EMBODIED ENERGY AUDIT: A TOOL FOR SUSTAINABLE CONSTRUCTION

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF ARCHITECTURE

By

RASHMI S. TIJARE

DEPARTMENT OF ARCHITECTURE AND PLANNING
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE-247 667 (INDIA)

JUNE, 2007

CANDIDATE'S DECLARATION

I hereby declare that the work which is presented in the dissertation entitled "**EMBODIED ENERGY AUDIT : A TOOL FOR SUSTAINABLE CONSTRUCTION**", in partial fulfillment of the requirements for the award of the degree of **MASTER OF ARCHITECTURE**, submitted in the Department of Architecture and Planning, **INDIAN INSTITUTE OF TECHNOLOGY ROORKEE, ROORKEE** is an authentic record of my own work carried out for a period of about one year from July 2006 to June 2007, under the supervision of **DR. P. S. CHANI** and **DR. MAHUA MUKHERJEE**, Department of Architecture and Planning, INDIAN INSTITUTE OF TECHNOLOGY ROORKEE, ROORKEE , INDIA.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Rashmi Tijare

Dated: 25th June 2007

Place: Roorkee

(RASHMI S. TIJARE)

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Dr. Mahua Mukherjee
Assistant Professor
Dept. of Architecture and Planning
IIT, Roorkee
Roorkee – 247667

Dr. P. S. Chani
Assistant Professor
Dept. of Architecture and Planning
IIT, Roorkee
Roorkee – 247667

ACKNOWLEDGEMENT

Expressing my gratitude to all those who are directly or indirectly helped in making this course of M Arch. and dissertation a success.

First of all my thanks to my guides, **Dr. P. S. CHANI**, and Dr. **MAHUA MUKHERJEE,** Assistant Professor, Department of Architecture And Planning, IIT Roorkee, for being helpful and a great source of inspiration. Their keen interest and constant encouragement gave me the confidence to complete my work. I wish to extend my sincere thanks for their excellent guidance and suggestions for the successful completion of my dissertation work.

My thanks are also due to all my teachers for their valuable knowledge, information and constant encouragement.

Express my thanks to Prof. S. Y. Kulkarni, H.O.D. Department of Architecture and Planning.

I thank my parents and my brother who been a constant source of inspiration to me throughout my career.

Finally I would like to thank all my friends who have, directly or indirectly contributed to the completion of my work.

Rashmi Tijare

(RASHMI S. TIJARE)

ABSTRACT

Embodied energy is the energy required for production of building materials.

It consists of energy required for,

- for quarrying of raw materials,
- for transportation of materials from quarry to manufacturing unit,
- for manufacturing of materials,
- for transportation of finished materials to distribution outlets,
- for transportation of finished materials from distribution outlets to site of construction.

There will be an exponential rise in building requirements particularly in our urban centers that means more and more building materials will be required resulting in more energy input in construction. As all the sources available for energy are conventional, it results in non-sustainable construction system.

To evolve a sustainable construction system, it is needed to provide more quantity of building materials, in minimum quantity of energy. That means it should be able to maintain the existing energy levels used. This can be done by first knowing the embodied energy of the existing building.

My objective will be to develop a methodology for calculating embodied energy, and application of that methodology in case studies. Analysis of data, giving inferences and conclusions will be drawn.

My scope will be limited to calculating only the embodied energy of construction of one type of building type, and it will be restricted to one topographical and climatic region.

LIST OF ABBREVIATIONS

EER: Embodied Energy Rate

EEV: Embodied Energy Value

TER: Transportation Energy Rate

TEV: Transportation Energy Value

EEC: Embodied Energy Cost

Subscripts

T Total

TABLE OF CONTENTS

CANDIDATES DECLARATION i
ACKNOWLEDGEMENT ii
ABSTRACT iii
LIST OF ABBREVIATIONS iv
CONTENTS v
LIST OF FIGURES ix
LIST OF TABLES xii

CHAPTER – I

1.0 INTRODUCTION 1.
1.1 General 1.
1.2 Need for Study 2.
1.3 Aims and Objectives 2.
1.4 Methodology 2.
1.4.1 Literature Review 2.
1.4.2 Case Study 3.
1.4.3 Conclusion and Recommendation 3.
1.5 Chapterisation Scheme 3.
1.6 Scope and Limitation of Work 5.

CHAPTER – II

2.0 REVIEW OF LITERATURE 6.
2.1 General 6.
2.2 Definition of Embodied Energy 6.
2.3 Its Role into Sustainable Construction 7.
2.4 Conclusion 10.

CHAPTER – III

3.0 METHOD OF EMBODIED ENERGY CALCULATION 11.
3.1 General 11.
3.2 Quantification of Embodied Energy 11.
3.3 Definitions of Terms 12.
3.4 Methodology of Calculations 13.
3.4.1 Embodied Energy Value 15.
3.4.2 Transport Energy Value 16.

CHAPTER – IV

4.0 RELATION BETWEEN AREA AND EMBODIED ENERGY 17.
4.1 General 17.
4.2 Residential Buildings as Case Studies 17.
4.3 Methodology 18.
4.4 Results Showing Embodied Energy Rate 18.
4.4.1 Derivation of Linear Equation for Relation Between Built Up Area and Embodied Energy 19.
4.4.2 Derivation Of Polynomial Equation For Relation Between Built Up Area and Embodied Energy 20.
4.5 Conclusion 21.

CHAPTER – V

5.0 DERIVING BEST PREDICTOR OF EMBODIED ENERGY 22.
5.1 General 22.
5.2 Definition 22.
5.3 Deriving Best Predictor 23.
5.4 Embodied Energy Cost for Case Studies 23.
5.5 (a) Break up of Embodied Energy Cost in RCC 24.
5.5(a).1Benefits of Deriving Best Predictor of Embodied Energy 27.
5.5 (b) Quantity of RCC and Brick Work 27.

5.6 Conclusion 30.

CHAPTER – VI

6.0 ENERGY EFFICIENT ALTERNATIVES FOR TRADITIONAL BRICK MASONRY 32.
6.1 General 32.
6.2 Alternatives 32.
6.3 Methodology 33.
6.4 Conclusion 34.

CHAPTER – VII

7.0 FURTHUR DISCUSSIONS 36.
7.1 General 36.
7.2 Lintels 36.
7.3 Mortar mix 37.

CHAPTER – VIII

8.0 CONCLUSIONS 38.
8.1 Future scope 40.

References 41.
Appendix IA. 45.
Appendix IB. 54.
Appendix II. 59.
Appendix III. 61.
Appendix IVA. 68.
Appendix IVB. 87.
Appendix V. 106.

LIST OF FIGURES

Figure No.	Title	Page No.
2.1	Sources of energy	9.
4.1	Linear trend line for derived EER for built up areas in case studies.	19.
4.2	Polynomial trend line for derived EER for built up areas in case studies.	20.
4.3	Polynomial trend line for calculated EER for assumed built up areas.	21.
5.1	Embodied Energy Break Up In RCC as Steel and Concrete	
	Case study 1- 3	25.
	Case study 4- 6	26.

LIST OF TABLES

Table No.	Title	Page No.
3.1	Sample excel sheet for embodied energy calculations	15.
4.1	Embodied Energy per sqm. of Built up area for Case studies.	18.
4.2	Results of Linear Trend Line.	19.
4.3	Results of Polynomial Trend Line.	20.
5.1	Embodied Energy Break up Material wise.	23.
5.2	Embodied Energy Break up for RCC as Concrete and Steel.	24.
5.3	EEC Break up for Case Studies.	27.
5.4	Percentage Break up for EEC in Case Studies.	28.
5.5	Percentage Break up for EEC in Case Studies in Previous Works.	29.
6.1	Percentage Embodied Energy Saved per sqm. Area with alternative masonry with given mortar mixes as compared to traditional brick masonry.	34.
7.1	Percentage of Embodied energy saved when mortar is changed from 1:3 to 1:6 .	37.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

This opening chapter discusses the objective which has been set for the thesis and the need of the study, emphasizing on the importance of the subject in the field of construction. The later part of the chapter provides with the methodology which has been followed in the thesis and the chapterisation scheme.

The Embodied energy of the materials includes the direct and indirect energy consumed in its entire production process. These values are needed to estimate impacts on energy consumption due to changes in consumption patterns. Energy use in buildings has always been a topic of concern. Until now, studies have primarily focused on energy conservation in building operation, even though recent research has indicated that the embodied energy can be the equivalent of many years of operational energy

Embodied energy for a building is the summation of the energies embodied in the various materials used in its production. Embodied energy is a significant component of the lifecycle impact of a home. It was thought until recently that the embodied energy content of a building was small compared to the energy used in operating the building over its life. Most effort was therefore put into reducing operating energy by improving the energy efficiency of the building envelope.

1.2 NEED FOR STUDY

Research has shown that, embodied energy used in residential buildings could account for up to 40% of the life-cycle energy used in residential buildings. [Paper on 'Analysis of embodied energy use in the residential building of Hong Kong' by T. Y. Chen, J. Burnett and C. K. Chau, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong]

Other researches in India proved that, the embodied energy used in residential buildings is coming out to be 84% of the life cycle energy used in residential building. And the total of 60% building materials produced are used in residential buildings in India. [Chani *et al.* (2002)] So residential buildings are taken as case studies.

1.3 AIMS AND OBJECTIVES

- To carry out Embodied Energy calculation
- To derive relation between floor Area and Embodied Energy
- To identify the Best Predictors of Embodied Energy in Construction
- To find out energy efficient alternatives

1.4 METHODOLOGY

1.4.1 Literature Review

The study was initiated with the available literature. The sources are published books, journals, technical papers and existing dissertation works previously done. The basic data for energy audit is derived from these studies.

1.4.2 Case Study

Eight case studies have been done. The chosen typology was the residential buildings. The geographic area for studies is the central Indian plains. The type of construction system was decided as RCC structures with bricks as partition materials, as it is the material for today's construction.

1.4.3 Conclusion and Recommendation

All the case studies are studied and the energy calculations are done for each of the case study and the results are generated. The software used for these calculations is MS office Excel. As per the calculations several results are derived and conclusions have been drawn.

1.5 CHAPTERISATION SCHEME

Chapter 1

This opening chapter discusses the objective which has been set for the thesis and the need of the study, emphasizing on the importance of the subject in the field of construction. The later part of the chapter provides with the methodology which has been followed in the thesis and the chapterisation scheme.

Chapter 2

This chapter deals with the definition of the term embodied energy, derived from various sources, and most accepted one is given and its role into sustainable construction. Several findings and quotes are given from papers.

Chapter 3

This chapter explains Quantification of energy its need and difficulties in quantifying energy. Then definitions of certain related terminologies are given. Further it explains the methodology which is used to calculate and audit Embodied Energy Cost of the eight case studies. And at the end embodied energy & transport energy value is explained.

Chapter 4

In this chapter, the results are derived from the calculations. And the conclusions are derived from those results.

Chapter 5

This chapter deals with the concept of best predictor of embodied energy. Then it explains upon the procedure to evaluate that. Then derived results from the case studies are presented. And at the end it talks about the energy efficient alternatives for best predictors of embodied energy.

Chapter 6

This chapter deals with, the energy efficient alternatives for traditional brick masonry. In all 8 case studies the traditional brick masonry is replaced by alternatives available for masonry units. The mortar is also replaced and the results are found out.

Chapter 7

This chapter deals with the small things which have been tried in the process, the things were small but it gave some astonishing results. Such interesting results are further discussed in this chapter.

Chapter 8

This chapter deals with the overall conclusions made.

1.6 SCOPE AND LIMITATION OF WORK

- To calculate Embodied Energy for framed structure, in plains, in composite climate.
- This study does not take into consideration the economic part.

CHAPTER 2

REVIEW OF LITERATURE

2.1 GENERAL

This chapter deals with the definition of the term embodied energy, derived from various sources, and most accepted one is given and its role into sustainable construction. Several findings and quotes are given from papers.

2.2 DEFINITION OF EMBODIED ENERGY

Embodied energy is the energy required for production of building materials. It is "Cumulative Energy Demand", because in this case, it represents the sum of all the energy inputs into the material.

Embodied Energy of any building material consists of energy required for

- for quarrying of raw materials,
- for transportation of materials from quarry to manufacturing unit,
- for manufacturing of materials,
- for transportation of finished materials to distribution outlets.
- for transportation of finished materials from distribution outlets to site of construction.

The World Watch Institute estimates that 40% of the world's materials and energy is used in buildings

One of the most difficult aspects of environmentally-responsible design is to find the most suitable materials and available products that help sustain the earth and human health.

2.3 ITS ROLE INTO SUSTAINABLE CONSTRUCTION

Now a day there is the greatest threat of Global Warming, and its effects, on the Ecology and the Climate of Earth.

As per the special report by Fred Pearce, **Instant Expert: Climate Change**, 01 September 2006, NewScientist.com news service, while stating the effects of global Warming and its effect on climate, report states that "Canada's see it in disappearing Arctic ice and permafrost. The shantytown dwellers of Latin America and Southern Asia see it in lethal storms and floods. Europeans see it in disappearing glaciers, forest fires and fatal heat waves."

It further quotes the figures of warmest years on earth, "Scientists see it in tree rings, ancient coral and bubbles trapped in ice cores. These reveal that the world has not been as warm as it is now for a millennium or more. The three warmest years on record have all occurred since 1998, 19 of the warmest 20 since 1980. And Earth has probably never warmed as fast as in the past 30 years - a period when natural influences on global temperatures, such as solar cycles and volcanoes should have cooled us down. Studies of the thermal inertia of the oceans suggest that there is more warming in the pipeline." and continues as "Climatologists reporting for the UN Intergovernmental Panel on Climate Change (IPCC) say we are seeing global warming caused by human activities and there are growing fears of feedbacks that will accelerate this warming."

About the green house effect this report states that "People are causing the change by burning nature's vast stores of coal, oil and natural gas. This releases billions of tones of carbon dioxide (CO_2) every year. The physics of the "greenhouse effect" has been a matter of scientific fact for a century. CO_2 is a greenhouse gas that traps the Sun's radiation within the troposphere, the lower atmosphere. It has accumulated along with other man-made greenhouse gases, such as methane and chlorofluorocarbons (CFCs).

Again while discussing the effects of greenhouse Effect author describes "If current trends continue, it will raise atmospheric CO_2 concentrations to double pre-industrial levels during this century. That will probably be enough to raise global temperatures by around 2°C to 5°C. Some warming is certain, but the degree will be determined by feedbacks involving melting ice, the oceans, water vapor, clouds and changes to vegetation.

Warming is bringing other unpredictable changes. Melting glaciers and precipitation are causing some rivers to overflow, while evaporation is emptying others. Diseases are spreading. Some crops grow faster while others see yields slashed by disease and drought. Strong hurricanes are becoming more frequent and destructive. Arctic sea ice is melting faster every year, and there are growing fears of a shutdown of the ocean currents that keep Europe warm for its latitude. Clashes over dwindling water resources may cause conflicts in many regions."

As well, as per the paper by Geeta Vaidyanathan and Arun Kumar, **Towards Sustainable Production Systems: Closing the Loops**, published in UNEP Industry and Environment April-June 1996, "The construction sector in India is a major user of natural resources, energy, manpower and capital. It is also the single largest sector, responsible for 22 % of total emissions."

"Further, there is a backlog amounting to 18 million houses, with diminished availability of biomass materials (wood, thatch) and a saturating supply of conventional materials (stone, slate)".

It further states that, "It has been established that the major energy users in the building materials industry are the producers of cement, steel, bricks and lime, which together contribute 80 % of total emissions in the construction sector". Also "Current demand for these four material requires energy amounting to 743 PJ, [1PJ=10^{15}J] with a corresponding 81 million tones of CO_2 emissions."

When talking about cement she states that "In the specific case of cement, per capita consumption is expected to increase from the existing level of 60 kg to 210 kg by the year 2020. The latter figure is equivalent to current consumption in developed countries."

When discussing about natural resources, she states that 'As these materials are largely material-intensive, their use puts increasing pressure on natural resources and on non-renewable energy resources."

Figure 2.1 above shows the energy sources used on time scale. As shown here the non

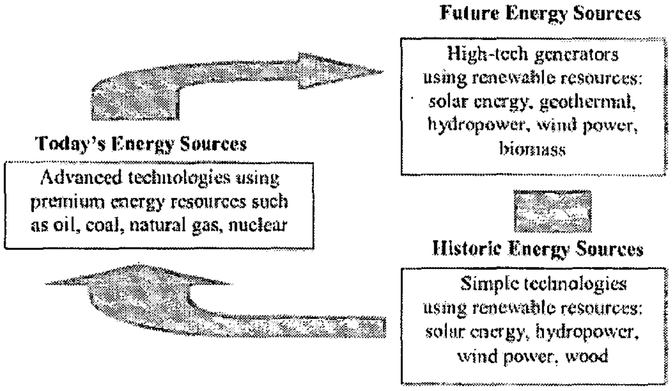


FIG.2.1 SOURCES OF ENERGY

renewable energy sources are shown as future energy sources, which means, if we can use them for production of building materials, then it will help in reducing energy consumed in actual production procedure in industry.

While talking about the effect of CO_2 emission she forecasts that, "It is expected that, by the year 2020, their use will result in a three-fold increase in energy requirement. The corresponding emissions will escalate to 285 million tones of CO_2 these projections are based on current technology mixes prevalent in the respective manufacturing sectors. Besides putting immense pressure on natural resources, this trend will mean a 4.3 per cent per year increase in emissions and a doubling of emissions in per capita terms. Such a trend is clearly unsustainable".

2.4 CONCLUSION

After reading the main points in the report as well as the paper, it is clear that, the Construction sector is one of the major sources of emission of CO_2. The building materials, with high embodied energy are consuming more non renewable sources of energy. And all these non renewable sources are carbon based so, they are increasing CO_2 emission in the atmosphere.

Thus by using low embodied energy building materials we will achieve two goals simultaneously, they are,

1. saving of nonrenewable sources of energy, and
2. to help lessen the CO_2 emission in atmosphere.

Good

CHAPTER 3

METHOD OF EMBODIED ENERGY CALCULATION

3.1 GENERAL

This chapter explains Quantification of energy its need and difficulties in quantifying energy. Then definitions of certain related terminologies are given. Further it explains the methodology which is used to calculate and audit Embodied Energy Cost of the eight case studies. And at the end embodied energy & transport energy value is explained.

3.2 QUANTIFICATION OF EMBODIED ENERGY

The quantification of embodied energy for any particular material is an inexact science, requiring a "long view" look at the entire manufacturing and utilization process, and filled with a large number of potentially significant variables. Consequently, the complexity of embodied energy calculations is frustrating even for scientists, and it is easy for the individual homeowner, builder, designer or government specifies to become discouraged at the difficulty of obtaining accurate figures. Fortunately, precise figures are not absolutely necessary for informed decisions on which building materials to use in order to lower the embodied energy in a structure. Builders need only recognize the potential differences in relative embodied energy to make wise material and system choices.

