often larger in size compared to traditional bricks. This means that fewer blocks are required to cover a given area. Not only that CSEBs be designed with interlocking features, allowing them to fit together securely without the need for excessive mortar or adhesive. Therefore, the production and use of CSEBs can be simpler compared to other construction methods. Another advantage is CSEBs can be produced on-site or near the construction site, reducing transportation time and delays associated with sourcing materials from external suppliers.

4.5.6 Thermal performance

The thermal performance of Compressed Stabilized Earth Blocks can contribute to cost savings in several ways.

- Reduced Heating and Cooling Costs: Because of the soil and air pockets within the blocks, CSEBs have natural thermal insulation capabilities. This insulation aids in the reduction of heat transfer through the walls, reducing the demand for mechanical heating and cooling systems. As a result, buildings built with CSEBs may consume less energy and have lower utility bills for heating and cooling.

- Reduced Reliance on Additional Insulation: Because CSEBs have intrinsic insulation qualities, they can reduce the requirement for additional insulation materials. Traditional building methods frequently necessitate the use of exterior insulating layers, which can raise the overall cost of the structure. The insulating features of CSEBs are already built into the blocks, potentially saving money on the expense of obtaining and installing separate insulation materials.

- Long-Term Energy Savings: Because of their thermal bulk, CSEBs may absorb and release heat slowly. This can aid in temperature regulation and eliminate the need for frequent heating or cooling adjustments. Buildings designed with CSEBs can realize long-term energy savings and lower operating costs by keeping more stable internal temperatures.

- Occupant Satisfaction and Comfort: The insulating properties of CSEBs lead to better thermal comfort within the building. The blocks aid in temperature regulation, resulting in a more pleasant indoor atmosphere. As a result, tenant happiness and well-being may improve [15].

4.6 Sustainability

The goal of sustainable development is to raise everyone's standard of living without harming the environment, and use natural resources beyond what nature can sustainably provide.

Sustainable development is defined as "development that satisfies current needs without compromising the ability of future generations to satisfy their own needs."
This means that it is important to take care not to deplete the available resources to the point that future generations are unable to meet their own demands when raising the standard of living of residents in a community by building infrastructure.

Compressed Stabilized Earth Blocks are a type of sustainable building material constructed of a combination of sand, cement, and earth. CSEB is connected to a number of environmental issues, both in terms of how it is produced and how it affects the environment [18].

Use of natural materials: Sand and soil are the two basic raw materials needed to produce CSEB. The environmental effects of obtaining these materials, such as soil erosion, habitat destruction, and the depletion of natural resources, must be taken into account. Sustainable techniques, such as careful soil extraction from authorized locations, can help allay these worries.

Low energy consumption: The earth and sand mixture must be compressed and stabilized during the CSEB manufacturing process. Energy consumption can vary based on the production techniques used. Energy-saving methods, alternative energy sources, or process optimization can all serve to lessen the impact that energy use has on the environment.

Carbon emission: Due to the calcination process employed in its manufacturing, cement, which is frequently utilized as a stabilizing agent in the production of CSEB, is a substantial source of carbon dioxide (CO_2) emissions. Emissions of CO_2 are a factor in global warming. In order to reduce the carbon footprint of CSEB production, it is crucial to look into solutions for lowering cement content or employing different stabilizing agents.

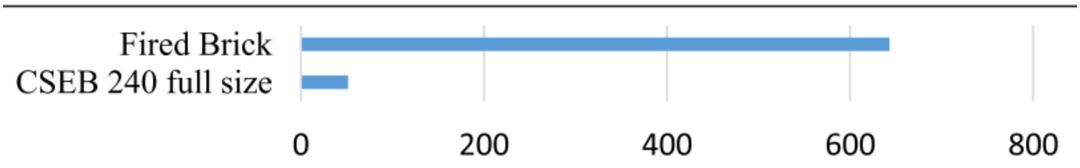

Figure 12 : CO2 emission (Kg of CO_2/m^3) comparison (fired brick/ CSEB) *[19]*

Water usage: Water is necessary for mixing and curing throughout the CSEB manufacturing process. Recyclable water uses and other sustainable water management techniques can assist cut water consumption and ease the burden on nearby water supplies.

Reduce waste: To handle any byproducts or leftover materials during CSEB manufacture, proper waste management is essential. Utilizing recycling and reuse techniques can reduce waste production and advance a circular economy strategy.

Transport & logistic: Moving CSEB between production and construction sites can have an impact on the environment in terms of fuel use, greenhouse gas emissions, and traffic congestion. The environmental impact of transportation can be minimized through effective logistics planning, the use of eco-friendly transportation techniques, and the encouragement of local production.

Building efficiency: As a building material, CSEB has various advantages for the environment. It has effective thermal characteristics, acting as natural insulation and obviating the need for power-hungry heating and cooling equipment. In addition, when compared to other materials like burned bricks or concrete blocks, CSEB may have a low embodied energy.

As a summary, it is crucial to take into account the entire life cycle of the material, including its manufacture, use, and disposal, in order to accurately analyze the environmental impact of CSEB. The use of CSEB as an environmentally friendly building option can be facilitated by sustainable practices, alternative materials, and cutting-edge technologies [20].

4.7 Other types of compressed stabilized earth blocks

Compressed Stabilized Earth Blocks are a type of building material composed of soil, stabilizers, and water. The composition of the mixture and the manner of preparation can influence the specific types of CSEBs. It should be noted that the availability and applicability of various types of CSEBs can vary depending on local soil composition, climate circumstances, and construction requirements. The selection of CSEB type should be based on careful consideration of criteria such as cost, material availability, and desirable structural qualities [21].

4.7.1 Lime-stabilized earth blocks (LSEB)

These CSEBs contain lime as a stabilizer. Lime stabilization improves soil workability and contributes to the strength and durability of the blocks. Lime-stabilized blocks are often utilized in areas where lime is abundant. LSEBs are frequently utilized in low-cost housing projects, particularly in places where resources such as cement are expensive or scarce. Lime stabilization gives the blocks essential strength and durability, allowing them to be used to create cheap houses and structures.

LSEBs also offer outstanding thermal characteristics. They have strong thermal insulation and can maintain pleasant indoor temperatures in both hot and cold climes. This decreases reliance on heating and cooling systems, resulting in energy savings and enhanced occupant comfort. LSEBs are used in a variety of building applications. They can be used to build load-bearing walls, non-load-bearing walls, partitions, and even arches and vaulted buildings. LSEBs are easily cut, shaped, and linked, allowing for design and construction flexibility [21].

4.7.2 Fly-ash stabilized earth blocks (FASEB)

Fly ash, a byproduct of coal-fired power plants, can be utilized in CSEBs as a stabilizer. By employing a waste material, fly ash stabilization improves the compressive strength of the blocks. Fly ash-stabilized earth blocks (FASEBs) have significant advantages and are used in a variety of construction applications. By employing fly ash, a byproduct of coal-fired power plants, FASEBs contribute to sustainable construction techniques.

FASEBs assist reduce the environmental impact of fly ash disposal and the consumption of typical building materials by using fly ash as a stabilizer. Fly ash is a pozzolanic substance that, when combined with lime and water, forms a cementitious compound. This reaction increases FASEBs' strength and durability, making them appropriate for load-bearing walls and constructions. FASEBs, like other earth blocks, have good thermal insulation qualities. They aid with temperature regulation, decreasing the need for artificial heating and cooling and helping to energy efficiency. The use of fly ash in the stabilizing process improves FASEB fire resistance. The pozzolanic process produces a denser and more heat-resistant substance, making FASEBs less flammable.

The utilization of fly ash in FASEBs helps reduce the carbon footprint of construction projects. By diverting fly ash from landfills and replacing a portion of cement, FASEBs contribute to the reduction of greenhouse gas emissions associated with cement production [22] [23].

4.7.3 Bitumen stabilized earth blocks (BSEB)

To create CSEBs, bitumen, a petroleum-based binder, can be added to the soil mixture. Bitumen stabilization improves the water resistance and strength of the blocks. The addition of bitumen to the soil mixture gives good water resistance to Bitumen stabilized earth blocks. As a result, they are appropriate for building in places with high rainfall, flood-prone zones, or when the water table is close to the surface.

BSEBs are frequently utilized in rural road and walkway building. The water resistance of BSEBs aids in the prevention of damage caused by water infiltration and subsequent road surface deterioration. In road construction, BSEBs can be utilized for both sub-base and base layers. BSEBs have a wide range of uses in construction, including load-bearing walls, non-load-bearing walls, and foundations.

They are easily cut, shaped, and linked, allowing for design and construction flexibility. Bitumen incorporation in the stabilization process increases BSEB strength and durability, making them resistant to weathering, erosion, and degradation over time. This ensures the durability of structures constructed with BSEBs [21].

4.7.4 Polymer stabilized earth blocks (PSEB)

Polymers can be employed as CSEB stabilizers. Polymer stabilization increases the strength of the blocks while decreasing water absorption, resulting in increased durability and weather resistance. Polymer-stabilized earth blocks have various advantages and are used in a variety of building applications. Polymers used as stabilizers improve the compressive strength and durability of PSEBs.

This makes them appropriate for load-bearing walls and constructions, with more structural integrity than ordinary earth blocks. PSEBs can use waste plastic materials by adding polymers, contributing to waste reduction and recycling activities. PSEBs also reduce the need for traditional building materials, resulting in a lower environmental imprint and promoting sustainable construction methods [24].

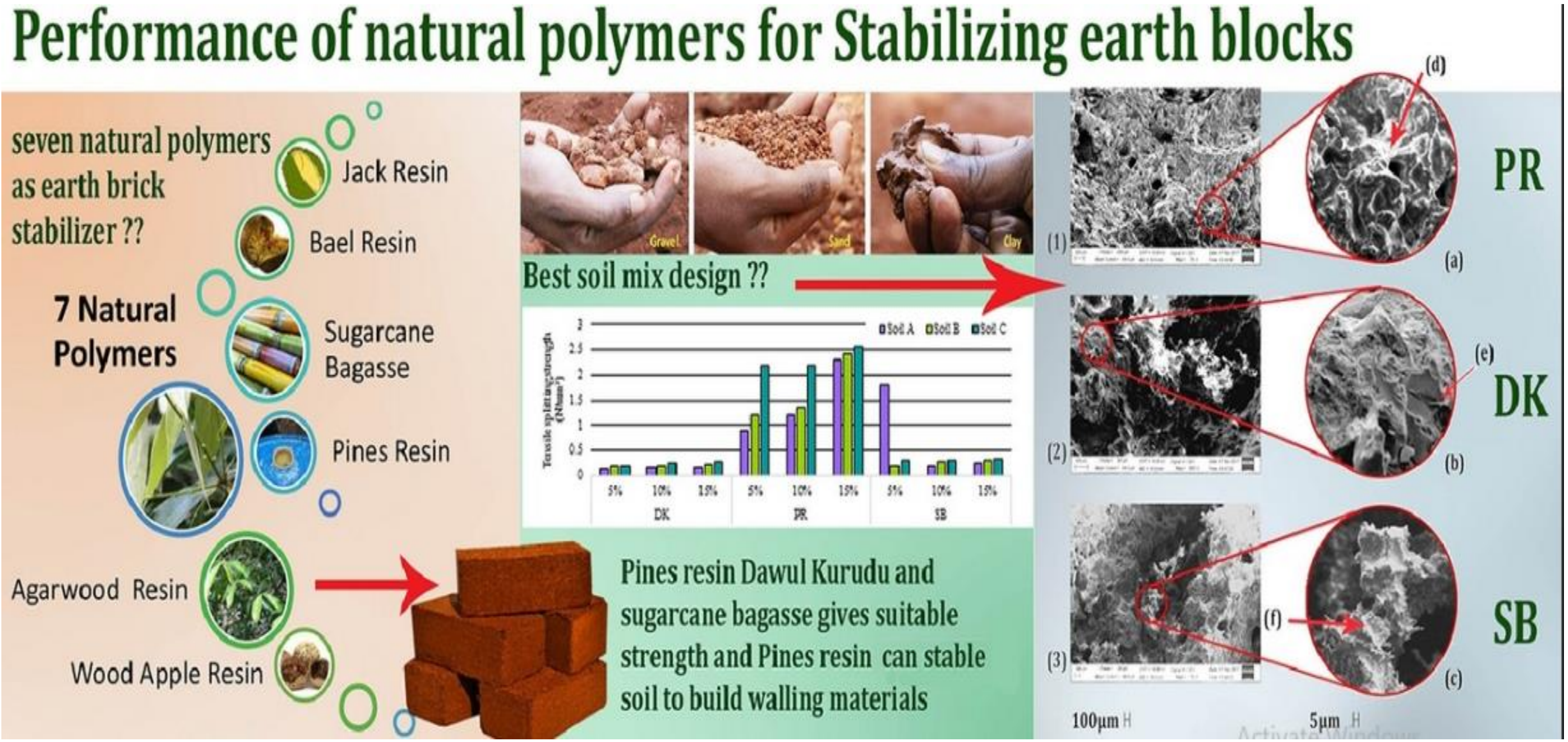

Figure 13 : Natural polymers for stabilizing earth blocks

CHAPTER 5

5. COMPARATIVE PERFORMANCE ASSESSMENT OF COMPRESSED STABILIZED EARTH BLOCKS WITH CONVENTIONAL MATERIALS

Compressed stabilized earth blocks (CSEBs) are made by compressing a mixture of soil, sand, and stabilizers & other components, such as cement or lime, polymer, bitumen, fly-ash. Soil compressed stabilized earth blocks are made by compressing a mixture of soil and stabilizers such as cement or lime. The difference between soil compressed stabilized earth blocks and other types of CSEBs is that soil compressed stabilized earth blocks are made only with soil and stabilizers while other types of CSEBs are made with soil, sand, and stabilizers. Because of the availability of raw material, it's easy to produced soil stabilized earth blocks. In this project mainly target on Soil stabilized earth blocks.

5.1 Compressive strength

The compressive strength of building materials can vary depending on factors such as the composition of the material, manufacturing process, and curing conditions.

Bricks: Bricks typically have compressive strengths ranging from 5 MPa (megapascals) to 50 MPa. Common clay bricks have compressive strengths between 5 MPa and 15 MPa, while engineering bricks or high-strength bricks can have compressive strengths exceeding 50 MPa.

Cement Blocks/Concrete Blocks: Concrete blocks, also known as cement blocks or concrete masonry units (CMUs), have compressive strengths ranging from 3 MPa to 8 MPa. The strength can vary based on factors such as the ratio of cement to aggregate, type of aggregate used, and curing conditions [25].

Compressed Stabilized Earth Blocks: The compressive strength of CSEBs can vary depending on the composition of the mixture, stabilizers used, and the manufacturing process. Generally, CSEBs have compressive strengths ranging from 2 MPa to 10 MPa. However, with appropriate soil selection, stabilization techniques, and quality control measures, it is possible to achieve higher compressive strengths for CSEBs.

5.2 Thermal conductivity & thermal mass

Building materials' thermal conductivity determines their ability to conduct heat. Lower thermal conductivity levels indicate better insulation.

Bricks: The thermal conductivity of bricks can vary depending on their composition and density. Generally, common clay bricks have thermal conductivity values ranging from 0.6 W/m·K to 1.2 W/m·K. However, high-density or specially designed bricks can have lower thermal conductivity values.

Bricks, particularly those formed of burnt clay, have a moderate thermal mass. Because of their thick composition, they may collect and retain heat throughout the day and slowly release it during cooler periods, so adding to thermal comfort and temperature regulation. However, as compared to materials such as concrete and earth-based blocks, bricks have a lower thermal mass.

Cement Blocks/Concrete Blocks: Concrete blocks typically have higher thermal conductivity compared to bricks. The thermal conductivity of concrete blocks ranges from 0.5 W/m·K to 1.5 W/m·K. The values can vary depending on factors such as the density, aggregate type, and insulation properties of the blocks.

Cement blocks, which are constructed of cement, aggregates, and water, have a larger thermal mass than burnt clay bricks. Concrete blocks are denser and may hold more heat. They may collect heat during the day and gently release it at night, helping to keep indoor temperatures stable. Cement blocks' larger thermal mass can help to improve thermal comfort and energy efficiency.

Compressed Stabilized Earth Blocks: The thermal conductivity of CSEBs can vary depending on the composition of the mixture and the presence of stabilizers. Generally, CSEBs exhibit lower thermal conductivity compared to bricks and concrete blocks. The thermal conductivity of CSEBs typically ranges from 0.3 W/m·K to 0.8 W/m·K. However, this can vary based on factors such as the soil composition, stabilizer type, and density of the blocks.

CSEBs with good thermal mass qualities are produced from soil, sand, and a stabilizer such as cement or lime. The soil and stabilizer combination provides suitable density and heat storage capacity. CSEBs may collect and store heat during the day and slowly release it at night, improving thermal comfort and decreasing temperature variations within the building. Because of their earth-based composition, CSEBs are a great choice for achieving appropriate thermal mass properties.

5.3 Durability

The durability of building materials such as bricks, cement blocks, and CSEBs can vary based on various factors.

Bricks: Bricks are noted for their long lifespan and toughness. Bricks, when correctly constructed and laid, can survive weathering impacts such as temperature changes, moisture, and chemical exposure. High-quality bricks have a long track record of durability.

Cement Blocks/Concrete Blocks: Cement blocks are known for their strength and durability. They are resistant to weathering, moisture, and chemical exposure, making them excellent for a wide range of building applications.

Compressed Stabilized Earth Blocks: The durability of CSEBs varies depending on soil composition, stabilizer type, and production procedures. When correctly made using appropriate stabilizing procedures and quality control systems, CSEBs can have a long life.

5.4 Environmental factors & sustainability

Several considerations must be addressed when evaluating the environmental factors of bricks, cement blocks, and compressed stabilized earth blocks.

Bricks: Bricks made up mainly of clay, a natural and abundant resource available in many areas. The extraction of clay has a low environmental impact. Brick production entails molding and heating clay in kilns. The fire process necessitates high temperatures, which consumes a lot of energy and contributes to greenhouse gas emissions. Because of the energy-intensive firing process and shipping needs, bricks have a comparatively high embodied energy.

Brick production, particularly the fire process, adds to CO_2 emissions and has a large carbon footprint. Brick debris from manufacture and building can be recycled and repurposed in a variety of uses.

Cement Blocks/Concrete Blocks: Cement blocks necessitate the use of cement, sand, gravel, and water. Cement manufacture necessitates the mining of limestone and other raw materials, which can have serious environmental consequences such as habitat disturbance and carbon emissions. Cement block manufacturing begins with the mixing of cement, sand, gravel, and water, followed by curing.

Cement production is an energy-intensive process that emits significant amounts of carbon dioxide (CO_2) during the manufacturing process. Because of the energy-intensive cement production process, transportation, and manufacturing, cement blocks have a high embodied energy. Because cement manufacture contributes significantly to global CO_2 emissions, cement blocks have a comparatively high carbon footprint. Although the recycling procedure can be difficult due to the presence of reinforcement, concrete block waste can be crushed and utilized as aggregate in new concrete or road building.

Compressed Stabilized Earth Blocks: Soil is used to make CSEBs, which is a commonly available and renewable material. The use of soil as a building material lowers the requirement for nonrenewable resources to be extracted. SEBs are created by compacting and stabilizing soil using cement, lime, fly ash, or polymers.

When compared to brick or cement block manufacture, the manufacturing process often requires less energy and produces fewer emissions. Because of its reduced embodied energy and the potential use of stabilizers with fewer environmental impact, CSEBs often have a lower carbon footprint than bricks and cement blocks. After demolition, CSEBs can be reused or repurposed, contributing to reduced waste generation and resource conservation.

