

**EMBODIED ENERGY ANALYSIS OF A PRECAST
BUILDING SYSTEM**

Dissanayake Mudiyanseelage Kasurika Widvanga Dissanayake

(158016N)

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa
Sri Lanka

February 2018

EMBODIED ENERGY ANALYSIS OF A PRECAST BUILDING SYSTEM

Dissanayake Mudiyanseelage Kasurika Widvanga Dissanayake

(158016N)

Thesis submitted in partial fulfillment of the requirements for the degree Master of
Science/ Master of Engineering in Electrical Engineering

Department of Civil Engineering

University of Moratuwa
Sri Lanka

February 2018

DECLARATION

“I declare that this is my own work and this thesis 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 our thesis, 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).

.....

D. M. K. W. Dissanayake

Date:

The above candidate has carried out research for the Masters Dissertation under our supervision.

.....

Prof. (Mrs.) C. Jayasinghe

Date:

.....

Prof. M.T.R. Jayasinghe

Date:

ABSTRACT

Buildings are evolving throughout the history of mankind. When a new building system is introduced, the usual evaluation method is the monetary value. The adaptability to the climate conditions, structural capabilities and constructability are some other criteria for the evaluation. The building industry is consuming a vast amount of natural resources and also been responsible for a significant energy usage. With the recent developments in the environmental concerns all over the world, there is an increased the attention for the building sector. Due to the above reason new buildings have to be more environmental friendly than more conventional building systems.

A novel walling system has been considered in this study, which consist of lightweight foam concrete panels manufactured with recycled expanded polystyrene (EPS) up to 50% of the total volume. Even though those panels have lot of advantages over the conventional construction methods, they need to be compared with the other conventional methods for the environmental aspects. Embodied energy analysis is such an established method to quantitatively analyse the environmental impact caused by a product. Therefore, detailed study was carried out to determine the embodied energy of those foam concrete panels. A comparative study carried out using a typical single storey and for a two-storey house and different building materials.

Final results done for the case studies, indicated that houses constructed with cement sand blocks has the least amount of embodied energy and embodied carbon. However, houses constructed with EPS based lightweight foam concrete precast panels, can be a good competitor in terms of embodied energy and embodied carbon analysis, since it yields results much closer to the cement sand blocks. Reduced sand usage of EPS panelled walls is also an added advantage. Hence, it has the potential to be promoted as a mainstream walling material.

ACKNOWLEDGEMENT

I wish to express my gratitude and warmest appreciation to the following people, who, have helped, contributed, encouraged and inspired me in many ways to the overall success of the undertaking:

- Prof. (Mrs) C. Jayasinghe and Prof. M. R. T. Jayasinghe, the dissertation supervisors, for their patience, assistance, encouragement and valuable guidance provided throughout the period of the research to make this a success
- Prof. J.M.S.J. Bandara, the Head, Department of Civil Engineering-University of Moratuwa, for giving me the opportunity to undergo the dissertation and for the knowledge I have gained.
- Very special thank should be given to the National Building Research Organization for the funding provided to carry out the research
- Mr. Neranjan Fernando for providing all the necessary details required at the data collection stage and for all the support given throughout the research work
- For all the academic and non-academic staff of the Department of Civil Engineering at University of Moratuwa, for their kind support extended to me to make this dissertation successful.
- My friends, who have been unselfishly extending their efforts and understanding.
- The management and staff of University of Moratuwa, Sri Lanka and National Building Research Organization.
- Last, but not least, I express my heartfelt gratitude to my parents and siblings for giving their utmost support, genuine advices, for always been very understanding and supportive both financially and emotionally and continuously motivating me to carry out the work successfully.

TABLE OF CONTENTS

| | |
|--|------|
| DECLARATION | i |
| ABSTRACT | ii |
| ACKNOWLEDGEMENT | iii |
| LIST OF FIGURES | vii |
| LIST OF TABLES | viii |
| LIST OF SYMBOLS | ix |
| 1. INTRODUCTION | 1 |
| 1.1. Background | 1 |
| 1.2. Objectives | 3 |
| 1.3. Methodology | 3 |
| 1.4. Arrangement of the Thesis | 3 |
| 2. LITERATURE REVIEW..... | 5 |
| 2.1. General | 5 |
| 2.2. The Precast building system..... | 5 |
| 2.2.1. Precast columns..... | 6 |
| 2.2.2. Precast beams | 8 |
| 2.2.3. Precast slab panels..... | 8 |
| 2.2.4. Junction Details..... | 11 |
| 2.3. The precast panel system..... | 12 |
| 2.3.1. The properties of EPS | 13 |
| 2.3.2. The mix used for foam concrete..... | 14 |
| 2.4. Life cycle energy of a building..... | 16 |
| 2.5. Embodied energy analysis..... | 17 |

| | | |
|--------|--|----|
| 2.5.1. | Building materials and embodied energy..... | 19 |
| 2.5.2. | Methods of embodied energy analysis..... | 20 |
| 2.6. | Embodied carbon analysis..... | 21 |
| 3. | FIELD SURVEYS..... | 23 |
| 3.1. | General..... | 23 |
| 3.2. | Precast pre-stressed beams and columns..... | 23 |
| 3.2.1. | Precast concrete slab panels..... | 24 |
| 3.2.2. | Foam concrete panels..... | 28 |
| 3.2.3. | Plywood manufactured at Gintota..... | 30 |
| 3.2.4. | Quantify the energy used at transportation..... | 34 |
| 3.3. | Summary..... | 35 |
| 4. | EMBODIED ENERGY OF A SINGLE STOREY HOUSE: CASE STUDY 1 | 36 |
| 4.1. | General..... | 36 |
| 4.2. | Embodied energy of materials and elements..... | 38 |
| 4.2.1. | Mortar..... | 38 |
| 4.2.2. | Concrete..... | 39 |
| 4.2.3. | Rubble foundation..... | 39 |
| 4.2.4. | Brick Masonry..... | 40 |
| 4.2.5. | Block Masonry..... | 40 |
| 4.2.6. | Septic Tank and soakage pit..... | 41 |
| 4.2.7. | Roof..... | 42 |
| 4.3. | Embodied energy of transportation activities..... | 43 |
| 4.4. | Results of the analysis..... | 44 |
| 4.4.1. | Total embodied energy..... | 44 |
| 4.4.2. | Contribution of individual materials..... | 45 |