Part of the challenge of assessing and making decisions based on embodied energy is the lack of current data. Many of the statistics it includes are old (about 10 years old), and most current papers and references on embodied energy still cite data drawn from this old study. While some of the data may still be relevant, the tremendous advances in processing technology and recycling during the past years limit the applicability of this information.

Even with computer programs and sample data, embodied energy of entire buildings is difficult to quantify, since production and installation of building components is a lengthy and complex process involving many variables. No measurement standards exist, either.

3.3 DEFINITIONS OF TERMS

EER (*Embodied Energy Rate*) Embodied Energy needed per unit item of civil work

EEV (*Embodied Energy Value*) Energy embodied in the Building Materials

TER (*Transportation Energy Rate*) Energy needed to transport per unit of Building Material

TEV (*Transport Energy Value*) Energy consumed in transportation f Building Materials

EEC (*Embodied Energy Cost*) The Embodied Energy value of an item of work listed in a detailed BOQ

3.4 METHODOLOGY OF CALCULATIONS

The method explained here uses three basic sources of information

- Detailed Bill of Quantities
- Detailed working drawings
- Detailed Specifications

For the building whose Embodied Energy is to be calculated.

Schedule of Embodied Energy Rates and Schedule of Transport Energy Rate is referred from Chani *et al.* (1997). The values for Embodied Energy Rates [EER] and Transport Energy Rate [TER] for individual building materials, used here are derived in India, as per the Indian conditions of manufacturing.

Though, the data is old (about 10 years), the exactness of the values can not be claimed in today's scenario, since in last 10 years, there is a tremendous change in the production procedure of the building materials and in the means of transport. The better machineries and better transport system will lead to reduced embodied energy values.

The Case studies studied here are the under construction projects, or new ones, so due to changes and lot of innovation in building materials itself, the EER and TER values of some building materials like Vitrified Tiles, Plastic Emulsion Paints *etc.* are not available in Schedule of Embodied Energy Rate, hence some assumptions were made while calculating Embodied Energy Cost [EEC] of the Buildings studied.

After gathering all the data, the estimates are subdivided under following five heads,

1. Concrete
2. RCC
3. Brick work
4. Finishing
5. Flooring

And calculated Embodied Energy for each item under this head separately.

e.g. for RCC:

RCC work for Foundation

RCC work for Columns

RCC work for Beams

RCC work for Slab,

as for each of the given subcategory, EEV, Values will very.

Similar calculations has done for all other 5 headings in Column A. Then the table will be made as shown below.

Using Table 3.1, the Embodied Energy Cost [EEC_T] in MJ, for the Case studies will be calculated.

Table 3.1 Sample Excel Sheet for Embodied Energy Calculations

Item No.	A	B	C	D	E	F	G	H
	Description	Unit	Quantity	EER (MJ/unit)	EEV (MJ)	TER (MJ/unit)	TEV (MJ)	EEC (MJ)
1	Concrete							
2	RCC							
3	Brick Work							
4	Finishing							
5	Flooring							
Total								EEC_T

After calculating EEC_T, the next calculation is to find out, Embodied Energy Rate for that building. For this, we have to calculate the floor area of the building including all the floors in sqm. Then by using the Eq 3.1, we can calculate Embodied Energy Rate [EER_T] for the given building.

$$EER_T = EEC / \text{Built up area in sqm.}$$

3.4.1 Embodied Energy Value

DA / BMTPC have presented a very detailed analysis in the Energy Directory and evaluated the EEV of the building materials using Process Analysis Technique. The energy contents of materials were computed as function of scale and technology of their production. For each scale of production, separate figures of energy were given for quarrying, production and transportation, which on addition, gave a single value for the total energy content or EEV of the material.

The analysis showed that 90-98 % of EEV of materials is the energy needed for production.

3.4.2 Transport Energy Value

Transport Energy Value is the energy needed to transport the material to the site of construction. To Evaluate the TEV it is essential to know the energy needed to transport a unit quantity of materials over a unit distance. These figures are given in DA/BMTPC directory are given as MJ/Unit of civil work. It is generally 2- 3 % of production energy cost of material.

{Unit civil work = Volume or Area of civil work in cum. or sqm.}

TEV is taken as for an average carriage distance of 50 kms, with 50 kms of return empty.

CHAPTER 4

RELATION BETWEEN AREA AND EMBODIED ENERGY

4.1 GENERAL

The calculations are done. In this chapter, the results are derived from the calculations. And the conclusions are derived from those results.

4.2 RESIDENTIAL BUILDINGS AS CASE STUDIES

Research has shown that, embodied energy used in residential buildings could account for up to 40% of the life-cycle energy used in residential buildings. [Paper on 'Analysis of embodied energy use in the residential building of Hong Kong' by T. Y. Chen, J. Burnett and C. K. Chau, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong]

Other researches in India proved that, the embodied energy used in residential buildings is coming out to be 84% of the life cycle energy used in residential building. And the total of 60% building materials produced are used in residential buildings in India. [Chani *et al.* (2002)] Thus residential buildings are taken as case studies for my dissertation. The RCC is the material of today, so RCC framed structures are taken for my analysis.

4.3 METHODOLOGY

By the method described in the chapter 3, the Embodied Energy Value has been calculated. In this chapter, the derived values of embodied energy are compared with the Built Up area of the building. And it is tried to evolve a relationship between area and EEC_T of that building. Total 8 samples are studied, so that, it reduce down to a thumb rule. To restrict my field of work, all the case studies done are on G +1 structures, in RCC and of housing typology.

4.4 RESULTS SHOWING EMBODIED ENERGY RATE

Table 4.1 Embodied Energy per sq.m. of Built Up area for Case studies.

	AREA (SQ.M.) [X]	EER (MJ/SQ.M.) [Y]
Case Study 1	154.93	3658.40
Case Study 2	375.17	3090.28
Case Study 3	215.74	2741.70
Case Study 4	242.28	2721.18
Case Study 5	119.39	3223.05
Case Study 6	204.54	3886.43
Case Study 7	120.92	3401.41
Case Study 8	171.45	3847.56

Refer Appendix IA & IB for details

4.4.1 Derivation of Linear Equation for relation between Built Up Area and Embodied Energy

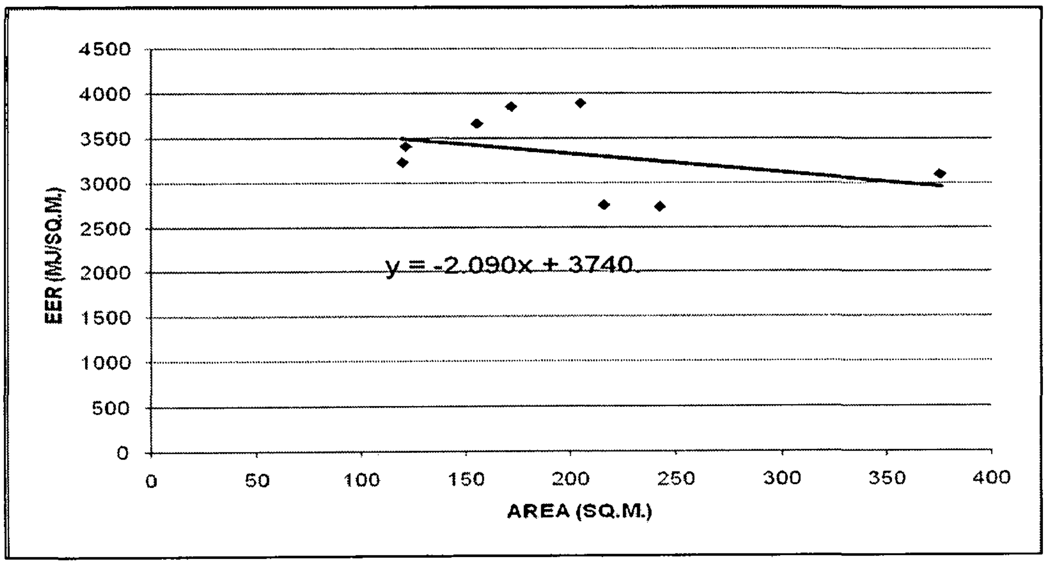


Fig 4.1 Showing linear trend line for derived EER for built up areas in case studies.

Table 4.2 Results of Linear Trend Line.

	Area (sqm.) [X]	EER Per sqm.[Y]	Value By Linear Eqn from Trend Line	Deviation	Percentage Deviation
CaseStudy 1	154.93	3658.40	3415.18	-243.21	-6.64
CaseStudy 2	375.17	3090.28	2952.88	-137.40	-4.44
CaseStudy 3	215.74	2741.70	3287.54	545.83	19.90
CaseStudy 4	242.28	2721.18	3231.83	510.64	18.76
CaseStudy 5	119.39	3223.05	3489.78	266.73	8.27
CasStudy 6	174.31	3886.43	3374.50	-511.93	-13.17
CaseStudy 7	120.92	3401.41	3486.57	85.16	2.50
CaseStudy 8	171.45	3847.56	3380.50	-467.05	-12.13

~ 20%

4.4.2 Derivation of Polynomial Equation for relation between Built up Area and Embodied Energy

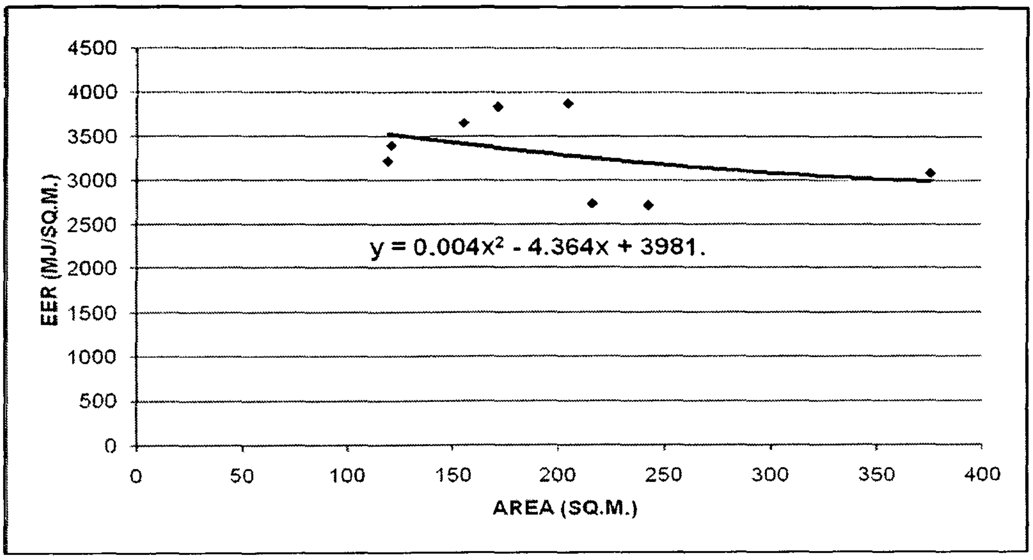


Fig 4.2 Showing Polynomial Trend Line for derived EER for built up areas in case studies.

Table 4.3 Results of Polynomial Trend Line

	Area (Sq.M.) [X]	EER Per SQ. M.[Y]	Value By Polynomial Eqn	Deviation	Percentage Deviation
CaseStudy 1	154.93	3658.40	3417.98	-240.41	-6.57
CaseStudy 2	375.17	3090.28	3005.55	-84.73	-2.74
CaseStudy 3	215.74	2741.70	3258.54	516.83	18.85
CaseStudy 4	242.28	2721.18	3199.85	478.66	17.59
CaseStudy 5	119.39	3223.05	3527.26	304.21	9.43
CaseStudy 6	174.31	3886.43	3363.39	-523.03	-13.45
CaseStudy 7	120.92	3401.41	3522.31	120.90	3.55
CaseStudy 8	171.45	3847.56	3371.23	-476.32	-12.38

4.5 CONCLUSION

In this chapter it has been tried to find out relation between Built up Area and Embodied Energy Rate, and derived some equations. Cross checking was done for the equations. And percentage deviation was calculated.

The basic purpose behind these calculations was to derive a point on trend line after which Embodied Energy Rate will remain constant for said area. The graph was plotted for calculated values of EER.

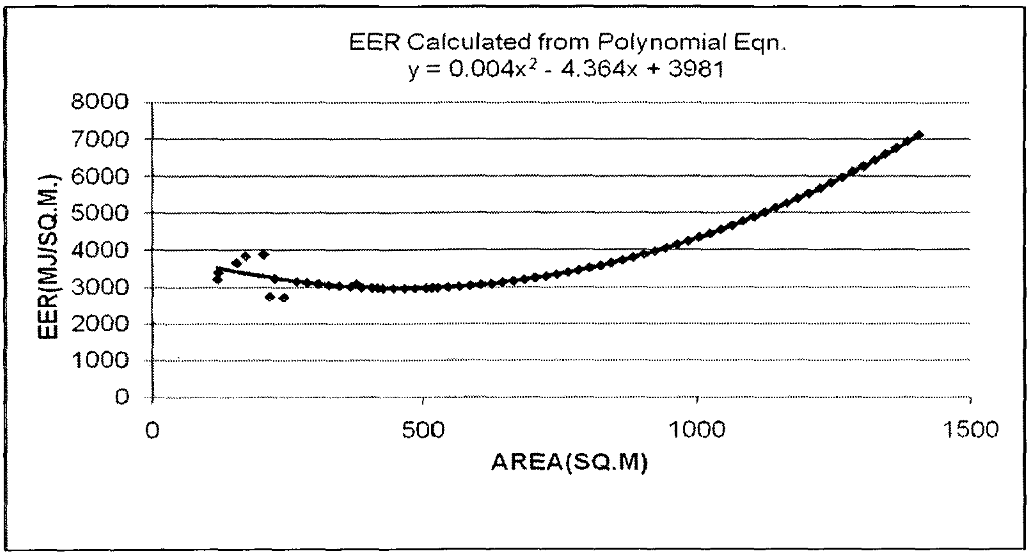


Fig 4.3 Showing Polynomial Trend Line for calculated EER for given built up areas.

The chart is progressive and did not reduce down to a constant value of area after which EER will become constant. This remains area for further studies.

CHAPTER 5

DERIVING BEST PREDICTOR OF EMBODIED ENERGY

5.1 GENERAL

Best Predictor of Embodied Energy means, the element which can give the rough idea of energy embodied in the building. This chapter deals with the concept of best predictor of embodied energy. Then it explains upon the procedure to evaluate that. Then derived results from the case studies are presented. And at the end it talks about the energy efficient alternatives for best predictors of embodied energy.

5.2 DEFINITION

A best predictor is the one which consumes maximum energy in any construction activity. If the best predictor is known, then by knowing its quantity, approximate embodied energy cost of a building can be calculated. The Best predictor of building can be derived by two ways, as follows

1. The best predictor could be the element in building, like staircase, or, walls of the building. Here we have to find out EEC value by calculating, it for each separate element of building.

2. The best predictor of EEC by materials. In this we can calculate it by calculating EEC for separate article of civil work, like Concrete, Brick work.

5.3 DERIVING BEST PREDICTOR

The second method is been used in this chapter. The Obvious reason of choosing second method is the way, in which it has been calculated. The second method includes, the Bill of quantities for whole building, which are readily available and are more familiar for Architects. And we are more comfortable with it. The methodology for calculating Embodied energy Cost, is described in Chapter 3, is used. To get basic energy values.

5.4 EMBODIED ENERGY COST FOR CASE STUDIES

After Deriving that result, the next, thing to find out was which material exactly is consuming more embodied energy.

Table 5.1 Embodied Energy Break up Material wise

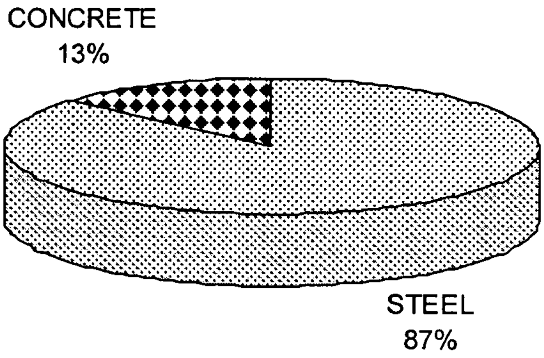
	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6
Concrete	17315.52	21719.00	4216.00	34622.57	5490.34	15304.57
RCC Total	**210239.56**	**487659.65**	**263361.36**	**417041.80**	**233000.21**	**484051.20**
Brick Work	296397.17	485568.90	233125.94	124918.40	94456.70	152900.64
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42
Flooring	51274.79	89878.59	50404.58	40932.71	36340.13	68847.55

5.5 (a) BREAK UP OF EMBODIED ENERGY COST IN RCC

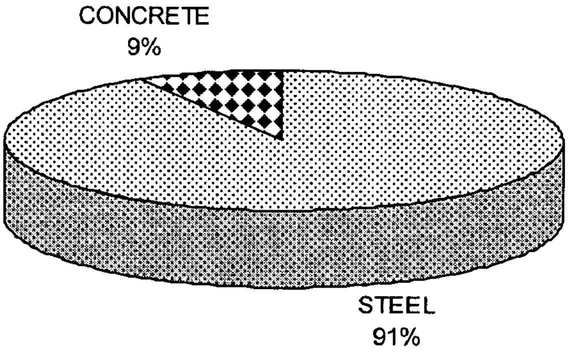
In next step, the RCC breakup was found out. The Embodied Energy for Concrete and reinforcement i.e. steel was calculated separately. The results were found out as follows

Table 5.2 Embodied Energy Break up of RCC as Concrete and Steel

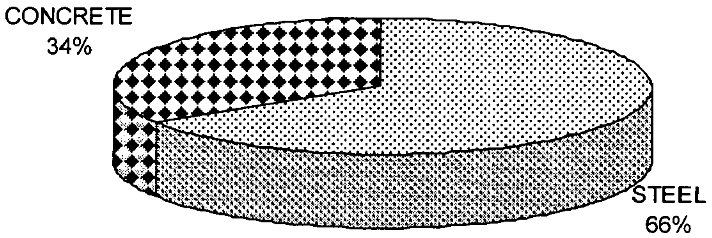
RCC Break Up	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6
Steel, EEC(MJ)	182208.00	445302.20	173721.60	212800.00	118894.40	253684.00
Concrete, EEC(MJ)	28031.56	42357.45	89639.76	204241.80	114105.81	230367.20
Total RCC	210239.50	487659.65	263361.36	417041.80	233000.21	484051.20



Case Study 1

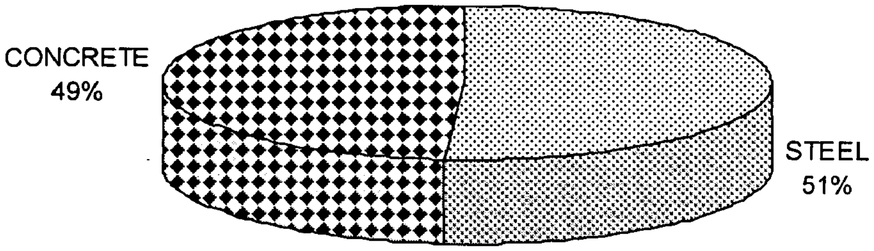


Case Study 2

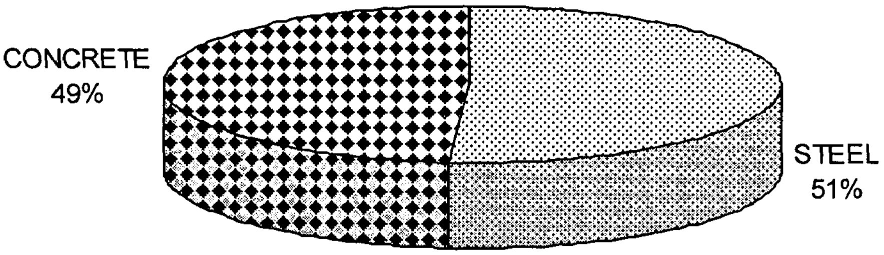


Case Study 3

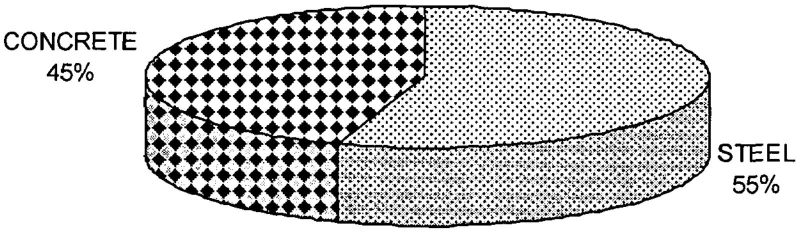
Fig 5.1 EMBODIED ENERGY BREAK UP IN RCC AS STEEL AND CONCRETE



Case Study 4



Case Study 5



Case Study 6

Fig 5.1 EMBODIED ENERGY BREAK UP IN RCC AS STEEL AND CONCRETE

5.5(a).1 BENEFITS OF DERIVING BEST PREDICTOR OF EMBODIED ENERGY

The basic purpose to derive Best Predictor of EEC is to identify the material which consumes maximum of energy in building and then try to replace that material by Low Energy Alternative. In addition to this it gives rough estimate of energy consumed in advance.