Table 2: Sustainability and environmental friendliness of CSEB [26]

SUSTAINABILITY AND ENVIRONMENTAL FRIENDLINESS OF CSEB	
• Earth is a local material and the soil should preferably be extracted from the site itself or not transported too far away	
• Earth construction is a labor-intensive technology and it is an easily adaptable and transferable technology	
• It is a cost and energy effective material.	
• It is much less energy consuming than country fired bricks (about 4 times less).	
• It is much less polluting than country fired bricks (about 4 times less).	
INITIAL POLLUTION EMISSION (Kg of CO_2) PER M^3 OF WALL	**POLLUTION EMISSION (Kg of CO_2) PER M^3 OF WALL**
CSEB wall = 631 MJ / m^3	CSEB wall = 56.79 Kg / m^3
Kiln Fired Brick (KFB) = 2,356 MJ / m^3	Kiln Fired Brick (KFB) = 230.06 Kg / m^3
Country Fired Brick (CFB) = 6,358 MJ / m^3	Country Fired Brick (CFB) = 547.30 Kg / m^3
Note: Kiln fired bricks are often called wire cut bricks	

Table 3: Energy effectiveness [27]

ENERGY EFFECTIVENESS	
Initial embodied energy (MJ/m^3 of materials)	**Carbon emission (Kg of CO_2 /m^3 of materials)**
CSEB are consuming 11 times less energy than country fired bricks:	CSEB are polluting 13 times less than country fired bricks:
CSEB produced on site with 5 % cement = 548.32 MJ/m^3	CSEB produced on site with 5 % cement = 49.37 Kg of CO_2 /m^3
Country fired bricks = 6,122.54 MJ/m^3	Country fired bricks = 642.87 Kg of CO_2 /m^3

5.5 Cost effectiveness

Bricks: Because of the costs of raw materials, manufacturing procedures, and transportation, bricks are frequently more expensive than other building materials. Cement blocks, bricks, and CSEBs: The labor cost involved with building with these materials might vary depending on factors such as design intricacy, project size, and local labor rates.

In general, labor costs for CSEB construction may be lower than for bricks or cement blocks because to their bigger size and simpler installation technique. Bricks are noted for their durability and low maintenance requirements. They can be used for numerous decades without damage.

Cement Blocks/Concrete Blocks: Cement blocks are typically less expensive than bricks since the raw ingredients (cement, sand, gravel) are more easily available and less expensive. Cement blocks are very long-lasting and require little maintenance. They have the potential to last as long as bricks.

Compressed Stabilized Earth Blocks: Because they are mostly made of soil, which is generally available and inexpensive, CSEBs can be cost-effective. The cost, however, may vary based on the precise soil type and stabilizer utilized. The longevity of CSEBs might vary based on factors such as soil composition, stabilizer utilized, and manufacturing quality control methods. CSEBs can have a decent lifespan with correct building techniques and maintenance [1].

5.6 Advantages of compressed stabilized earth blocks usage for school buildings

The usage of compressed stabilized earth blocks for school buildings offers several advantages.

Cost effectiveness: Because CSEBs are often produced from locally available soil, material prices can be greatly reduced when compared to traditional building materials such as bricks or cement blocks. The cost savings are especially advantageous for educational institutions with limited budgets.

Sustainability: CSEBs utilize soil, a natural and renewable resource, as the primary material. By reducing the reliance on non-renewable resources, CSEBs contribute to sustainable construction practices. Additionally, the lower embodied energy and carbon footprint of CSEBs compared to other materials make them an environmentally friendly choice.

Local availability & community involvement: CSEBs can be created utilizing soil from the construction sites near neighborhood, lowering transportation costs and associated environmental concerns. This method also encourages community participation in the construction process, which fosters a sense of ownership and pride in the school building.

Energy efficiency: CSEBs offer good thermal mass properties, helping to regulate indoor temperatures. This can reduce the reliance on artificial heating and cooling systems, leading to energy savings and improved comfort for students and staff.

Acoustic insulation: CSEBs have the potential to provide good acoustic insulation, reducing noise transmission from outside sources or between different areas within the school building. This can create a conducive learning environment by minimizing distractions and improving concentration.

Durability & safety: Properly manufactured CSEBs can have excellent durability and structural strength. They can withstand seismic forces and provide resistance against fire, contributing to the safety and longevity of school buildings.

Educational opportunities: Constructing school buildings using CSEBs can offer educational opportunities for students and the local community. It provides hands-on experience in sustainable construction practices and promotes awareness of environmentally friendly building materials.

Aesthetics & design flexibility: CSEBs can be designed and customized to create aesthetically pleasing school buildings. They offer design flexibility, allowing for various architectural styles and the incorporation of unique features [21].

5.7 Disadvantages of compressed stabilized earth blocks usage for school buildings and solutions

- **Limited structural strength:** CSEBs may have inferior structural strength as compared to typical concrete or steel structures. This could limit the school buildings' height and overall design freedom.

Solution: Building multi-story or large-span structures with CSEBs may necessitate additional reinforcing and engineering knowledge.

- **Moisture sensitivity:** Earth-based materials, such as CSEBs, are vulnerable to moisture degradation. If the blocks are not adequately protected from excessive moisture, they may degrade and cause structural difficulties.

Solution: To prevent moisture-related difficulties, adequate measures such as waterproofing and proper drainage systems must be adopted.

- **Limited availability and skilled labor:** The manufacture of CSEBs necessitates the use of specialized equipment and processes. The availability of machinery and skilled manpower for CSEB manufacture may be limited in some places. This can increase construction expenses and cause delays.

Solution: Training and capacity-building programs may be required to ensure a skilled staff in CSEB construction.

- **Quality control issues:** It can be difficult to maintain consistent quality control during the fabrication of CSEBs. The strength and durability of the blocks can be affected by changes in soil content, curing period, and compression techniques.

Solution: To maintain the dependability and lifespan of CSEB structures, strict quality control techniques and regular testing are required.

- **Perceived social status:** There may be a notion in some communities that earth-based construction is inferior to modern building materials such as concrete or steel. This perception may influence community members', students', and parents' acceptance and desirability of CSEB school buildings.

Solution: Such biases might be eliminated by public awareness campaigns and educational activities.

- **Fire resistance:** CSEBs have poorer fire resistance than materials such as concrete or steel.

Solution: Additional fire protection measures may be required to maintain the safety of CSEB school buildings in locations prone to wildfires or with rigorous fire safety standards.

- **Long-term maintenance:** CSEB constructions may necessitate routine maintenance and repair to address issues such as erosion, cracking, or settling.

Solution: To ensure the sustainability and lifespan of the school buildings, adequate provisions for ongoing maintenance should be addressed [20] [21].

CHAPTER 6

6. COMPARAYIVE PERFORMANCE ANALYSIS ON ENERGY, & COMPRESSIVE STRENGTH

Using software (Revit & HAP) tools to evaluate and optimize several aspects of building design and operation to lower energy consumption and enhance overall performance is known as modeling and simulation for energy-efficient buildings.

Figure 14 : Modeled building for the design – Mahanama College, Colombo 03

6.1 Analysis on energy

6.1.1 Establish the project's aims and objectives.

Establish the aims and objectives of your energy-efficient building project in explicit terms first. Establish the sustainability objectives, intended energy efficiency targets, and any performance standards hope to meet.

Plans for the building's energy systems and services include crucial decision factors that might affect the energy performance of the building throughout the engineering design phase.

A newly constructed Four stored multipurpose school building (Proposed four storied building with library, ordinary science labs, aesthetic unit, cafeteria and special education unit at Mahanama college, Colombo 03.) in Colombo district has the above facilities. The school building can accommodate 480 people at a time and is in the coastal area in western province. As the school building is an educational unit, it is required to maintain the internationally accepted thermal comfort levels in the classroom areas, 25°C DBT and 50% RH respectively. A schematic plan of the school building is shown in Figure Ground floor, first floor, second floor & third floor plans. The building will be operated from 7.30am – 1.30pm during the weekdays.

(Architectural drawings attached as annex 01)

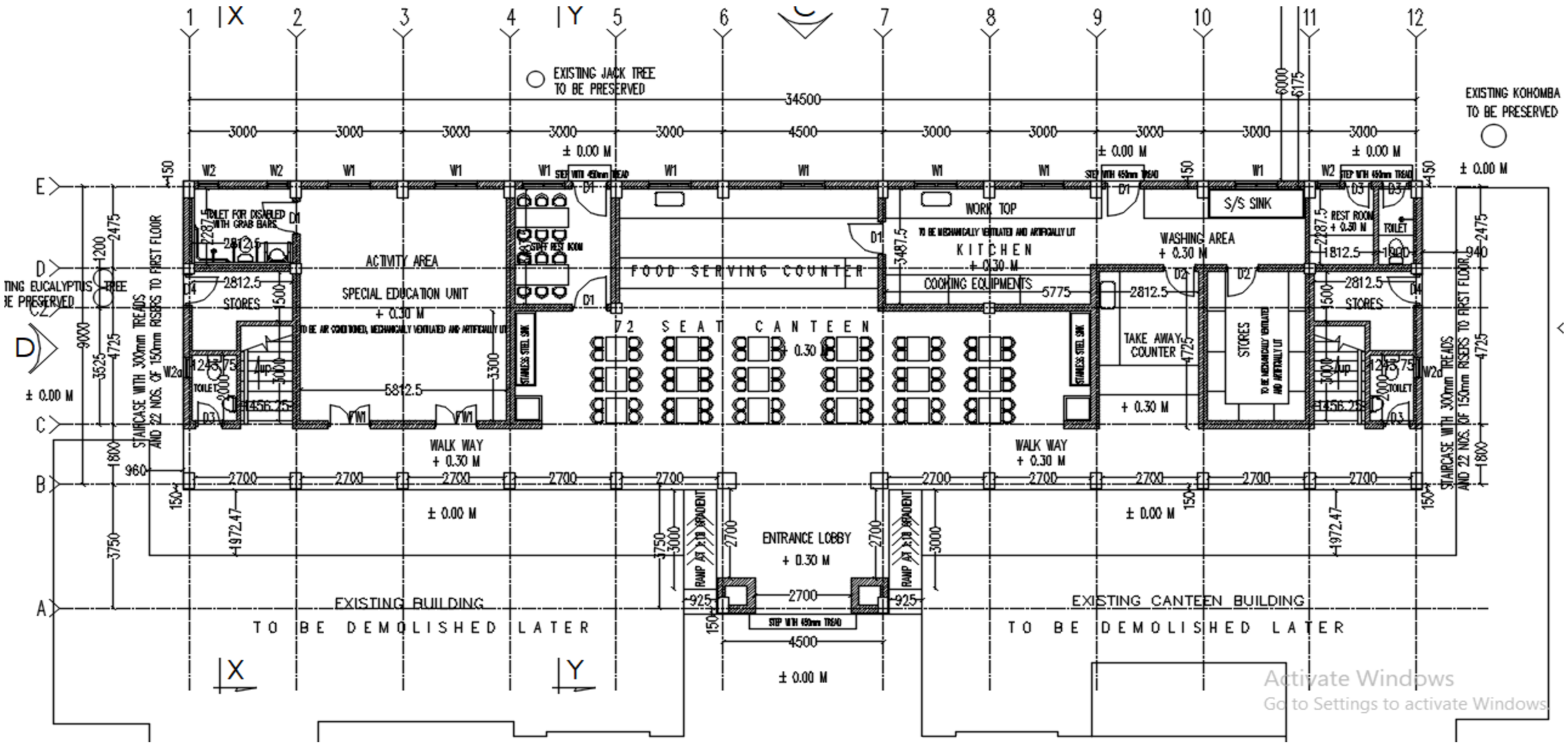

Figure 15 : Ground floor plan – Mahanama college, Colombo 03.

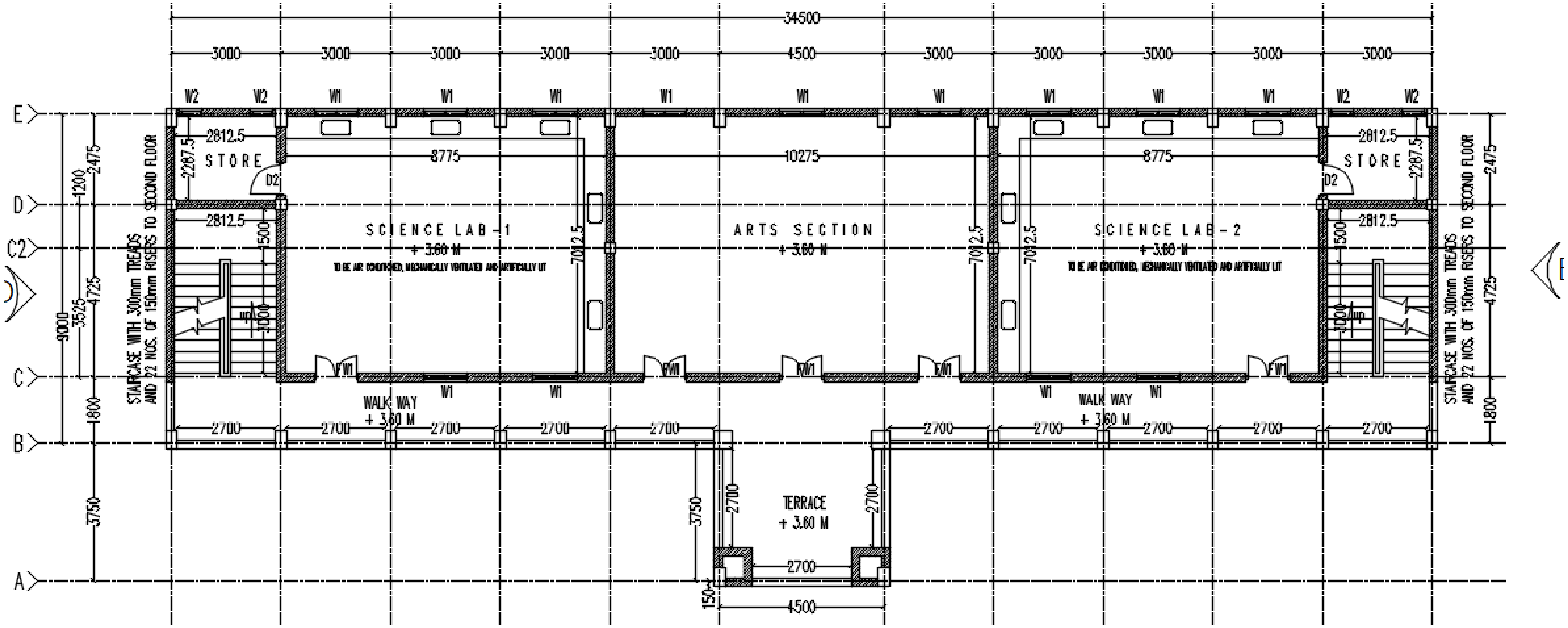

Figure 16 : First floor plan – Mahanama college, Colombo 03.

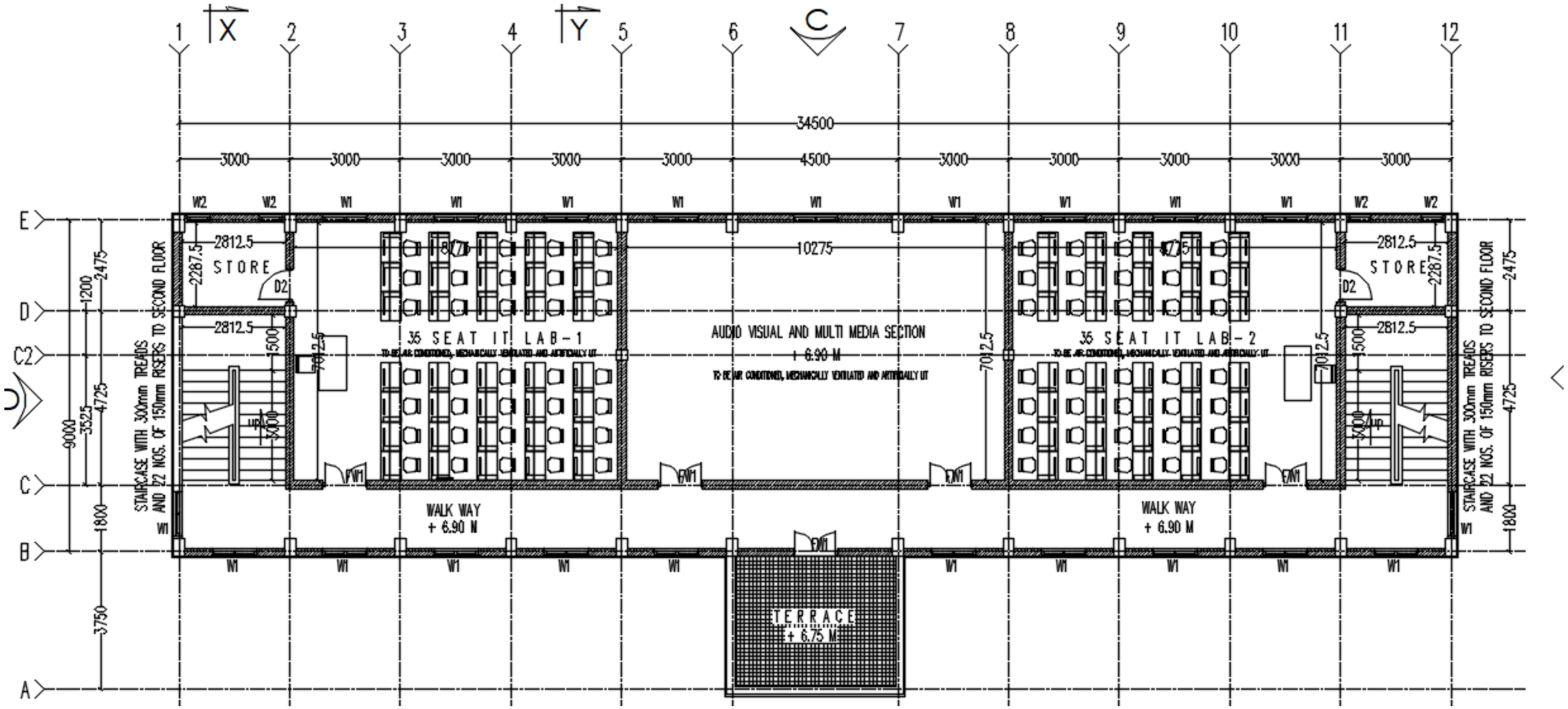

Figure 17 : Second floor plan – Mahanama college, Colombo 03.

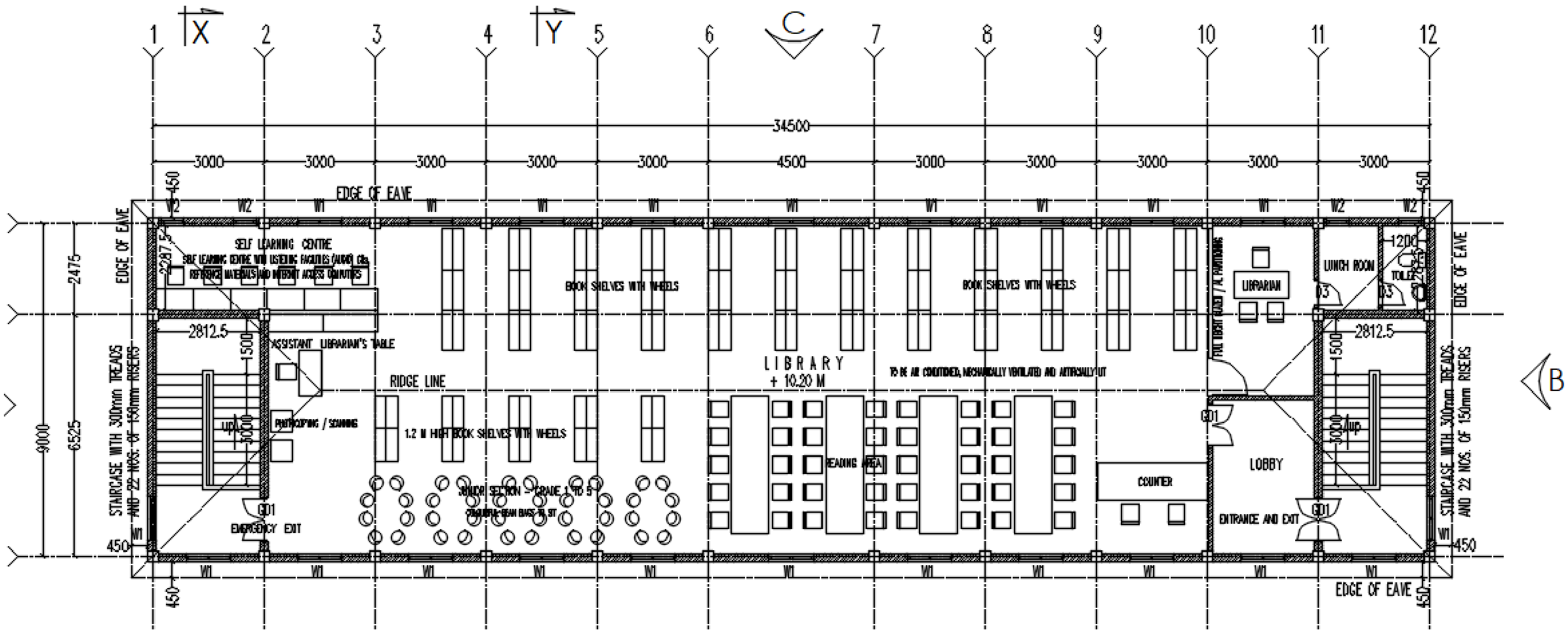

Figure 18 : Thid floor plan – Mahanama college, Colombo 03.

