

LB/TH/39/2025

FINAL PROJECT REPORT - G.S PRIYASHAN 228457P

TH5990

**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

June 2024

DECLARATION OF THE CANDIDATE AND THE SUPERVISOR

I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis/dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date: 12.02.2025

The supervisor/s should certify the thesis/dissertation with the following declaration.

The above candidate has carried out research for the Masters/MPhil/PhD thesis/dissertation under my supervision.

10.03.2025

Signature of the supervisor:

Date:

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

ACKNOWLEDGEMENT

I would like to express my gratitude and appreciate my supervisor, Prof. Sanjeewa Witharana, co-supervisor Dr. Hirushi Karunathilaka & Mr. Viraj Nimarshana from Department of Mechanical engineering, for making this work possible. Their persistent help and advice saw me through the entire process of writing my report. I appreciate their taking the time out of their hectic schedule to work on my assignment. Thank you for your amazing ideas and suggestions, as well as those of my classmates.

I'd want to express my gratitude to my entire family for their unwavering support and patience while I was conducting research and writing my thesis. We appreciate the time and effort you put into this project. My completion of this assignment would not have been possible without the help of my friends (Batch mates). Your unwavering support and prayers for me have helped me get this far.

Finally, I want to thank God for guiding me through all of the difficulties. Every day, I sensed your presence. Because of you, I was able to finish my degree. I'll continue to place my faith in you for my future.

CONTENTS

DECLARATION OF THE CANDIDATE AND THE SUPERVISOR..... i

ABSTRACT..... ii

ACKNOWLEDGEMENT iii

LIST OF FIGURES xi

LIST OF TABLES xiii

LIST OF NOMENCLATURE..... xv

CHAPTER 1 1

1. INTRODUCTION 1

CHAPTER 2 3

2. TYPES OF BUILDINGS & THEIR ENERGY USAGE 3

2.1 Types of buildings..... 3

2.2 School buildings 4

2.3 Specific requirements for school building construction in Sri Lanka..... 4

2.4 Expected properties & characteristics of building materials..... 5

CHAPTER 3 7

3. MATERIAL USED IN BUILDING CONSTRUCTION..... 7

3.1 Deferent types of wall construction materials & blocks 7

3.1.1 Cement sand block (CSB) 7

3.1.2 Hollow core fired brick (HCFB) 8

3.1.3 Country fired brick (CFB)..... 8

3.1.4 Earth concrete block (ECB) 9

3.1.5 Compressed stabilized earth block (CSEB) 10

3.2 Comparison of properties between different conventional wall materials..... 13

CHAPTER 4	15
4. COMPRESSED STABILIZED EARTH BLOCKS & THEIR PROPERTIES	15
4.1 Compressive strength	15
4.1.1 Soil properties.....	16
4.1.2 Stabilized agent.....	16
4.1.3 Curing time.....	16
4.1.4 Production techniques	17
4.1.5 Block size & shape.....	18
4.2 Thermal values	18
4.2.1 Thermal conductivity	19
4.2.2 Thermal mass.....	19
4.3 Durability	20
4.3.1 Quality of material (soil properties).....	21
4.3.2 Design of building.....	21
4.3.3 Maintenance.....	22
4.4 Environmental factors.....	23
4.5 Cost effectiveness.....	25
4.5.1 Raw material availability	25
4.5.2 Low material cost	26
4.5.3 Labor efficiency.....	27
4.5.4 Energy efficiency	27
4.5.5 Construction speed.....	28
4.5.6 Thermal performance	28
4.6 Sustainability	29
4.7 Other types of compressed stabilized earth blocks.....	31