The Best predictor of Embodied energy as per the figs 5.1 is Steel.

5.5(b) QUANTITY OF RCC AND BRICK WORK

As per the studies conducted and values calculated for residential buildings at Nagpur, the chart showing EEC for each civil item is shown here. The buildings chosen are *RCC framed structures.*

Table 5.3 EEC Break Up For Case Studies

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315	21719	4216	34622	5490	15304	22886	117249
RCC	**210239**	**487659**	**263361**	**417041**	**233000**	**512394**	**192671**	**281776**
Brick Work	**296397**	**485568**	**233125**	**124918**	**94456**	**152900**	**127485**	**357058**
Finishing	25710	74563	40393	41773	15503	45496	45994	616909
Flooring	51274	89878	50404	40932	36340	68847	22253	81917
$[EEV_T]$	600937	1159389	591501	659289	384790	794943	411291	899692

Table 5.4 Percentage Break Up For EEC in Case Studies

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8	**Average of Percentag**
Concrete	2.88	1.87	0.72	5.25	1.43	1.92	5.57	13.03	4.08
RCC	**34.99**	**42.07**	**44.52**	**63.25**	**60.55**	**64.46**	**46.84**	**31.32**	**48.50**
Brick Work	**49.32**	**41.88**	**39.41**	**18.95**	**24.55**	**19.23**	**31**	**39.68**	**33.00**
Finishing	4.28	6.43	6.82	6.34	4.03	5.73	11.18	6.86	6.45
Flooring	8.53	7.75	8.53	6.21	9.44	8.66	5.41	9.11	7.95
RCC+Brick Work	**84.31**	**83.95**	**83.93**	**82.2**	**85.1**	**83.69**	**77.84**	**71**	**81.50**

i. The range here for total of RCC and Brick work is around 71 % to 88% or lets say from 80 to 90% of total EEC for RCC framed structures.

As per Chani *et al.* 2002 the EEC break up for Load bearing structures in housing building projects is as under.

Table 5.5 Percentage Break up of EEC in Case Studies in Previous Works

	Case Study1	Case Study2	Case Study3
Concrete	7.54	6.59	8.90
RCC	26.95	31.96	28.93
Brick Work	56.15	52.27	54.06
Finishing	5.40	5.05	4.28
Flooring	3.96	4.13	3.84
RCC + Brick Work	**83.10**	**84.23**	**82.99**

ii The range here for total or RCC ad Brick work is around 82 % to 85% or lets say from, 80 to 90 % of total EEC for Load bearing structures.

From statements (i) and (ii) we get, irrespective of, the structural system the total of EEC for RCC Work and Brick Masonry will remain in the range of 80 to 90 % of total EEC for the (G+1) housing buildings.

EEC for [RCC + Brick Work] = 80-90 % of total EEC for (G+1) housing building

5.6 CONCLUSION

The Best Predictor of Embodied energy as per the Steel.[as per 5.5 (a)] The further study, did not suggest me to alter RCC because of lack of data available, and building materials are not there, so as to replace RCC.

So, the next thing which could be thought of was Bricks. After Steel, Bricks is only material which is consuming more Embodied Energy.[as per 5.5 (b)] So best alternatives for Brick Work with various mortar mixes are found out, so as to reduce, the total Embodied Energy Cost of the building in coming chapters.

The main cause for the high energy share of masonry work is primarily because of the high EEV of traditional burnt clay bricks, which generally account for 80-85% in the energy share of masonry work. Hence, it is imperative to find out energy efficient substitutes for bricks to reduce the energy cost of masonry work. Along with this, alternatives for the conventional cement mortar need to be studied. The alternatives for the Brick Masonry could be as follows.

Alternatives for Masonry Units

1. Traditional bricks (22.9cm x 11.4cm x 7.6cm)
2. Modular bricks (20cm x 10cm x 10cm)
3. Clay fly ash bricks (20cm x 10cm x 10cm)
4. Sand lime bricks (20cm x 10cm x 10cm)
5. Hollow concrete blocks (40cm x 20cm x 10cm)
6. Hollow concrete blocks (40cm x 20cm x 20cm)
7. Aerated concrete blocks (40cm x 20cm x 20cm)
8. Solid concrete blocks (30cm x 20cm x 15cm)

9. FAL-G blocks (30cmx20cmx 15cm)

Alternatives for Mortar Mixes

1. Lime mortar 1:1:1 (1 lime putty: 1 fly ash: 1 fine sand)
2. Cement mortar 1:3 (1 cement: 3 fine sand)
3. Cement mortar 1:4 (1 cement: 4 fine sand)
4. Cement mortar 1:5 (1 cement: 5 fine sand)
5. Cement mortar 1:6 (1 cement: 6 fine sand)
6. Composite mortar 1:1:6 (1 cement: 1 lime putty: 6 Fine sand)
7. Composite mortar 1:1:7 (1 cement: 1 lime putty: 7 fine sand)
8. Composite mortar 1:1:8 (1 cement: 1 lime putty: 8 fine sand)
9. Composite mortar 1:2:9 (1 cement: 2 lime putty; 9 fine sand)

CHAPTER 6

ENERGY EFFICIENT ALTERNATIVES FOR TRADITIONAL BRICK MASONRY

6.1 GENERAL

This chapter deals with the energy efficient alternatives for traditional brick masonry. In all 8 case studies the traditional brick masonry is replaced by masonry and mortar alternatives. The mortar is also replaced from existing to 1:3 [1 cement : 3 sand] then to 1:6 [1 cement : 6 sand] and the results are found out.

6.2 ALTERNATIVES

The energy estimation of the 8 projects reveals that masonry work is the second largest contributor to the EEC after RCC in nearly all the projects. Its share is about 30-35% in the EEC for double storied units, in RCC framed structures.

The main cause for the high energy share of masonry work is primarily because of the high EEV of traditional burnt clay bricks, which generally account for 80-85% in the energy share of masonry work. Hence, it is imperative to find out energy efficient substitutes for bricks to reduce the energy cost of masonry work. Along with this, alternatives for the conventional cement mortar need to be studied.

The alternatives for the Brick Masonry and Mortar studied here are as follows:

Masonry Units

1. Traditional bricks (22.9cm x 11.4cm x 7.6cm)
2. Modular bricks (20cm x 10cm x 10cm)
3. Clay fly ash bricks (20cm x 10cm x 10cm)
4. Sand lime bricks (20cm x 10cm x 10cm)
5. Hollow concrete blocks (40cm x 20cm x 10cm)
6. Hollow concrete blocks (40cm x 20cm x 20cm)
7. Aerated concrete blocks (40cm x 20cm x 20cm)
8. Solid concrete blocks (30cm x 20cm x 15cm)
9. FAL-G blocks (30cmx20cmx 15cm)

Refer to Appendix II for short notes.

Mortar Mixes

1. Cement mortar 1:3 (1cement: 3 fine sand)
2. Cement mortar 1:6 (1cement: 6 fine sand)

6.3 METHODOLOGY

First of all the embodied energy was calculated for each of the case studies. And there break up was found out. Then, the brickwork in each case study was replaced by alternative masonry. And values were calculated. Also the mortar was changed form 1:3 to 1:6. The difference in values showed the embodied energy saved.

Table 6.1 Percentage of Embodied Energy Saved per sqm. Area with alternative masonry with given mortar mixes as compared to traditional brick masonry.

Percentage of Embodied Energy Saved Per Sq. M.	**Mortar Mix 1:3**	**Mortar Mix 1:6**
Clay Fly Ash Bricks	4.45	6.83
Sand Lime Bricks	2.54	4.88
Hollow Concrete Block (40x20x10)	3.56	5.97
Hollow Concrete Block (40x20x20)	8.48	***11.21***
Aerated Concrete Block(40x20x20)	8.00	10.73
Solid Concrete Block(30x20x15)	5.47	7.35
FAL-G Block(30x20x15)	***8.81***	10.77

Refer to Appendix IVA and IVB for detail calculations

6.4 CONCLUSION

When compared to existing traditional brick work, when the masonry was changed then, it showed that maximum energy was saved in FAL-G Blocks, when used with 1:3 mortar [1 cement : 3 sand] and the next best alternative was Hollow Concrete Block (40x20x20) and Aerated Concrete Block (40x20x20), and the third is aerated concrete blocks (40x20x20).

And when the mortar was changed to 1:6 (1cement : 6sand) the best alternative for traditional bricks was Hollow Concrete Block (40x20x20) and next best alternatives were FAL-.G Blocks and Aerated Concrete Block(40x20x20) respectively.

The energy saved in FAL-G block masonry is about 8 to 11% and that by Hollow Concrete Block (40x20x20) is 8 to 12 % and Aerated Concrete Block (40x20x20) is about 8 to 11%.

When mortar in masonry work is changed from 1:3 to 1:6, the saving in embodied energy is about 1.5 – 3 %, irrespective of the masonry used.

CHAPTER 7

FURTHER DISCUSSION

7.1 GENERAL

This chapter deals with the small things which have been tried in the process, the things were small but it gave some astonishing results. Such interesting results are further discussed in this chapter.

7.2 LINTELS

The idea started with, replacing an existing element in building with other. Then the lintel was chosen for replacement being simple in form .

A sample opening was considered and then embodied energy cost of Flat Brick Arch was first calculated, then for the same span lintel in RCC, embodied energy cost was calculated and compared.

Some assumptions were made to calculate exact EEC for these two elements as follows,

Clear span = 1.25 m

Minimum bearing = 150 mm =0.15 m

Overall depth= 100mm = 0.10 m

Thickness of wall = 230mm = 0.23m

The result proved that, it is not a good option to replace the RCC lintels with flat brick arch. The RCC lintels are cheap in Embodied Energy Rate than Flat Brick Arch.

See Appendix V for details.

7.3 MORTAR MIX

In this section, it has been tried to found that how much energy could be saved, with alteration of mortar. Mostly in practice 1:3 [1cement : 3 sand] or 1:4 [1cement : 4 sand] mortar mix is used, even though the mortar mix with ratio 1:6 [1cement : 6 sand] is sufficient to hold bricks.

Table 7.1 Percentage of Embodied Energy saved when Mortar is changed from 1:3 to 1:6

Alternatives For Traditional Brick Masonry	**Mortar Mix 1:3**	**Mortar Mix 1:6**	**Percentage of Embodied Energy saved when mortar is changed from 1:3 to 1:6**
Clay Fly Ash Bricks	4.45	6.83	2.38
Sand Lime Bricks	2.54	4.88	2.34
Hollow Concrete Block (40x20x10)	3.56	5.97	2.41
Hollow Concrete Block (40x20x20)	8.48	11.21	2.73
Aerated Concrete Block (40x20x20)	8.00	10.73	2.73
Solid Concrete Block (30x20x15)	5.47	7.35	1.88
FAL-G Block (30x20x15)	8.81	10.77	1.96

It is observed from Table 7.1 that when mortar in masonry work is changed from 1:3 to 1:6, the saving in embodied energy is about 1.5 – 3 %, irrespective of the masonry used.

CHAPTER 8

CONCLUSIONS

This chapter deals with the overall conclusions made. The various case studies were studied, and some results were drawn from them. These results give some general idea about the embodied energy and its significance in field of construction. The behavior of embodied energy was studied, it was tried to find out certain trends in that. Some times results were astonishing, some times whole concept of calculations was failed, but it gave a concluder remark, which has been tried to trace in this chapter.

By using low embodied energy building materials we will achieve two goals simultaneously, they are,

1. saving of nonrenewable sources of energy, and
2. to help lessen the CO_2 emission in atmosphere.

The analysis showed that 90-98% of EEV of materials is the energy needed for production, and transport energy is generally 2-3% of production energy cost of material.

Embodied energy used in residential buildings could account for up to 40% of the life-cycle energy used in residential buildings for foreign countries. In India, the embodied energy used in residential buildings is coming out to be 84% of the life cycle energy used in residential building. And the total of 60% building materials produced are used in residential buildings in India. So this is an important field for further studies.

Irrespective of, the structural system the total of EEC for RCC Work and Brick Masonry will remain in the range of 80 to 90 % of total EEC for the (G+1) housing buildings.

The Best predictor of Embodied energy as per studies done is RCC. And further break up of RCC showed steel as the best predictor of Embodied Energy.

The energy estimation of the 8 projects reveals that masonry work is the largest contributor to the EEC after RCC for nearly all the projects. Its share is about 30-35% in double storied units, in RCC framed structures.

When compared to existing traditional brick work, when the masonry was changed then, it showed that maximum energy was saved in FAL-G Blocks, when used with 1:3 mortar [1cement :3 sand] and the next best alternative was Hollow Conc. Block (40x20x20) and Aerated Concrete Block (40x20x20), and the third is aerated concrete blocks (40x20x20).

And when the mortar was changed to 1:6 (1 cement: 6 sand) the best alternative for traditional bricks was Hollow Conc. Block (40x20x20) and next best alternatives were FAL-G Blocks and Aerated Concrete Block (40x20x20).

The energy saved in FAL-G block masonry is about 8 to 11 % and that by Hollow Conc. Block (40x20x20) is 8 to 12 % and Aerated Concrete Block (40x20x20) is about 8 to 11%.

When mortar in masonry work is changed from 1:3 to 1:6, the saving in embodied energy is about 1.5–3 %, irrespective of the masonry used.

8.1 FUTURE SCOPE

- The present study does not include commercial viability and its cost effectiveness for common people, so this area can be further explored.
- Further Research is needed in the areas of material science, and light weight materials, for cladding to get better options.
- Some low embodied energy alternative for RCC and steel shall be found out.
- Relation between Built up area and Embodied Energy shall be studied.
- Relation between Built Form and Embodied Energy shall be studied.

REFRENCES

Books, Ph.D. Dissertation

- Dutta, B.N., Estimating and Costing in Civil Engineering – Theory And Practice, 24th edition, UBB Publishers' Distributers Ltd., New Delhi, India,1998.
- Rangwala, S.C., Estimating, Costing and Valuation [Professional Practice], Tenth Revised and Enlarged Edition, Charotar Publishing House, Anand, India, 2001.
- Chen, W.F., Handbook of Structural Engineering, CRC Press, Boca Raton, New York, 1997.
- Chani *et al.* (2002) Primary Energy Estimation for Contemporary Housing In Northern India, IIT Roorkee, Ph.D. Thesis.
- Centre of Sustainable Construction at Bre. Uk.
- Sustainable Homes: Embodied Energy in Residential Property Development.
- Geiger O., Embodied Energy in Straw bale Houses, Geiger research institute of sustainable building, Crestone, Colorado.
- Vaidyanathan, Geeta *et al.*, Energy in Building Materials, DA/BMTPC Project Report, 1995.

Papers

- Geeta Vaidyanathan and Arun Kumar, Towards Sustainable Production Systems: Closing The Loops, UNEP Industry and Environment April-June 1996.
- Reddy B.V. and Jagadish K.S. Embodied Energy Of Common And Alternative Building Materials And Technologies, Energy and Buildings, Volume 35, Number 2, February 2003, pp. 129-137(9)
- Tiwari P. Energy Tax and Choice of House Construction Techniques in India, Journal of Infrastructure System, Vol 7, No.3, Sept.2001.
- Chani, P.S., Sahu, Sarla and Kaushik, S.K., 'Comparative Energy Cost Analysis of Walling Elements in India', Proc. International Conference on Civil Engineering for Sustainable Development, Feb. 1997, pp. 781-789.
- Tracy Mumma, Reducing the Embodied Energy of Building, Energy and Building, 20 1994.
- Chani, P.S., Sahu, Sarla and Kaushik, S.K., 'Energy Auditing as a Tool for Sustainable Housing Construction', Proc. International Conference on Planning for 21st Century Concepts and Systems, Vol. II, Oct. 1997, 525-533.
- Thormark C., A Low Energy Building In A Life Cycle-Its Embodied Energy, Energy Need For Operation And Recycling Potential Building and Environment, Volume 37, Number 4, April 2002, pp. 429-435(7)
- Wright Catherine and Gardiner P., Energy and Housing, Built Environment vol.5 No.4, 1979, pp.287-297.
- Chani, P.S., Sahu, S. and Kaushik, S.K., 'Energy Efficient Alternatives for Masonry Work in Housing Construction', Proc. South-Asian Countries

Conference on Challenges to Architects and Civil Engineers During Twenty - First Century, Vol. III, April 7-9, 1999, pp. 61-67.