6.1.2 Gather building data.

For the comparative performance analysis, here considered fire clay bricks, cement blocks & compressed stabilized earth blocks as walling material of the designed building and the thickness of the wall is 225mm & 112.5mm.

The main government organization in Sri Lanka in charge of keeping an eye on the weather and offering meteorological services, climate data, and predictions is the Department of Meteorology. They provide historical weather data for research, energy analysis, and climate studies, among other uses. The required weather details such as monthly average temperature & humidity obtained from Department of Meteorology. (weather data attached as annex 02)

Telephones:
Director General 2694104
General Office 2694846, 2694847, 2681647, 2675946
Fax 2698311, 2691443

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வளிமண்டலவியல் திணைக்களம்
DEPARTMENT OF METEOROLOGY

My No. Com/CR/202
Your No.
Website www.meteo.gov.l
E-mail meteo@sltnet.lk

Bauddhaloka Mawatha, Colombo 07, Sri Lanka.

Monthly Mean Maximum Temperature at Colombo – January 2022 to March 2024

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2022	32.2	32.1	32.4	31.8	31.0	30.7	30.5	30.0	30.3	29.9	30.7	30.4
2023	31.0	31.5	32.0	32.3	31.7	31.3	30.7	31.6	30.2	30.3	31.3	31.8
2024	31.9	33.5	33.2									

Values in Celsius

Monthly Mean Minimum Temperature at Colombo – January 2022 to March 2024

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2022	23.9	24.1	25.9	25.3	26.4	26.6	26.3	26.1	26.1	25.1	24.3	23.7
2023	23.2	24.1	24.6	25.3	26.3	26.7	26.7	27.0	24.9	24.6	24.6	24.7
2024	24.4	25.3	26.3									

Figure 19 : Weather details obtained from Department of Meteorology for Colombo.

Project Management Unit (PMU) of the Ministry of Education in Sri Lanka, plays a key role in education infrastructure. All designed drawings & other related details such as bills of quantities, Architectural design & MEP design received from Ministry of education.

6.1.3 Using software for energy consumption of the building

HVAC (heating, ventilation, and air conditioning) system maker Carrier Corporation developed software known as HAP (Hourly Analysis Program). HAP software was developed to precisely calculate the heating and cooling loads for commercial buildings. It helps engineers and designers to accurately evaluate and improve HVAC system designs to meet the comfort and energy efficiency goals of a building.

With HAP software, the heating and cooling loads for various sections inside a building may be precisely computed. It considers several factors, such as the structure's orientation, external characteristics, internal heat gains, occupancy schedules, and climatic data, to accurately predict the thermal loads of the building.

To evaluate HVAC systems' energy consumption throughout a range of operating conditions, HAP.

Type of Air conditioner used for the energy calculation: **Daikin Split Air conditioners.** (Daikin split air conditioner catalogue attached as annex 03)

Daikin's split and multi-split air conditioning systems offer outstanding comfort, energy efficiency, and performance in stylish solutions that complement any decor or way of life. Numerous goods employ Daikin technology to cut costs and their impact on the environment.

Benefits

1. Personal Command

If required, each indoor unit may be turned on separately to supply only the specified rooms with comfortable air.

2. Cost and Energy Savings

Contemporary inverter and heat pump technologies reduce costs and boost efficiency while conserving energy.

3. Adaptable setup

Daikin's compact split/multi-split air conditioners are easy to install in small spaces or residences.

4. Vast array of items

It is feasible to match performance and elegance to any interior area with a variety of models.

6.1.4 Building system data

Heating, Ventilation, and Air Conditioning (HVAC)

Type of cooling system – Split system

Type of ventilation system – Natural

Lighting

Types of lighting fixtures – Recessed unvented down lights

6.1.5 Calculation of thermal resistance in 225mm thick fire clay bricks, 200mm cement blocks & compressed stabilized earth blocks.

6.1.5.1 Thermal resistance calculation for 225mm thick brick walls

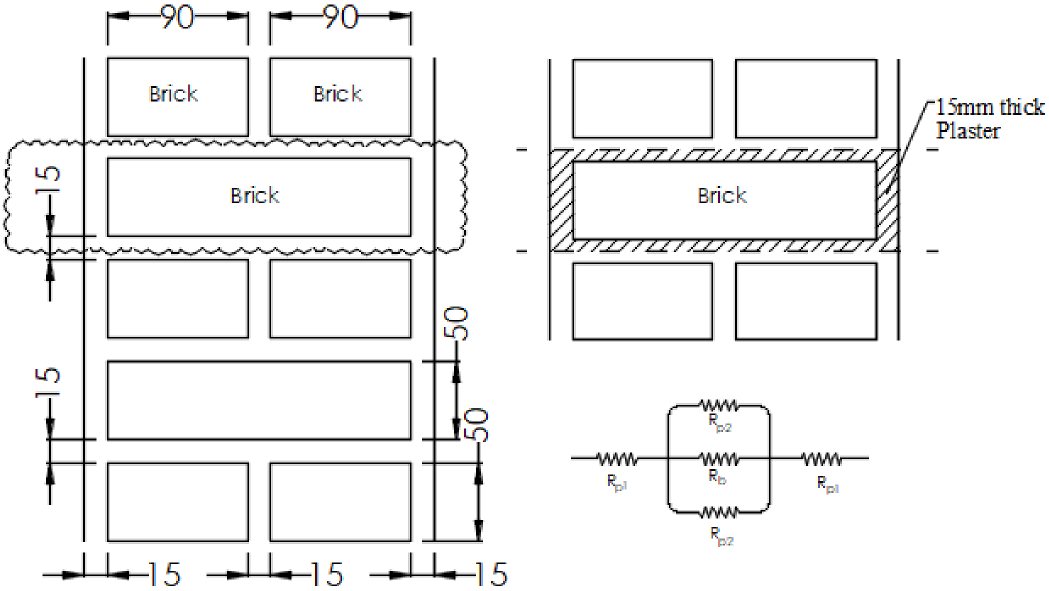

Figure 20 : Details of a cross section – 225mm thick brick wall

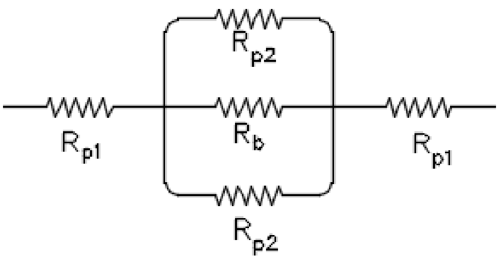

Figure 21 : Details of a cross section – 225mm thick brick wall

Where the thermal resistance represents as

R_{p1} – Outer plaster layer
R_{p2}– Bonding mortar layer
R_b – Brick layer

Thermal conductivity values (average) as follows: [28]

$K_{plaster}$ = 0.5 W/mK

K_{brick} = 0.75 W/mK

Average density = 1700 kg/m^3

$$R = L/_{KA} \qquad \text{Eq. 1}$$

Where R – Thermal resistance

L - Thickness of the layer

K - Thermal conductivity of the material

A - Cross sectional area

Take 1m length strip for the calculation.

$$R_{p1} = 0.015/_{(0.5 \times 0.03 \times 1)} = 1.0\ m^2K/W$$

$$R_{p2} = 0.15/_{(0.5 \times 0.0075 \times 1)} = 40.0\ m^2K/W$$

$$R_b = 0.205/_{(0.75 \times 0.05 \times 1)} = 5.47\ m^2K/W$$

$$R_{com} = 1/_{R_{p2}} + 1/_{R_b} + 1/_{R_{p2}}$$

$$R_{com} = 1/_{40} + 1/_{5.47} + 1/_{40} = 0.233\ m^2K/W$$

$$R_{Total} = R_{p1} + R_{com} + R_{p2}$$

$$R_{Total} = 1 + 0.233 + 1 = 2.233 m^2K/W$$

Total thermal resistance for 225mm thick brick wall is **2.233 m^2.K/W**

6.1.5.2 Thermal resistance calculation for 200mm thick cement block walls

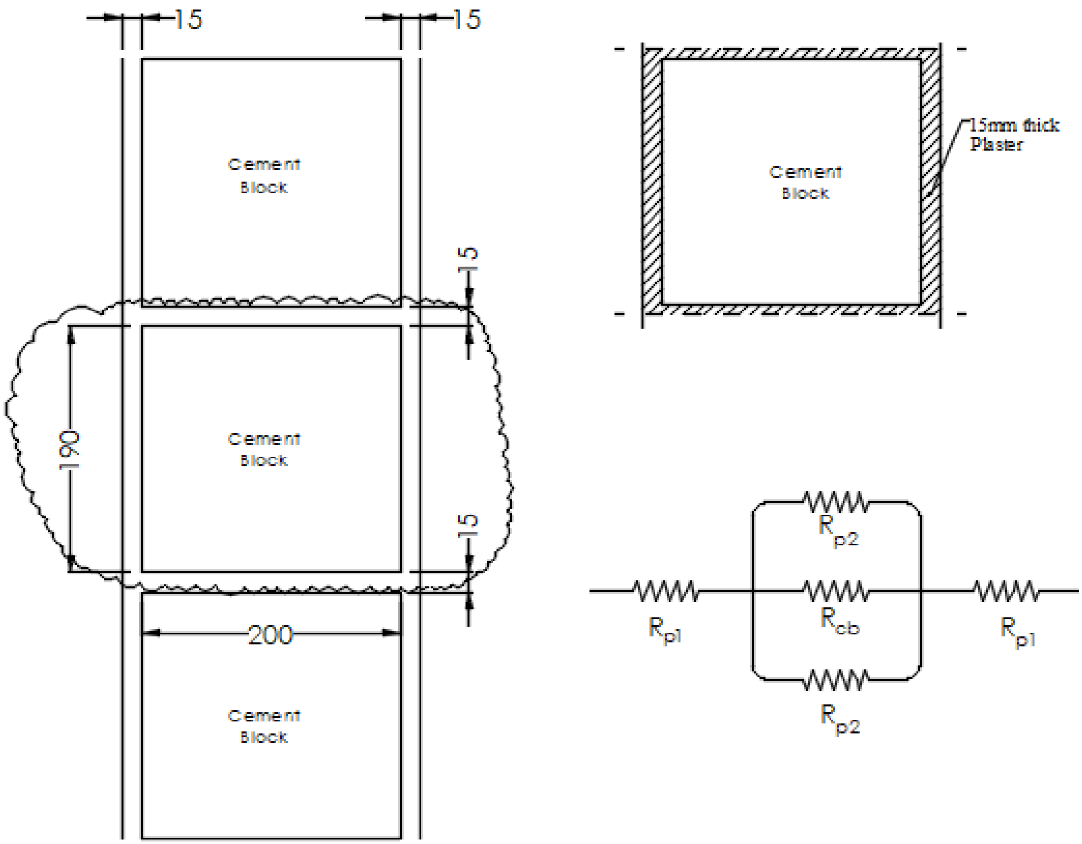

Figure 22 : Details of a cross-section – 200mm thick cement block wall.

Where the thermal resistance represents as

R_{p1} – Outer plaster layer

R_{p2} – bonding mortar layer

R_{cb} – Cement block layer

Take 1m length strip for the calculation.

Thermal conductivity values (average) as follows: [29]

$K_{plaster}$ = 0.5 W/mK

$K_{cement\ block}$ = 0.76 W/mK

Average density = 2450 kg/m^3

$R_{p1} = {}^{0.015}/_{(0.5 \times 0.205 \times 1)} = 0.146\ m^2K/W$

$R_{p2} = {}^{0.2}/_{(0.5 \times 0.0075 \times 1)} = 53.33\ m^2K/W$

$R_{cb} = {}^{0.2}/_{(0.76 \times 0.19 \times 1)} = 1.385\ m^2K/W$

$R_{com} = {}^{1}/_{R_{p2}} + {}^{1}/_{R_b} + {}^{1}/_{R_{p2}}$

$R_{com} = {}^{1}/_{53.33} + {}^{1}/_{1.385} + {}^{1}/_{53.33} = 0.7595\ m^2K/W$

$R_{Total} = R_{p1} + R_{com} + R_{p2}$

$R_{Total} = 0.146 + 0.7595 + 0.146 = 1.052m^2K/W$

Total thermal resistance for 200mm thick cement block wall is **1.052 m^2.K/W**

6.1.5.3 Thermal resistance calculation for 225mm thick compressed stabilized earth block walls

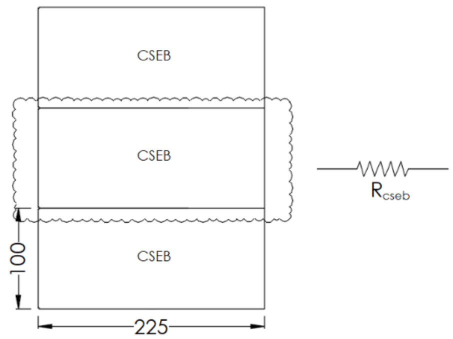

Figure 23 : Details of a cross section – 225mm thick CSEB wall.

Thermal conductivity values (average) as follows: [30]

K_{cseb} = 0.4 W/mK

Average density = 1780 kg/m^3

Take 1m length strip for the calculation.

$R_{cseb} = {}^{0.225}/_{(0.4 \times 0.15 \times 1)} = 3.750\ m^2K/W$

Total thermal resistance for 150mm thick CSEB wall is **3.750 m^2.K/W**

Table 4: Thermal resistance values of wall materials

Thermal Resistance values (m^2K/W)		
Brick	Cement Block	CSEB
2.233	1.052	3.750

Table 5: Specific heat values of wall materials

Material	**Specific Heat Capasitc (kJ/kg.℃)**
Fire clay bricks	0.84
Cement blocks	0.84
CSEB	0.85

Results obtained from the Hourly Analysis Program 4.51 software.
(results attached as annex 04)

Table 6: Total cooling load for brick walls building.

HAP analysis for Brick walls			
Total Coil load = 99.3 kW			
Space	**Sensible load (W)**	**Latent load (W)**	**Total load (W)**
Art Section	6,105	2,769	8,874
AV & MMS	4,998	4,666	9,664
IT Lab 1	8,457	2,848	11,305
IT Lab 2	8,456	2,848	11,304
Library	24,651	7,119	31,770
Science Lab 1	3,821	2,769	6,590
Science Lab 2	4,315	2,769	7,084
SEU	3,581	1,582	5,163
Totals	**64,384**	**27,370**	**91,754**

Bypass factor: 0.1

Table 7: Total cooling load for cement block walls building.

HAP analysis for Cement block walls			
Total Coil load = 100.8 kW			
Space	**Sensible load (W)**	**Latent load (W)**	**Total load (W)**
Art Section	6,260	2,769	9,029
AV & MMS	5,160	4,666	9,826
IT Lab 1	8,657	2,848	11,505
IT Lab 2	8,566	2,848	11,414
Library	25,046	7,119	32,165
Science Lab 1	4,021	2,769	6,790
Science Lab 2	4,515	2,769	7,284
SEU	3,707	1,582	5,289
Totals	**65,932**	**27,370**	**93,302**

Bypass factor: 0.1

Table 8: Total cooling load for 225mm thick CSEB walls building.

HAP analysis for CSEB walls			
Total Coil load = 98.1 kW			
Space	Sensible load (W)	Latent load (W)	Total load (W)
Art Section	5,982	2,769	8,751
AV & MMS	4,871	4,666	9,537
IT Lab 1	8,335	2,848	11,183
IT Lab 2	8,334	2,848	11,182
Library	24,415	7,119	31,534
Science Lab 1	3,699	2,769	6,468
Science Lab 2	4,194	2,769	6,963
SEU	3,484	1,582	5,066
Totals	**63,314**	**27,370**	**90,684**

Bypass factor: 0.1

According to the results obtained from Carrier HAP 4.51 there are few variations on cooling loads when changing the walling materials.

6.1.6 Energy consumption calculations.

6.1.6.1 Calculating the heat gain through different types of walling materials

Understanding the thermal characteristics of the various walling materials and using the appropriate formulae are necessary to calculate the heat gain through them. The area of the wall, its thickness and its thermal conductivity are the important variables.

Through the optimization of wall materials and thickness based on thermal performance criteria, this technique aids in the construction of energy-efficient buildings. For more precise findings, think about utilizing thermal modeling software for large structures.

According to the results obtained from Carrier HAP 4.51 the sensible heat gaining through different wall materials as follows.

Table 9: Total sensible heat load through walls

Space	**Sensible load through walls (W)**		
	Bricks	**Cement blocks**	**225mm CSEB**
Art Section	344	498	221
AV & MMS	358	519	230
IT Lab 1	380	580	258
IT Lab 2	378	578	257
Library	659	1,171	423
Science Lab 1	380	580	258
Science Lab 2	378	578	257
SEU	264	390	169
Total sensible heat load through walls (W)	**3,141**	**4,894**	**2,073**

Calculation for the impact on energy usage for heat & ventilation of the building due to sensible heat loads through walls (refer table no.5,6 & 7)

1. Due to brick walls;

   Total sensible heat load through brick walls = 3,141 W

   Total sensible load of the building (bricks) = 64,384 W

   Impact of sensible heat load on total cooling load of the building (bricks) =

   $$3{,}141\ W / 64{,}384\ W = 0.0488 = 4.88\%$$

2. Due to Cement block walls;

   Total sensible heat load through cement block walls = 4,894 W

   Total sensible load of the building (cement block) = 65,932 W

   Impact of sensible heat load on total cooling load of the building (cement blocks) =

   $$4{,}894\ W / 65{,}932\ W = 0.0742 = 7.42\%$$

3. Due to 225mm thick CSEB walls;

   Total sensible heat load through CSEB walls = 4,894 W

   Total sensible load of the building (CSEB) = 65,932 W

   Impact of sensible heat load on total cooling load of the building ($CSEB_{225mm}$) =

$$2{,}073\ W / 63{,}314\ W = 0.0327 = 3.27\%$$

Table 10: Impact on energy usage for heat & ventilation of the building due to sensible heat loads through walls

Material	**Bricks**	**Cement blocks**	**225mm CSEB**
Impact on total cooling load	0.0488	0.0742	0.0327
%	4.88	7.42	3.27

6.1.6.2 Converting cooling loads to Tons of refrigerants

To convert the cooling loads to Tons of refrigeration.

$$Cooling\ loads\ in\ Tons = \frac{Total\ cooling\ load\ (W)}{3517\ W} \quad \text{Eq. 2}$$

Where 1 Ton of refrigeration (TR) = 3517 W.

Example: For **Art** section construction in brick walls,

Total cooling load = 8,874 W

$$Cooling\ loads\ in\ Ton = 8{,}874 / 3517 = 2.523\ TR$$

1 ton of refrigeration = 12000 BTU.

To fulfill the requirement of the art section, should provide 3 nos of 12000 BTU split A/C units.

6.1.6.3 Split A/C units' arrangements for room spaces

Table 11: Split A/C unit arrangement for Brick & cement block walls.

Space	12000 BTU	18000 BTU	24000 BTU
Art Section	3		
AV & MMS	3		
IT Lab 1			2
IT Lab 2			2
Library	1	6	
Science Lab 1	2		
Science Lab 2	1	1	
SEU			1

Table 12: Split A/C unit arrangement for CSEB walls.

Space	12000 BTU	18000 BTU	24000 BTU
Art Section	1		
AV & MMS	3		
IT Lab 1			2
IT Lab 2			2
Library		6	
Science Lab 1	2		
Science Lab 2	2	2	
SEU		1	

6.1.6.4 Converting cooling loads to Tons of refrigerants

Table 13: Total energy consumption in several types of walling materials.

Material	**Bricks**	**Cement Blocks**	**CSEB**
Cooling load	91,754	93,302	90,684
Split A/C Units			
12000 btu	10	10	8
18000 btu	7	7	9
24000 btu	5	5	4
Rated Energy consumption (W)			
12000 btu	1,142	1,142	1,142
18000 btu	1,550	1,550	1,550
24000 btu	2,403	2,403	2,403
Efficiency factor (%)			
12000 btu	95.7	95.7	95.7
18000 btu	97.7	97.7	97.7
24000 btu	98	98	98

To calculate the power consumption of a split air conditioning system over a specific period, such as 6 hours, & according to the Diakin manufacturer catalogue power rating of the AC unit and its efficiency can be obtained.

