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Growth of housing sector in India - application of Cost-effective Construction Technologies to reduce Greenhouse Gas Emission

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Abstract

Building construction sector can play a major role in reducing Greenhouse Gas emission through application of technologies aimed at reduction of use of building materials. Energy consumed during production of building materials and components plays a crucial role in creating environmental pollution. India is witnessing high growth in urban and rural housing, which needs more production of building materials. Permanent or semi-permanent type buildings which consume easily available conventional materials like brick, reinforced cement concrete etc. can be made Economic and Eco-friendly by lowering use of energy-consuming building materials through Cost-effective Construction Technologies. Buildings with Cost-effective Construction Technology can be designed within the parameters of the existing Indian Standards. Awareness generation among the users, proper technical and architectural guidance and easy availability of skilled manpower are of utmost importance for promotion of cost-effective technologies in India and to make them as the most acceptable case of sustainable building technologies both in terms of cost and environment.

Keywords: Cost-effective Construction Technology, Economic and Eco-friendly construction, Greenhouse Gas Emission, Housing.

1.0 Introduction

Carbon dioxide, produced from burning of fossil fuels, is the principle Greenhouse Gas and efforts are being made at international level to reduce its emission through adoption of energy efficient technologies.

In the document on “Buildings and Climate Change – Status, Challenges and Opportunities” published by United Nations Environment Programme (UNEP) in 2007 it has been mentioned, “Every building is a complex combination of many processed materials, each of which contributes to the building's total embodied energy. The more complex the material is and the greater the amount of processing that is required, the higher is the amount of energy consumed. High levels of embodied energy imply higher levels of pollution at the end of the production line, as the consumption of energy usually results in emissions. Concrete, aluminium and steel, for instance, are among the materials with the highest embodied energy content and they are also responsible for large quantities of CO_2 emissions.”

The policy makers in India have planned to provide shelter to every shelterless people by providing disaster-resistant housing in urban and rural areas. In all the policy documents on urban and rural housing stress has been given on ‘affordable and durable houses’. Adoption of cost-effective, environment-friendly housing construction practices can serve both the purpose. It may not only reduce the cost of construction but also have the potential to lower the CO_2 emission by way of reducing consumption of building materials.

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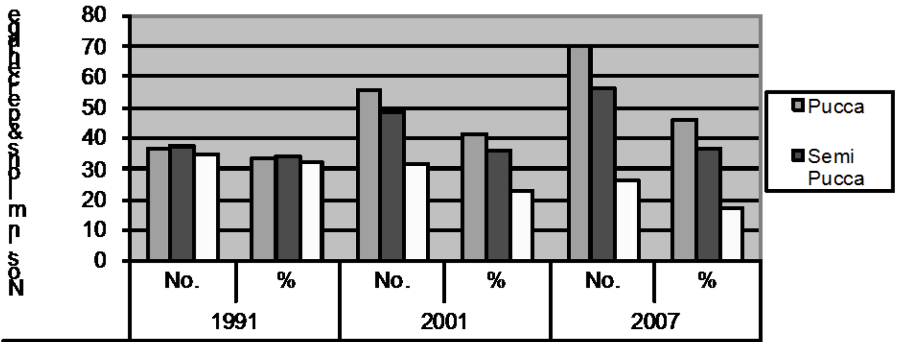
2.0 Trends in Housing Sector in India

In India demand of housing particularly in residential sector is increasing rapidly. As per the Census reports and other reports by different Government Departments, the house types are gradually transforming to Permanent ("Pucca" Houses – in which the walls and roof of which are made of permanent material) and Semi Permanent ("Semi Pucca Houses" – in which either the walls or the roof is made of permanent material) types from Temporary ("Kutcha Houses" - in which both the walls and roof are made of materials that needs to be replaced frequently) in both rural and urban areas as will be evident from the tables 1 and 2.