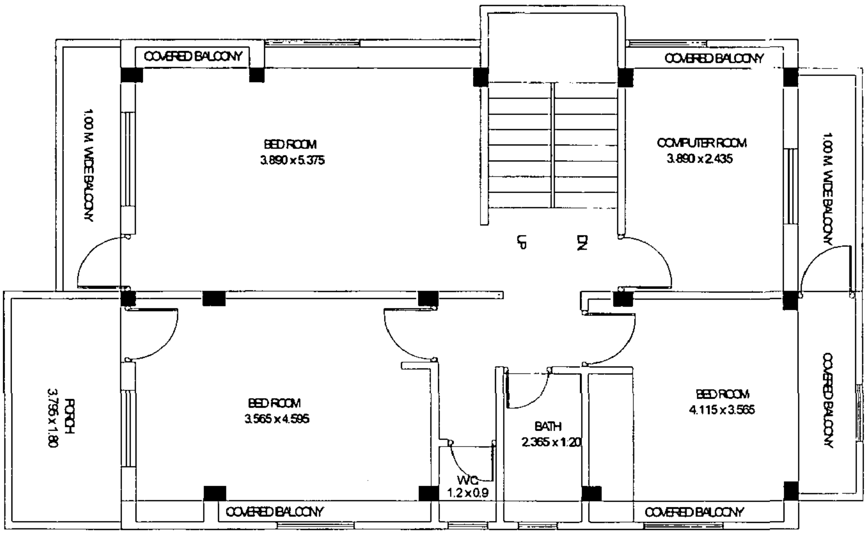
- Graham J. T., Peter E.D. L., Gary D. H., Using National Input–Output Data For Embodied Energy Analysis Of Individual Residential Buildings, Construction Management & Economics. Volume (Year): 19 (2001)Issue (Month): 1 (January) Pages: 49-61
- Chani, P.S., Sahu, Sarla and Kaushik, S.K., 'Energy Cost Relationship for Housing Projects in India', Proc. International Seminar on Civil Engineering Practices in Twenty First Century, Feb. 1996, pp. 1436-1443.
- Grwford R. H.& Grahm J., An assessment of the Energy and Water Embodied In Commercial Building Construction
- Grahm J Jreloar, Andrew Mc Coubie, Peter E.D. and Usha Iyer-Raniga, Embodied Energy Analysis Of Fixtures, Fittings And Furniture In Office Building
- Chen, T.Y., Burnett J. and Chau C.K, Analysis Of Embodied Energy Use In The Residential Building Of Hong Kong , Energy, Volume 26, Number 4, April 2001, pp. 323-340(18)
- Brown, G. and Stellon, P., 'The Material Account', Built Environment, Aug. 1974, pp. 415-417.
- Buchanan, A.H. and Honey, B.G., `Energy and Carbon Dioxide Implications of Building Construction, `Energy and Buildings, Vol. 20, No. 3, pp 205-217, 1994.

Websites

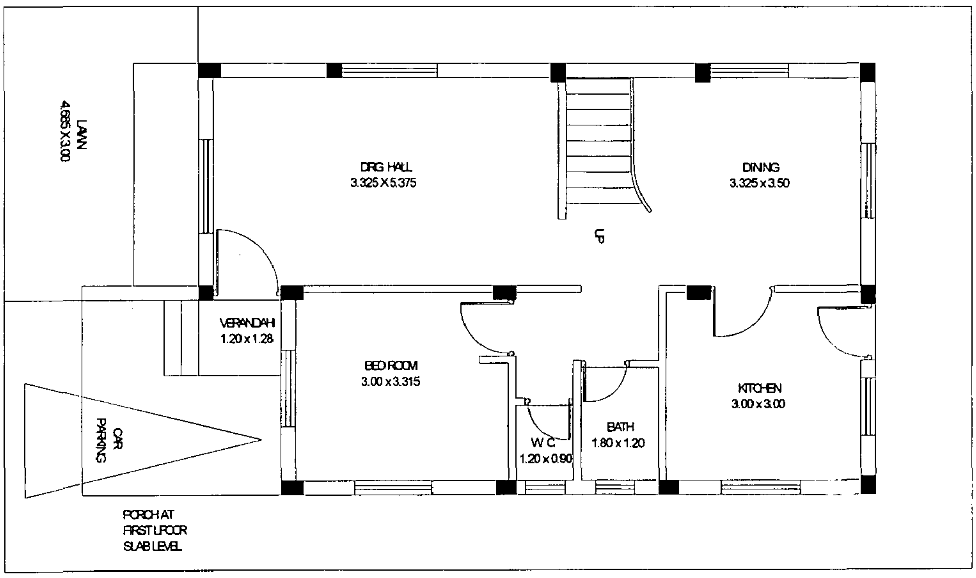
- special report by Fred Pearce, Instant Expert: Climate Change, 01 September 2006, NewScientist.com news service
- http://dfe-sce.nrc-cnrc.gc.ca
- www.dbce.csiro.au/ind
- http://www.sustainableabc.com
- http://www.greenhouse.gov.au/yourhome/technical/fs31.htm
- http://www.sustainable-development.gov.uk/what/priority/consumption-production/index.htm
- http://taylorandfrancis.metapress.com/link.asp

APPENDIX IA

Floor Plans of Case Studies

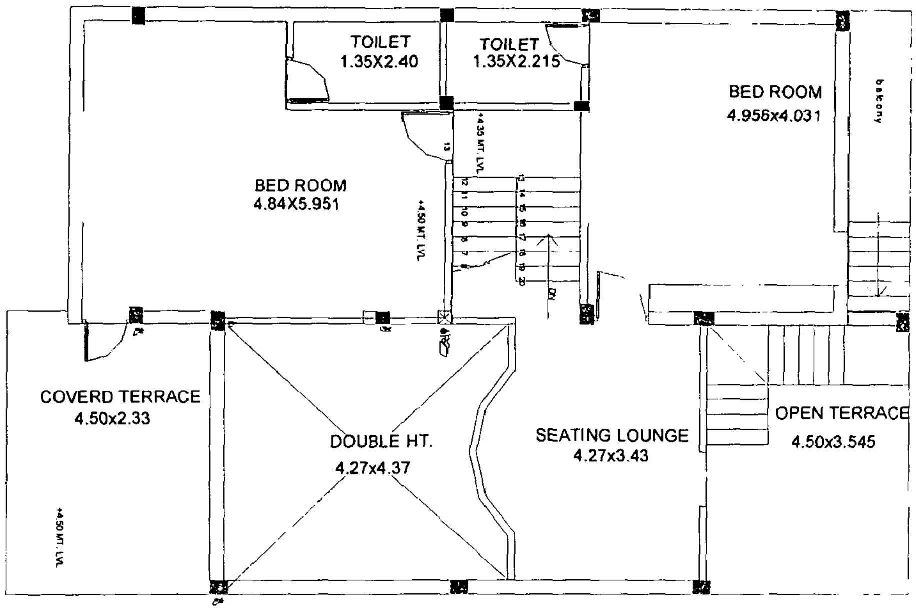


FIRST FLOOR PLAN

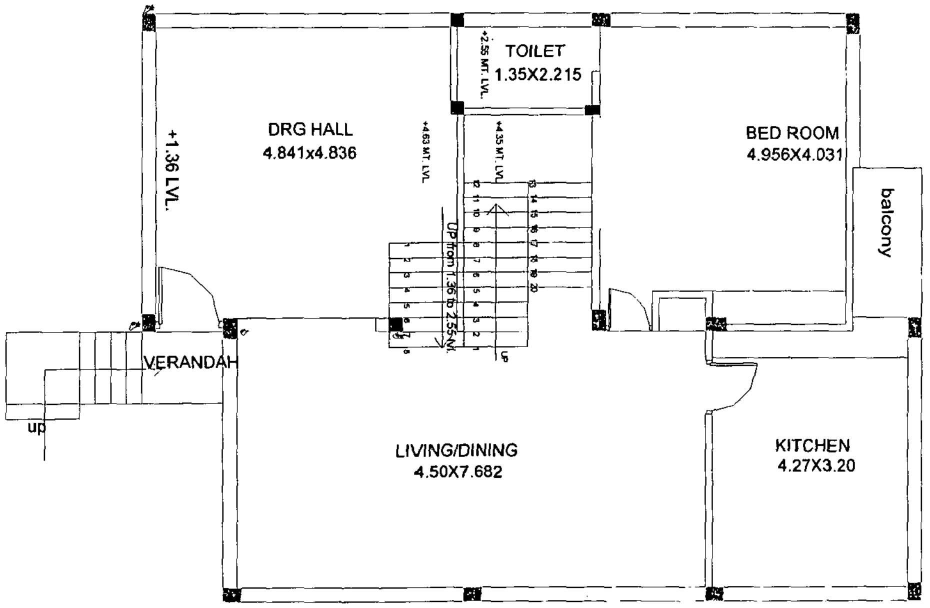


GROUND FLOOR PLAN

FIG 1: FLOOR PLANS OF CASE STUDY 1

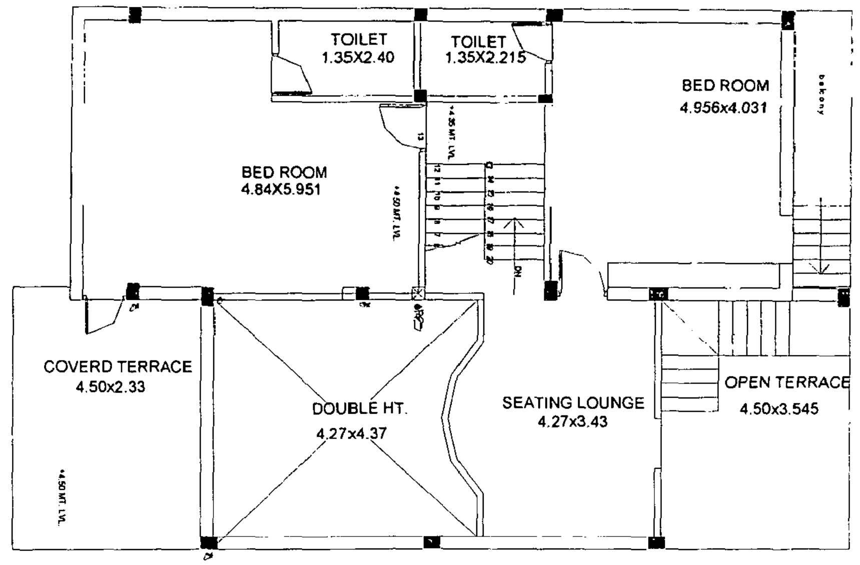


FIRST FLOOR PLAN

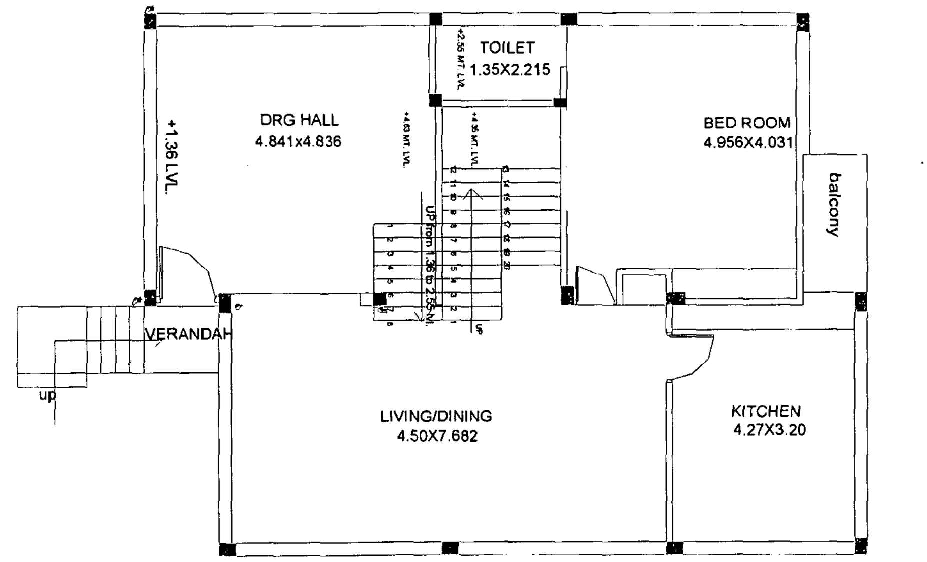


GROUND FLOOR PLAN

FIG 2 : FLOOR PLANS OF CASE STUDY 2

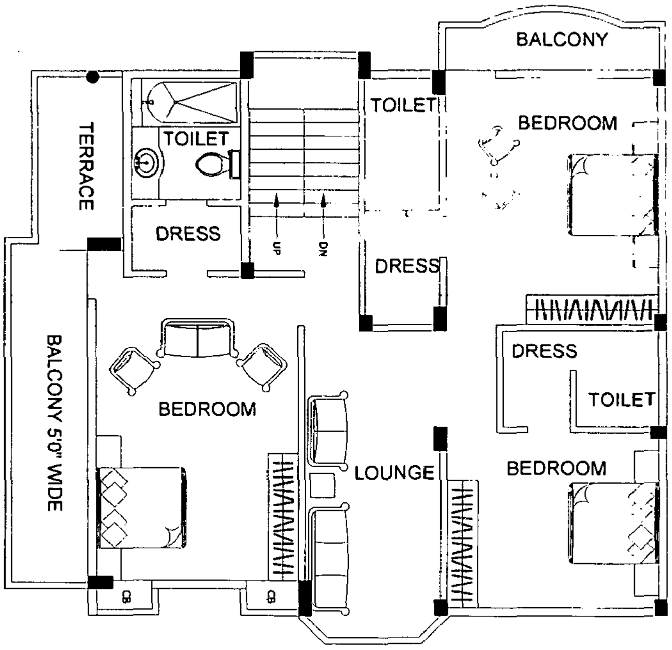


FIRST FLOOR PLAN



GROUND FLOOR PLAN

FIG 3 : FLOOR PLANS OF CASE STUDY 3



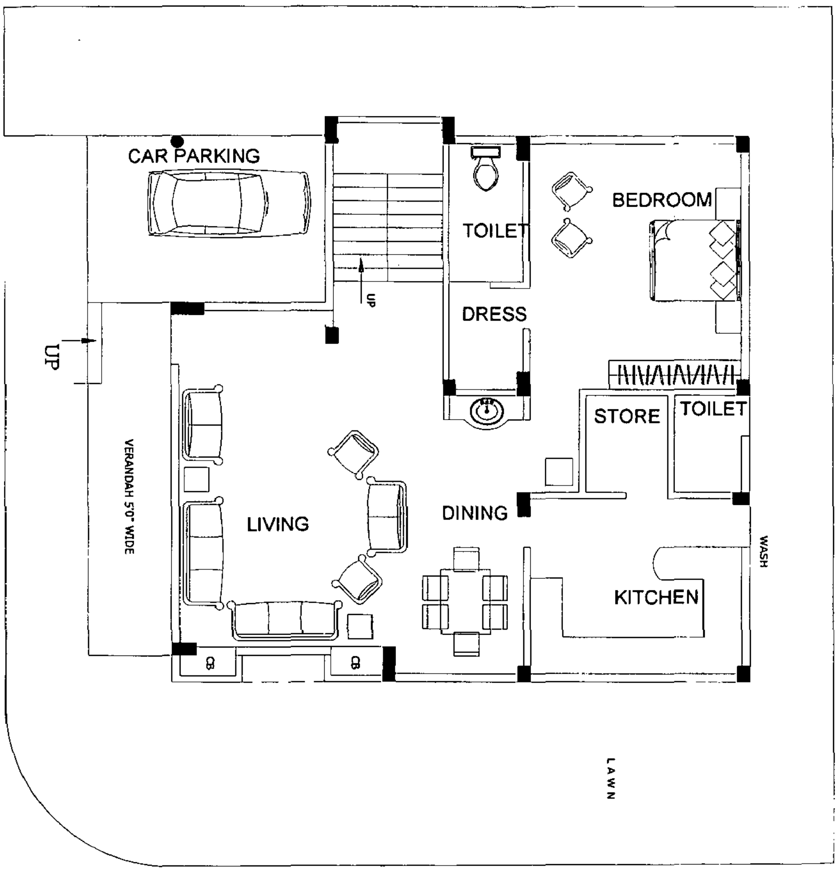
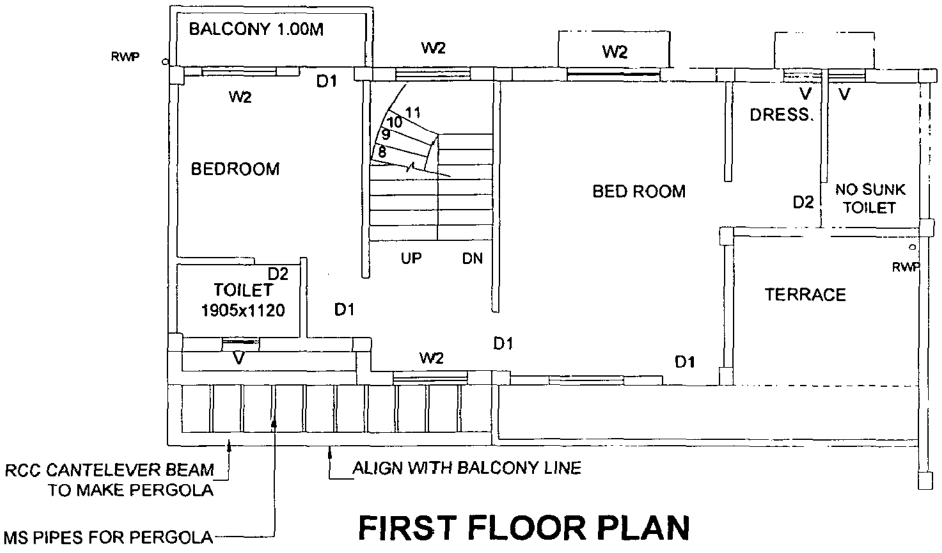
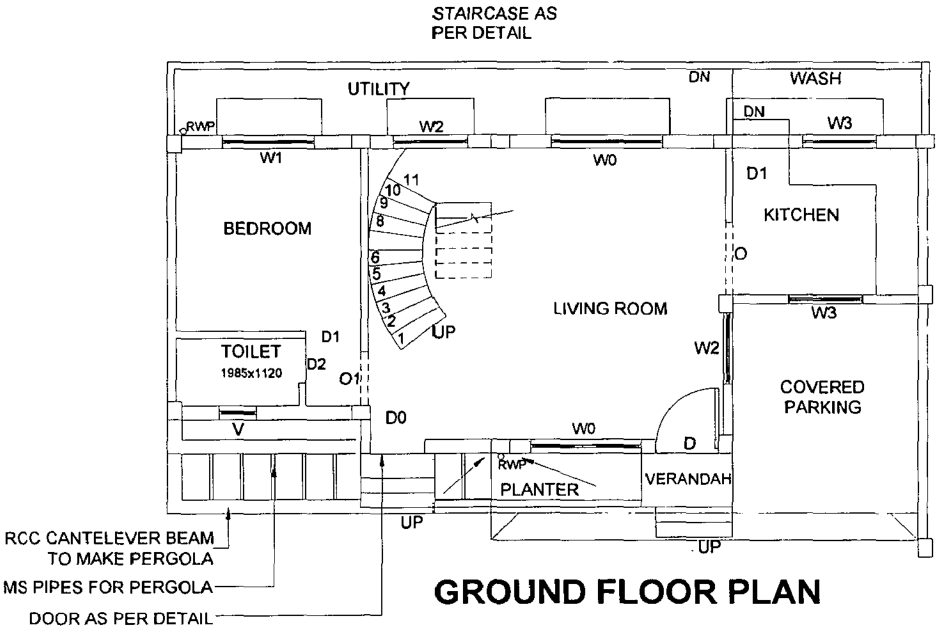