| | | |
|--------|---|----|
| 4.4.3. | Embodied carbon analysis of the building materials used | 46 |
| 4.5. | Discussion | 47 |
| 5. | EMBODIED ENERGY OF A TWO-STOREY HOUSE: CASE STUDY 2 | 48 |
| 5.1. | General | 48 |
| 5.2. | Embodied energy of materials | 49 |
| 5.3. | Embodied energy of transportation activities | 49 |
| 5.4. | Results of the analysis | 51 |
| 5.4.1. | Total embodied energy | 51 |
| 5.4.2. | Contribution of individual materials | 55 |
| 2.6.1. | Embodied Carbon Analysis | 56 |
| 5.5. | Discussion | 57 |
| 6. | CONCLUSIONS AND RECOMMENDATIONS | 58 |
| | REFERENCES | 60 |

LIST OF FIGURES

| | |
|--|-----------|
| <i>Figure 2-1: 150×250mm column with the provision of two 40mm grout holes (left) and three 150×150mm columns with T25 anchor bar fixed (right).....</i> | <i>7</i> |
| <i>Figure 2-2: 150×150mm columns- stacked at the yard with untrimmed prepressing strands</i> | <i>7</i> |
| <i>Figure 2-3: Pre-stressed strands of an 85mm thick slab panel (From casting yard at Ekala)</i> | <i>8</i> |
| <i>Figure 2-4: Concreting of slab panels with at the casting yard at Ekala (2015)</i> | <i>9</i> |
| <i>Figure 2-5: Lifting a panel using a crane at a construction site (A photo from the construction of a new hospital building at Negambo Hospital-2015).....</i> | <i>9</i> |
| <i>Figure 2-6: The joint between two slab panels is interlocked with pieces of 10mm steel bars (A photo from the construction of a new hospital building at Negambo Hospital-2015)</i> | <i>10</i> |
| <i>Figure 2-7: 6mm BRC mesh is used to reinforce the screed- before concreting (Fernando, 2016).....</i> | <i>10</i> |
| <i>Figure 2-8: A typical beam-column connection (Fernando,2016)</i> | <i>11</i> |
| <i>Figure 2-9: Foam concrete panels are manufactured in three thicknesses</i> | <i>12</i> |
| <i>Figure 2-10: Expanded polystyrene beads</i> | <i>14</i> |
| <i>Figure 4-1: Plan view of the single storey house</i> | <i>37</i> |
| <i>Figure 4-2: 3D model of the single storey house</i> | <i>38</i> |
| <i>Figure 5-1: Ground floor plan of the house</i> | <i>50</i> |
| <i>Figure 5-2: 1st floor plan.....</i> | <i>50</i> |
| <i>Figure 5-3: Comparison of the total embodied energy of the four houses.....</i> | <i>52</i> |

LIST OF TABLES

| | |
|---|----|
| Table 2.1: Mix proportions used ((<i>Fernando, 2016</i>) | 15 |
| Table 2.2: Different definitions for Embodied Energy found in important literature | 18 |
| Table 3.1: Manufacturing of pre-stressed beams (7 numbers of 350*150*4000mm) | 25 |
| Table 3.2: Manufacturing of pre-stressed columns (7 numbers of 200*200*3000mm) | 26 |
| Table 3.3: Manufacturing of pre-stressed slab panels (60*1000*4000mm)..... | 27 |
| Table 3.4: EE of transportation of materials to the factory | 29 |
| Table 3.5: EE of materials for producing 18 number of 100mm thick EPS panels ... | 29 |
| Table 3.6: Monthly Electricity usage of the factory | 31 |
| Table 3.7: Monthly diesel consumption for the lorries which transport logs | 32 |
| Table 3.8: Embodied energy of Glue | 33 |
| Table 3.9: Average operation efficiencies of commonly used vehicles at construction activities | 35 |
| Table 3.10: Average energy consumption of the considered vehicles in the study ... | 35 |
| Table 4.1: Embodied energy of a cement- sand block | 41 |
| Table 4.2: Embodied energy calculation for 1m ² of zinc-alum sheet | 42 |
| Table 4.3: Embodied energy of roof the single storey house..... | 43 |
| Table 4.4: Total embodied energy of single storey houses | 45 |
| Table 4.5: Contribution of individual materials to the embodied energy | 46 |
| Table 4.6: Carbon emission from building materials used in the case study (Carbon Coefficients based on ICE database)..... | 47 |
| Table 5.1: Total embodied energy of the two-story house..... | 53 |
| Table 5.2: Contribution of Individual materials to the Embodied Energy..... | 54 |
| Table 5.3: Results of embodied carbon analysis | 57 |

LIST OF SYMBOLS

| Abbreviation | Description |
|--------------|----------------------------|
| EE | Embodied Energy |
| EPS | Expanded Polystyrene |
| LCEA | Life Cycle Energy Analysis |