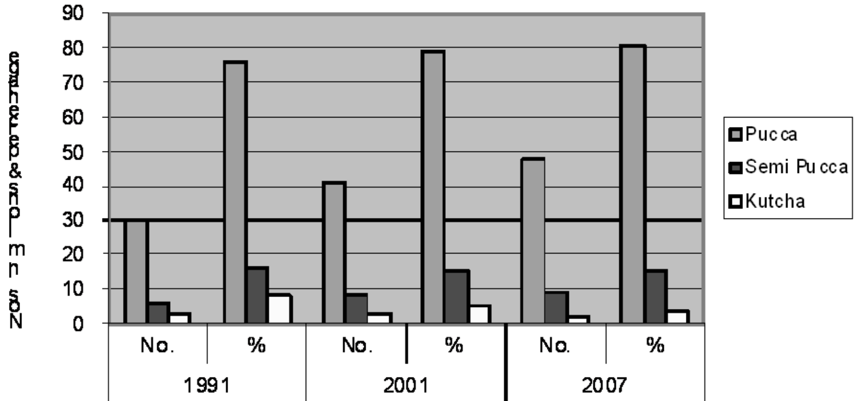
Table - 1: Housing Types in Rural India 1991-2007 (source: Working Group on Rural Housing for formulation of 11th Plan. Ministry of Rural Development, Govt. of India)



	1991 No.	1991 %	2001 No.	2001 %	2007 No.	2007 %
Pucca	36.43	33.53	55.43	41.03	70.14	45.83
Semi Pucca	37.2	34.24	48.32	35.77	56.37	36.84
Kutcha	35.02	32.23	31.34	23.20	26.52	17.33

Year

Table - 2: Housing Types in Urban Area 1991-2007 (source: National Urban Housing and Habitat Policy 2007. Ministry of Urban Housing & Urban Poverty Alleviation, Govt. of India)



	1991 No.	1991 %	2001 No.	2001 %	2007 No.	2007 %
Pucca	29.8	76.02	41.17	79.19	47.49	80.72
Semi Pucca	6.2	15.82	8.08	15.54	9.16	15.57
Kutcha	3.2	8.16	2.74	5.27	2.18	3.71

Year

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In addition different committees have also assessed the housing shortage during the 11th Five Year Plan Period (2007-2012) as follows:

Housing shortage in Urban Areas - 26.53 million units
Housing shortage in Rural Areas - 47.43 million units

If the trend as shown in Tables 1 and 2 continues it is expected that by 2012, about 81% permanent houses in urban areas and about 50% of permanent houses in rural areas will be constructed to fulfil the declaration of “Housing for All” by the Government of India under the National Housing and Habitat Policy 1998. It means by 2012 about 45.2 million (81% of 26.53 million + 50% of 47.43 million) new permanent housing units will come up in different parts of the country.

The trend of conversion from Temporary to Permanent or Semi-Permanent structures is likely to continue in view of economic upliftment of common people and different government schemes on providing durable shelters to people of economically weaker section and lower income group. It is expected that large no. of buildings with durable and easily available conventional materials like brick, sand, cement, steel reinforcement etc. will be constructed in near future and demand of such building materials will shoot up.

It has been stated in the Government Policies that about 99% of the housing shortage pertains to Economically Weaker Sections and Lower Income Group sectors. To provide minimum basic housing need if we consider that the said 45.2 million housing units will have a minimum area of 25 square meters as per the standards of Indira Awaas Yojna scheme, a total of 1130 million square meter of built-up space needs to be constructed by 2012.

As per Indian Standards, the peripheral and main load-bearing masonry walls of any permanent building should be of thickness not less than 230 mm (one brick thickness). Even if we conservatively consider that about 50% of the above 1130 million square meter i.e. 565 million square meter of the built-up space will have masonry wall and R.C.C. roof to ensure durability and meet with the provisions in the Indian Standard Codes, the requirement of building materials like brick, cement, steel reinforcements, sand and crushed stonechips will be huge and have been discussed later in this article.

4.0 Green House Gas (GHG) Emission during Production of Building Materials

The process of construction of buildings consumes huge amount of energy and in turn produces large volume of GHG. Among the top seven sectors contributing to CO_2 emission in India, Construction sectors tops the list with about 17% of the total share, when both direct and indirect emission are considered. This emission comes from production and transportation of building materials like brick, cement, steel, crushed stonechips (coarse aggregate), sand (fine aggregate) etc.