Energy consumption is given by the product of power and time. Since power is measured in kW and time in hours, the energy consumption E in kilowatt-hours (kWh) over 6 hours can be calculated as:

$$E = P \times t \qquad \text{Eq. 3}$$

Where:

P = Power rating of the AC unit (kW)

t = Time duration (hours), in this case, 6 hours

Adjust for Efficiency:

To account for the efficiency factor, multiply the energy consumption by the efficiency:

$$E_{adjusted} = E \times \eta \qquad \text{Eq. 4}$$

Where;

$E_{adjusted}$ = Adjusted energy consumption (kWh)

E = Energy consumption without considering efficiency (kWh)

η = Efficiency factor

Finally

$$E_{adjusted} = (P \times t) \times \eta \qquad \text{Eq. 5}$$

<u>When using **bricks & cement blocks** as walling material.</u>

Total power consumption of the building for air conditioning;

Total operational time in the school building = 6 hours

$$Average\ energy\ consuption\ per\ day =$$

$$6[(10 \times 1142 \times 0.957) + (7 \times 1550 \times 0.977) + (5 \times 2403 \times 0.98)]$$

$$= 199{,}824.54\ W = 199.8245\ kW$$

Average its takes 180 school days per year.

Average Energy consumption per year

$$Average\ energy\ consuption\ per\ year = 199.8245 \times 180 = \mathbf{35{,}968.41\ kWh}$$

6.1.6.5 Annual operational cost calculation

Customer Type: General Purpose

Supply of electricity to be used in shops, offices, banks, warehouses, public buildings, hospitals, educational establishments, places of entertainment and other premises not covered under any other tariffs.

Customer Category GP-1

This rate shall apply to supplies at each individual point of supply delivered and metered at 400/230 Volt nominal and where the contract demand is less than or equal to 42 kVA.

Consumption per month(kWh)	Energy Charge (LKR/kWh)	Fixed Charge(LKR/month)	Maximum Demand Charge Per month(LKR/kVA
les than or equal 300	18.30	240	-
more than 300	22.85		

Figure 24 : Customer Category GP-1 tariff

Average operational cost per year for brick walls

$E_{cost} = 35{,}968.41 \times 22.85 = \boldsymbol{Rs\ 821{,}876.17}$

Average operational cost per year for Cement block walls

$E_{cost} = 35{,}968.32 \times 22.85 = \boldsymbol{Rs\ 821{,}876.17}$

When using **CSEB** as walling material.

Total power consumption of the building for air conditioning;

Total operational time in the school building = 6 hours

$Average\ energy\ consuption\ per\ day =$

$$6[(8 \times 1142 \times 0.957) + (9 \times 1550 \times 0.977) + (4 \times 2403 \times 0.98)]$$

$$= 190{,}752.37\ W = 190.7523\ kW$$

Average its takes 180 school days per year.

Average Energy consumption per year

$$Average\ energy\ consuption\ per\ year = 190.7523 \times 180 = \mathbf{34,335.41\ kWh}$$

Average operational cost per year for CSEB walls

$$E_{cost} = 34{,}335.41 \times 22.85 = \mathbf{Rs\ 784,564}/=$$

Table 14: Comparison of operational cost for different walling materials.

Material	**Bricks**	**Cement Blocks**	**CSEB**
Total energy consumption (kW)	35,968.41	35,968.41	34,335.41
Operational cost per year (LKR)	**821,876**	**821,876**	**784,564**

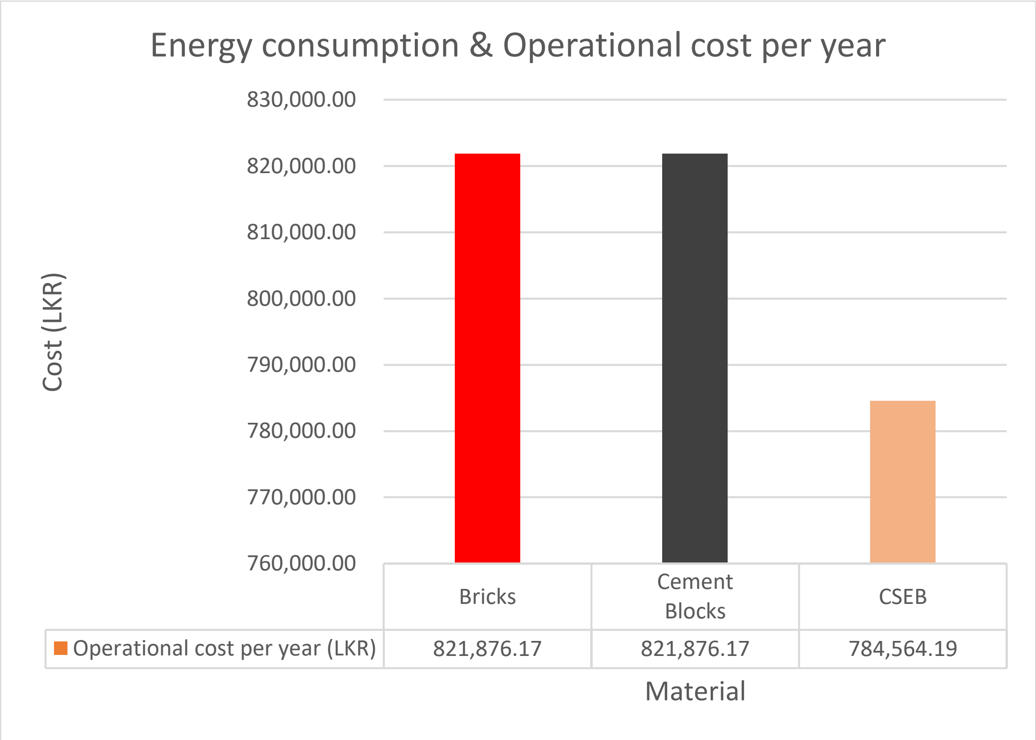

Figure 25 : Operational cost per year

6.2 Compressive strength analysis for different walling materials.

The ability of a substance to withstand pressures that compress or crush it. It is defined as the maximum stress that a material can endure without failing when a compressive load is applied. Compressive strength is commonly measured in pressure units such as megapascals (MPa) or pounds per square inch (PSI).

A compressive strength test involves inserting a material sample (such as a concrete cylinder, brick, or CSEB) into a compression testing equipment. The machine progressively applies compressive force to the sample until it fails or fractures. The greatest force applied is recorded, and the compressive strength is derived by dividing the force by the sample's cross-sectional area.

- Structural Integrity: Materials with high compressive strength are essential for load-bearing applications such as the construction of walls, columns, and foundations.
- Material Selection: It assists engineers and builders in selecting suitable materials for specific structural applications, assuring safety and performance.
- Quality Control: Regular compressive strength testing is required to ensure the quality and uniformity of building materials.

6.2.1 The relationship among clay, sand, silt & stabilizer in compressed stabilized earth blocks

The relationship among clay, sand, silt, and stabilizer in Compressed Stabilized Earth Blocks is critical for determining the strength, durability, and overall performance of the blocks. Each component plays a specific role, and the proportions must be carefully balanced to achieve the desired properties.

Clay: Serves as the soil mixture's binder. Because of its fluidity, the earth may be crushed and formed into blocks. On the other hand, excessive clay can cause drying-related shrinkage and cracking.

Sand: Gives the combination structure and bulk. It strengthens the blocks and aids in lowering shrinking. Sand guarantees that the blocks can be compacted to a high density and makes the soil more workable.

Silt: Increases the mixture's solidity and bonding by filling in the spaces between the sand grains. The performance of the block can be improved by adding a little quantity of silt, but too much silt might harm the block by decreasing its compaction and stability.

Stabilizer: Typically cement, lime, or other additives, the stabilizer binds the soil particles together, significantly enhancing the block's compressive strength and durability. It also reduces the water absorption of the blocks.

6.2.2 Role of each component

Clay: The finer-grained clay particles provide the soil mixture cohesion and aid in the particles' adhesion to one another during compaction. The soil's elasticity, which comes from clay, makes it easy to shape into blocks. Using an excessive amount of clay can lead to problems such as drying-out shrinkage and cracking, which can impair the block's structural integrity.

Sand: Sand adds the necessary volume to the combination, increasing the block's overall strength. By reducing the clay's shrinkage, the likelihood of breaking is decreased. Sand improves the workability of the mixture, making compression and shaping easier.

Silt: The density of the block is increased by silt filling the spaces created by the sand particles. A block becomes denser and stronger when there is a considerable amount of silt present. By absorbing more water and decreasing the soil's general stability, too much silt might erode the block.

stabilizer: Through a chemical reaction between the stabilizer and the silt and clay, a stronger and more resilient matrix is formed inside the block. It lessens the porosity of the block, increasing its resistance to erosion and water absorption. The kind and quantity of stabilizer have a direct impact on the compressive strength of the block; blocks with a higher stabilizer content are often stronger.

6.2.3 Optimal Proportions of components in Compressed stabilized earth blocks

Typical Soil Composition:

Clay: 15-30%

Sand: 50-75%

Silt: 15-20%

Stabilizer Content:

Cement: Typically, 5-10% by weight of the soil.

High Clay concentration: To avoid shrinkage and cracking, more stabilizer is needed if the clay concentration is too high.

High Sand Content: Too much sand might cause the mixture to become less cohesive, which means that more stabilizer will be needed to provide enough bonding.

High Silt Content: An excessive amount of silt can weaken and compress the blocks, requiring the use of stabilizer.

The precise ratio of clay, sand, silt, and stabilizer determines how well CSEB performs. While silt fills gap and helps with compaction, sand gives strength and lessens shrinkage, and clay serves as a binder, the stabilizer improves strength and durability. For the blocks to have the appropriate workability, durability, and compressive strength, the ratios of each component must be tuned.

6.2.4 Minimum compressive strength required for brick, cement blocks & CSEB wall construction

The minimum compressive strength required for wall construction, whether using bricks, cement blocks, or CSEB, depends on whether the wall is load-bearing or non-load-bearing, as well as local building codes and standards. These values are typical guidelines; actual requirements can vary based on local building codes, climate conditions, and specific construction practices.

Clay Bricks:

Non-Load-Bearing Walls:

Minimum Compressive Strength: Typically, around 3.5 to 7 MPa (megapascals).

Load-Bearing Walls (bricks):

Minimum Compressive Strength: Generally, 7.5 MPa or higher is required, with some standards recommending at least 10.5 MPa.

Cement Blocks:

Non-Load-Bearing Walls:

Minimum Compressive Strength: Usually around 3 to 5 MPa.

Load-Bearing Walls (cement blocks):

Minimum Compressive Strength: Generally, 7.5 MPa or higher, depending on the load and building height, with some standards recommending up to 15 MPa or more.

Compressed Stabilized Earth Blocks:

Non-Load-Bearing Walls:

Minimum Compressive Strength: Typically, around 2 to 3 MPa.

Load-Bearing Walls (CSEB):

Minimum Compressive Strength: Generally, 3.5 MPa to 5 MPa, depending on the mix design and stabilizer content (e.g., cement).

6.2.5 Compressive strength of Compressed Stabilized Earth Blocks

The compressive strength of CSEB is a critical performance parameter that determines their load-bearing capability and structural applicability. This strength, which typically ranges between 2 and 10 MPa, is controlled by soil type, stabilizer content (such as cement or lime), compaction pressure, and curing techniques. In this research it was found as 4.82 MPa in 22.5% clay, 60% sand, 17.5% silt & 0.06% of cement mix. (Compressive strength test report attached as annex 05)

Table 15: Results of compressive strength test

Sample	Cement (%)	Clay (%)	Sand (%)	Silt (%)	Compressive strength (MPa)
MSc - 01	0.60	15	75	10	1.74
MSc - 02	0.60	15	70	15	3.24
MSc - 03	0.60	22.5	60	17	4.82
MSc - 04	0.60	30	50	20	3.14
MSc - 05	0.60	30	55	15	2.29
MSc - 06	0.60	35	45	20	1.39

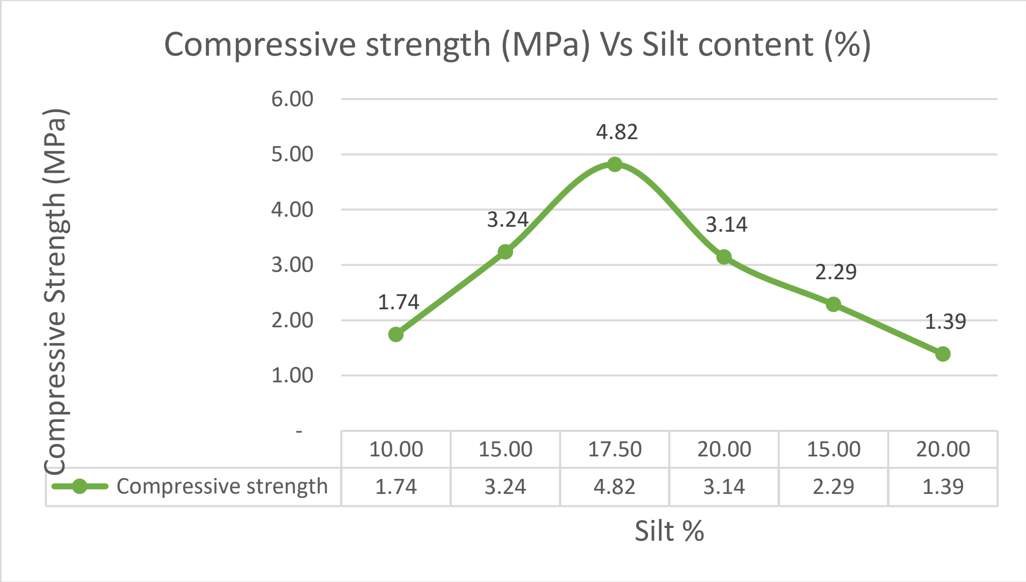

Figure 26 : Compressive strength (MPa) Vs Silt content (%)

7.

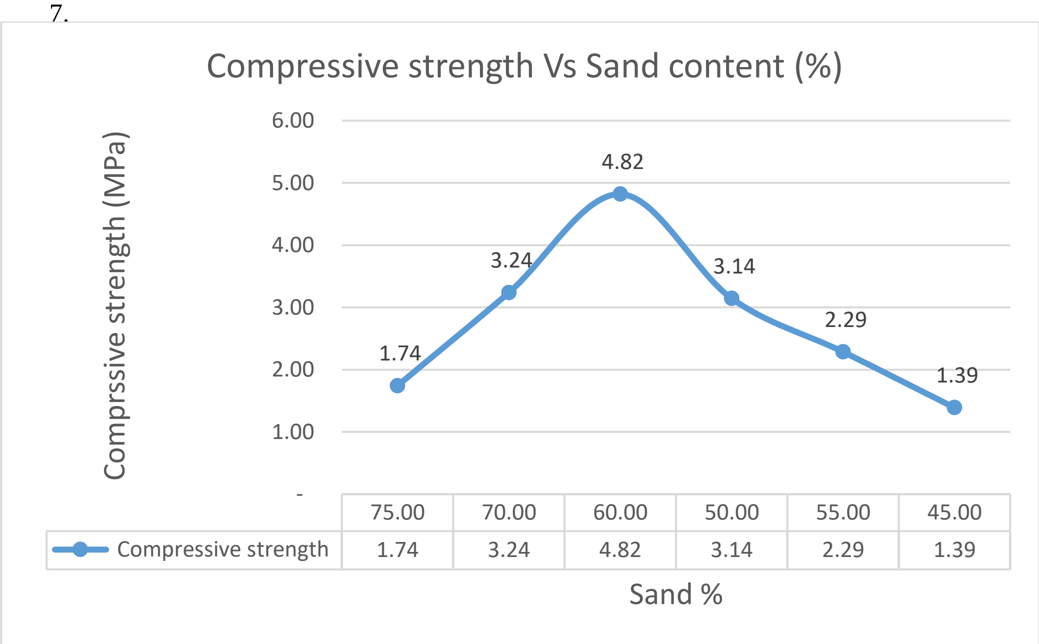

Figure 27 : Compressive strength (MPa) Vs Sand content (%)

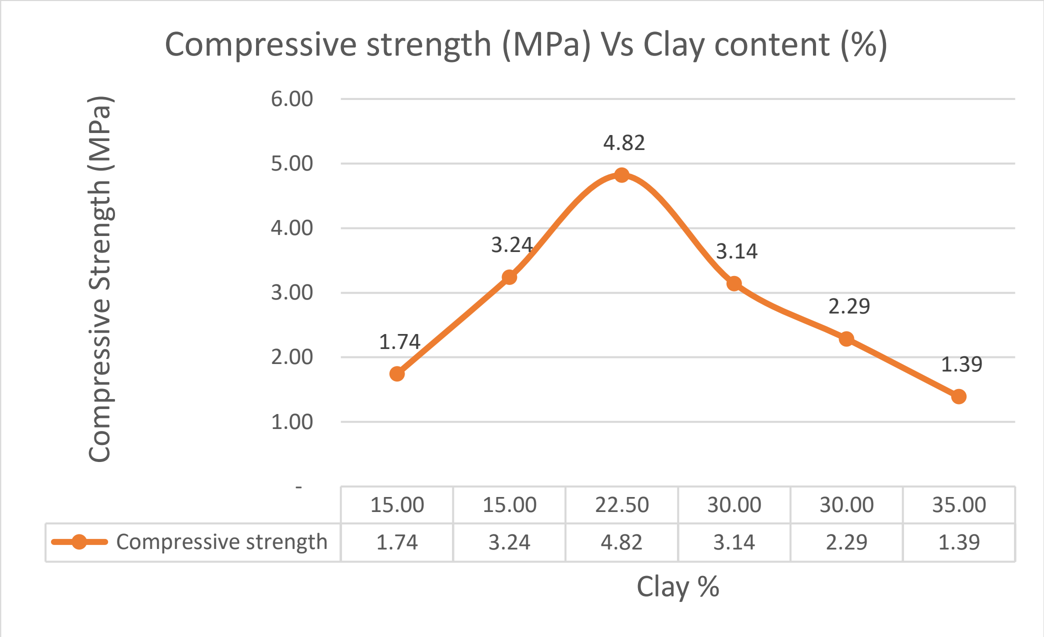

Figure 28 : Compressive strength (MPa) Vs Clay content (%)

A suitable blend of clay, sand, and silt is required for maximum compressive strength in CSEBs. A larger proportion of sand, paired with an acceptable quantity of clay and little silt, typically results in stronger, more lasting blocks. The exact amounts of these components should be adapted to the soil's unique qualities as well as the desired block strength. The compressive strength of CSEBs is optimized by adjusting the amounts of clay, sand, and silt. The proper balance enables high cohesion, little shrinkage, and a thick, robust block, making it appropriate for a variety of building applications.

The average compressive strength of walling materials varies with the kind of material utilized. The following are typical average compressive strength values for frequently used walling materials:

Clay bricks have an average compressive strength of 7.5 to 15 MPa and are commonly employed in load-bearing and non-load-bearing walls. The strength varies according to the quality of the bricks and the fire procedure.

Cement Blocks: Average compressive strength ranges from 3 to 15 MPa. Used in both load-bearing and non-load-bearing walls. The compressive strength of the blocks varies with their density and whether they are hollow or solid.

Compressed Stabilized Earth Blocks have an average compressive strength of 2-10 MPa and are often used in both load-bearing and non-load-bearing walls. Particularly in sustainable or eco-friendly construction.