4.7.1	Lime-stabilized earth blocks (LSEB)	32
4.7.2	Fly-ash stabilized earth blocks (FASEB)	32
4.7.3	Bitumen stabilized earth blocks (BSEB)	33
4.7.4	Polymer stabilized earth blocks (PSEB)	33
CHAPTER 5		36
5.	COMPARATIVE PERFORMANCE ASSESSMENT OF COMPRESSED STABILIZED EARTH BLOCKS WITH CONVENTIONAL MATERIALS	36
5.1	Compressive strength	36
5.2	Thermal conductivity & thermal mass	37
5.3	Durability	38
5.4	Environmental factors & sustainability	39
5.5	Cost effectiveness	41
5.6	Advantages of compressed stabilized earth blocks usage for school buildings	42
5.7	Disadvantages of compressed stabilized earth blocks usage for school buildings and solutions	43
CHAPTER 6		46
6.	COMPARAYIVE PERFORMANCE ANALYSIS ON ENERGY, & COMPRESSIVE STRENGTH	46
6.1	Analysis on energy	46
6.1.1	Establish the project's aims and objectives	46
6.1.2	Gather building data	52
6.1.3	Using software for energy consumption of the building	53
6.1.4	Building system data	54
6.1.5	Calculation of thermal resistance in 225mm thick fire clay bricks, 200mm cement blocks & compressed stabilized earth blocks	55
6.1.5.1	Thermal resistance calculation for 225mm thick brick walls	55

6.1.5.2	Thermal resistance calculation for 200mm thick cement block walls	57
6.1.5.3	Thermal resistance calculation for 225mm thick compressed stabilized earth block walls.....	58
6.1.6	Energy consumption calculations.....	61
6.1.6.1	Calculating the heat gain through different types of walling materials.....	61
6.1.6.2	Converting cooling loads to Tons of refrigerants	63
6.1.6.3	Split A/C units' arrangements for room spaces.....	64
6.1.6.4	Converting cooling loads to Tons of refrigerants	65
6.1.6.5	Annual operational cost calculation.....	67
6.2	Compressive strength analysis for different walling materials.....	69
6.2.1	The relationship among clay, sand, silt & stabilizer in compressed stabilized earth blocks	69
6.2.2	Role of each component.....	70
6.2.3	Optimal Proportions of components in Compressed stabilized earth blocks... ..	71
6.2.4	Minimum compressive strength required for brick, cement blocks & CSEB wall construction	72
6.2.5	Compressive strength of Compressed Stabilized Earth Blocks	73
6.3	Comparative Assessment of Thermal Lag in Clay Bricks, Cement Blocks, and Compressed Stabilized Earth Blocks.....	77
6.3.1	Fire clay bricks.....	77
6.3.2	Cement blocks.....	78
6.3.3	Compressed stabilized Earth blocks	78
6.3.4	Calculation of Thermal lag in different walling materials.....	78
6.3.5	Thermal Properties materials.....	79
6.3.6	Thermal Lag Calculation.....	79
6.3.7	Influence of Thermal Lag in School Building Construction with CSEB Walls	81

CHAPTER 7	82
7. COMPARAYIVE PERFORMANCE ANALYSIS ON, ENVIRONMENTAL IMPACT & COST OF WALLING MATERIAL.....	82
7.1 CO ₂ emission calculation in walling material production & wall construction..	82
7.1.1 Brick production & CO ₂ emissions.....	83
7.1.1.1CO ₂ emission calculation for bricks production for the project	84
7.1.1.2Calculate the CO ₂ emission in brick wall construction.....	85
7.1.2 Cement production & CO ₂ emission	86
7.1.2.1CO ₂ emission calculation due to cement production for the project only in wall construction.	86
7.1.3 Cement block (sand with quarry dust) production & CO ₂ emission	88
7.1.3.1CO ₂ emission calculation for cement block production for the project.....	89
7.1.3.2Calculation cement requirement for mortar.....	91
7.1.4 Compressed stabilized earth block production & CO ₂ emission.....	92
7.1.4.1CO ₂ emission calculation for CSEB production for the project	92
7.1.4.2Calculation cement requirement for chip concrete in wall construction.....	94
7.1.5 Comparative Assessment of CO ₂ Emissions in Fire Clay Brick, Cement Sand Block, and CSEB Production and Wall Construction	95
7.2 Wall construction cost analysis for different walling materials.....	96
7.2.1 Cost calculation for brick wall construction of the project	98
7.2.2 Cost calculation for the plastering work of the project	99
7.2.3 Cost calculation for Cement block wall construction of the project	100
7.2.4 Cost calculation for CSEB wall construction of the project	101
7.2.5 Comparative cost analysis for fire clay brick, cement block, and CSEB wall construction in the project.	103