Brick manufacturing using existing brick kilns in India, which use coal as principal fuel, produces CO_2 at the rate of 38 tons per one lakh (0.1 million) of brick. The above figure was calculated by Global Environment Facility (GEF) in their study on brick production in Bangladesh (the neighbouring country of India where the same method of production is followed) Apart from production of CO_2, production of burnt clay bricks also results in serious

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environmental degradation through exploitation of the top soil mainly from arable lands at the rate of about 1000 sq.km. (300mm depth) in a year presently, which is witnessing a growth of 2.5% per year.

Production processes of cement and steel are also energy-intensive and huge amount of CO_2 is emitted during the process. It has been found that about 0.9 tons of CO_2 is produced during manufacturing of 1 ton of **cement**.

Emission from crude **steel** production in sophisticated plants is about 2.75 ton CO_2 per ton of crude steel. We may take it as 3.00 ton per ton of processed steel. The actual figure should be more, but is not available readily.

Sand is another important ingredient of modern building construction and is available from natural sources like riverbeds or queries. But transportation of the same by trucks requires energy. The trucks, in Indian condition, carry about 8.5 cu.m of sand and consume about 0.25 litre of diesel per km of run (mileage 4km/litre). About 2.62 kg of CO_2 is produced per litre of diesel consumption. If it is considered that average transportation distance for sand from the point of collection to point of use is 50 km then the CO_2 emission per cu.m of sand will be 3.85 kg or 0.004 ton.

Crushed aggregate or **stonechips** are produced in queries and transported to the point of use either by railway or road transport. About 108 MJ of energy is used per cu.m. of production of stonechips and transportation of the same at a distance of 50 km. Considering diesel-operated machines at production point and transportation by diesel-run trucks, we can find out that CO_2 emission per cu.m. of use of stonechips is about 8.2 kg or 0.008 ton (Greenhouse Gas Emission by diesel fuel is 0.076 kg per MJ.

Emission of CO_2 from the major building materials required for construction of permanent or ‘pucca’ buildings has been summarized in Table-3:

Table – 3: CO_2 emission due to production and use of building materials

Material	Unit	CO_2 emission (ton)
Brick	1 lakh (0.1 million)	38
Cement	1 ton	0.9
Steel Reinforcement	1 ton	3.0
Sand	1 cu.m.	0.004
Stonechips	1 cu.m.	0.008

5.0 Alternate Technology Options for reduction of Green House Gas (GHG) emission from use of Building Materials

There are ample scopes of reduction of emission of GHG from construction activities by reducing use of building materials as far as practicable using innovative and cost-effective technologies by lowering use of energy-consuming building materials. Since the cost of construction will also be reduced without any change in type of building materials, a strong market force will also be created facilitating use of such technologies. The ‘**Eco**-houses’ (**Eco**nomic and **Eco**-friendly) would be an ideal and effective solution for the construction sector.

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India is a country of diversity and there are various processes and practices involved in building construction in rural areas at different parts of the country. Mud wall, Thatched roof, Bamboo structures with CGI sheet / burnt clay tile roof, stone-masonry walls and stone slab on roof etc. are most common practices till now. However, while permanent or 'pucca' buildings are considered, people opt for masonry wall and R.C.C. roof if cost is permitted. In India general trend in the housing sector is either to build new houses or conversion of old temporary/semi permanent houses into permanent ones.

Cost-effective and eco-friendly technologies, which can provide a sustainable solution to the need of common people of India, do not mean low-cost construction with inferior quality materials or compromising with the safety of the buildings and comfort of the inhabitants. Rather the technologies follow the relevant building codes and can also improve the comfort level of the users if designed properly.

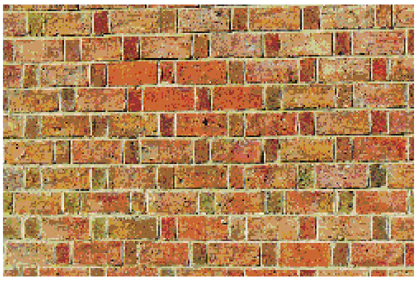
The most popular and time-tested cost-effective and eco-friendly technologies for construction of permanent buildings in India are:

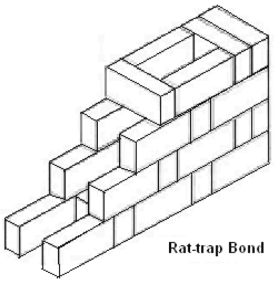
1. Rat-trap bond wall
2. Brick Arches
3. Filler Slab roof

There are some more available technologies like Compressed Earth Block (CEB) wall, Bamboo Reinforced Cement Concrete (BRCC) panels in walls and roof, Ferroconcrete tiles in roof, Composite Brick Panel roof etc., which require specialised manpower and machinery and also involves production of building components separately. But Rat-trap Bond wall, Brick Arches and Filler Slab Roof do not require any specialisation or equipment for production. Rather any ordinary mason with some initial guidance from an experienced person can adopt those technologies as the materials are not alien to him.