FIG 4 : FLOOR PLANS OF CASE STUDY 4

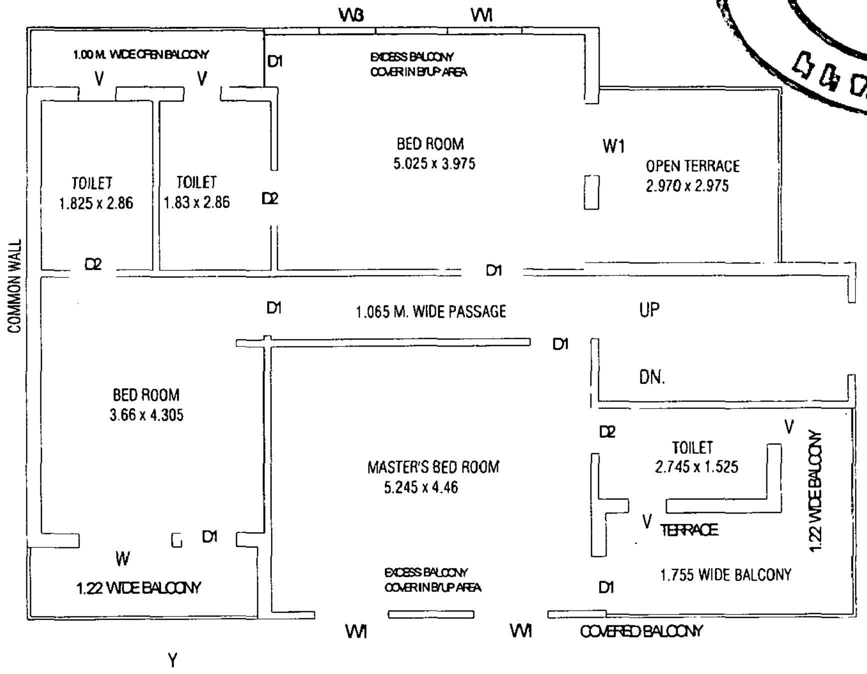


FIRST FLOOR PLAN

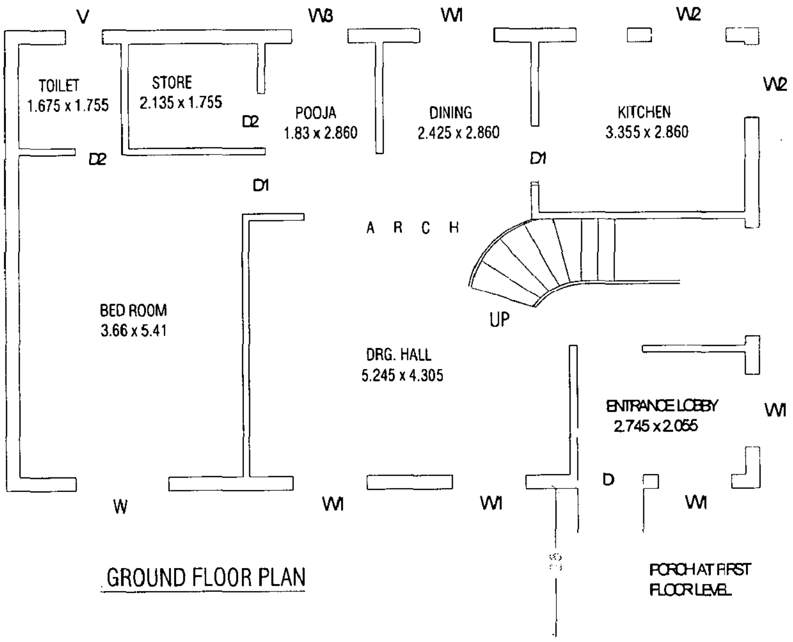


GROUND FLOOR PLAN

FIG 5 : FLOOR PLANS OF CASE STUDY 5

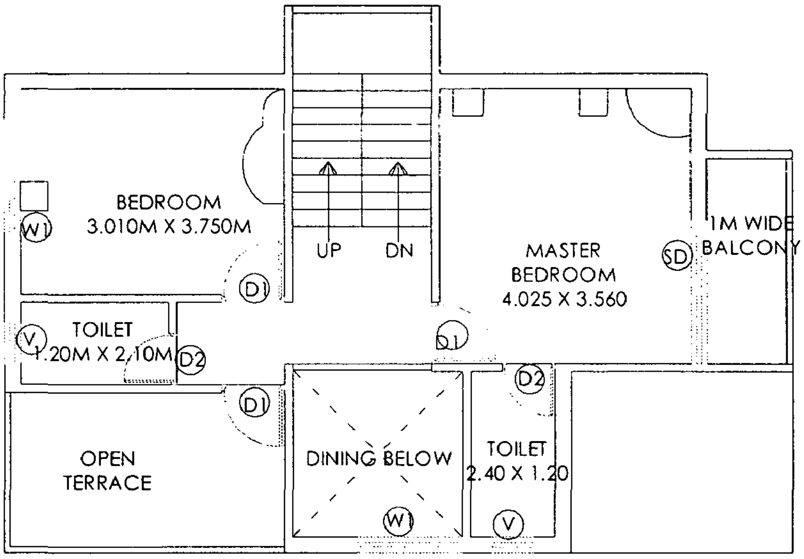


FIRST FLOOR PLAN

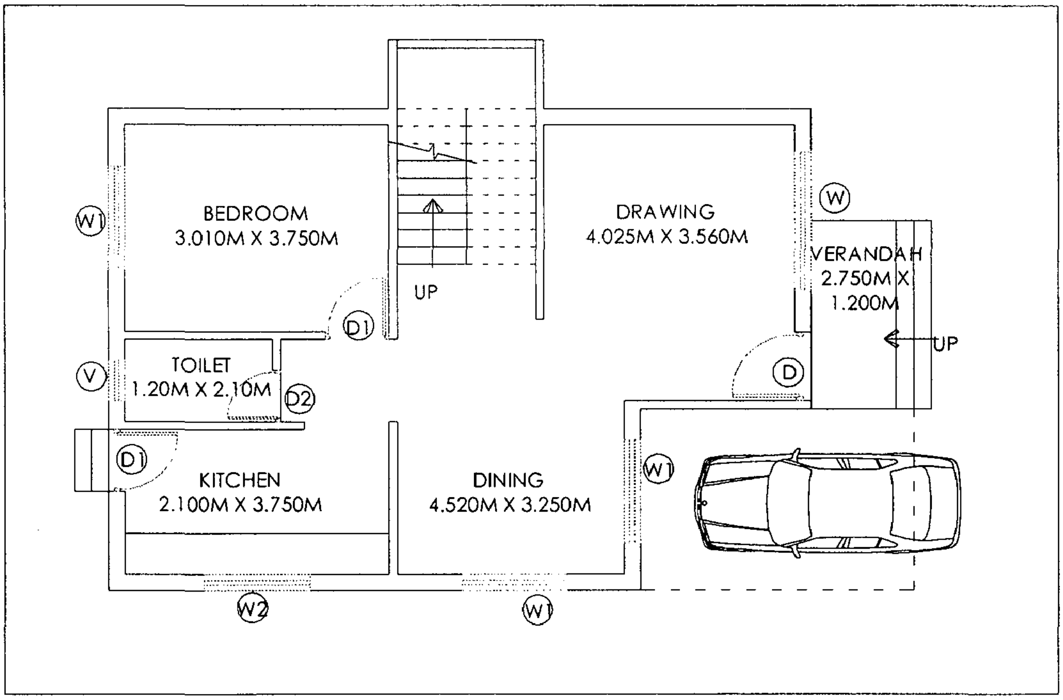


GROUND FLOOR PLAN

FIG 6 : FLOOR PLANS OF CASE STUDY 6



FIRST FLOOR PLAN



GROUND FLOOR PLAN

FIG 7: FLOOR PLANS OF CASE STUDY 7

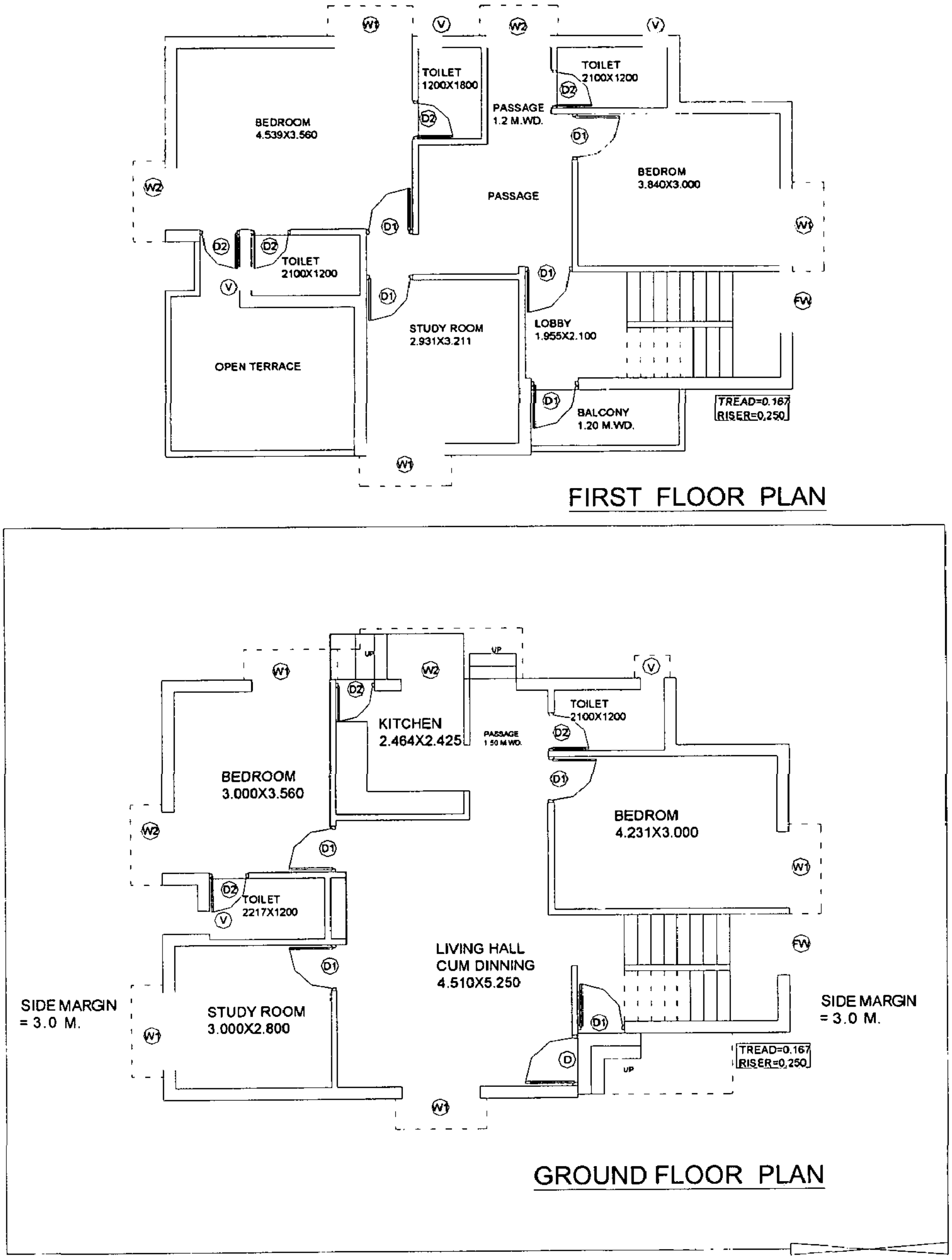


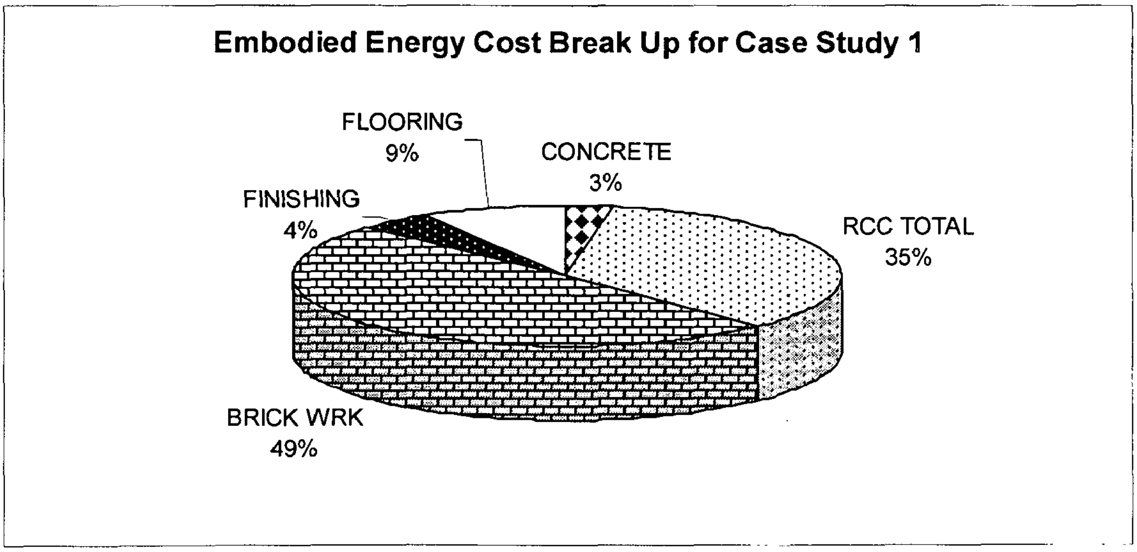
FIG 8 : FLOOR PLANS OF CASE STUDY 8

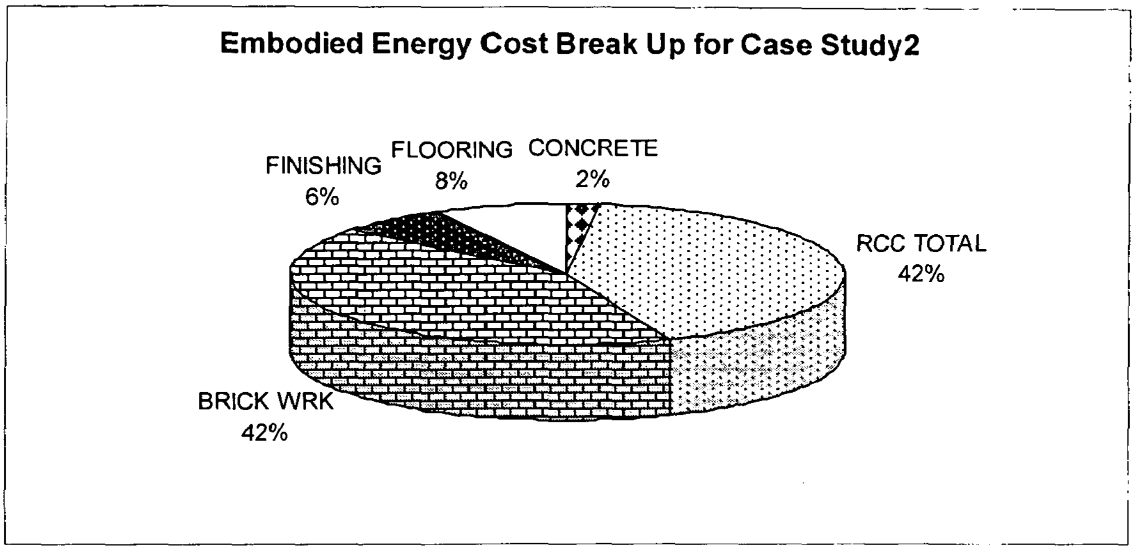
APPENDIX IB

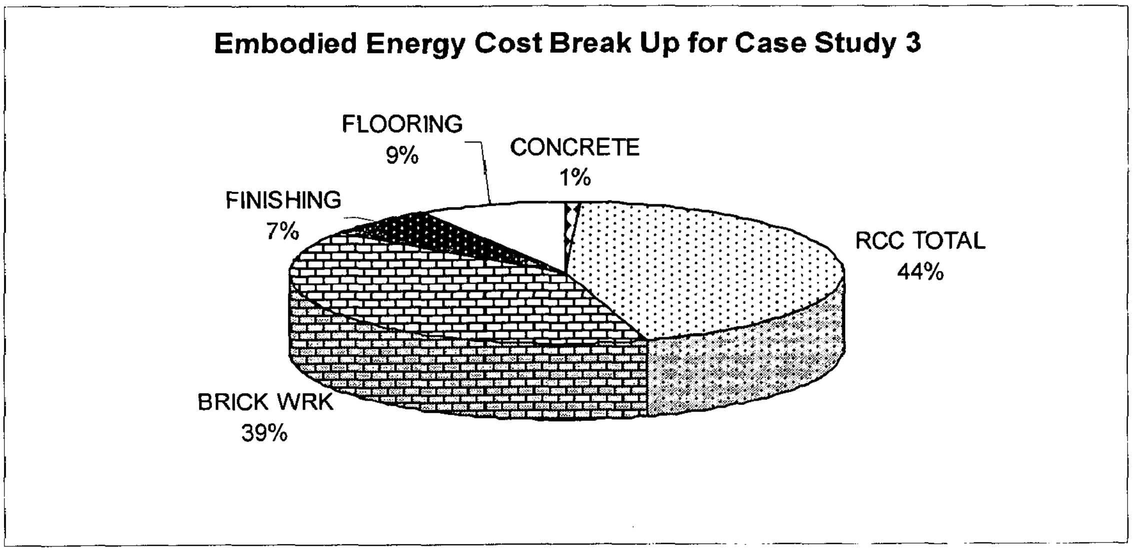
Embodied Energy Cost Break Up for all Case Studies

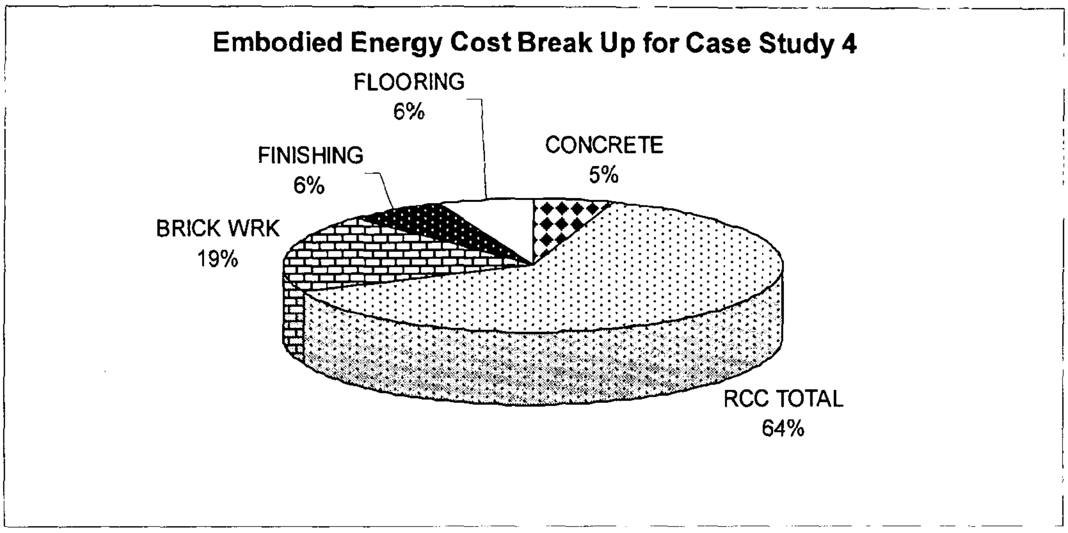
Table 1B.2 EEC Break Up For Case Studies