Table 16: Comparative summary compressive strength of different walling materials

Factor	**Fire Clay Bricks**	**Cement Blocks**	**CSEB (0.6% Cement)**
Compressive strength (MPa)	7.5-15	3-15	1.3 - 4.8

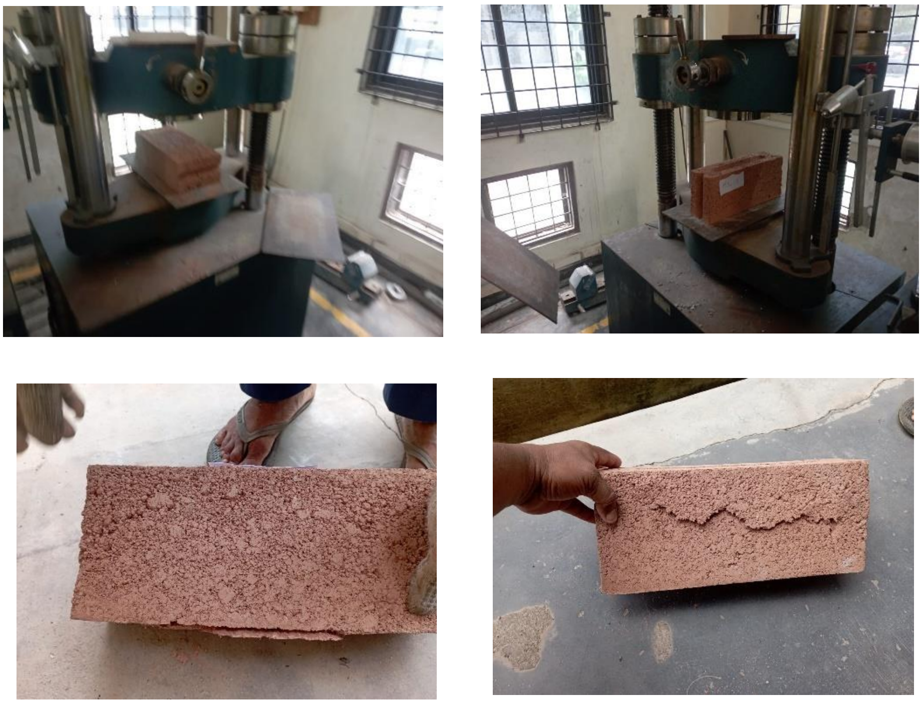

Figure 29 : Performance of compressive strength test

6.3 Comparative Assessment of Thermal Lag in Clay Bricks, Cement Blocks, and Compressed Stabilized Earth Blocks

Thermal lag is the time delay between the peak exterior temperature and the corresponding peak interior temperature in a building material. It is a critical factor in passive cooling strategies and energy-efficient building design, as materials with a higher thermal lag help maintain comfortable indoor temperatures even during temperature fluctuations outside. [31]

6.3.1 Fire clay bricks

Fire clay bricks have a moderate thermal lag, making them ideal for applications that require both thermal management and strong temperature resistance. While they may not have the greatest thermal lag for energy-efficient housing, they excel in applications where thermal stability and longevity are critical. [32]

6.3.2 Cement blocks

Cement blocks have slight greater thermal lag, owing to their strong thermal diffusivity. While they are strong and durable, they require extra insulation for optimal thermal performance in locations with large temperature changes. Lightweight or hollow cement blocks are ideal for situations that prioritize thermal comfort above structural strength. [33]

6.3.3 Compressed stabilized Earth blocks

CSEB has a **long thermal lag** due to its low thermal diffusivity, making it a superior choice for thermal comfort in climates with significant diurnal temperature variations. Its ability to delay and moderate heat transfer makes it an eco-friendly, energy-efficient, and sustainable building material. [34]

6.3.4 Calculation of Thermal lag in different walling materials.

The thermal lag depends on the material's thermal properties such as **thermal conductivity (*k*), density (*ρ*), specific heat capacity (*C*), and thickness (*d*)**. The primary equation to estimate thermal lag is:

$$Thermal\ Lag\ (\Delta t)\ =\ \frac{L}{\sqrt{2\alpha\Omega}} \qquad \text{Eq. 6}$$

Where:

- Δt: Thermal lag (time delay in hours)
- L: Thickness of the material (m)
- α: Thermal diffusivity (m^2/s)
- Ω: Angular Frequency ($rad{\cdot}s^{-1}$)

Thermal diffusivity is a measure of how quickly heat propagates through a material compared to its ability to store heat. It plays a critical role in the study of heat transfer in materials and is mathematically defined as:

$$Thermal\ diffusivity\ (\alpha) = \frac{k}{\rho.C} \qquad \text{Eq. 7}$$

Where:

- k: Thermal conductivity (W/m.K
- ρ : Density of the material (kg/m^3)
- C : Specific heat capacity at constant pressure (J/kg.K)

Angular Frequency (Ω): Relates to the periodicity of external temperature changes. For daily temperature cycles, $\Omega=2\pi f$ radians per second, considering there are 86,400 seconds in a day.

For diurnal temperature cycles, f is approximately 1/86400 s^{-1} (one cycle per day).

6.3.5 Thermal Properties materials.

Table 17: The following are the thermal properties of clay bricks, cement blocks, and CSEB (from chapter 6.1.5):

Material	Thermal conductivity (k) [W/m·K]	Density (ρ) [kg/m³]	Specific Heat (C) [J/kg·K]	Thickness (d) [m]
Clay Bricks	0.75	1700	840	0.225
Cement Blocks	0.76	2450	840	0.2
CSEB	0.4	1780	850	0.225

6.3.6 Thermal Lag Calculation.

Using the equation mentioned earlier, substitute α and material thickness values to estimate the thermal lag.

For a diurnal temperature cycle (f=1/86400 s^{-1}):

Clay Bricks:

$$Thermal\ diffusivity\ (\alpha)\ = \frac{k}{\rho C}$$

$$\alpha_{\text{bricks}} = \frac{0.75}{1700 \times 840} = 5.25 \times 10^{-7}$$

$$\Omega_{bricks} = \frac{2\pi}{86400} = 7.26\ \times 10^{-5}$$

$$Thermal\ Lag\ (\Delta t_{bricks})\ =\ \frac{L}{\sqrt{2\alpha\Omega}} = \frac{0.225}{\sqrt{2 \times 5.25 \times 10^{-7} \times 7.26\ \times 10^{-5}}}$$

$$=\ 7\ hours\ 09\ mins$$

Cement Blocks:

$$Thermal\ diffusivity\ (\alpha)\ = \frac{k}{\rho C}$$

$$\alpha_{cement\ block} = \frac{0.76}{2450 \times 840} = 3.69 \times 10^{-7}$$

$$\Omega_{cement\ block} = \frac{2\pi}{86400} = 7.26\ \times 10^{-5}$$

$$Thermal\ Lag\ (\Delta t_{cement\ block})\ = \frac{L}{\sqrt{2\alpha\Omega}} = \frac{0.225}{\sqrt{2 \times 3.69 \times 10^{-7} \times 7.26\ \times 10^{-5}}}$$

$$=\ 7\ hours\ 35\ mins$$

CSEB:

$$Thermal\ diffusivity\ (\alpha)\ = \frac{k}{\rho C}$$

$$\alpha_{CSEB} = \frac{0.4}{1780 \times 840} = 2.64 \times 10^{-7}$$

$$\Omega_{CSEB} = \frac{2\pi}{86400} = 7.26\ \times 10^{-5}$$

$$Thermal\ Lag\ (\Delta t_{CSEB})\ = \frac{L}{\sqrt{2\alpha\Omega}} = \frac{0.225}{\sqrt{2 \times 2.64 \times 10^{-7} \times 7.26\ \times 10^{-5}}}$$

$$=\ 10\ hours\ 05\ mins$$

Table 18: Comparative Analysis summery of thermal lag

Material	Thermal Lag (hours)	Remarks
Clay Bricks	7 h 09 mins	Moderate thermal lag; suitable for walls in warm climates.
Cement Blocks	7 h 35 mins	Balanced performance; eco-friendly option with reasonable thermal performance.
CSEB	10 h 05 mins	Higher thermal lag due to greater thickness; helps maintain indoor comfort longer.

6.3.7 Influence of Thermal Lag in School Building Construction with CSEB Walls

Generally, the schools are open from 7.30 a.m. to 1.30 p.m. The peak external temperature at 2:00 PM will have an impact on the internal temperature later in the evening or at night since CSEB walls slow down heat transfer. Classrooms stay colder during school hours, making it more pleasant for both teachers and pupils.

Particularly during the hours of maximum sunlight, the delayed heat transmission lessens the need for artificial cooling systems. This is especially advantageous in areas with high energy costs or limited access to air conditioning.

Extreme heat-induced distractions are reduced by the steady indoor environment provided by the high thermal mass of CSEB walls. When temperatures are naturally controlled, both teachers and students can concentrate better.

CSEB is a sustainable, locally made material with a low embodied energy. Thermal lag lowers the building's operational carbon footprint by promoting energy efficiency.

CSEB have the most thermal lag because to its density, thermal conductivity, and thickness. Highly effective in tropical and dry areas, encouraging energy efficiency and sustainability. Clay bricks have the shortest thermal lag of the three, making them less efficient in delaying heat transmission indoors. While cement blocks are somewhat more effective than bricks in terms of thermal lag, they give a sustainable option with equivalent performance. Bricks are ideal for structural strength, but they require extra insulation for better thermal comfort.

CHAPTER 7

7. COMPARAYIVE PERFORMANCE ANALYSIS ON, ENVIRONMENTAL IMPACT & COST OF WALLING MATERIAL

7.1 CO_2 emission calculation in walling material production & wall construction.

The CO_2 emissions associated with building construction can vary significantly depending on various factors, including the type of materials used, construction techniques, energy sources, transportation methods, and project scale [35].

The term "embodied carbon" describes the emissions of carbon dioxide (CO_2) resulting from the manufacturing, shipping, and installation of construction supplies and parts. The amount of embodied carbon in common building materials including steel, concrete, aluminum, glass, and plastics varies according on how they are made and how far they are transported. For instance, the making of cement, a necessary component of concrete, uses a lot of energy and produces a lot of CO_2 [36].

CO_2 emissions are increased during the transportation of building supplies to the project site, especially when those supplies are acquired from a distance. Construction-related heavy machinery and equipment produce CO_2 and require fossil fuels.

Energy is frequently needed for power tools, lighting, heating, and cooling during construction projects. The burning of fossil fuels, such as coal, natural gas, or diesel, results in the emission of CO_2 into the atmosphere and is the usual method of consuming energy [37].

When construction trash is dumped in landfills, it releases carbon dioxide into the atmosphere together with demolition waste and leftover materials. Methane (CH_4) is a strong greenhouse gas that is produced during the breakdown of organic materials in landfills and contributes to global warming. Deforestation, soil disturbance, and habitat loss are examples of land use changes linked to building that can release stored carbon into the atmosphere and interfere with natural carbon cycles. [38]

7.1.1 Brick production & CO_2 emissions

Sri Lanka's building industry and infrastructure development both benefit greatly from the substantial industry of brick manufacture in the nation. In Sri Lanka, bricks are often utilized as building materials for industrial, commercial, and residential construction projects [39].

The following steps are commonly included in the production of bricks:

1. Raw Material Acquisition
2. Preparation of Raw Materials
3. Brick Forming
4. Drying
5. Firing
6. Cooling and Sorting
7. Packaging and Distribution [40]

Brick production in Sri Lanka faces challenges related to environmental sustainability, energy efficiency, and emissions control. Despite being widely used, traditional brick kilns frequently contribute to air pollution and greenhouse gas emissions because biomass fuels are not burned efficiently. In an effort to lessen negative effects on the environment, continuous efforts are being made to increase kiln efficiency, embrace cleaner technology, and use sustainable practices.

Sri Lankan brick production's average CO_2 emissions might differ based on a number of variables, such as the kind of kiln used, the energy sources employed, how well the manufacturing process works, and regional circumstances. I can, however, give you a ballpark figure based on current data and market patterns.

Bricks are often produced in Sri Lanka using conventional kilns like clamp kilns or fixed chimney kilns. Usually, to fire bricks, these kilns use biomass fuels like coal, wood, or agricultural waste. In comparison to more recent, energy-efficient kiln technologies, the burning of these fuels in conventional kilns is often less efficient and produces larger CO_2 emissions.

The CO_2 emissions from brick manufacture utilizing traditional kilns can vary from about 0.5 to 1.5 kg CO_2 released every kilogram of burnt brick produced, based on data from similar locations and industry averages. [41]

7.1.1.1 CO_2 emission calculation for bricks production for the project

According to the bill of quantities of the project, the required brick quantities as follows:

Table 19: Brick wall quantity for the building

NO	DESCRIPTION	UNIT	QTY
	From DPC to Frist floor level		
1	225mm thick brick walls ground floor level to first floor level.	m^3	66
2	112mm thick brick internal walls in cement and sand 1:5 (Ground floor)	m^2	51
	From first floor level to second floor level		
3	225mm thick brick walls first floor level to second floor level.	m^3	67
4	112mm thick brick internal walls in cement and sand 1:5 (First floor)	m^2	5
	From second floor level to third floor level		
5	225mm thick brick walls second floor level to third floor level.	m^3	81

6	112mm thick brick internal walls in cement and sand 1:5 (Second floor)	m^2	3
	<u>From third floor level to roof level</u>		
7	225mm thick brick walls third floor level.	m^3	50
8	112mm thick brick internal walls in cement and sand 1:5 (Third floor)	m^2	6
	Total 225mm thick walls	m^3	264
	Total 112.5mm thick walls	m^2	65

7.1.1.2 Calculate the CO_2 emission in brick wall construction.

The size of the modular bricks is 190 mm x 100 mm x 50 mm. After adding a 10 mm mortar thickness on all sides of the brick, the dimensions become 200 mm x 110 mm x 60 mm. The volume of one brick with mortar is approximately 0.00132 m^3 & actual brick volume is 0.00095. Hence 758 nos of bricks required for $1m^3$ of wall construction & 84 nos of bricks required for $1m^2$ of wall construction in bricks.

Brick wastage typically ranges from 5% for hard bricks.

Total number of bricks for 225mm walls ≈ 758 + 5% = 800 brick per 1m3
Total number of bricks for 112.5mm walls ≈ 84 + 5% = 90 brick per 1m2

No. Of bricks required for 225mm thick walls in project = 211,200 nos
No. Of bricks required for 112.5mm thick walls in project = 5,850 nos

Total brick requirement for the project = 217,050 nos

CO_2 emission in one brick production = 0.5 kg - 1.5 kg

Average CO_2 emission in one brick production (assume) = 1.0 kg

Total CO_2 emission in brick production for the project = 217.05 Tons

7.1.2 Cement production & CO_2 emission

One of the aspects is the carbon dioxide produced during cement manufacture the primary component in concrete production. The process of converting limestone, comprising one of the main components of cement, into clinker, also a fundamental component of a cement product, is because of the chemical process.

The carbon dioxide emissions per ton of cement made on average differ, although such an amount is approximately estimated at 0.5 to 0.9 ton of CO_2 per ton of cement. Carbonates in chalk or marble, which generate CO_2 during de-carbonization, are mainly responsible for emissions, while the main source is combusting fossil fuels.

Estimating the carbon dioxide emissions for the production of one cement bag which approximates to 50 kg, or 0.05 metric tons requires multiplying the carbon emissions per ton of cement by the weight of the bag in tons [42].

The use of alternative, lower-carbon fuels, increased energy efficiency, and research into novel cement formulas with lower clinker concentration are all efforts to lessen the carbon footprint of cement manufacturing. To lessen the environmental effect of cement and concrete manufacturing, research is also being done on the creation and application of substitute, more environmentally friendly binders [43].

7.1.2.1 CO_2 emission calculation due to cement production for the project only in wall construction.

Calculation cement requirement for mortar.

As per the calculation in 6.5.1.1;

758 nos of bricks required for 1m^3 of wall construction & 84 nos of bricks required for 1m^2 of wall construction in bricks. (without wastage)

Required mortar volume for 1m^3 brick wall construction =

$$(758 \times 0.00132) - (758 \times .00095) = 0.2805\ m^3$$

Required mortar volume for 1m^2 brick wall construction =

$$(84 \times 0.00132) - (84 \times .00095) = 0.0311\, m^3$$

Total mortar requirement for the building =

$$(264 \times 0.2805) + (65 \times 0.0311) = 76.07 m^3$$

<u>50 kg Cement Bag:</u>

The standard weight of a cement bag in Sri Lanka is 50 kg. The dry density of Portland cement is approximately 1440 kg/m³

Volume of a 50 kg cement bag = Mass / Density

Volume = 50 kg / 1440 kg/m³ ≈ 0.0347 m³

For a mix ratio of 1:5,

Total no. Of cement bags required for mortar in brick wall construction in project (including 5% wastage) =

$$\left[{}^{76.07}/_{(0.0347 \times 5)}\right] \times 5\% = \mathbf{460.37\ bags}$$

<u>Calculation cement requirement for wall plaster.</u>

According to the bill of quantities of the project, the wall plasters quantities as follows:

Table 20: Wall plaster quantities for the building

NO	DESCRIPTION	UNIT	QTY
	From DPC to Frist floor level		
1	Internal plaster 5/8" thick in cement and sand in ground floor 1:5 finished semi rough to masonry walls in ground floor, including reveals with fine sand top layer.	m²	525
2	External plaster 1/2" thick in cement and sand in ground floor 1:5 finished semi rough including reveals in ground floor.	m²	175
	From frist floor level to second floor level		

3	-Do- First floor	m²	395
4	-Do- First floor	m²	225
	From second floor level to third floor level		
5	-Do- Second floor	m²	395
6	-Do- Second floor	m²	225
	From third floor level to roof level		
7	-Do- Third floor	m²	395
8	-Do- Third floor	m²	225
	Total Internal plaster 5/8" thick in cement and sand	m²	1,710
	Total External plaster 1/2" thick in cement and sand	m²	850

Total plaster volume (15 mm thick & 1:5 cement, sand) =

$$(1710 \times 0.015) + (850 \times .0125) = 36.275m^3$$

No. of cement bags required for plastering work (including 5% wastage) =

$$[\frac{36.275}{5 \times 0.0347}] \times 5\% = \mathbf{219.5\ bags}$$

Total cement bags requirement for both wall construction & plastering work =

$$460.37 + 219.5 = 679.87\ bags$$

CO_2 emission in one cement bag production (average) = 40 kg

CO_2 emission in wall construction & plastering work for project (average)

$$679.87 \times 40 = 27.195\ tons$$

Total CO_2 emission for project only in brick production, wall construction & plastering work

$$217.05 + 27.195 = \mathbf{244.245\ tons\ of\ CO_2}$$

7.1.3 Cement block (sand with quarry dust) production & CO_2 emission

The carbon dioxide emissions connected with cement block production might vary based on factors such as the energy source utilized for cement making, the manufacturing method employed, transportation, and the specific environmental practices of the producer. But because it requires a lot of energy to calcine limestone, the process of making cement is generally recognized to be a major contributor to CO_2 emissions.

The extraction and processing of raw materials is the main cause of CO_2 emissions in the manufacturing of quarry dust. The kind of rock being quarried, the equipment employed, and the material transportation all affect the precise emissions [44].

Significant amounts of power and fossil fuels are used in the production process, which increases CO_2 emissions.

Sand and quarry dust are combined to create cement blocks, which are an economical and useful building material. However, because of the cement manufacturing process, their creation is linked to large CO_2 emissions. Thus, the computation will just take into account the cement block production process.

7.1.3.1 CO_2 emission calculation for cement block production for the project

According to the bill of quantities of the project, the required blocks quantity as follow:

Table 21: Cement block wall quantities for the building (Data from BOQ Mahanama College)

NO	DESCRIPTION	UNIT	QTY
	From DPC to Frist floor level		
1	8" (200mm) thick cement sand solid block wall (blocks confirming to S.L.S. 855 and subject to the approval in sample blocks) in cement and sand mortar 1:5 in ground floor.	m^2	293
2	4" (100mm) thick cement sand solid block wall (blocks confirming to S.L.S.855 and subject to the approval of sample blocks) in cement and sand mortar 1:5 in ground floor.	m^2	51

	From first floor level to second floor level		
3	-Do- First floor.	m^2	297
4	-Do- First floor.	m^2	5
	From second floor level to third floor level		
5	-Do- Second floor	m^2	360
6	-Do- Second floor.	m^2	3
	From third floor level to roof level		
7	-Do- Third floor.	m^2	222
8	-Do- Third floor	m^2	6
	Total 200mm thick walls	m^2	1,173
	Total 100mm thick walls	m^2	65

200mm thick cement block.

The size of the cement block is 390 mm x 200 mm x 190 mm. After adding a 15 mm mortar thickness on all sides of the block, the dimensions become 405 mm x 215 mm x 205 mm. The area covers on the wall by one block with mortar is approximately 0.083 m^2 & actual brick area is 0.074 m^2. Hence 12 nos of blocks required for $1m^2$ of wall construction in bricks.

100mm thick cement block

The size of the cement block is 390 mm x 100 mm x 190 mm. After adding a 15 mm mortar thickness on all sides of the block, the dimensions become 405 mm x 115 mm x 205 mm. The area covers on the wall by one block with mortar is approximately 0.083 m^2 & actual brick area is 0.074 m^2. Hence 12 nos of blocks required for $1m^2$ of wall construction in bricks.