5.1 <u>Rat-trap Bond in Wall Construction</u>

Rat-trap bond is laid by placing the bricks on their sides having a cavity of 4"(100mm) with alternate course of stretcher and headers. The headers and stretchers are staggered in subsequent layers to give more strength to the walls (Picture – 1). The main advantage of this bond is economy in use of bricks, giving a wall of one brick thickness with fewer bricks than a solid bond [for design and material consumption comparisons between common masonry wall of one brick thick and rat-trap bond wall please see Annexure-I.





Rat-trap Bond Wall
Picture – 1
(Source: FOSET)

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Structurally Rat-trap bond wall is a form of masonry cavity wall. In the Publication no. 793 of National Academy of Science – National Research Council, Washington D.C. in the year 1960, Mr. Harry C Plummer, Director of Engineering and Technology Dept., Structural Clay Product Institute, while discussing on the history of cavity walls had mentioned, "Demolition projects has discovered that cavity walls were built in the United States 60 or more years ago". From this fact it is evident that cavity walls were in use in United States and also in United Kingdom since early of the 20^{th} century and the U.S. Army has adopted the technology to build their barracks, officers' mess etc. since middle of the 20th century. Performance of those constructions were reported to be very good in terms of maintenance and thermal insulation by Mr. Harry B. Zackirson Sr., Chief of the Engineering Division, Military Construction of U.S. Army. Mr. C.B.Monk Jr. who was with the Theoretical and Applied Mechanics Department of University of Illinois in his paper on 'Review of Recent Research' published in the same journal had observed that the U factor (conductivity) of the 200 mm. thick solid brick wall is 0.61 BTU/hr/sq.ft./^{o}F, whereas that for the 250 thick cavity walls is 0.38. It means the conductivity of cavity walls is substantially reduced by about 37.7%, which ensures more comfort for the inhabitants and reduction in use of air-coolers or room-heaters.

There was an apprehension that cavity walls may absorb moisture through the outer surface and the entrapped moisture in the cavity may ultimately harm the structure. But, normally good quality bricks possess very low moisture movement (0.002% to 0.01%) and use of the material does not call for much precautions. In India and abroad, buildings having exposed brickwork in cement sand mortar with joints properly sealed by pointing are being constructed for more than 100 years without any major complaint about moisture absorption from the sides of the walls. However improper construction, impurity in the mortar, use of inferior quality of bricks, faulty damp-proof course at bottom may result into moisture absorption and that may occur in any type of masonry construction. Proper precaution and care have to be adopted during selection of materials and supervision of the construction work.

The main features of Rat-trap bond wall may be summarised as below:

- Strength is equal to standard 10" (250mm) brick wall, but consumes 20% less bricks.
- The overall saving on cost materials used for construction compared to the traditional 10" wall is about 26%.
- The air medium created in between the brick layers helps in maintaining a good thermal comfort inside the building. This phenomenon is particularly helpful for tropical climate of South Asian and other countries.
- As the construction is done by aligning the bricks from both sides with the plain surfaces facing outwards, plastering is not necessary except in a few places. The finished surface is appealing to the eye from both internally & externally,
- Buildings up to two stories can easily be constructed with this technique (Picture – 2 and 3). Mr. Laurie Baker has pioneered this type of construction and had built such houses more than 40 years ago without having any signs of distress till now.
- In R.C.C. framed structures, the filler walls can at-ease be made of rat-trap bond.
- Due to lesser load on the base of the walls, the width of foundation is also decreased, resulting in a saving of about 8% on use of bricks, cement and sand in foundation and plinth [Please see Annexure-II]

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Two-storied Office Building with Rat-trap bond wall
Picture – 2
(Source: FOSET)

Two-storied Residential Building with Rat-trap bond wall under construction
Picture – 3
(Source: FOSET)

5.2 Brick Arches

The traditional R.C.C. lintels, which involve use of cement, stonechips, sand and steel reinforcements, can be replaced by brick arches for small spans and save construction cost upto 30 to 40% (Picture – 4). Arches of different shapes combined with brick corbelling (Picture – 5) produce pleasing architectural appearance to the external brick masonry wall surfaces.