7.3	Maintenance cost analysis for different walling materials.....	105
7.3.1	Maintenance cost for brick walls	106
7.3.2	Maintenance cost for cement block walls	106
7.3.3	Maintenance cost for CSEB walls.....	107
CHAPTER 8.....		108
8. LIFE CYCLE COST(LCC) ANALYSIS		108
8.1	Base case school building	109
8.2	Selection of walling materials.	109
8.3	Life cycle cost accounting period.....	110
8.3.1	Life cycle cost accounting period for brick wall building.....	110
8.3.2	Life cycle cost accounting period for cement block wall building	111
8.3.3	Life cycle cost accounting period for cement block wall building.....	111
8.4	Financial Analysis.....	112
8.4.1	Simple payback period.....	112
8.4.2	Net present value	112
8.4.2.1	Inflation rate	113
8.4.2.2	Discount or Interest rate.....	113
8.4.3	Comparative Financial Analysis.....	114
8.4.3.1	Net present value calculation for brick walls	114
8.4.4	End of life cost analysis for bricks, cement blocks & CSEB walls	117
CHAPTER 9.....		120
9. KEY FINDINGS & DISCUSSION		120
9.1	Sustainability recommendation.....	120
9.2	Construction cost evaluation.....	122
9.3	Operational & maintenance cost evaluation.....	122
9.4	Life cycle cost evaluation	124

9.5	Compressive strength evaluation.....	125
9.6	Comparative performance assessment on 150mm thick CSEB & 225mm thick CSEB walls.....	125
9.6.1	Energy consumption & operational cost analysis.....	126
9.6.2	CO ₂ emission calculation in 150mm thick CSEB production & wall construction.....	128
9.6.3	Life cycle cost analysis for 150mm thick CSEB walls.....	129
9.7	Summery.....	130
	CHAPTER 10.....	132
10.	CONCLUSION & RECOMMENDATION.....	132
	REFERENCES.....	1
	ANNEXTURE 1.....	4
	ANNEXTURE 2.....	4
	ANNEXTURE 3.....	4
	ANNEXTURE 4.....	4
	ANNEXTURE 5.....	4

LIST OF FIGURES

Figure 1 : Cement Sand Block (CSB)	7
Figure 2 : Hollow Core Fired Brick (HCFB)	8
Figure 3 : Country Fired Bricks (CFB)	9
Figure 4 : Earth Concrete Blocks (ECB).....	9
Figure 5 : Compressed Stabilized Earth Blocks (CSEB).....	10
Figure 6 : Content of good soil for CSEB.....	11
Figure 7: Types of CSEB	12
Figure 8: Compressive strength testing for CSEB	15
Figure 9: Hand pressed block manufacturing	17
Figure 10 : Machine Pressed Block Manufacturing.....	18
Figure 11 : Improper maintenance of CSEB buildings.....	23
Figure 13 : CO ₂ emission (KgCO ₂ /m ³) comparison (fired brick/ CSEB) [19].....	30
Figure 14 : Natural polymers for stabilizing earth blocks	35
Figure 17 : Modeled building for the design – Mahanama College, Colombo 03....	46
Figure 18 : Ground floor plan – Mahanama college, Colombo 03.	48
Figure 19 : First floor plan – Mahanama college, Colombo 03.....	49
Figure 20 : Second floor plan – Mahanama college, Colombo 03.	50
Figure 21 : Thid floor plan – Mahanama college, Colombo 03.....	51
Figure 22 : Weather details obtained from Department of Meteorology for Colombo.	52
Figure 23 : Details of a cross section – 225mm thick brick wall.....	55
Figure 24 : Details of a cross section – 225mm thick brick wall.....	55
Figure 25 : Details of a cross-section – 200mm thick cement block wall.	57
Figure 26 : Details of a cross section – 225mm thick CSEB wall.	58
Figure 27 : Customer Category GP-1 tariff	67
Figure 28 : Operational cost per year.....	68
Figure 29 : Compressive strength (MPa) Vs Silt content (%)	74
Figure 30 : Compressive strength (MPa) Vs Sand content (%).....	74
Figure 31 : Compressive strength (MPa) Vs Clay content (%)	75
Figure 32 : Performance of compressive strength test.....	77