Blocks wastage typically ranges from 5% for hard blocks.

Total number of blocks for 200mm wall ≈ 12+ 5% = 12.5 blocks per $1m^3$

Total number of blocks for 200mm wall ≈ 12 + 5% = 12.5 blocks per $1m^2$

No. Of blocks required for 200mm thick walls = 14,667 nos

No. Of blocks required for 100mm thick walls = 813 nos

Average cement use in one200mm thick block production = 6.0 kg

Average cement use in one100mm thick block production = 3.0 kg

Total cement bag requirement for block production

$$(14667 \times 6) + (813 \times 3) = 90{,}441\ kg$$

$$\frac{90{,}441}{50} = 1808.8\ cement\ bags$$

CO_2 emission in one cement bag production (average) = 40 kg

Average CO_2 emission in block production for this project

$$1808.8 \times 40 = 72.352\ ton\ of\ CO_2$$

7.1.3.2 Calculation cement requirement for mortar.

As per the calculation in 6.5.2.1.2;

12.5 nos of bricks required for 1m^2 of 200mm thick wall construction & 12.5 nos of bricks required for 1m^2 of 100mm thick wall construction in blocks.

Required mortar volume for 200mm thick 1m^2 block wall construction =

$$[(12.5 \times 0.083) - (12.5\ \times\ .0074)] \times 0.2 = 0.0225\ m^3$$

Required mortar volume for 1m^2 brick wall construction =

$$[(12.5 \times 0.083) - (12.5\ \times\ .0074)] \times 0.1 = 0.0113\ m^3$$

Total mortar requirement for the building (including wastage) =

$$[(1173 \times 0.0225) + (65 \times 0.0113)] \times 5\% = 28.48m^3$$

Total no. Of cement bags required for mortar in block wall construction in project =

$$\left[{}^{28.48}/_{(0.0347 \times 5)}\right] = 164.169\ bags$$

As per the calculation in 6.5.2.1.2;

No. of cement bags required for plastering work (including 5% wastage)

= 219.5 bags

Total cement bags requirement for both wall construction & plastering work =

$$164.169 + 219.5 = 383.669\ bags$$

CO_2 emission in one cement bag production (average) = 40 kg

CO_2 emission in wall construction & plastering work for project (average)

$$383.669 \times 40 = 15.35\ tons$$

Total CO_2 emission for project only in block production, wall construction & plastering work

$$72.352 + 15.35 = \mathbf{85.702\ tons\ of\ CO_2}$$

7.1.4 Compressed stabilized earth block production & CO_2 emission

Compressed Stabilized Earth Blocks are building materials prepared from earth, cement, and other stabilizing components at times. The production of CSEBs does not normally require a kiln, and the emissions of carbon dioxide are generally lower for this kind of block compared to the emissions of conventional fired bricks. However, the emissions would differ by production processes, materials, and the energy uses. [45]

In general, the production of CSEBs can be said to emit low carbon compared to traditional fired bricks, with estimates ranging from 0.1 to 0.3 kilograms of CO2 per block. However, this figure covers general estimates with variations in the case of differences in cement content, transportation distances, and type of energy used in the production process. [45]

The environmental benefits are often given as CSEBs may be compatible with more eco-friendly bricks than conventional bricks since they are made from locally available materials, need low energy consumption during production, and also appear to be having excellent thermal functionality in buildings. In addition, no firing of bricks in a kiln, eliminating the carbon footprint from these energy-intensive firing procedures. [46]

7.1.4.1 CO_2 emission calculation for CSEB production for the project

<u>225mm thick CSEB block</u>.

The size of the CSEB is 225 mm x 225 mm x 100 mm. Actual brick area is 0.0225 m2. Hence 45 nos of blocks required for 1m2 of wall construction in bricks. There is a chip concrete mixture use to fill the gap of this wall construction.

150mm thick CSEB block.

The size of the CSEB is 300 mm x 150 mm x 100 mm. Actual brick area is 0.03 m2. Hence 34 nos of blocks required for 1m2 of wall construction in bricks. There is a chip concrete mixture use to fill the gap of this wall construction.

Table 22: CSEB wall quantities for the building (Data from BOQ Mahanama College)

NO	DESCRIPTION	UNIT	QTY
	From DPC to Frist floor level		
1	9" (225mm) thick compressed stabilized earth block wall (subject to the approval in sample blocks) in cement, sand & chip metal concrete in grade 15 in ground floor.	m^2	293
2	6" (150mm) thick compressed stabilized earth block wall (subject to the approval in sample blocks) in cement, sand & chip metal concrete in grade 15 in ground floor.	m^2	51
	From first floor level to second floor level		
3	-Do- First floor	m^2	297
4	-Do- First floor.	m^2	5
	From second floor level to third floor level		
5	-Do- Second floor	m^2	360
6	-Do- Second floor	m^2	3
	From third floor level to roof level		
7	-Do- Third floor	m^2	222
8	-Do- Third floor	m^2	6
	Total 225mm thick walls	m^2	1,173
	Total 150mm thick walls	m^2	65

Blocks wastage typically ranges from 5% for hard blocks.

Total number of CSEBs for 225mm wall ≈ 45+ 5% = 48 blocks per 1m2

Total number of CSEBs for 150mm wall ≈ 34 + 5% = 36 blocks per 1m2

No. Of CSEBs required for 225mm thick walls = 56,304 nos

No. Of CSEBs required for 150mm thick walls = 2,340 nos

Average cement use in one225mm thick block production =0.5625 kg

Average cement use in one150mm thick block production = 0.5 kg

Total cement bag requirement for block production

$$(56{,}304 \times 0.5625) + (2{,}340 \times 0.5) = 32{,}841\ kg$$

$$\frac{32{,}841}{50} = 656.82\ cement\ bags$$

CO_2 emission in one cement bag production (average) = 40 kg

Average CO_2 emission in block production for this project

$$\mathbf{656.82 \times 40 = 26.27\ ton\ of\ CO_2}$$

7.1.4.2 Calculation cement requirement for chip concrete in wall construction.

The British Standard (BS) code designates Grade 15 concrete, often known as M15, as a mix design where the concrete's compressive strength is 15 MPa (megapascals) after 28 days of curing. This grade of concrete is usually used for small-scale constructions, floors, and pavements—applications where great strength is not a necessary requirement.

Figure 30 : Grade 15 Chip concrete (1:2:4)

Overall, grade 20 concrete is appropriate for a variety of building applications where moderate strength is required since it strikes a compromise between strength, work ability, and cost-effectiveness.

Volume of concrete required for CSEB wall construction

$$\pi \times 0.025^2 \times 0.1 \times 2 \times 58{,}644 = 23.03\ m^3$$

Total no. Of cement bags required 1m^3 of grade 15 concrete = 6.4 bags

Total CO_2 emission in CSEB wall construction for the project

$$23.03 \times 6.4 \times 40 = 5.896\ tons\ of\ CO_2$$

Total CO_2 emission for project only in CSEB production, wall construction

$$26.27 + 5.896 = \mathbf{32.166\ tons\ of\ CO_2}$$

7.1.5 Comparative Assessment of CO_2 Emissions in Fire Clay Brick, Cement Sand Block, and CSEB Production and Wall Construction

One of the main industries contributing to the world's CO_2 emissions is building. The environmental effects of producing construction materials like compressed stabilized earth blocks, cement sand blocks, and fire clay bricks vary greatly. The CO_2 emissions related to the manufacture and building of walls made from these three types of materials are compared in this evaluation.

In fire clay brick production large amounts of energy, usually from coal or other fossil fuels, are used in the fire process, which raises CO_2 emissions. around 0.5–1.5 kg CO_2 per brick, based on fuel type and kiln performance. Furthermore, the widespread usage of cement mortar increases the CO_2 emissions from cement manufacture. [47]

In cement sand/quarry dust block production the energy-intensive process of making cement releases around 0.9 kg of CO_2 every kilogram of cement. A typical 200 mm block with a 1:5 mix ratio has between 5.85 and 6.15 kg of cement, which produces noticeable emissions. Use of Mortars Cement mortar is utilized, similar to fire clay bricks, which increases CO_2 emissions.

Compared to cement blocks, less cement or lime is utilized, which greatly lowers emissions. Between 0.5 and 1.0 kg of CO_2 each block, based on soil type and stabilizer concentration. To further cut CO_2 emissions, mud mortar or mortar with very little cement might be utilized.

Table 23: CO_2 emission in different walling materials for the project

Material name	Fire clay brick	Cement Block	CSEB
CO_2 emission (tons)	244.245	85.702	32.166

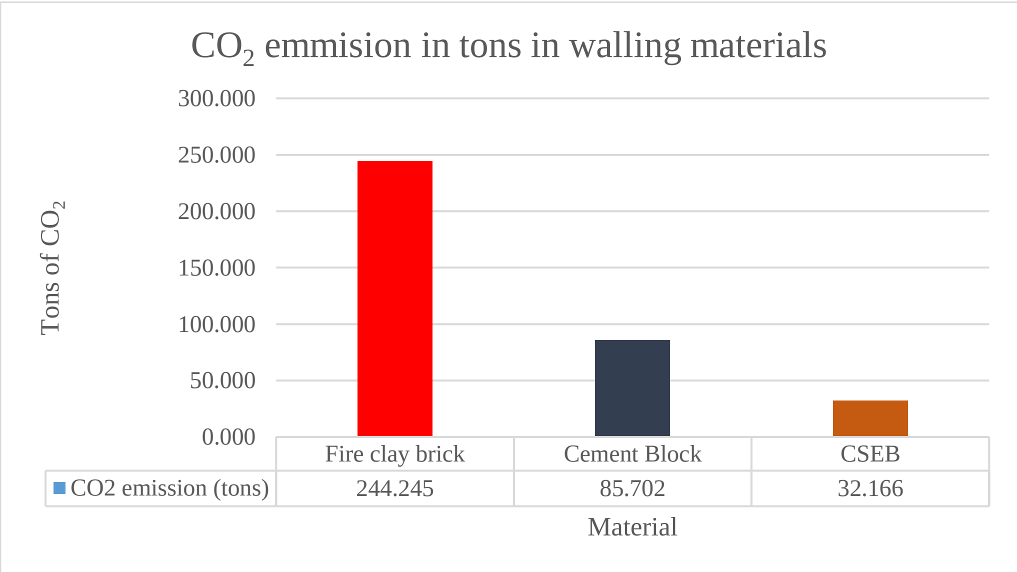

Figure 31 : CO_2 emission in different walling materials for the project

7.2 Wall construction cost analysis for different walling materials

A cost study of various walling materials for a structure must take into account a number of expenses, including labor and material prices as well as extras like installation and shipping. Three popular walling materials will be examined here: compressed stabilized earth blocks, cement sand blocks, and fire clay bricks.

A comprehensive document that offers uniform prices for different building tasks, materials, labor, and equipment is the Building Schedule of Rates (BSR). Contractors, quantity surveyors, architects, engineers, and other construction industry players often utilize the BSR in Sri Lanka. It acts as a manual for creating budgets, tenders, and cost estimates for building projects. Standardized pricing for materials, labor, and equipment rental are provided by the BSR for construction-related operations.

These rates are regularly updated to reflect shifts in the building sector and are based on current market values. The BSR encompasses a broad spectrum of construction tasks, including finishing and interior design as well as preliminary work.
Rates for excavation, bricklaying, concrete work, plastering, painting, roofing, and electrical installations, plumbing & more are included.

In order to guarantee uniformity and quality in construction procedures, comprehensive requirements for building materials are given. This contains details on the sizes, grades, and standards that must be followed for the materials. For both expert and unskilled laborers engaged in building projects, the BSR provides labor rates. Rates for carpenters, masons, electricians, plumbers, and other crafts are included. The paper lists the rental costs for several pieces of gear and equipment used in construction, including scaffolding, cranes, concrete mixers, and excavators.

These prices aid in precisely calculating the expense of utilizing machines for particular jobs. The BSR is used by quantity surveyors and contractors to create comprehensive cost estimates for building projects. It acts as a standard by which to compare contractor bids and tenders.

The Institute for Construction Training and Development (ICTAD) in Sri Lanka normally publishes the BSR. The digital and printed versions can be bought separately. The most recent edition of the BSR is available to construction professionals through authorized distributors or ICTAD.

7.2.1 Cost calculation for brick wall construction of the project

As per the BSR, brick wall construction cost as follows:

Brick work in cement sand 1:5 in 4 1/2" & 9” (112.5mm &225mm) thick walls in ground floor,1st floor, 2nd floor & 3rd floor rates.

Table 24: 225mm & 112.5mm thick brick wall rates (Rates from BSR 2024)

DESCRIPTION	Unit	RATE 2024 (Rs-with o/h)- Metric
Brick work in cement and sand 1:5 in 4 1/2" thick walls of ground floor.	m^2	4,908
-Do- 1st floor	m^2	5,153
-Do- 2nd floor	m^2	5,251
-Do- 3rd floor.	m^2	5,447
Brick work in cement and sand 1:8 in 9" thick walls of ground floor.	m^3	35,375
-Do- 1st floor level.	m^3	37,144
-Do- 2nd floor level.	m^3	37,851
-Do- 3rd floor level.	m^3	39,266

As per the bill of quantities (BOQ) of the project 112.5mm &225mm thick wall quantity is in table 09.

Table 25: Cost for the brick wall construction in the project (Data from BSR 2024)

DESCRIPTION	Unit	RATE 2024 (Rs-with o/h)-Metric	Qty	Amount (Rs)
Brick work in cement and sand 1:5 in 4 1/2" thick walls of ground floor.	m^2	4,908	51	250,308
-Do- of 1st floor	m^2	5,153	5	25,765
-Do- 2nd floor	m^2	5,251	3	15,753
-Do- of 3rd floor.	m^2	5,447	6	32,682
Brick work in cement and sand 1:8 in 9" thick walls of ground floor.	m^3	35,375	66	2,334,750
-Do- 1st floor level.	m^3	37,144	67	2,488,648
-Do- 2nd floor level.	m^3	37,851	81	3,065,931
-Do- 3rd floor level.	m^3	39,266	50	1,963,300

Total amount for brick wall construction in this project = Rs. 10,177,137.00

7.2.2 Cost calculation for the plastering work of the project

As per the BOQ of the project wall plastering quantity is in table 10.

Table 26: Cost for the brick wall construction in the project (Data from BSR 2024)

DESCRIPTION	Unit	RATE 2024 (Rs-with o/h)-Metric	Qty	Amount (Rs)
Plastering 5/8" thick to walls in cement and sand 1:5 finished semi-rough in ground floor level	m^2	1,340	700	938,000
-Do- 1st floor level	m^2	1,407	620	872,340
-Do- 2nd floor level	m^2	1,433	620	888,956
-Do- 3rd floor level	m^2	1,460	620	905,572

Total amount for wall plastering in this project = Rs. 3,604,868.00

Total Cost for brick wall construction & plastering work of the project.

$$10{,}177{,}137.00 + 3{,}604{,}868.00 = Rs.\,13{,}782{,}005.00$$

= Rs 13.782 Mn

7.2.3 Cost calculation for Cement block wall construction of the project

As per the BSR, cement block wall construction cost as follows:

Cement block work in cement sand 1:5 in 8" & 4" (200mm &100mm) thick walls in ground floor,1st floor, 2nd floor & 3rd floor rates & cost for the project.

Table 27: Cost for the cement block wall construction in the project (Data from BSR 2024)

DESCRIPTION	Unit	RATE 2024 (Rs-with o/h)- Metric	Qty	Amount (Rs)
4" (100mm) thick cement sand solid block wall (blocks confirming to S.L.S.855 and subject to the approval of sample blocks) in cement and sand mortar 1:5 in ground floor.	m^2	3,950	51	201,450
-Do- First floor.	m^2	4,148	5	20,738
-Do- Second floor.	m^2	4,226	3	12,678
-Do- Third floor.	m^2	4,305	6	25,830
8" thick cement sand solid block wall (blocks confirming to S.L.S. 855 and subject to the approval of sample blocks) in cement and sand mortar 1:5 in ground floor.	m^2	7,248	293	2,123,664

-Do- First floor.	m^2	7,610	297	2,260,170
-Do- Second floor.	m^2	7,755	360	2,791,800
-Do- Third floor.	m^2	7,900	222	1,753,800

Total amount for cement block wall construction in this project=Rs. 9,190,130.00

Total amount for wall plastering in this project = Rs. 3,604,868.00 (from 6.6.2)

Total Cost for cement block wall construction & plastering work of the project.

$$9{,}190{,}130.00 + 3{,}604{,}868.00 = Rs.\,12{,}794{,}998.00$$

= Rs 12.795 Mn

7.2.4 Cost calculation for CSEB wall construction of the project

The process of rate analysis for CSEB wall construction include figuring out the overall cost of the wall per unit area, which is typically square meters. The costs of supplies, labor, machinery, and other related expenses are included in this study.

Table 28: Rate analysis of CSEB wall construction for 8" (200mm) thick one square meter.

CSEB work with concrete including cement sand & chip metal 1:2:4 in 8" thick walls in ground floor				
Per 10 square meters	Unit	Qty	Value	Amount (Rs)
Materials				
Compressed stabilized earth blocks - Ordinary (plant located at Wathuragama including 30 km transport)	Nos	450.00	100.00	45,000.00
Add 5% wastage				2,250.00
0.43 cwt cement (50 Kg bags)	Nos	0.50	2,260.00	1,130.00

0.136 cubes sand	m^3	0.85	9,365.00	7,960.25
0.272 Chip metal	m^3	1.75	4,120.00	7,210.00
Water (100 liters)	liters	120.00	3.50	420.00
material cost				63,970.25
Labour				
1 1/2 days mason	day	2.00	3,750.00	7,500.00
2 days U/SK labour	day	2.00	2,550.00	5,100.00
total labour cost				12,600.00
tools cost 2%	%	12,600.00	0.02	252.00
Basic cost				76,822.25
overhead and profit 20%	%	76,822.25	0.20	15,364.45
Net amount				92,186.70
Rate per square meter (Rate per SLS-573)				**8,567.54**

Table 29: Rate analysis of CSEB wall construction for 6” (150mm) thick one square meter.

CSEB work with concrete including cement sand & chip metal 1:2:4 in 6" thick walls in ground floor				
Per 10 square meters	Unit	Qty	Value	Amount (Rs)
		-		
Materials				
Compressed stabilized earth blocks - Ordinary (plant located at Wathuragama including 30 km transport)	Nos	340.00	85.00	28,900.00

Add 5% wastage				1,445.00
0.43 cwt cement (50 Kg bags)	Nos	0.43	2,260.00	971.80
0.136 cubes sand	m^3	0.77	9,365.00	7,211.05
0.272 Chip metal	m^3	1.54	4,120.00	6,344.80
Water (100 liters)	liters	100.00	3.50	350.00
material cost				45,222.65
Labour				
1 1/2 days mason	day	1.50	3,750.00	5,625.00
2 days U/SK labour	day	2.00	2,550.00	5,100.00
total labour cost				10,725.00
tools cost 2%	%	10,725.00	0.02	214.50
Basic cost				56,162.15
overhead and profit 20%	%	56,162.15	0.20	11,232.43
Net amount				67,394.58
Rate per square meter (Rate per SLS-573)				**6,263.44**

Total Cost for CSEB wall construction of the project. (wall quantity is in table 09)

$$1173.33 \times 8567.54 + 65 \times 6263.44 = Rs. 10{,}459{,}675.31$$

= Rs 10.459 Mn

7.2.5 Comparative cost analysis for fire clay brick, cement block, and CSEB wall construction in the project.

This research indicates that fire clay brick walls are the most expensive option, and that CSEB walls are the most cost-effective option, followed by cement block walls.

Aside from availability, the choice of material should take the project's unique requirements and the influence on the environment into account.

- Fire Clay Brick Wall : The most expensive option with a total cost of LKR13,782,005/-for the project.
- Cement Block Wall : A more cost-effective option with a total cost of LKR 12,805,387/- for the project.
- CSEB Wall : The most cost-effective option with a total cost of LKR 10,459,675/- for the project.