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Brick Arch
Picture – 4
(Source: FOSET)

Brick Corbelling
Picture – 5
(Source: FOSET)

5.3 Filler Slab in Roof

This is normal R.C.C. slab where bottom half (tension) concrete portions are replaced by filler materials such as bricks, tiles, cellular concrete blocks, etc., These filler materials are so placed as not to compromise with structural strength and also becomes lighter than normal slabs. As use of steel, cement and other aggregates are less, the filler slab becomes less costly. These are safe in terms of load bearing capacity [for design and material consumption comparisons between ordinary R.C.C. slab and Filler Slab, please see Annexure-III].

The main features of Filler Slab are:

- Consumes less concrete and steel due to the reduced weight of the slab by the introduction of a less-heavy, low-cost filler material like two layers of burnt clay tiles. Slab thickness minimum 110 mm. Reinforcements are placed in between the filler materials (Picture – 6).
- Enhances the thermal comfort inside the building due to heat resistant qualities of the filler materials and the gap between two burnt clay tiles.
- Make saving on cost of this slab compared to the traditional slab by about 23%.
- Reduces use of concrete and saves cement, sand & stonechips by about 49%.
- Reduces use of steel by about 13%

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- Plastering of the ceiling is optional and depends upon the taste of the owner/user. It produces an aesthetically good view if plastering is done only on concrete surface of the ceiling (Picture – 7)

Filler Slab Roof under construction
Picture – 6
(Source: FOSET)

A Railway Ticket Counter with Filler Slab Roof
Picture – 7
(Source: FOSET)

6.0 Use of Cost Effective Technologies in India – Reduction in Cost of Construction and Greenhouse Gas Emission

As already mentioned that there are other available improved alternate technologies like Bamboo Panels, Bamboo-reinforced Concrete, Masonry Stub Foundation etc. and all of them can contribute significantly, if not more, in reduction of cost of construction and CO_2 emission. For academic purpose this paper restrict the discussion within Rat-trap Bond Wall and Filler Slabs only, for which neither special skill is necessary for the workmen nor is any new material required.

By adopting the techniques mentioned above a straightaway reduction of 17% can be achieved in cost of construction of the basic structure without compromising with the safety, durability and aesthetic aspect of the buildings (See Picture 2 & 4). In 2009 in Eastern part of India the cost of basic structural work in foundation, superstructure and roof slab for a single

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storied building with ordinary masonry wall and R.C.C. slab comes to be approximately Rs.6137/- per square meter (Rs.570/- per sq.ft.). It may vary by 5% to 10% depending upon the location and availability of materials. A 17% saving in cost means reduction by Rs.1042/- per square metre (Rs.97/- per sq.ft.) and for a 25 sq.m. single-storied residential house, the saving will be to the tune of Rs.26000/-. (Table – 4)

Table - 4 : Cost analysis for basic structural work in foundation, superstructure and roof for a single-storied residential building of 25 sq.m. built-up area

Material	Rate (as on May 2009)	Conventional Technology		Cost-effective technology	
		Quantity (Table. 10)	Cost (Rs.)	Quantity (Table. 10)	Cost (Rs.)
Brick	Rs.5/- per pc.	13667 Nos.	68335	11193 Nos.	55965
Cement	Rs.275/- per bag	89.82 bags	24701	62.07 bags	17069
Sand	Rs.600/- per cu.m.	13.76 cu.m.	8256	9.59 cu.m.	5754
Stonechips	Rs.1400/- per cu.m.	2.12 cu.m.	2968	1.08 cu.m.	1512
Steel	Rs.38/- per kg.	82.8 kg	3146	72 kg	2736
Tiles	Rs.10/- per pc.			480 nos.	4800
Total Material (70% of total cost)			107406		87836
Labour Cost (30% of total cost)			46031		37644
Extra Labour cost 5% for new technology					1882
TOTAL			153437		127363
Difference					26074
Cost per sq.m.			6137		5095
Cost per square feet			570.35		473.50
Saving					17%

The figures in Table-5, when related to the Table–3 show reduction in CO_2 emission for construction of basic foundation and superstructure of a 25 square meter single-storied residential building.