Figure 33 : Grade 15 Chip concrete (1:2:4)	94
Figure 34 : CO ₂ emission in different walling materials for the project.....	96
Figure 35 : Construction cost analysis of walling material.....	105
Figure 36 : Life cycle stages according to EN 15804:2012.....	111

LIST OF TABLES

Table 1: Properties of different conventional wall materials [3]	13
Table 2: Sustainability and environmental friendliness of CSEB [26]	40
Table 3: Energy effectiveness [27]	41
Table 4: Thermal resistance values of wall materials	59
Table 5: Specific heat values of wall materials.....	59
Table 6: Total cooling load for brick walls building.....	60
Table 7: Total cooling load for cement block walls building.	60
Table 8: Total cooling load for 225mm thick CSEB walls building.....	61
Table 9: Total sensible heat load through walls.....	62
Table 10: Impact on energy usage for heat & ventilation of the building due to sensible heat loads through walls	63
Table 11: Split A/C unit arrangement for Brick & cement block walls.....	64
Table 12: Split A/C unit arrangement for CSEB walls.....	64
Table 13: Total energy consumption in several types of walling materials.....	65
Table 14: Comparison of operational cost for different walling materials.	68
Table 15: Results of compressive strength test	73
Table 16: Comparative summary compressive strength of different walling materials	76
Table 17: The following are the thermal properties of clay bricks, cement blocks, and CSEB (from chapter 6.1.5):	79
Table 18: Comparative Analysis summary of thermal lag.....	81
Table 19: Brick wall quantity for the building.....	84
Table 20: Wall plaster quantities for the building.....	87
Table 21: Cement block wall quantities for the building (Data from BOQ Mahanama College).....	89
Table 22: CSEB wall quantities for the building (Data from BOQ Mahanama College).....	93
Table 23: CO ₂ emission in different walling materials for the project	96
Table 24: 225mm & 112.5mm thick brick wall rates (Rates from BSR 2024)	98
Table 25: Cost for the brick wall construction in the project (Data from BSR 2024).....	99

Table 26: Cost for the brick wall construction in the project (Data from BSR 2024)	99
Table 27: Cost for the cement block wall construction in the project (Data from BSR 2024)	100
Table 28: Rate analysis of CSEB wall construction for 8” (200mm) thick one square meter.	101
Table 29: Rate analysis of CSEB wall construction for 6” (150mm) thick one square meter.	102
Table 30: Comparative summary of wall construction cost analysis.	104
Table 31: Comparative summary of maintenance cost of different walling materials	107
Table 32: Construction, operational & maintenance cost of walling materials	114
Table 33: Comparative summary of life cycle cost analysis of different walling materials	117
Table 34: End of life cost analysis	119
Table 35: CO ₂ emissions across different stages	121
Table 36: Comparative summary of wall construction cost analysis.	122
Table 37: Comparison of operational cost for different walling materials	123
Table 38: Comparison of operational cost for different walling materials.	124
Table 39: Comparison of maintenance cost for different walling materials.	124
Table 40: Comparative summary of life cycle cost analysis of different walling materials	125
Table 41: Total cooling load for CSEB walls building.	126
Table 42: Total cooling load for 150mm thick CSEB walls building.	127
Table 43: Total cooling load for different walling materials.	127
Table 44: CO ₂ emission comparison between 150mm & 225mm thick CSEB walls	128
Table 45: Life cycle cost comparison between 150mm & 225mm thick CSEB walls	130
Table 46: Overall comparative performance assessment on walling materials	131

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