Table 30: Comparative summary of wall construction cost analysis

Material	Brick 225mm & 112.5mm thick wall	Cement Block 200mm & 100mm thick wall	CSEB 225mm & 150mm thick wall
Wall construction (Rs)	10,177,137	9,190,130	10,459,675
Plastering (Rs)	3,604,868	3,604,868	
Total Amount in wall construction (LKR)	13,782,005 (13.782 Mn)	12,794,998 (12.794 Mn)	10,459,675 (10.459 Mn)

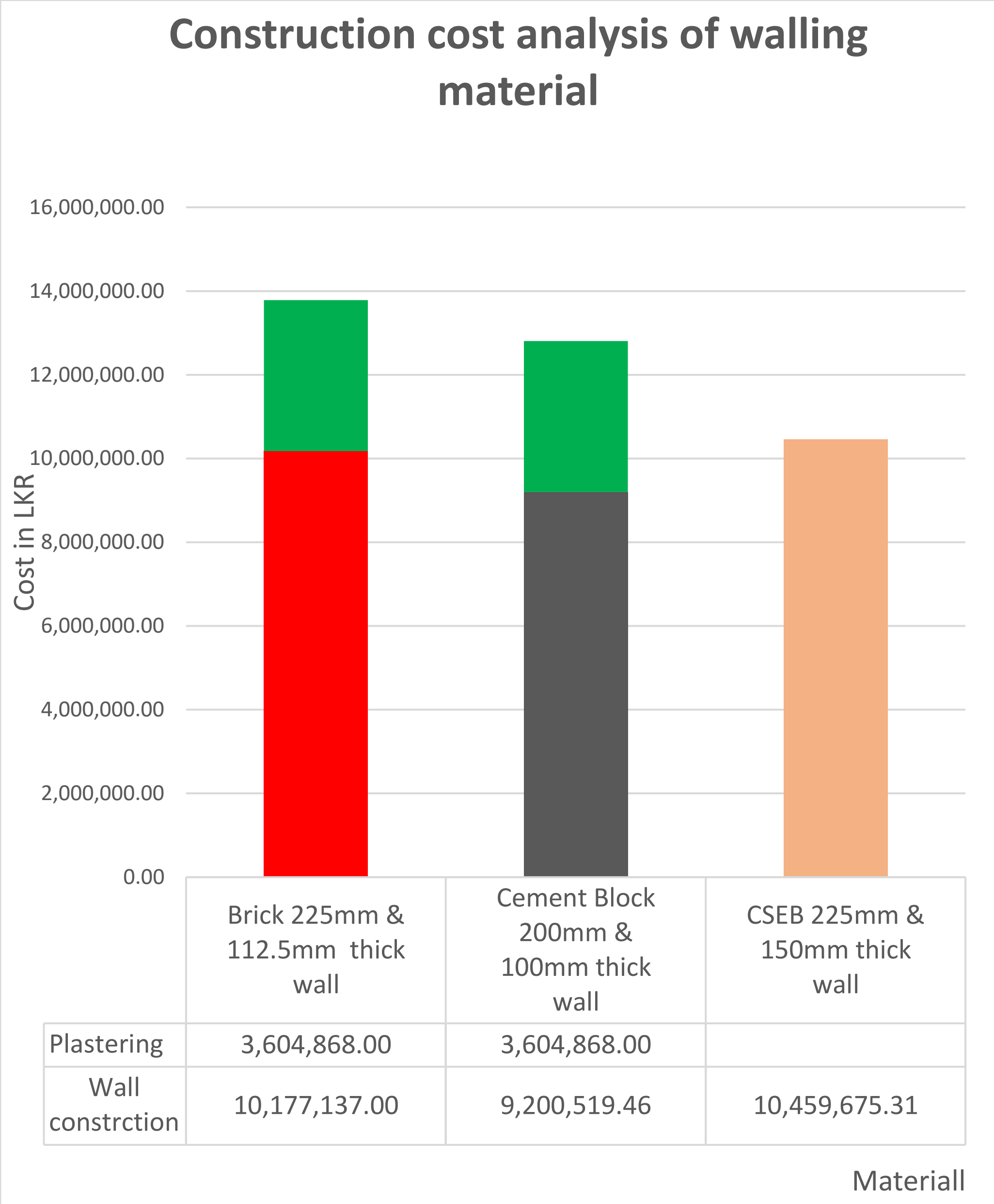

Figure 32 : Construction cost analysis of walling material

7.3 Maintenance cost analysis for different walling materials.

There are a few things to take into account while comparing the upkeep of compressed stabilized earth block (CSEB), cement block, and fire clay brick walls. These variables include longevity, exposure to the environment, the kind and frequency of necessary maintenance, and the total yearly maintenance cost.

7.3.1 Maintenance cost for brick walls

Natural clay is used to make fire clay bricks, which are then burnt in kilns to gain strength. They are often utilized for walls that support weight. Fire clay bricks are low maintenance and long-lasting. It is advised to clean frequently to get rid of dust, efflorescence, and filth. Periodically check for damage or cracks and make the necessary repairs. Water migration can cause efflorescence, or white, powdery deposits, on brick surfaces. Bricks made of fire clay are renowned for their durability and strength. They can tolerate high temperatures and are weather-resistant. [48]

Requires cleaning, infrequent waterproofing, and repointing of mortar joints on a regular basis. Major repairs like as repointing should be done every five to ten years, along with yearly inspections and little fixes. Maintenance cost LKR 150.00 to LKR 600.00 annually per square foot. Cleaning, waterproofing, and repointing mortar joints. Provide exceptional longevity and comparatively minimal upkeep, rendering them an economical option for extended periods of upkeep.

7.3.2 Maintenance cost for cement block walls

Although they are very strong, cement block walls occasionally need to be repaired. Cleaning and inspection must be done on a regular basis. Patch up spalling or cracks right away. If they are not properly sealed, they can absorb water and become damaged by frost in colder locations. Every three to five years, apply surface treatments, and check for cracks and other problems every year. require little upkeep, with an emphasis on surface treatments and crack repairs, which will raise the yearly cost a little. Maintenance cost LKR 300.00 to LKR 600.00 annually per square foot.

7.3.3 Maintenance cost for CSEB walls

Needs regular surface treatments, waterproofing, and fast damage repair to stop erosion. Exposed to damage, deterioration, and dampness in the absence of proper protection. Despite being more eco-friendly, their vulnerability to moisture and erosion means that they require more frequent and intensive upkeep. It takes average Maintenance cost LKR 200.00 to LKR 500.00 annually per square foot. (data taken from manufacturer)

Table 31: Comparative summary of maintenance cost of different walling materials

Factor	Fire Clay Bricks	Cement Blocks	CSEB
Durability	High	Moderate	Variable
Environmental Susceptibility	Low	Moderate	High
Maintenance Frequency	Every 5-10 years (major)	Every 3-5 years (surface)	Every 3-5 years (surface)
Maintenance Requirements	Low to Moderate	Moderate	Moderate to High
Annual Maintenance Cost	**LKR 150.00-LKR 600**	**LKR 300-LKR 600**	**LKR 200-LKR 500**
As per the bills of quantities total cost of maintenance (Average LKR)	**464,250**	**557,100**	**433,300**

CHAPTER 8

8. LIFE CYCLE COST(LCC) ANALYSIS

A technique called life cycle cost analysis, or LCC, is employed to evaluate an asset's overall cost of ownership across its whole life. This covers all expenses involved in the phases of purchase, use, upkeep, and disposal. By contrasting the long-term economic effects of various choices, LCCA aids in the development of well-informed judgments.

More than 70% of Sri Lanka's building blocks are mixed-use residential structures constructed under contracts, and studying these structures is important. Determining optimal cost efficiency in order to symmetrically line with building energy costs is therefore necessary for appropriate asset management and investment decision-making. Therefore, the researcher suggests that life cycle cost analysis be done in order to use creative building materials and safer construction techniques [49].

The US Department of Defense developed and used the LCC analysis technique in the 1960s."The cost of an asset or its parts throughout its life cycle, which comprises all stages from construction, operation and maintenance to end-of-life," is how the ISO Standard 15686-5 defines life cycle costs (LCC) [50] [51].

Three steps can be used to summarize the research technique. Relevant LCC characteristics, such as life span, discount rates, construction and operating expenses, were determined in the first stage. The second step involved calculating the preliminary bill of quantities (BOQ), which took into consideration the quantity of materials needed to construct the base house based on 2024 market prices. In the third step, a spreadsheet life cycle cost model for a span of sixty years (one life span) was created using the entire initial cost of construction. The beginning costs of several scenarios were contrasted and compared using a comparable approach.

8.1 Base case school building

This study considers the building at Colombo district as a case study. Technical drawings of ground,1st, 2nd & 3rd floors and other relevant details for base case school building is attached as annex.

The direction of the structure is northeast. It is a four-story, 16m tall structure with 1332m^2 square feet of different activities space on each floor including a cafeteria, Art section, two number of science labs, two number of IT labs, Multimedia section & a library. The building wall space is around 264 m^3 of 225mm thick brick walls & 65m^2 of 112.5mm thick brick walls.

When selecting a walling material for a construction project, there are a number of elements to take into account, including cost, durability, insulating qualities, sustainability, aesthetics, and local building codes. Thermal insulation influences the envelope's interior surface temperature, which in turn directly impacts thermal comfort, according to the passive design toolkit. It is necessary for the internal surface temperature to stay high enough to prevent heat exchange that leads to temperature rise. (That is, by Conduction, radiation/convection, or both). Building envelopes should use high thermal mass materials, such as concrete, brick, and tiles, to help achieve this effect.

8.2 Selection of walling materials.

Brick is the most sociocultural sustainable wall material, with a sustainability rating. More practical and affordable conventional masonry blocks, such as CSEB and cement blocks, can be used to replace external walls of buildings without sacrificing the sociocultural index of the brick or work ability [52]. These blocks have the lowest embodied energy and the lowest carbon emission during the manufacturing and construction phases. The impact of exterior walls alone has been examined in this study report, with interior walls remaining fixed at 225mm (External) & 112.5mm (internal) inches of brick in every instance [53].

Cement blocks, also known as concrete blocks or cement bricks, are typically composed with cement 5%-10% by volume, but according to the SLS 855 standard It's vary up to 10% -20%. A common ratio is approximately 60% to 75% aggregates by volume. Typically, the water-to-cement ratio is kept between 0.4 and 0.6 by weight.

15% of the soil is gravel, 50% is sand, 15% is silt, and 20% is clay. 7–10% of the soil is stabilized with cement is the mix of CSEB. [54]

Regardless of the material used in construction, it is important to remember that routine maintenance and recurring inspections are necessary for extending the lifespan of any structure. Building owners may contribute to ensuring the lifetime and durability of their facilities by swiftly resolving concerns including moisture penetration, structural integrity, and degeneration.

The utility of the materials used in construction determines a building's lifespan. Brick homes typically have a predicted lifespan of 35 to 60 years, Cement blocks are anticipated to have a life of over 80 years, and CSEBs have a minimum service life of 50 years. The material itself will most likely live longer than that, but even with routine maintenance, the electrical and other parts of the building envelope won't hold up in that amount of time [54]. However, an equivalent life of 50 years is assumed for the purpose of calculating life cycle cost.

8.3 Life cycle cost accounting period

A structure's typical lifetime made of bricks, cement blocks, or compressed stabilized earth blocks (CSEBs) might vary based on a number of variables, such as the caliber of the constructing process, upkeep procedures, local climate, and the particular materials utilized.

8.3.1 Life cycle cost accounting period for brick wall building

When properly maintained, buildings made of brick can endure for several decades or even centuries. Brick buildings are renowned for their sturdiness, weather resilience, and pest and fire resistance. Nonetheless, a brick building's longevity may be affected by elements including the caliber of the mortar, the structural layout, moisture exposure, and seismic activity.

8.3.2 Life cycle cost accounting period for cement block wall building

When built and maintained correctly, buildings made of cement blocks, also called concrete blocks, may last as long as brick buildings. Because of its strength, resilience, and adaptability, cement blocks may be used in a variety of building applications. A cement block building's longevity may be impacted by elements like seismic resilience, exposure to chemicals and moisture, and the caliber of the reinforcing.

8.3.3 Life cycle cost accounting period for cement block wall building

When manufactured and erected properly, structures made of compressed stabilized earth blocks (CSEBs) can last as long as buildings made of brick or cement blocks. The thermal performance, affordability, and sustainability of CSEBs are well-known. A CSEB building's lifespan may be affected by environmental variables, soil quality, stabilizing methods, waterproofing measures, and exposure to the elements.

Life cycle stages	Product			Construction		Use stage							End-of-life			
						Related to the building fabric					Related to the building operation					
Modules	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4
	Raw material supply	Transport	Manufacturing	Transport	Construction	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Demolition	Transport	Waste processing	Disposal
				Scenarios												

Figure 33 : Life cycle stages according to EN 15804:2012

In this analysis included the followings:

In construction stage: A5 – Construction

In related to building fabric B2 - Maintenance

In related too the building operation: B6 - Operational energy use

8.4 Financial Analysis

The life cycle cost of a school building structure may be computed using a variety of techniques. The purpose of this research is to compare walling material LCC; so, other building expenses and equipment costs were disregarded. However, the life cycle cost of this kind of building unit is determined using the most used LCC costing approaches while the walling materials are substituted.

1. Simple payback period
2. Net present value (NPV)

8.4.1 Simple payback period

The simple payback period is a measure used to determine how long it will take for an investment to generate enough savings or profits to cover its initial cost. It is calculated by dividing the initial investment cost by the annual savings or returns generated by the investment.

$$Pay\ back\ period = {Initial\ inverment}/{Annual\ savings\ or\ Returns} \quad \text{Eq. 8}$$

8.4.2 Net present value

The present value of anticipated future cash flows, discounted at a certain rate, less the original investment cost is how the net present value (NPV), a financial statistic, assesses the profitability of an investment. Considering the time worth of money, net present value (NPV) is a tool used to determine if an investment or project will yield a profit.

$$\boldsymbol{NPV = C\,\frac{\left(1 + {i}/{100}\right)^{n-1}}{\left(1 + {d}/{100}\right)^{n}}} \quad \text{Eq. 9}$$

Where C – Any cost element at n^{th} year i – Inflation rate

d – Discount rate/ Interest rate

8.4.2.1 Inflation rate

The pace at which prices for goods and services generally increase and a currency's buying power declines is known as inflation. It shows the amount that prices have climbed over the previous year and is usually monitored yearly. Because inflation has an impact on the stability and expansion of the economy, central banks and governments keep a careful eye on it.

Sri Lanka suffered from severe inflation in 2023, which varied throughout the year. According to data from the Central Bank of Sri Lanka, the annual rate of inflation in December 2023 was **7.6%.** Compared to earlier in the year, when rates were higher, this indicates a significant decline. Sharper drops in inflation have occurred by mid-2023, in part because of stabilization initiatives and outside funding intended to lessen the nation's economic predicament [55]

The Asian Development Bank offers thorough studies and predictions that give forecasts and analysis for a thorough grasp of Sri Lanka's economic situation. According to the Asian Development Bank, their projections for inflation rates indicate a trend towards economic stabilization, with further declines to 7.5% in 2024 and 5.5% in 2025 [55].

8.4.2.2 Discount or Interest rate

The Central Bank of Sri Lanka's major interest rates changed during the year in 2023 in reaction to the state of the economy. Especially for a significant portion of the year, the Standing Deposit Facility Rate (SDFR), which serves as a floor for overnight market rates, was kept at around 14.50%. Standing Lending Facility Rate (SLFR): This rate was maintained at around **15.50%** (CBSL Gov Lk) in order to act as a ceiling for overnight market rates [55].

8.4.3 Comparative Financial Analysis

To perform a comparative financial analysis of walls made from bricks, cement blocks, and Compressed Stabilized Earth Blocks (CSEB), we need to consider various cost factors including initial construction costs, maintenance costs, and the operational cost with time value of money.

Table 32: Construction, operational & maintenance cost of walling materials

Factor	Fire Clay Bricks	Cement Blocks	CSEB	Time phase
Construction cost (LKR)	13,782,005.00	12,805,387.46	10,459,675.31	0-1 year
Operational cost (LKR)	821,876.17	821,876.17	784,564.19	2-60 years
Maintenance Cost per year (LKR)	464,250.00	557,100.00	433,300.00	2-60 years
Inflation Rate (%)	7.6			
Discount or Interest rate (%)	15.5			
Total operational & maintenance cost per year (LKR)	**1,286,126.17**	**1,378,976.17**	**1,217,864.19**	2-60 years

8.4.3.1 Net present value calculation for brick walls

NPV for Construction cost (from equation 7.4.2)

$$NPV_{con} = 13{,}782{,}005.00\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{0}}{\left(1+{}^{15.5}/_{100}\right)^{1}}\right)$$

$$NPV_{con} = \mathbf{Rs\ 11.932\ Mn}$$

<u>NPV for operational & maintenance cost (OM)</u>

Cumulative value of operational & maintenance cost after nth year

$$\sum_{n=2}^{50}\left(OM\frac{(1+{}^{i}/_{100})^{n-1}}{(1+{}^{d}/_{100})^{n}}\right) \qquad \text{Eq. 10}$$

$$NPV_{OM}$$

$$= 1{,}286{,}126.17\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{1}}{\left(1+{}^{15.5}/_{100}\right)^{2}}\right)+1{,}286{,}126.17\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{2}}{\left(1+{}^{15.5}/_{100}\right)^{3}}\right)$$

$$+1{,}286{,}126.17\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{3}}{\left(1+{}^{15.5}/_{100}\right)^{4}}\right)\ldots\ldots+1{,}286{,}126.17\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{49}}{\left(1+{}^{15.5}/_{100}\right)^{50}}\right)$$

$$NPV_{OM} = \mathbf{Rs\ 14.66\ Mn}$$

Hence;

Total life cycle cost for Brick walls in 50 years = LCC $_{Bricks}$

$$NPV_{OM} + NPV_{CON} = 14{,}695{,}386.32 + 11{,}932{,}471.86$$

$$LCC_{Bricks} = \text{Rs } \mathbf{26.62\ Mn}$$

Net present value calculation for Cement block walls

NPV for Construction cost (from equation 7.4.2)

$$NPV_{con} = 12{,}805{,}387.46\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{0}}{\left(1+{}^{15.5}/_{100}\right)^{1}}\right)$$

$$NPV_{con} = \text{Rs } \mathbf{11.09\ Mn}$$

NPV for operational & maintenance cost (OM) (from equation 7.4.3.1)

Cumulative value of operational & maintenance cost after nth year

$$NPV_{OM} = 1{,}378{,}976.17\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{1}}{\left(1+{}^{15.5}/_{100}\right)^{2}}\right) + 1{,}378{,}976.17\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{2}}{\left(1+{}^{15.5}/_{100}\right)^{3}}\right) + 1{,}378{,}976.17\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{3}}{\left(1+{}^{15.5}/_{100}\right)^{4}}\right)\ldots\ldots + 1{,}378{,}976.17\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{49}}{\left(1+{}^{15.5}/_{100}\right)^{50}}\right)$$

$$NPV_{OM} = \boldsymbol{Rs}\ \mathbf{15.76\ Mn}$$

Hence;

Total life cycle cost for Cement block walls in 50 years = LCC $_{\text{cement blocks}}$

$$NPV_{con} + NPV_{OM} = 11{,}086{,}915.54 + 15{,}756{,}298.26$$

$$LCC_{cement\ block} = Rs.\mathbf{26.84\ Mn}$$

Net present value calculation for CSEB walls

NPV for Construction cost (from equation 7.4.2)

$$NPV_{con} = 10{,}459{,}675.31\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{0}}{\left(1+{}^{15.5}/_{100}\right)^{1}}\right)$$

$$NPV_{con} = \boldsymbol{Rs}\ \mathbf{9.05\ Mn}$$

NPV for Operational & maintenance cost (OM) (from equation 7.4.3.1)

Cumulative value of operational & maintenance cost after nth year

$$NPV_{OM} = 1{,}217{,}864.19\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{1}}{\left(1+{}^{15.5}/_{100}\right)^{2}}\right) + 1{,}217{,}864.19\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{2}}{\left(1+{}^{15.5}/_{100}\right)^{3}}\right) + 1{,}217{,}864.19\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{3}}{\left(1+{}^{15.5}/_{100}\right)^{4}}\right)\ldots\ldots + 1{,}217{,}864.19\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{49}}{\left(1+{}^{15.5}/_{100}\right)^{50}}\right)$$

$$NPV_{OM} = \boldsymbol{Rs}\ \mathbf{13.91\ Mn}$$

Hence;

Total life cycle cost for CSEB walls in 50 years = LCC $_{CSEBs}$

$$NPV_{con} + NPV_{OM} = 9{,}055{,}995.93 + 13{,}915{,}419.16$$

$$LCC_{CSEB} = \boldsymbol{Rs}\ \mathbf{22.97\ Mn}$$

Table 33: Comparative summary of life cycle cost analysis of different walling materials

Factor	Fire Clay Bricks	Cement Blocks	CSEB
Total NPV in construction cost (LKR)	11,932,471.86	11,086,915.54	9,055,995.94
Total NPV in operation & maintenance cost (LKR)	14,695,386.32	15,756,298.26	13,915,419.16
Total NPV (LKR)	**26,627,858.18** **(26.628 Mn)**	**26,843,213.80** **(26.843 Mn)**	**22,971,415.10** **(22.971 Mn)**

8.4.4 End of life cost analysis for bricks, cement blocks & CSEB walls

End-of-life costs include all of the costs and factors related to construction material disposal, recycling, or repurposing at the end of a building's useful life.