Table - 5 : CO_2 emission from building materials used for basic structural work in foundation, superstructure and roof for a single-storied residential building of 25 sq.m. built-up area

Material	CO_2 emission rate*	Conventional Technology		Cost-effective Technology		Reduction in CO_2 emission (ton)
		Quantity$	CO_2 emission (ton)	Quantity$	CO_2 emission (ton)	
Brick	38 ton per 1 lakh	13667 nos.	5.19	11193 nos.	4.25	0.94
Cement	0.9 ton per ton	4.491 ton	4.04	3.1035 ton	2.79	1.25
Sand	0.004 cu.m per cu.m	13.76 cu.m	0.06	9.59 cu.m	0.04	0.02
Stonechips	0.008 cu.m per cu.m	2.12 cu.m	0.02	1.08 cu.m	0.01	0.01
Steel	3 ton per ton	0.0828 ton	0.25	0.072 ton	0.22	0.03
Tiles	25 ton per 1 lakh£	0	0.00	480 nos.	0.12	- 0.12
Total			9.56		7.43	2.13
CO_2 emission per sq.m.			0.3824		0.2972	0.0852
* (Table-3)						
$ (Table-9)						
£ Data not available. Interpolated from volume of brick						

We earlier considered that about 50% of 1130 million square meters i.e. 565 million square meter of built-up area that has to be constructed in India to meet the housing shortage would be of permanent nature. In most of the cases as these houses of the economically weaker section of the society will be constructed under Government schemes and grant-in-aid assistance, From the figures in Table-5, we could find out that there would be a huge saving of about 588 billion Indian Rupees if cost-effective construction technologies are used [565 x 10^6 square meter x (Rs.6137-Rs.5035) per square meter].

Similarly from Table-5, we could derive that in terms of emission of GHG, there would be a reduction of about 48.14 million tons of CO_2 emission [565 x 10^6 square meter x (0.3824 – 0.2972) ton CO_2 per sq.m.]

As 17% saving is a sizeable amount also for people from lower and middle income groups, the '**Eco-houses'** will be a natural choice for people of India and it will, in turn, be beneficial to the environment also.

7.0 Conclusion

There is a popular belief among common people and even among some portion of the technical persons that Cost-effective Technology implies low cost materials, poor workmanship and unstable structures. But the calculations and techniques provided in this paper clearly indicate that the perception is totally wrong and it will be eventually suitable for both people and environment for the unique 'Eco' approach. Now it is the task of scientists, engineers, architects and policy makers of our country to popularise these technologies so that India can significantly contribute to reduction in CO_2 emission from its vast, rapidly growing housing sector and can also reduce the burden on the state exchequer and the common people.

Till now most of the Government bodies, P.W.D.s and Municipalities of India are reluctant to accept this technology and give permission to people to build their house with Cost-effective Technologies.

The following steps may be taken to ensure proper and extensive use of the technologies in the light of sustainable development and protection of environment:

- Sensitisation of People: Extensive awareness campaigns and demonstrations among general public and also among the engineers and architects have to be made to make them familiar with these technologies. The market force of cost reduction will definitely play a major role in acceptance of Cost-effective Technologies if Governments / Municipal Bodies acknowledge these technologies and direct their concerned departments to adopt them. Promotion of cost effective technologies through institutes like the HUDCO sponsored Building Centres has to be rejuvenated.
- Manpower Development: Shortage of skilled manpower can play a crucial role in implementing any sort of new technologies in construction sector. To promote cost-effective technologies skill upgradation programmes have to be organised for masons. Not only in workers segment, these technologies should also be a part of syllabus for the students of civil engineering and architecture at graduation and diploma level.