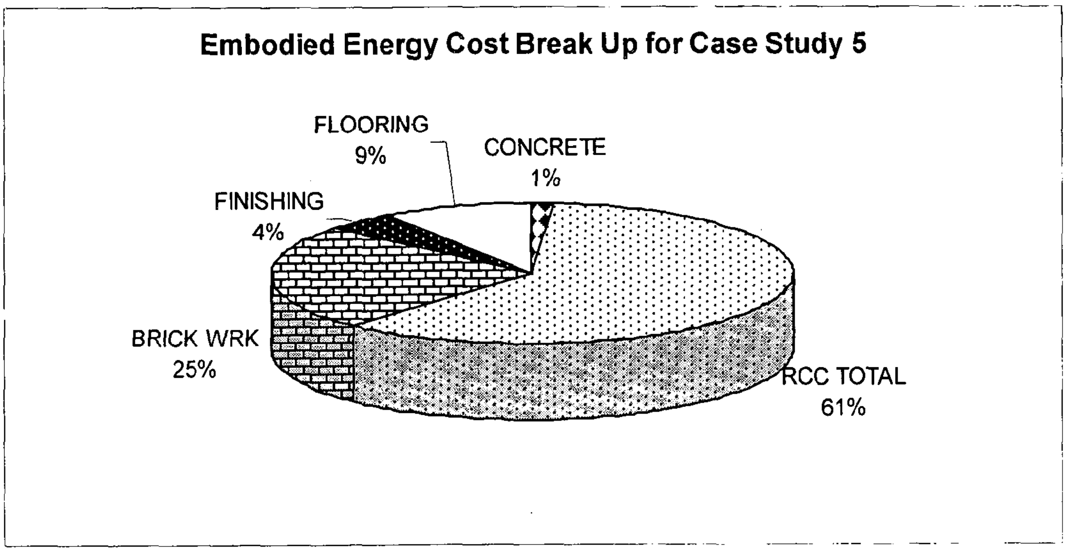
	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315	21719	4216	34622	5490	15304	22886	117249
RCC	**210239**	**487659**	**263361**	**417041**	**233000**	**512394**	**192671**	**281776**
Brick Work	**296397**	**485568**	**233125**	**124918**	**94456**	**152900**	**127485**	**357058**
Finishing	25710	74563	40393	41773	15503	45496	45994	616909
Flooring	51274	89878	50404	40932	36340	68847	22253	81917
[EEV$_T$]	600937	1159389	591501	659289	384790	794943	411291	899692

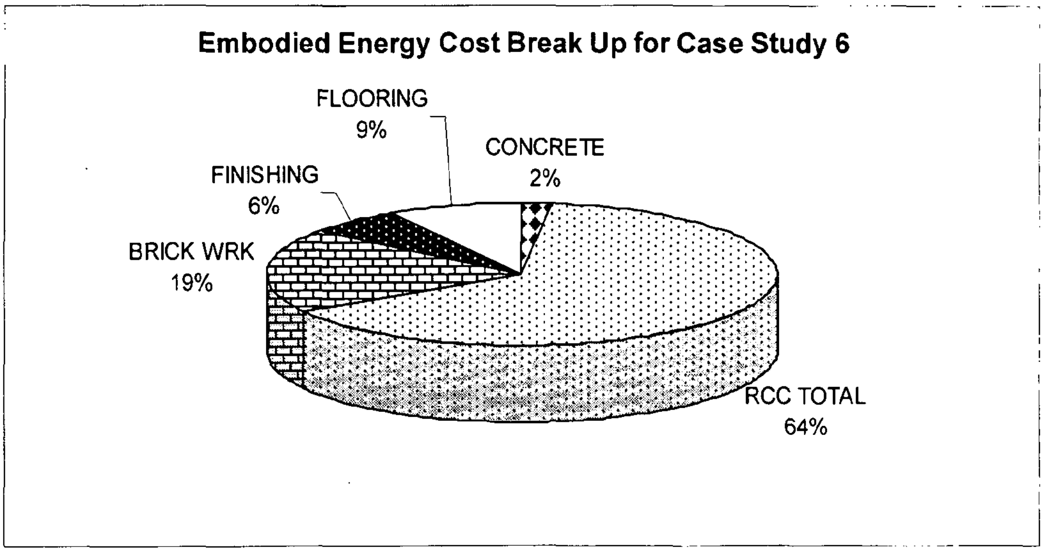

Embodied Energy Cost Break Up for Case Study 1

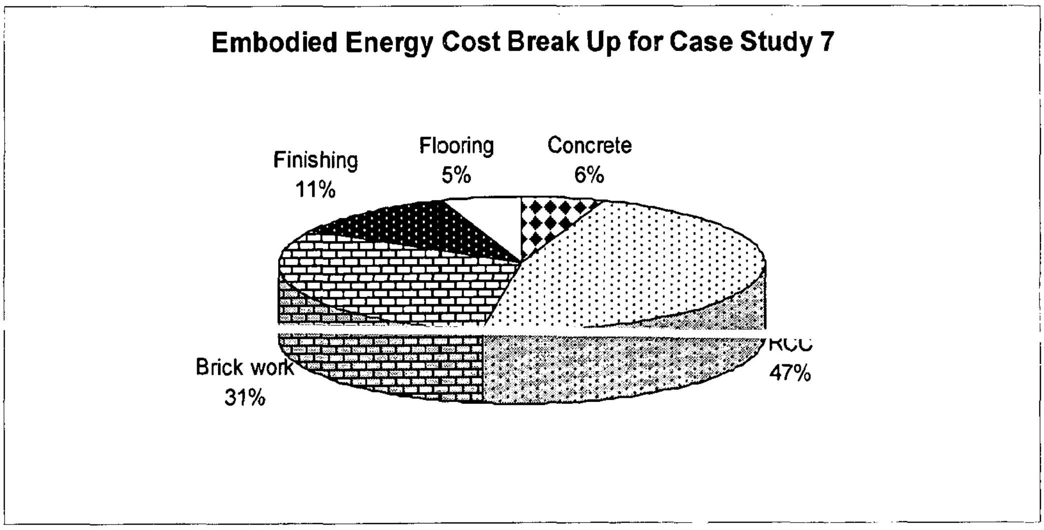

Embodied Energy Cost Break Up for Case Study2


Embodied Energy Cost Break Up for Case Study 3


Embodied Energy Cost Break Up for Case Study 4
FLOORING 6%
CONCRETE 5%
FINISHING 6%
BRICK WRK 19%
RCC TOTAL 64%


Embodied Energy Cost Break Up for Case Study 5
FLOORING 9%
CONCRETE 1%
FINISHING 4%
BRICK WRK 25%
RCC TOTAL 61%


Embodied Energy Cost Break Up for Case Study 6


Embodied Energy Cost Break Up for Case Study 7

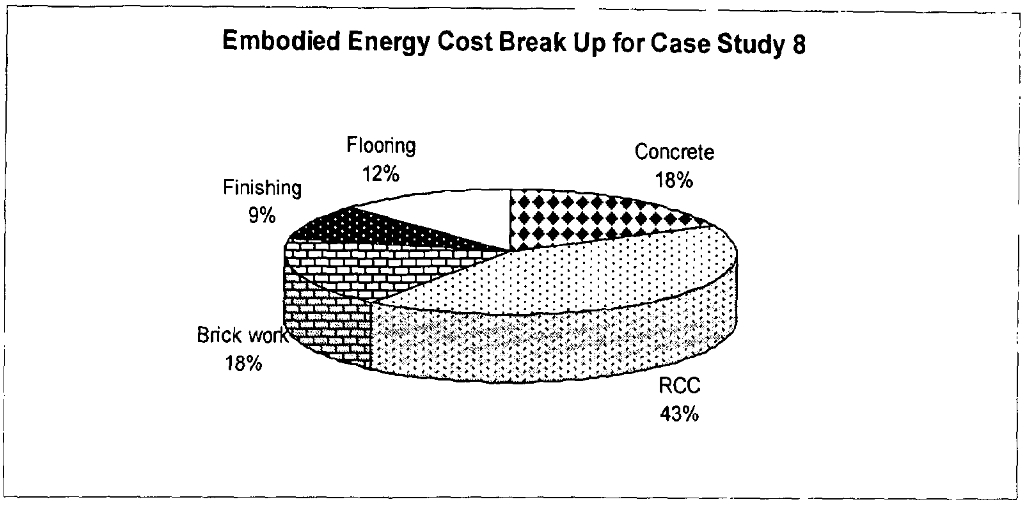


Table 1B.2 Embodied Energy Rates for Case Studies

	AREA (sqm.)	EER (MJ/sqm.)
case study 1	154.93	3658.4
case study 2	375.17	3090.29
case study 3	215.74	2741.71
case study 4	242.28	2721.19
case study 5	119.39	3223.05
case study 6	174.31	5687.52
case study 7	120.92	6932.73
case study 8	171.45	5247.7

APPENDIX II

Methods of Analysis for Estimating Embodied Energy Values (EEV) of Building Materials

Methods of analysis for estimating the EEV of building materials are as follows

1. Statistical Method
2. Input / Output Method
3. Process Analysis Method

1. Statistical Method

In this method, the EEV for a material is computed by dividing the energy input of an industry by its output.

For example, in U.K., the brick industry consumed 68.4x 109 MJ of energy in 1968 for the production of 7.5x109 bricks. This gave an EEV of 9.12 MJ per brick.

But the disadvantage of the statistical method is that it gives an average EEV of the building material, irrespective of the quality of the raw material used or the process applied to manufacture it.

For example, in brick production, the method can not distinguished between bricks made from highly carboniferous clays which provide some of their own firing energy and those which are made from low carbon clays which need a heavier fuel input to the kiln. It also cannot distinguish between the output of bricks from the more and less efficient brick manufacturing processes. Though the Statistical Method has the above disadvantages, it provides a useful rough estimate of the EEV of building materials. Brown *et al.* (1974).

2. Input/Output Method

This method is more elaborate than the Statistical Method. The interactions between the various sectors of industry are tabulated in matrix form so that the input of each industry to the other industry is available. It is possible by an alternate series of calculations to evaluate the direct and indirect energy inputs to each sector of industry. The disadvantage

.industry and the fact that few industries produce a homogenous range of products.

3. Process Analysis Method

This method of estimation of the EEV deals with the actual process of manufacture itself. The energy inputs are quantified at each stage of production and summed to give the EEV of the finished material. Using this method, every stage of production can be analyzed in detail. But this method also has several difficulties. Firstly, there has to be a thorough understanding of the manufacturing process, which is not an easy task as the required information about the process may not be available, particularly in some of the more complex industries. Moreover, it is impossible to assess how representative the process being analyzed is to the whole of the industry concerned.

All the methods of analysis for accounting the EEV produce different results for the same material. Even using the same method of analysis can result in different EEV for the same material, because of the differing manufacturing processes used. However, given the time and effort, the Process Analysis Method is more likely to cover all the important variables thus invalidating the use of either of the other two methods.

APPENDIX III

Alternate Masonry Units

1. *Clay Fly Ash Bricks*

Fly ash can be utilized as an integral mix with brick making soils, yielding good quality building bricks. Bricks confirming in the range of grades 50 to 300 as prescribed in IS:1077-1992 can be manufactured. These bricks can be used *for* all types of brick masonry and paving purposes. Strength of bricks in case of red and black soils is significantly increased with the addition of fly ash while, in case of alluvial soils, brick strength is slightly improved. The bulk density of the clay fly ash bricks is less than the traditional bricks, which provides better thermal insulation in the masonry walls and reduces the dead load on the brick masonry structure. Clay fly ash bricks are ecologically advantageous because they utilize a hazardous waste like fly ash. Waste fly ash unto 100-125 tones per 100,000 bricks in case of red and black soils and 30-40 tones per 100,000 bricks in case of alluvial soils can be utilized. They are also an economically and ecologically sound option as replacement of clay with fly ash saves topsoil and hence, prime agricultural land. Fly ash also reduces the energy required in the firing of bricks in the kiln, thus saving coal up to 3-5 tones per 105 bricks.

2. *Sand Lime Bricks*

Calcium silicate bricks, generally known as sand lime bricks, are made from sand or siliceous waste (like fly ash, tailings from gold, copper, iron and zinc) and hydrated lime. Manufacture of these bricks is economically feasible where sand or siliceous waste and lime arc readily available and good quality clay is not found, these bricks consume about 30% less energy in IS:1077-1992, Common Burnt Clay Building Bricks their production as compared to traditional bricks. Moreover, good quality sand lime bricks havc been manufactured by using different raw materials at the Central Building Research Institute (CBRI) and they compare favorably with the traditional bricks.

3. *Concrete Blocks*

Cement based alternatives for masonry applications have become extremely popular in large areas of the country where block availability is adversely affected due to depleted clay resources and fuel shortages. In areas with black cotton soil, the switch over to concrete blocks is already highly advanced. This is aided by easy availability of crushed stone and cement. The concrete blocks can be designed to suit the needs of varying types of construction, ranging from load bearing walls to partition walls.

The main categories of Concrete blocks that exist are

- Hollow load bearing concrete blocks
- Hollow non-load bearing concrete blocks
- Solid load bearing concrete blocks
- Aerated Concrete blocks

As per IS: 2185 (Part I)l and IS: 2185 (Part 3)2, hollow, solid and aerated concrete blocks are defined as follows;

3.1 Hollow Concrete Block

A block having one or more large holes of cavities, which either pass through the block (open cavity) or do not effectively pass through the block (closed cavity). The solid material in the block is between 50-75% of the total volume of the block calculated from the overall dimensions. 815 code IS: 2185 (Part I) —1979, Indian Standard Specification for Concrete Masonry Units — Hollow and Solid Concrete Blocks 2 code IS: 2185 (Part 3) 1984, Indian Standard Specification for Concrete Masonry Units — Autoclaved.

3.2 *Cellular (Aerated) Concrete Blocks*

A block, which has solid material not less than 75% of the total volume of the block, calculated from the overall dimensions.

3.3 Aerated Concrete Block

A block involving the use of aerated concrete, which is made by introducing air or other gases into slurry, composed of cement or lime and siliceous filler so that when the mixture sets hard after autoclaving, a uniform cellular structure is obtained. Concrete blocks are manufactured from varying mixes which consist mainly of cement, sand and coarse aggregates, various combinations substituting fly ash for sand are also possible. Fly ash addition also reduces the cement requirement of blocks. The mix ratios have been found to be varying from I part cement to 15 part of the other additives to richer mixes in the ratio of 1:5.

3.4 Solid and hollow concrete blocks:

The strength of the solid concrete blocks can vary from 80-150 kg/sqm. There is a drastic reduction in strength in the case of hollow blocks with typical strength of 35 *kg/sqm.* The sizes of the blocks are normally 30cm x 20cm x 15 cm for solid blocks and 40cm x 20cm x 10cm or 40cm x 20cm x 20cm for hollow blocks. The size for aerated blocks is 40cm x 20cm x20cm.

Concrete blocks may be manufactured either manually or using a block making machine. The blocks made by the machine are far superior in strength and finish vis-à-vis the manually made blocks.

4. *FAL-G Blocks*

FAL-G blocks have gained widespread acceptance in the southern Indian state of Andhra Pradesh and are made of fly ash, lime and gypsum. If the fly ash is too fine, sand or cinder fines may have to be added. The blocks are made in the same manner as the concrete blocks and cured for 21 days. The compressive strength achieved is reported to be 70-110 kg/sqm.

Advantages of Alternative Masonry Units

All the alternative masonry units have several advantages vis-a-vis traditional bricks:

- They are more appealing due to their accurate shapes, edges and corners. There is saving in mortar volume due to their uniform shapes and sizes.
- Moreover, the large size of the concrete blocks result in fewer joints, resulting in considerable saving in
- Mortar and also increases the strength of the wall.
- The production of these alternative masonry units can be assured throughout the year and is not subject to the vagaries of weather.
- The large size of the concrete and Fal-G blocks also ensures rapid construction as more walls can be laid per man-hour than in the traditional brick construction.
- Alternatives like the hollow blocks, while providing adequate support as load bearing members, also ensure good insulation, thus reducing the net thermal gain.
- The true plane surfaces obtained by these alternatives reduce the requirement of plaster for satisfactory coverage.
- Alternative units like clay fly ash bricks, with fly ash as an additive, not only help in utilizing a hazardous waste, but also help in saving precious top soil needed to make traditional bricks.
- All the alternatives have attractive appearance and are readily adaptable to any style of architecture. Bricks of different colors are also possible in clay fly ash and sand lime bricks.

Poly Vinyl Chloride (PVC)

It is versatile thermoplastic material, which can use in the production of highly rigid products, such as pipes, doors, windows, roofing and walling elements.

Cement Bonded Boards (CBB)

These boards are made up of 62% cement and 28% wood. CBB panels have the strength and durability of cement and the easy workability of wood. They can be used for door shutters, floors, roofs, partitions and even prefabricated structures.

Ferro cement

It is a highly versatile form of reinforced concrete made of cement mortar and wire mesh reinforcement and possesses the unique qualities of strength and serviceability. The advantages of ferrocement construction are:

- Structures can be thin and light
- They can be easily pre-cast
- They are amenable to repairs in case of local damage
- Considerable savings in framework particularly of complex shapes
- High cost saving potentials

Since the construction techniques for ferrocement is simple, the workmen can be easily trained in using it on site. It can be an efficient prefabricated system for mass scale projects.

Ferrocement can be used for roofing, understructure elements, doors, partitions and water tanks etc.

Medium Density Fibre boards

MDF is manufactured by a dry process where the fibres are dried before they are formed into a mat for pressing; MDF is made stronger by adding synthetic resin binders. The physical properties of MDF approach those of solid wood.

Plyboards

Plywood and ply boards are used for panels in furniture, doors, windows and partitions etc. They consist of sheets of veneers bonded by a synthetic resin glue, urea formaldehyde or phenol formaldehyde.