Bricks may be reused a lot. The demand for new materials and related expenses can be decreased when a building is demolished because unbroken bricks can be cleaned and used in future construction projects. [56] Bricks can be recycled into aggregate for use in road building and other uses if they are not needed again. Bricks are inert and can be disposed of in landfills without posing any environmental risks, hence the cost of disposal is modest. But the expenses of processing and shipping may mount up. Reusing or recycling bricks has very less of an influence on the environment. They take up room in landfills when disposed of, although they don't really endanger the environment. [57]

Compared to bricks, cement blocks have a lower recyclability. They are more prone to shatter during demolition and become unfit for direct reuse in new constructions. Compared to bricks, cement blocks require more money for disposal. These stones are frequently broken and utilized as aggregate for freshly laid concrete or road construction, requiring transportation and processing. Cement blocks take up a lot of landfill area if they are not recycled, which raises disposal expenses. In the event that cement blocks are not recycled, the environmental effect increases. They add to the debris that ends up in landfills, and the process of making cement has a big carbon impact. Recycling them aids in reducing some of these effects. [54]

CSEB walls are both extremely recyclable and eco-friendly. They can be broken down and utilized as a foundation for newly constructed structures or for landscaping. The reintegration of CSEB into the ecosystem is facilitated by their soil-based nature. Costs of disposal for CSEB are minimal. They can be let to break down naturally without damaging the environment if they are not to be reused. Compared to bricks and cement blocks, processing and transportation expenses are negligible. There is not much of an influence on the environment. CSEB do not considerably increase the amount of garbage that ends up in landfills because they are composed of natural materials. Compared to traditional cement blocks, they have a smaller carbon footprint if stabilized using less cement or lime.

Table 34: End of life cost analysis

End-of-Life Aspect	Bricks	Cement Blocks	CSEB
Reusability	High	Low	High
Disposal Costs	Moderate	High	Low
Environmental Impact	Low	High	Very Low

CHAPTER 9

9. KEY FINDINGS & DISCUSSION

More and more people are using compressed stabilized earth blocks (CSEB) as an affordable and environmentally friendly building material, particularly in poor nations. CSEB is a desirable alternative for developing school buildings in Sri Lanka, where there is a great demand for reasonably priced, long-lasting, and ecologically friendly construction techniques. Comparing CSEB to conventional materials like bricks and cement blocks, this examination looks at how well it performs in terms of cost, environmental effect, structural performance, thermal comfort, and compatibility for the local area.

The expanding population of Sri Lanka necessitates a swift growth and enhancement of the country's educational infrastructure. Despite being widely utilized, traditional building materials like bricks and cement blocks have drawbacks in regard to cost, environmental effect, and energy efficiency. A sustainable substitute is provided by CSEB, which is created from local dirt combined with a stabilizer (such cement or lime), crushed into blocks, and allowed to cure.

9.1 Sustainability recommendation

When evaluating the environmental effect of various building materials, it is important to consider the materials' complete lifespan, especially with regard to CO_2 emissions. This covers the stages of building, manufacture, transportation, extraction of raw materials, and end of life. Because of the clay mining and kiln-firing procedures, there are considerable CO_2 emissions during the manufacture of clay bricks. The kilns produce a lot of carbon dioxide because they are frequently fuelled by coal or other fossil fuels. Bricks are among the materials that produce the most carbon dioxide due to the energy-intensive nature of the burning process. Cement manufacture is the main cause of the large carbon footprint of cement blocks, particularly those constructed from Portland cement. Because the process of producing cement requires the calcination of limestone (calcium carbonate), which produces carbon dioxide, it accounts for around 8% of all CO_2 emissions worldwide.

As a summery,

To provide a clear comparative analysis, the following table summarizes the CO_2 emissions across different stages of the life cycle for bricks, cement blocks, and CSEB;

Table 35: CO_2 emissions across different stages

Life Cycle Stage	Bricks	Cement Blocks	CSEB
Raw Material Extraction & Processing	High	Very High	Low
Manufacturing	Very High	High	Low
Transportation	High	Moderate	Low
Construction	Moderate	Moderate	Low
End-of-Life	Low	Moderate	Very Low

By considering the entire life cycle, including extraction, manufacturing, transportation, construction, and end-of-life stages, it is clear that CSEB offers a significant reduction in CO_2 emissions compared to traditional bricks and cement blocks, making it a superior choice for environmentally conscious construction. As per the results obtained from this research;

When production of fire clay bricks for the project, it emits 244.245 tons of CO_2 & cement blocks emits 85.702 tons of CO_2. But in CSEB production, it emits only 32.166 tons of CO_2. Comparatively it is reduction of 86.83% & 62.46% than bricks & cement blocks respectively

9.2 Construction cost evaluation

It's important to take into account all of the factors that go into the overall cost when comparing walling materials and building expenses. These expenses include of the costs of materials, labor, transportation, and any other costs associated with the building process.

A thorough document called the Building Schedule of Rates (BSR) is used in building projects to manage budgets, assign resources, and predict costs. It includes thorough lists of all the different construction tasks, supplies, labor, tools, and related expenses related to building projects. BSRs offer standard rates or pricing for every item and are often arranged according to trade or activity. In this research most of the rates based on BSR.

As per the results obtained from the calculations, CSEB is the best option for projects that are budget careful, particularly in areas where soil is easily accessible. Cement blocks are an excellent substitute for those looking to strike a balance between price and building efficiency. Despite being the most expensive option when it comes to construction, bricks are classic and long-lasting.

Table 36: Comparative summary of wall construction cost analysis

Factor	**Fire Clay Bricks**	**Cement Blocks**	**CSEB**
Total Amount in wall construction	13.728 Mn	12.805 Mn	10.459 Mn

9.3 Operational & maintenance cost evaluation

The continuous expenditures related to upkeep, repairs, and operation of a structure during its lifetime are referred to as operational costs for walling materials. Long-term performance, durability, energy consumption, and maintenance and repair expenses are the key elements affecting operating costs.

Bricks are durable and have strong thermal qualities, but they need to be maintained sometimes, particularly the mortar joints. Due to energy savings in temperature control and the requirement for routine but reasonable maintenance, their operating costs are modest. Although cement blocks are robust and long-lasting, their tendency to retain heat makes them more expensive to heat in warm areas. Compared to bricks, maintenance is less expensive, although any moisture and fracture problems still need to be addressed. Because of its exceptional thermal qualities and low energy consumption, CSEB is unique in the industry and offers substantial cost savings for both heating and cooling. While upkeep is necessary to guard against moisture, overall maintenance expenses are minimal. Because of its low long-term operating expenses, CSEB is an extremely economical and sustainable walling material alternative.

Table 37: Comparison of operational cost for different walling materials

Cost Aspect	Bricks	Cement Blocks	CSEB
Energy Consumption	Moderate to Low	Moderate to Low	Low
Heating and Cooling Costs	Moderate to Low	Moderate to Low	Low
Energy Efficiency	Moderate	Moderate	High
Maintenance Frequency	low to Moderate	Moderate	Moderate
Repair Costs	Moderate	Moderate	Low to Moderate
Durability	High	High	Moderate to High
Long-Term Performance	Excellent	Excellent	Good
Long-Term Costs	Low to Moderate	Moderate	Low

It was found that the operational cost for CSEB was lowest compared to bricks & cement blocks. Further the maintenance cost of CSEB also lowest compared to other two building materials.

Table 38: Comparison of operational cost for different walling materials.

Material	**Bricks**	**Cement Blocks**	**CSEB**
Operational cost per year (LKR)	**821,876**	**821,876**	**784,564**

Table 39: Comparison of maintenance cost for different walling materials.

Factor	Fire Clay Bricks	Cement Blocks	CSEB
Annual Maintenance Cost	**LKR 150.00-LKR 600**	**LKR 300-LKR 600**	**LKR 200-LKR 500**
As per the bills of quantities total cost of maintenance (Average LKR)	**464,250**	**557,100**	**433,300**

9.4 **Life cycle cost evaluation**

In conclusion, the life cycle cost study indicates that CSEB offer a potential alternative for sustainable building, especially in areas like Sri Lanka, even though each wall material has advantages and disadvantages of its own. by taking into account elements including starting costs, operational effectiveness, and environmental impact. Moreover, CSEB show promise for long-term sustainability and economic viability, particularly in areas with adequate soil supply and an emphasis on environmental preservation. In building projects, stakeholders may make well-informed decisions to achieve both environmental and economic goals. (refer table 26)

Table 40: Comparative summary of life cycle cost analysis of different walling materials

Factor	Fire Clay Bricks	Cement Blocks	CSEB
Total NPV (LKR)	26.627 Mn	26.843 Mn	22.971 Mn

9.5 Compressive strength evaluation

Compressed Stabilized Earth Blocks are a sustainable construction material created by compressing earth, stabilizer (such as cement or lime), and water into blocks. The compressive strength of CSEB is an important feature that influences the load-bearing capability and longevity of the blocks. Typically, the strength ranges between 2 and 10 MPa, depending on soil type, stabilizer concentration, and curing circumstances. In this research it was found as 4.82 MPa in 22.5% clay, 60% sand, 17.5% silt & 0.06% of cement mix.

Higher stabilizer content and correct curing procedures, such as wet curing, improve compressive strength. Stabilizers promote soil particle cohesion, hence increasing overall structural integrity. Testing is often performed after 28 days after curing, in accordance with standards like as ASTM or IS regulations.

9.6 Comparative performance assessment on 150mm thick CSEB & 225mm thick CSEB walls

When comparing the performance of 150mm thick Compressed Stabilized Earth Block (CSEB) walls to 225mm thick CSEB walls, again considered the above factors. These include thermal insulation, energy consumption, cost-effectiveness and environmental impact.

CSEB walls are typically 150mm thick and used for non-load-bearing walls or low-rise constructions. Adequate for mild weights, but may require reinforcing for heavier load-bearing applications. Provides basic thermal insulation, however extra insulating materials may be required in harsh conditions. Higher heat transfer might result in more heat loss or gain.

9.6.1 Energy consumption & operational cost analysis

As per the calculation in 6.3.1 & 6.3.3;

the thermal resistance value for 150mm thick CSEB wall is 2.5m^2.K/W [30]

Table 41: Total cooling load for CSEB walls building.

Material	**150mm thick CSEB**	**225mm thick CSEB**
Thermal Resistance (m2.K/W)	2.5000	3.7500

According to the HAP 4.51 analysis; (attached as annex 03)

Total coil load for 150 mm thick CSEB walls building is 98.9 kW & the arrangement of split A/C units for the building, as same as brick wall building. Hence the operation cost for the heat & ventilation is same as brick walls & cement block walls.

Table 42: Total cooling load for 150mm thick CSEB walls building.

HAP analysis for 150mm CSEB walls Total Coil load = 99.3 kW			
Space	**Sensible load (W)**	**Latent load (W)**	**Total load (W)**
Art Section	6,061	2,769	8,830
AV & MMS	4,953	4,666	9,619
IT Lab 1	8,440	2,848	11,288
IT Lab 2	8,439	2,848	11,287
Library	24,602	7,119	31,721
Science Lab 1	3,804	2,769	6,573
Science Lab 2	4,298	2,769	7,067
SEU	3,554	1,582	5,136
Totals	**64,151**	**27,370**	**91,521**

Bypass factor: 0.1

Table 43: Total cooling load for different walling materials.

Material	**Bricks**	**Cement blocks**	**225mm CSEB**	**150mm CSEB**
Total cooling load of the building (W)	64,384	65,932	63,314	64,151

Bypass factor: 0.1

Sensible heat gain through 150mm thick CSEB walls

Total sensible heat load through CSEB walls = 3,024 W

Total sensible load of the building (CSEB) = 64,151 W

Impact of sensible heat load on total cooling load of the building ($CSEB_{150mm}$) =

$$3{,}024\ W / 64{,}151\ W = 0.047 = 4.71\%$$

9.6.2 CO_2 emission calculation in 150mm thick CSEB production & wall construction.

As per the calculation in 6.5.4.1;

No of 150 mm thick CSEB required for the project = 44,568 nos

Average cement use in one 150mm thick block production = 0.5 kg

Total cement bag requirement for block production

$$44{,}568 \times 0.5 = 28{,}152\ kg$$

$$\frac{28{,}152}{50} = 563.04\ cement\ bags$$

CO_2 emission in one cement bag production (average) = 40 kg

Average CO_2 emission in block production for this project

$$563.04 \times 40 = 22.521\ ton\ of\ CO_2$$

As per the calculation in 6.5.4.2;

Total CO_2 emission in CSEB wall construction for the project

$$23.03 \times 6.4 \times 40 = 5.896\ tons\ of\ CO_2$$

Total CO_2 emission for project only in CSEB production, wall construction

$$22.521 + 5.896 = \mathbf{28.417\ tons\ of\ CO_2}$$

Table 44: CO_2 emission comparison between 150mm & 225mm thick CSEB walls

Material name	CSEB (225mm thick)	CSEB (150mm thick)
CO_2 emission (tons)	32.166	28.417

9.6.3 Life cycle cost analysis for 150mm thick CSEB walls

As per the calculation in 6.6.4;

Rate analysis of CSEB wall construction for 6" (150mm) thick one square meter is Rs. 6,263.44 & total wall area is 1,238.33 m^2

Total Cost for CSEB wall construction of the project. (wall quantity is in table 09)

$$1{,}238.33 \times 6{,}263.44 = Rs.\mathbf{7,756,205.65}$$

$$Rs.\mathbf{7.76\ Mn}$$

LIFE CYCLE COST(LCC) ANALYSIS

Net present value calculation for 150mm thick CSEB walls

NPV for Construction cost (from equation 7.4.2)

$$NPV_{con} = 7{,}756{,}205.65\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{0}}{\left(1+{}^{15.5}/_{100}\right)^{1}}\right)$$

$$NPV_{con} = Rs\ \mathbf{6.71\ Mn}$$

NPV for Operational & maintenance cost (OM) (from equation 7.4.3.1)

Cumulative value of operational & maintenance cost after n^{th} year

$$NPV_{OM}$$

$$= 1{,}255{,}176.17\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{1}}{\left(1+{}^{15.5}/_{100}\right)^{2}}\right) + 1{,}255{,}176.17\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{2}}{\left(1+{}^{15.5}/_{100}\right)^{3}}\right)$$

$$+ 1{,}255{,}176.17\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{3}}{\left(1+{}^{15.5}/_{100}\right)^{4}}\right) \ldots\ldots + 1{,}255{,}176.17\left(\frac{\left(1+{}^{7.6}/_{100}\right)^{49}}{\left(1+{}^{15.5}/_{100}\right)^{50}}\right)$$

$$\mathrm{NPV_{OM}} = \mathbf{Rs\ 14.34\ Mn}$$

Hence;

Total life cycle cost for CSEB walls in 50 years = LCC $_{CSEBs}$

$$\mathrm{NPV_{con}} + \mathrm{NPV_{OM}} = 6{,}715{,}329.57 + 14{,}341{,}749.00$$

$$\text{LCC}_{150\text{mm CSEB}} = \text{Rs } \mathbf{21.06\ Mn}$$

Table 45: Life cycle cost comparison between 150mm & 225mm thick CSEB walls

Factor	225mm thick CSEB	150mm thick CSEB
Total NPV in construction cost (LKR)	9,055,995.94	6,715,329.57
Total NPV in operation & maintenance cost (LKR)	13,915,419.16	14,341,749.00
Total NPV (LKR)	**22,971,415.10** **(22.971 Mn)**	**21,057,078.57** **(21.057 Mn)**

9.7 Summery

Different walling materials display varying performance in terms of CO_2 emissions, construction cost, operational cost, and life cycle factors. Traditional materials, such as brick and concrete, have greater CO_2 emissions and moderate life cycle costs, but novel materials, such as CSEB blocks, have superior environmental and financial efficiency. Sustainable may be a wonderful alternative if properly handled. Choosing the best material requires balancing these elements depending on the unique project needs and environmental goals.

Table 46: Overall comparative performance assessment on walling materials

Factor	Fire Clay Bricks	Cement Blocks	225mm thick CSEB	150mm thick CSEB
Compressive strength (MPa)	7.5-15	3-15	2-10	2-10
Thermal resistance (m^2K/W)	2.233	1.052	3.750	2.500
Thermal Lag (Hours/mins)	7 h 09 mins	7 h 35 mins	10 h 05 mins	6 h 43 mins
Building Cooling load (W)	91,754.00	93,302.00	90,684.00	91,521.00
Sensible heat load due to conduction through walls (%)	4.88	7.42	3.27	4.71
Annual energy consumption for A/C system (kW)	35,968.41	35,968.41	34,968.41	35,968.41
Average CO2 emission in production & construction stage (tons)	244.25	85.70	32.17	28.42
Wall construction cost in Mn (LKR)	13.782	12.805	10.459	7.756
Total operational & maintenance cost per year in Mn (LKR)	1.287	1.379	1.218	1256
Life Cycle cost in Mn (LKR)	26.628	26.843	22.917	21.057

CHAPTER 10

10. CONCLUSION & RECOMMENDATION

Finally, numerous criteria should be considered while comparing the performance of compressed stabilized earth blocks for school buildings in Sri Lanka, including cost, durability, thermal comfort, and sustainability. Because they may use locally accessible soil and require less energy-intensive production methods, CSEBs have the potential to offer economic advantages over standard building materials. This can help to reduce construction costs, making CSEBs an economically viable choice for Sri Lankan school buildings.

CSEB structures that are properly designed and built can last a long time. To prevent deterioration, the moisture sensitivity of earth-based materials must be properly handled. To ensure the long-term longevity of CSEB school buildings, adequate measures such as moisture control, waterproofing, and regular maintenance are required.

While CSEBs have lower structural strength than traditional materials such as concrete or steel, they can nonetheless provide appropriate strength for low and medium-rise school buildings. To maintain structural integrity, proper engineering expertise and reinforcement procedures are required.

Based on their intrinsic thermal qualities, CSEBs can help to increase thermal comfort in school buildings. Their great thermal mass aids in the regulation of indoor temperatures, eliminating the need for more artificial heating or cooling. This can result in energy savings and a more comfortable learning environment for pupils in the tropical heat of Sri Lanka.

CSEBs provide various benefits to school buildings in terms of sustainability. They are made with locally available materials, which reduces the need for transportation and the resulting carbon, CO_2 emissions including the manufacturing process. When compared to the production of traditional building materials, the manufacturing method has a smaller environmental impact. Furthermore, CSEBs can generate local employment and help Sri Lanka establish sustainable construction methods.

However, CSEBs have lower structural strength compared to typical materials, requiring reinforcement and engineering skills for structural integrity. Proper moisture management and protective measures are crucial for CSEB construction. Initial training and capacity-building programs may be necessary to provide a competent workforce. Addressing social biases and fire resistance concerns is crucial for CSEB school building acceptance in Sri Lanka. The comparative performance of CSEBs depends on factors like local soil conditions, construction procedures, design considerations, and maintenance practices. Proper planning, adherence to quality control standards, and regular maintenance can reduce disadvantages and ensure the longevity and sustainability of Sri Lankan CSEB school buildings.

And also, **CSEBs will show promise in terms of cost-effectiveness, durability, thermal comfort, and sustainability for school buildings in Sri Lanka.**

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ANNEXTURE 1

Annexture 01: Architectural drawings of proposed four storied building with library, ordinary science labs, aesthetic unit, cafeteria and special education unit at Mahanama college, Colombo 03.

ANNEXTURE 2

Annexture 02: Weather data received from Department of Meteorology

ANNEXTURE 3

Annexture 03: Daikin split air conditioner catalogue

ANNEXTURE 4

Annexture 04: Coolong load results obtained from HAP 4.51 software for different walling materials

ANNEXTURE 5

Annexture 05: Compressive strength test reports