APPENDIX IVA

TRADITIONAL BRICK MASONRY

Table 1(a). Quantity for Traditional Brick Masonry in 1:3 mortar (1 cement: 3 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	2223.00	2855.60	240561.57	69.12	7368.81	247930.38
case study 2	102.32	52.86	2223.00	2855.60	378412.94	69.12	10726.25	389139.19
case study 3	46.24	27.55	2223.00	2855.60	181452.51	69.12	5100.09	186552.60
case study 4	30.00	19.20	2223.00	2855.60	121517.52	69.12	3400.70	124918.22
case study 5	21.55	15.41	2223.00	2855.60	91910.45	69.12	2554.68	94465.12
case study 6	52.03	27.13	2223.00	2855.60	193131.00	69.12	5471.47	198602.47
case study 7	38.45	16.22	2223.00	2855.60	131781.07	69.12	3778.44	135559.51
case study 8	43.39	9.12	2223.00	2855.60	122494.60	69.12	3629.35	126123.95

Table 1(b). EER for Traditional Bricks Masonry in 1:3 mortar (1 cement: 3 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	247930.38	389139.19	186552.60	124918.22	94465.12	198602.47	135559.51	126123.95
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV$_T$]	**552470.86**	**973081.24**	**544927.79**	**659289.18**	**384799.14**	**840645.41**	**419365.64**	**668757.98**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/SQ.M.)	3565.94	2593.71	2525.85	2721.19	3223.04	4109.93	3468.12	3900.60

Calculations For Alternative For Traditional Brick Masonry In 1:3 Mortar (1 Cement: 3 Sand)

ALTERNATIVE 1 : CLAY FLY ASH BRICKS

Table 2(a). Quantity of Clay Fly Ash Brick Masonry in 1:3 mortar (1 cement: 3 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	1881.60	2130.25	201998.63	51.54	5494.63	207493.25
case study 2	102.32	52.86	1881.60	2130.25	305136.72	51.54	7998.13	313134.85
case study 3	46.24	27.55	1881.60	2130.25	145685.30	51.54	3802.93	149488.23
case study 4	30.00	19.20	1881.60	2130.25	97348.80	51.54	2535.77	99884.57
case study 5	21.55	15.41	1881.60	2130.25	73375.63	51.54	1904.92	75280.55
case study 6	52.03	27.13	1881.60	2130.25	155690.70	51.54	4079.85	159770.56
case study 7	38.45	16.22	1881.60	2130.25	106890.77	51.54	2817.43	109708.20
case study 8	43.39	9.12	1881.60	2130.25	101066.74	51.54	2706.26	103773.00

Table 2(b). EER for Clay Fly Ash Bricks Masonry in 1:3 mortar (1 cement: 3 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	207493.25	313134.85	149488.23	99884.57	75280.55	159770.56	109708.20	103773.00
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV_T]	**512033.73**	**986955.49**	**507863.42**	**634255.53**	**365614.57**	**801813.50**	**393514.33**	**646407.03**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/SQ.M.)	3304.94	2630.69	2354.05	2617.86	3062.36	3920.08	3254.34	3770.24

ALTERNATIVE 2 : SAND LIME BRICKS

Table 3(a). Quantity of Sand Lime Brick Masonry in 1:3 mortar (1 cement: 3 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	2110.50	2388.75	226568.46	69.12	7368.81	233937.27
case study 2	102.32	52.86	2110.50	2388.75	342222.85	69.12	10726.25	352949.10
case study 3	46.24	27.55	2110.50	2388.75	163390.31	69.12	5100.09	168490.39
case study 4	30.00	19.20	2110.50	2388.75	109179.00	69.12	3400.70	112579.70
case study 5	21.55	15.41	2110.50	2388.75	82291.91	69.12	2554.68	84846.59
case study 6	52.03	27.13	2110.50	2388.75	174613.16	69.12	5471.47	180084.63
case study 7	38.45	16.22	2110.50	2388.75	119883.70	69.12	3778.44	123662.14
case study 8	43.39	9.12	2110.50	2388.75	113355.77	69.12	3629.35	116985.13

Table 3(b). EER for Sand Lime Bricks in 1:3 mortar (1 cement: 3 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	233937.27	352949.10	168490.39	112579.70	84846.59	180084.63	123662.14	116985.13
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV$_T$]	**538477.75**	**936891.15**	**526865.59**	**646950.66**	**375180.61**	**822127.57**	**407468.27**	**659619.16**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/SQ.M.)	3475.62	2497.24	2442.13	2670.26	3142.48	4019.40	3369.73	3847.30

ALTERNATIVE 3 : HOLLOW CONCRETE BLOCK (40X20X10)

Table 4(a). Quantity of Hollow Concrete Block (40x20x10) in 1:3 mortar (1 cement: 3 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	2135.91	2036.94	227148.74	64.00	6822.98	233971.72
case study 2	102.32	52.86	2135.91	2036.94	326225.07	64.00	9931.71	336156.78
case study 3	46.24	27.55	2135.91	2036.94	154873.93	64.00	4722.30	159596.23
case study 4	30.00	19.20	2135.91	2036.94	103186.55	64.00	3148.80	106335.35
case study 5	21.55	15.41	2135.91	2036.94	77418.11	64.00	2365.44	79783.55
case study 6	52.03	27.13	2135.91	2036.94	166391.74	64.00	5066.18	171457.92
case study 7	38.45	16.22	2135.91	2036.94	115154.23	64.00	3498.56	118652.79
case study 8	43.39	9.12	2135.91	2036.94	111249.76	64.00	3360.51	114610.27

Table 4(b). EER for Hollow Concrete Blocks (40X20X10) in 1:3 mortar (1 cement: 3 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	233971.72	336156.78	159596.23	106335.35	79783.55	171457.92	118652.79	114610.27
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV_T]	**538512.20**	**920098.83**	**517971.43**	**640706.31**	**370117.57**	**813500.86**	**402458.92**	**657244.30**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/sqm.)	3475.84	2452.49	2400.91	2644.49	3100.07	3977.22	3328.31	3833.45

ALTERNATIVE 4 : HOLLOW CONCRETE BLOCK (40X20X20)

Table 5(a). Quantity of Hollow Concrete Block (40x20x20) masonry in 1:3 mortar (1 cement: 3 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick) (x2)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	1256.81	1256.81	141079.44	59.54	6347.50	147426.94
case study 2	102.32	52.86	1256.81	1256.81	261474.29	59.54	9239.60	270713.89
case study 3	46.24	27.55	1256.81	1256.81	127356.33	59.54	4393.22	131749.55
case study 4	30.00	19.20	1256.81	1256.81	85965.80	59.54	2929.37	88895.17
case study 5	21.55	15.41	1256.81	1256.81	65819.14	59.54	2200.60	68019.74
case study 6	52.03	27.13	1256.81	1256.81	133581.31	59.54	4713.13	138294.43
case study 7	38.45	16.22	1256.81	1256.81	89088.98	59.54	3254.75	92343.73
case study 8	43.39	9.12	1256.81	1256.81	77454.69	59.54	3126.33	80581.01

Table 5(b). EER for Hollow Concrete Blocks (40X20X20) in 1:3 mortar (1 cement: 3 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	147426.94	270713.89	131749.55	88895.17	68019.74	138294.43	92343.73	80581.01
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV_T]	**451967.41**	**944534.53**	**490124.74**	**623266.13**	**358353.76**	**780337.38**	**376149.86**	**623215.04**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER **(MJ/sqm.)**	2917.24	2517.62	2271.83	2572.50	3001.54	3815.08	3110.73	3634.97

ALTERNATIVE 5 : AERATED CONCRETE BLOCK(40X20X20)

Table 6(a). Quantity of Aerated Concrete Block (40x20x20) in 1:3 mortar (1 cement: 3 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick) (x2)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	1288.31	1288.31	144615.37	58.75	6263.28	150878.65
case study 2	102.32	52.86	1288.31	1288.31	268027.74	58.75	9117.00	277144.74
case study 3	46.24	27.55	1288.31	1288.31	130548.32	58.75	4334.93	134883.24
case study 4	30.00	19.20	1288.31	1288.31	88120.40	58.75	2890.50	91010.90
case study 5	21.55	15.41	1288.31	1288.31	67468.79	58.75	2171.40	69640.19
case study 6	52.03	27.13	1288.31	1288.31	136929.32	58.75	4650.59	141579.91
case study 7	38.45	16.22	1288.31	1288.31	91321.85	58.75	3211.57	94533.42
case study 8	43.39	9.12	1288.31	1288.31	79395.97	58.75	3084.85	82480.81

Table 6(b). EER for Aerated Concrete Block (40X20X20) in 1:3 mortar (1 cement: 3 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	150878.65	277144.74	134883.24	91010.90	69640.19	141579.91	94533.42	82480.81
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV$_T$]	**455419.13**	**950965.38**	**493258.44**	**625381.86**	**359974.21**	**783622.85**	**378339.55**	**625114.84**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/sqm.)	2939.52	2534.76	2286.36	2581.24	3015.11	3831.15	3128.84	3646.05

ALTERNATIVE 6 : SOLID CONCRETE BLOCK(30X20X15)

Table 7(a). Quantity of Solid Concrete Block (30x20x15) in 1:3 mortar (1 cement: 3 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	1848.20	1782.83	196665.87	87.55	9333.62	205999.49
case study 2	102.32	52.86	1848.20	1782.83	283353.57	87.55	13586.27	296939.84
case study 3	46.24	27.55	1848.20	1782.83	134570.54	87.55	6459.96	141030.50
case study 4	30.00	19.20	1848.20	1782.83	89676.34	87.55	4307.46	93983.80
case study 5	21.55	15.41	1848.20	1782.83	67302.12	87.55	3235.85	70537.97
case study 6	52.03	27.13	1848.20	1782.83	144528.37	87.55	6930.37	151458.74
case study 7	38.45	16.22	1848.20	1782.83	99971.55	87.55	4785.92	104757.47
case study 8	43.39	9.12	1848.20	1782.83	96449.11	87.55	4597.08	101046.19

Table 7(b). EER for Solid Concrete Block (30X20X15) in 1:3 mortar (1 cement: 3 sand)

	Cases Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	205999.49	296939.84	141030.50	93983.80	70537.97	151458.74	104757.47	101046.19
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV_T]	**510539.97**	**970760.48**	**499405.70**	**628354.76**	**360871.99**	**793501.69**	**388563.60**	**643680.22**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/sqm.)	3295.29	2587.52	2314.85	2593.51	3022.63	3879.45	3213.39	3754.33

ALTERNATIVE 7 : FAL-G BLOCK (30X20X15)

Table 8(a). Quantity of in FAL-G Block 1:3 mortar (1 cement: 3 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	1568.20	1510.33	166857.67	87.55	9333.62	176191.29
case study 2	102.32	52.86	1568.20	1510.33	240298.80	87.55	13586.27	253885.07
case study 3	46.24	27.55	1568.20	1510.33	114117.06	87.55	6459.96	120577.02
case study 4	30.00	19.20	1568.20	1510.33	76044.34	87.55	4307.46	80351.80
case study 5	21.55	15.41	1568.20	1510.33	57068.90	87.55	3235.85	60304.74
case study 6	52.03	27.13	1568.20	1510.33	122567.30	87.55	6930.37	129497.67
case study 7	38.45	16.22	1568.20	1510.33	84787.00	87.55	4785.92	89572.92
case study 8	43.39	9.12	1568.20	1510.33	81815.27	87.55	4597.08	86412.35

Table 8(b). EER for FAL-G Block (30X20X15) in 1:3 mortar (1 cement: 3 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	176191.29	253885.07	120577.02	80351.80	60304.74	129497.67	89572.92	86412.35
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV_T]	**480731.77**	**927705.71**	**478952.22**	**614722.76**	**350638.76**	**771540.62**	**373379.05**	**629046.38**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/sqm.)	3102.90	2472.76	2220.04	2537.24	2936.92	3772.08	3087.82	3668.98

Table 9. Comparison of Embodied Energy Rates in case studies with traditional masonry and alternate masonry with mortar 1:3 (1 cement : 3 fine sand)

	CASE STUDY 1	CASE STUDY 2	CASE STUDY 3	CASE STUDY 4	CASE STUDY 5	CASE STUDY 6	CASE STUDY 7	CASE STUDY 8	AVERAGE%
AREA (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45	
EER (MJ/sqm.) TRADITIONAL BRICK WORK	3565.94	2593.71	2525.85	2721.19	3223.04	4109.93	3468.12	3900.60	
%	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	
CLAY FLY ASH BRICKS	3304.94	2630.69	2354.05	2617.86	3062.36	3920.08	3254.34	3770.24	
%OF ALT. EE WITH TRAD BRICK WRK	92.68	101.43	93.20	96.20	95.01	95.38	93.84	96.66	
%EMBODIED ENERGY SAVED PER SQ.M.	**7.32**	**-1.43**	**6.80**	**3.80**	**4.99**	**4.62**	**6.16**	**3.34**	**4.45**
SAND LIME BRICKS	3475.62	2497.24	2442.13	2670.26	3142.48	4019.40	3369.73	3847.30	
%OF ALT. EE WITH TRAD BRICK WRK	97.47	96.28	96.69	98.13	97.50	97.80	97.16	98.63	
%EMBODIED ENERGY SAVED PER SQ.M.	**2.53**	**3.72**	**3.31**	**1.87**	**2.50**	**2.20**	**2.84**	**1.37**	**2.54**

HOLLOW CONC.BLOCK (40X20X10)	3475.84	2452.49	2400.91	2644.49	3100.07	3977.22	3328.31	3833.45	
%OF ALT. EE WITH TRAD BRICK WRK	97.47	94.56	95.05	97.18	96.18	96.77	95.97	98.28	
%EMBODIED ENERGY SAVED PER SQ.M.	**2.53**	**5.44**	**4.95**	**2.82**	**3.82**	**3.23**	**4.03**	**1.72**	**3.57**
HOLLOW CONC.BLOCK (40X20X20)	2917.24	2517.62	2271.83	2572.50	3001.54	3815.08	3110.73	3634.97	
%OF ALT. EE WITH TRAD BRICK WRK	81.81	97.07	89.94	94.54	93.13	92.83	89.69	93.19	
%EMBODIED ENERGY SAVED PER SQ.M.	**18.19**	**2.93**	**10.06**	**5.46**	**6.87**	**7.17**	**10.31**	**6.81**	**8.48**
AERATED CONC BLOCK(40X20X20)	2939.52	2534.76	2286.36	2581.24	3015.11	3831.15	3128.84	3646.05	
%OF ALT. EE WITH TRAD BRICK WRK	82.43	97.73	90.52	94.86	93.55	93.22	90.22	93.47	
%EMBODIED ENERGY SAVED PER SQ.M.	**17.57**	**2.27**	**9.48**	**5.14**	**6.45**	**6.78**	**9.78**	**6.53**	**8.00**
SOLID CONC.BLOCK(30X20X15)	3295.29	2587.52	2314.85	2593.51	3022.63	3879.45	3213.39	3754.33	
%OF ALT. EE WITH TRAD BRICK WRK	92.41	99.76	91.65	95.31	93.78	94.39	92.66	96.25	
%EMBODIED ENERGY SAVED PER SQ.M.	**7.59**	**0.24**	**8.35**	**4.69**	**6.22**	**5.61**	**7.34**	**3.75**	**5.47**

FAL-G BLOCK(30X20X15)	3102.90	2472.76	2220.04	2537.24	2936.92	3772.08	3087.82	3668.98	
%OF ALT. EE WITH TRAD BRICK WRK	87.01	95.34	87.89	93.24	91.12	91.78	89.03	94.06	
%EMBODIED ENERGY SAVED PER SQ.M.	**12.99**	**4.66**	**12.11**	**6.76**	**8.88**	**8.22**	**10.97**	**5.94**	**8.81**

APPENDIX IVB

TRADITIONAL BRICK MASONRY

Table 1(a). Quantity for Traditional Brick Masonry in 1:6 mortar (1 cement: 6 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	2013.04	2822.07	219173.54	69.12	7368.81	226542.35
case study 2	102.32	52.86	2013.04	2822.07	355157.34	69.12	10726.25	365883.59
case study 3	46.24	27.55	2013.04	2822.07	170820.52	69.12	5100.09	175920.61
case study 4	30.00	19.20	2013.04	2822.07	114574.94	69.12	3400.70	117975.65
case study 5	21.55	15.41	2013.04	2822.07	86869.11	69.12	2554.68	89423.79
case study 6	52.03	27.13	2013.04	2822.07	181296.79	69.12	5471.47	186768.26
case study 7	38.45	16.22	2013.04	2822.07	123165.30	69.12	3778.44	126943.74
case study 8	43.39	9.12	2013.04	2822.07	113079.06	69.12	3629.35	116708.41

Table 1(b). EER for Traditional Bricks Masonry in 1:6 mortar (1 cement: 6 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	226542.35	365883.59	175920.61	117975.65	89423.79	186768.26	126943.74	116708.41
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV_T]	**531082.83**	**949825.64**	**534295.80**	**652346.61**	**379757.81**	**828811.20**	**410749.87**	**659342.44**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/SQ.M.)	3427.89	2531.72	2476.57	2692.53	3180.82	4052.07	3396.87	3845.68

Calculations For Alternative For Traditional Brick Masonry In 1:6 Mortar (1 Cement: 6 Sand)

ALTERNATIVE 1 : CLAY FLY ASH BRICKS

Table 2(a). Quantity of Clay Fly Ash Brick Masonry in 1:6 mortar (1 cement: 6 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	1498.34	1878.38	161881.09	51.54	5494.63	167375.72
case study 2	102.32	52.86	1498.34	1878.38	252606.95	51.54	7998.13	260605.08
case study 3	46.24	27.55	1498.34	1878.38	121025.48	51.54	3802.93	124828.41
case study 4	30.00	19.20	1498.34	1878.38	81015.10	51.54	2535.77	83550.86
case study 5	21.55	15.41	1498.34	1878.38	61235.06	51.54	1904.92	63139.98
case study 6	52.03	27.13	1498.34	1878.38	128916.44	51.54	4079.85	132996.30
case study 7	38.45	16.22	1498.34	1878.38	88071.00	51.54	2817.43	90888.44
case study 8	43.39	9.12	1498.34	1878.38	82140.80	51.54	2706.26	84847.06

Table 2(b). EER for Clay Fly Ash Masonry in 1:6 mortar (1 cement: 6 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick wrk	167375.72	260605.08	124828.41	83550.86	63139.98	132996.30	90888.44	84847.06
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV_T]	**471916.20**	**934425.72**	**483203.60**	**617921.82**	**353474.00**	**775039.24**	**374694.57**	**627481.09**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/SQ.M.)	3046.00	2490.67	2239.75	2550.45	2960.67	3789.18	3098.70	3659.85

ALTERNATIVE 2 : SAND LIME BRICKS

Table 3(a). Quantity of Sand Lime Brick Masonry in 1:6 mortar (1 cement: 6 sand)

	Quantity Full brick Thick	Quantity Half brick Thick	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	1727.23	2136.88	186449.92	69.12	7368.81	193818.73
case study 2	102.32	52.86	1727.23	2136.88	289692.06	69.12	10726.25	300418.31
case study 3	46.24	27.55	1727.23	2136.88	138730.02	69.12	5100.09	143830.11
case study 4	30.00	19.20	1727.23	2136.88	92845.00	69.12	3400.70	96245.70
case study 5	21.55	15.41	1727.23	2136.88	70151.13	69.12	2554.68	72705.80
case study 6	52.03	27.13	1727.23	2136.88	147838.38	69.12	5471.47	153309.85
case study 7	38.45	16.22	1727.23	2136.88	101063.55	69.12	3778.44	104842.00
case study 8	43.39	9.12	1727.23	2136.88	94429.40	69.12	3629.35	98058.75

Table 3(b). EER for Sand Lime Brick Masonry in 1:6 mortar (1 cement: 6 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	193818.73	300418.31	143830.11	96245.70	72705.80	153309.85	104842.00	98058.75
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV$_T$]	**498359.21**	**884360.36**	**502205.30**	**630616.66**	**363039.82**	**795352.79**	**388648.13**	**640692.78**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/SQ.M.)	3216.67	2357.23	2327.83	2602.84	3040.79	3888.50	3214.09	3736.91

ALTERNATIVE 3 : HOLLOW CONCRETE BLOCK (40X20X10)

Table 4(a). Quantity of Hollow Concrete Block (40x20x10) in 1:6 mortar (1 cement: 6 sand)

	Quantity Full brick Thick	Quantity Half brick Thick	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	1735.25	1815.29	185444.93	64.00	6822.98	192267.91
case study 2	102.32	52.86	1735.25	1815.29	273512.46	64.00	9931.71	283444.17
case study 3	46.24	27.55	1735.25	1815.29	130242.02	64.00	4722.30	134964.32
case study 4	30.00	19.20	1735.25	1815.29	86911.07	64.00	3148.80	90059.87
case study 5	21.55	15.41	1735.25	1815.29	65368.26	64.00	2365.44	67733.70
case study 6	52.03	27.13	1735.25	1815.29	139531.90	64.00	5066.18	144598.08
case study 7	38.45	16.22	1735.25	1815.29	96155.69	64.00	3498.56	99654.25
case study 8	43.39	9.12	1735.25	1815.29	91844.47	64.00	3360.51	95204.98

Table 4(b). EER for Hollow Concrete Blocks (40X20X10) in 1:6 mortar (1 cement: 6 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	192267.91	283444.17	134964.32	90059.87	67733.70	144598.08	99654.25	95204.98
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV_T]	**496808.39**	**867386.22**	**493339.52**	**624430.83**	**358067.72**	**786641.02**	**383460.38**	**637839.01**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/sqm.)	3206.66	2311.98	2286.73	2577.31	2999.14	3845.90	3171.19	3720.26

ALTERNATIVE 4 : HOLLOW CONCRETE BLOCK (40X20X20)

Table 5(a). Quantity of Hollow Concrete Block (40x20x20) masonry in 1:6 mortar (1 cement: 6 sand)

	Quantity Full brick Thick	Quantity Half brick Thick (x2)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	969.38	969.38	108814.84	59.54	6347.50	115162.34
case study 2	102.32	52.86	969.38	969.38	201675.63	59.54	9239.60	210915.23
case study 3	46.24	27.55	969.38	969.38	98230.18	59.54	4393.22	102623.40
case study 4	30.00	19.20	969.38	969.38	66305.59	59.54	2929.37	69234.96
case study 5	21.55	15.41	969.38	969.38	50766.43	59.54	2200.60	52967.03
case study 6	52.03	27.13	969.38	969.38	103031.52	59.54	4713.13	107744.65
case study 7	38.45	16.22	969.38	969.38	68714.50	59.54	3254.75	71969.26
case study 8	43.39	9.12	969.38	969.38	59740.95	59.54	3126.33	62867.28

Table 5(b). EER for Hollow Concrete Blocks (40X20X20) in 1:6 mortar (1 cement: 6 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	115162.34	210915.23	102623.40	69234.96	52967.03	107744.65	71969.26	62867.28
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV$_T$]	**419702.82**	**884735.87**	**460998.60**	**603605.92**	**343301.05**	**749787.59**	**355775.39**	**605501.31**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER **(MJ/sqm.)**	2708.98	2358.23	2136.82	2491.36	2875.46	3665.73	2942.24	3531.65

ALTERNATIVE 5 : AERATED CONCRETE BLOCK (40X20X20)

Table 6(a). Quantity of Aerated Concrete Block (40x20x20) in 1:6 mortar (1 cement: 6 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick) (x2)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	1001.00	1001.00	112364.25	58.75	6263.28	118627.53
case study 2	102.32	52.86	1001.00	1001.00	208254.05	58.75	9117.00	217371.05
case study 3	46.24	27.55	1001.00	1001.00	101434.33	58.75	4334.93	105769.26
case study 4	30.00	19.20	1001.00	1001.00	68468.40	58.75	2890.50	71358.90
case study 5	21.55	15.41	1001.00	1001.00	52422.37	58.75	2171.40	54593.77
case study 6	52.03	27.13	1001.00	1001.00	106392.29	58.75	4650.59	111042.88
case study 7	38.45	16.22	1001.00	1001.00	70955.89	58.75	3211.57	74167.45
case study 8	43.39	9.12	1001.00	1001.00	61689.63	58.75	3084.85	64774.47

Table 6(b). EER for Aerated Concrete Block (40X20X20) in 1:6 mortar (1 cement: 6 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	118627.53	217371.05	105769.26	71358.90	54593.77	111042.88	74167.45	64774.47
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV_T]		**891191.69**	**464144.45**	**605729.86**	**344927.79**	**753085.82**	**357973.58**	**607408.50**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/sqm.)	2731.35	2375.43	2151.41	2500.12	2889.08	3681.85	2960.42	3542.77

ALTERNATIVE 6 : SOLID CONCRETE BLOCK(30X20X15)

Table 7(a). Quantity of Solid Concrete Block (30x20x15) in 1:6 mortar (1 cement: 6 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	1499.80	1591.41	160409.13	87.55	9333.62	169742.75
case study 2	102.32	52.86	1499.80	1591.41	237586.24	87.55	13586.27	251172.51
case study 3	46.24	27.55	1499.80	1591.41	113187.82	87.55	6459.96	119647.79
case study 4	30.00	19.20	1499.80	1591.41	75549.07	87.55	4307.46	79856.53
case study 5	21.55	15.41	1499.80	1591.41	56844.32	87.55	3235.85	60080.17
case study 6	52.03	27.13	1499.80	1591.41	121207.77	87.55	6930.37	128138.14
case study 7	38.45	16.22	1499.80	1591.41	83472.48	87.55	4785.92	88258.40
case study 8	43.39	9.12	1499.80	1591.41	79586.98	87.55	4597.08	84184.06

Table 7(b). EER for Solid Concrete Block (30X20X15) in 1:6 mortar (1 cement: 6 sand)

	Cases Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	169742.75	251172.51	119647.79	79856.53	60080.17	128138.14	88258.40	84184.06
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV_T]	**474283.23**	**924993.15**	**478022.98**	**614227.49**	**350414.19**	**770181.09**	**372064.53**	**626818.09**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/sqm.)	3061.27	2465.53	2215.74	2535.20	2935.04	3765.43	3076.95	3655.98

ALTERNATIVE 7 : FAL-G BLOCK (30X20X15)

Table 8(a). Quantity of in FAL-G Block 1:6 mortar (1 cement: 6 sand)

	Quantity (Full brick Thick)	Quantity (Half brick Thick)	EER (Full brick)	EER (Half brick)	EEV	TER	TEV	EEV TOTAL
case study 1	100.97	5.64	1219.80	1318.91	130600.94	87.55	9333.62	139934.55
case study 2	102.32	52.86	1219.80	1318.91	194531.48	87.55	13586.27	208117.75
case study 3	46.24	27.55	1219.80	1318.91	92734.35	87.55	6459.96	99194.31
case study 4	30.00	19.20	1219.80	1318.91	61917.07	87.55	4307.46	66224.53
case study 5	21.55	15.41	1219.80	1318.91	46611.09	87.55	3235.85	49846.94
case study 6	52.03	27.13	1219.80	1318.91	99246.71	87.55	6930.37	106177.08
case study 7	38.45	16.22	1219.80	1318.91	68287.93	87.55	4785.92	73073.85
case study 8	43.39	9.12	1219.80	1318.91	64953.14	87.55	4597.08	69550.22

Table 8(b). EER for FAL-G Block (30X20X15) in 1:6 mortar (1 cement: 6 sand)

	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5	Case Study 6	Case Study 7	Case Study 8
Concrete	17315.53	21719.00	4216.00	34622.57	5490.34	15304.58	22886.96	117249.50
RCC total	210239.57	487659.65	263361.37	417041.80	233000.21	512394.39	192671.25	281776.47
Brick work	139934.55	208117.75	99194.31	66224.53	49846.94	106177.08	73073.85	69550.22
Finishing	25710.59	74563.40	40393.24	41773.88	15503.34	45496.42	45994.15	61690.95
Flooring	51274.79	89878.59	50404.59	40932.71	36340.13	68847.56	22253.77	81917.11
Total EEV [EEV_T]	**444475.03**	**881938.39**	**457569.50**	**600595.49**	**340180.96**	**748220.02**	**356879.98**	**612184.25**
Area (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45
EER (MJ/sqm.)	2868.88	2350.77	2120.93	2478.93	2849.33	3658.06	2951.37	3570.63

Table 9. Comparison of Embodied Energy Rates in case studies with traditional masonry and alternate masonry with mortar 1:6 (1cement : 6 fine sand)

	CASE STUDY 1	**CASE STUDY 2**	**CASE STUDY 3**	**CASE STUDY 4**	**CASE STUDY 5**	**CASE STUDY 6**	**CASE STUDY 7**	**CASE STUDY 8**	Average of Percentage Energy Saved
AREA (sqm.)	154.93	375.17	215.74	242.28	119.39	204.54	120.92	171.45	
TRADITIONAL BRICK WORK EER (MJ/sqm.)	3427.89	2531.72	2476.57	2692.53	3180.82	4052.07	3396.87	3845.68	
PERCENTAGE	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	
CLAY FLY ASH BRICKS	3046.00	2490.67	2239.75	2550.45	2960.67	3789.18	3098.70	3659.85	
% OF ALT. EE WITH TRAD BRICK WRK	88.86	98.38	90.44	94.72	93.08	93.51	91.22	95.17	
%EMBODIED ENERGY SAVED PER sqm.	**11.14**	**1.62**	**9.56**	**5.28**	**6.92**	**6.49**	**8.78**	**4.83**	**6.83**
SAND LIME BRICKS	3216.67	2357.23	2327.83	2602.84	3040.79	3888.50	3214.09	3736.91	
%OF ALT. EE WITH TRAD BRICK WRK	93.84	93.11	93.99	96.67	95.60	95.96	94.62	97.17	
%EMBODIED ENERGY SAVED PER sqm.	**6.16**	**6.89**	**6.01**	**3.33**	**4.40**	**4.04**	**5.38**	**2.83**	**4.88**

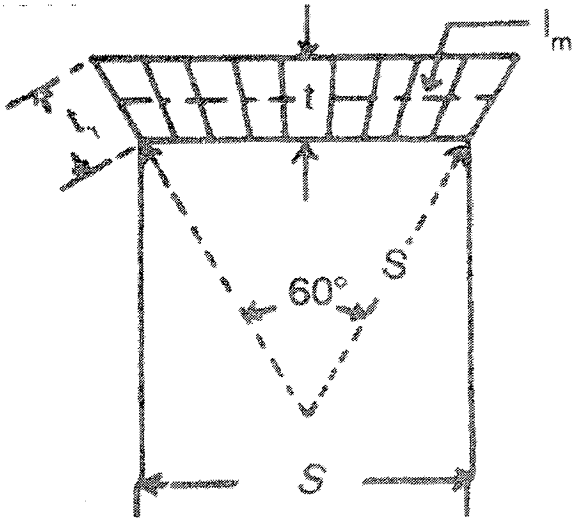
HOLLOW CONC.BLOCK (40X20X10)	3206.66	2311.98	2286.73	2577.31	2999.14	3845.90	3171.19	3720.26	
%OF ALT. EE WITH TRAD BRICK WRK	93.55	91.32	92.33	95.72	94.29	94.91	93.36	96.74	
%EMBODIED ENERGY SAVED PER SQ.M.	**6.45**	**8.68**	**7.67**	**4.28**	**5.71**	**5.09**	**6.64**	**3.26**	**5.97**
HOLLOW CONC.BLOCK (40X20X20)	2708.98	2358.23	2136.82	2491.36	2875.46	3665.73	2942.24	3531.65	
%OF ALT. EE WITH TRAD BRICK WRK	79.03	93.15	86.28	92.53	90.40	90.47	86.62	91.83	
%EMBODIED ENERGY SAVED PER SQ.M.	**20.97**	**6.85**	**13.72**	**7.47**	**9.60**	**9.53**	**13.38**	**8.17**	**11.21**
AERATED CONC BLOCK(40X20X20)	2731.35	2375.43	2151.41	2500.12	2889.08	3681.85	2960.42	3542.77	
%OF ALT. EE WITH TRAD BRICK WRK	79.68	93.83	86.87	92.85	90.83	90.86	87.15	92.12	
%EMBODIED ENERGY SAVED PER SQ.M.	**20.32**	**6.17**	**13.13**	**7.15**	**9.17**	**9.14**	**12.85**	**7.88**	**10.73**
SOLID CONC.BLOCK(30X20X15)	3061.27	2465.53	2215.74	2535.20	2935.04	3765.43	3076.95	3655.98	
%OF ALT. EE WITH TRAD BRICK WRK	89.30	97.39	89.47	94.16	92.27	92.93	90.58	95.07	
%EMBODIED ENERGY SAVED PER SQ.M.	**10.70**	**2.61**	**10.53**	**5.84**	**7.73**	**7.07**	**9.42**	**4.93**	**7.35**

FAL-G BLOCK (30X20X15)	2868.88	2350.77	2120.93	2478.93	2849.33	3658.06	2951.37	3570.63	
%OF ALT. EE WITH TRAD BRICK WRK	83.69	92.85	85.64	92.07	89.58	90.28	86.88	92.85	
%EMBODIED ENERGY SAVED PER SQ.M.	**16.31**	**7.15**	**14.36**	**7.93**	**10.42**	**9.72**	**13.12**	**7.15**	**10.77**

APPENDIX V

Embodied Energy for Flat Brick Arch:

A sample lintel was considered and then embodied energy cost of Flat Brick Arch it was first calculated, then for the same span and sized lintel in RCC embodied energy cost was calculated and compared.



$$t_1 = \frac{t}{\sin 60°} = \frac{t}{.866} = 1.15\,t$$

Mean length of arch $l_m = s + \frac{t_1}{2}$

For practical purposes** t_1 **may be considered as equal to** t **and mean length of arch may be taken as, $l_m = s + \frac{t}{2}$

Quantity of arch masonry work $Q = l_m \times b \times t$

As per Estimating and Costing in Civil Engineering, Theory and Practice,(Twenty-fourth Edition) By B. N. Dutta, page no.56

Consider a Flat Arch (Brick Lintel),With
Span, S= 1.25m
t = 230mm= 0.23 m
b = 230mm= 0.23m
lm = 1.25 + 0.115 = 1.365m
Quantity = 1.365 x 0.23 x 0.23
= 0.0722 Cu.m.

I class Brickwork in Arches with 1:3 Cement Course Sand Mortar , for 10 Cu . M.

Materials	Units	Quantity	Units	Quantity
Brick I class (500 nos per cu.m)	nos	5000	nos	5000
Cement (22 .5) bags	Cu. M.	0.75	kg	1125
Sand Coarse	Cu. M.	2.25	Cu. M.	2.25

As per Estimating and Costing in Civil Engineering, Theory and Practice,(Twenty-fourth Edition) By B. N. Dutta, page no.493

So, for 1 Cu.m.

Materials	Units	Quantity
Brick I class	nos	500
Cement (2.25)bags	Kg.	112.5
Sand Coarse	Cu. M.	0.225

And for 0.0722 Cu.m.

Materials	Units	Quantity	Quantity for 0.0722 Cu.m.
Brick I class	nos	500	36.1
Cement	kg	112.5	8.1225
Sand Coarse	Cu. M.	0.225	0.016245

Embodied Energy Calculations For Brick Flat Arch, will be..

Item No.	Description	Unit	Quantity	EER (MJ/Unit)	EEV (MJ)
1	Brick I class	nos	36	4.5	162
2	Cement	kg	8.1225	6.7	54.42075
3	Sand Coarse	Cu. M.	0.0162	0	0
				Total EEV	216.42075

Transport Energy Rate for Masonry work with traditional Bricks, in cement mortar is 69.12MJ/Cu.m

Transport Energy Cost, **TEV** = 0.0722 x 69.12 = **4.991 MJ**
So,

EEC = EEV + TEV = 216.421 + 4.991 = **221.412 MJ**

Embodied Energy for Concrete Lintel:

RRC lintel proportions (1:2:4) with steel reinforcement for 1 cu.m:

Materials	Units	Quantity
coarse aggregate	Cu.M.	0.900
fine aggregate	Cu. M.	0.450
cement (7 bags)	kg	350.000
reinforcement (mild)	quin	0.140
reinforcement (torsteel)	quin	0.560

As per, Estimating, Costing and Valuation [Professional Practice], by S.C. Rangwala, (Tenth revised and enlarged edition) page no.158

Consider a lintel with,
Clear span = 1.25 m
Minimum bearing = 150 mm =0.15 m
Overall depth= 100mm = 0.10 m
Thickness of wall = 230mm = 0.23m

l = 1.25 + (2 x0.15) = 1.55 m

Q = l x b x t
= 1.55 x 0.10 x 0.23
=0.03565 cu.m.

And 1 quin = 100 kgs

RRC lintel proportions (1:2:4) with steel reinforcement for 0.03565 cu.m:

Materials	Units	Quantity
coarse aggregate	Cu.M.	0.032
fine aggregate	Cu. M.	0.016
cement (7 bags)	kg	12.47
reinforcement (mild)	kg	0.500
reinforcement (torsteel)	kg	2.000

Embodied Energy Values for RCC Lintel:

Item No.	Materials	Units	Quantity	EER (MJ/Unit)	EEV (MJ)
1	coarse aggregate	Cu.M.	0.032	0	0
2	fine aggregate	Cu. M.	0.016	0	0
3	cement (7 bags)	kg	12.47	8.1225	101.287575
4	reinforcement (mild)	kg	0.5	32	16
5	reinforcement (torsteel)	kg	2	32	64
				Total	**181.287575**

Transport Energy Rate for RCC work 90 MJ/Cu.m

Transport Energy Cost, **TEV** = 0.03565 x 90= **3.2085 MJ**
So,

EEC = EEV + TEV = 181.288 + 3.209 = **184.497 MJ**

Comparing Values of Embodied Energy for Brick Flt Arch and RCC Lintel, of clear span 1.25 m, for 1 lintel is as below.

EEC $_{\text{(brick Flat arch)}}$ = **221.412 MJ**

EEC $_{\text{(RCC lintel)}}$ = **184.497 MJ**

The difference = EEC $_{\text{(brick Flat arch)}}$ -- EEC $_{\text{(RCC lintel)}}$
= 36.915 MJ.

So it is not a good option to replace the RCC lintels with brick flat arch.
The RCC lintels are cheap in embodied energy rate.