- Material Development: The Central and State Governments should encourage setting-up of centres at Regional, Rural and District levels for production of cost effective building materials at the local level. The Building Centres set-up by HUDCO for this purpose should be further strengthened also. Appropriate field-level research and Land to Lab methodology should be adopted by leading R&D Institutes and Universities to derive substitutes to common energy-intensive materials and technologies. Reuse of harmless industrial wastes for this should also be given priority.
- Technical Guidance: Proper guidance to general people through design, estimation, and supervision has to be provided by setting up of 'Housing Guidance Centres' in line with the concept mooted by the HUDCO Building Centres.

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ANNEXURE – I

Comparison between Common Masonry Wall and Rat-trap Bond wall

The Cross-section of a two storied residential building with masonry load bearing walls and R.C. slab in floor and roof is shown in figure-1.

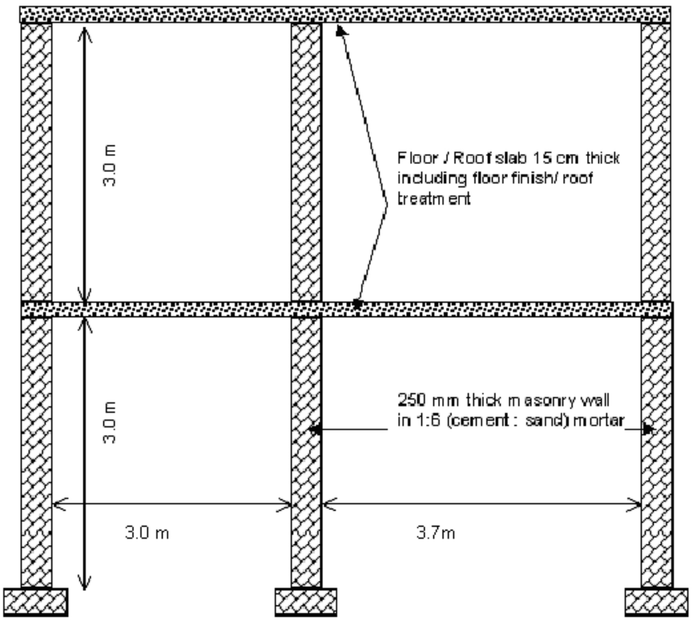

Fig.1 : Cross-section of a two-storied Residential Building (Not to scale)

Design calculation of the most critical wall (central wall) has been illustrated below:

Design of Conventional Masonry Wall

Let us consider wall thickness of 250mm or 0.25m (one brick thick)
Consider a central wall width of 1.0m
Loads:
a) Self weight of wall = 2 x (1.0 x 0.25 x 3.0) x 1900 kg/m^3 = 2850.00 kg
b) Dead load of floor and roof slabs =
2 x {0.15 x 1.0 x (3/2 + 3.7/2 + 0.25)} x 2400 kg/m^3 = 2592.00 kg
c) Live load of floor = 1.0 x (3.0 + 3.7)/2 x 200 kg/m^2 = 670.00 kg
d) Live load of roof = 1.0 x (3.0 + 3.7)/2 x 150 kg/m^2 = 502.50 kg
Total Load = a) + b) + c) + d) = 6614.50 kg
Compressive stress developed at the base of the wall = 6614.50/(25 x 100) kg/cm^2
= 2.65 kg/cm^2 = 0.265 N/mm^2
Assuming a crushing strength of 5.0 N/mm^2 and the wall is built using M2 type (1:6) cement mortar as per IS 1905-1987,
Basic compressive stress in masonry = σ_B = 0.44 N/mm^2 [Table-8, I.S. 1905 – 1987]
Clear wall height = 3.0 m
Effective wall height = 0.75 x 3.0 = 2.25 m [Table-4, I.S. 1905 – 1987]
Slenderness Ratio = 2.25m / 0.25 m = 9

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Stress reduction factor for slenderness ratio 9 and eccentricity 1/12 (assumed) = 0.905

[Table-9, I.S. 1905 – 1987]

The permissible compressive stress may be increased by 25% as per clause 5.4.1.4 (a) of I.S.1905 - 1987

Permissive compressive stress = $\sigma_B \times k_s \times k_p$ = 0.44 x 0.905 x 1 x 1.25

= 0.497 N/mm^2 > 0.265 N/mm^2 O.K.

Design of Rat-trap Bond Wall (to be designed as cavity wall)

Let us consider wall thickness of 250mm or 0.25m (one brick thick) with cavities inside and intermediate buttresses as shown in Figure -2.

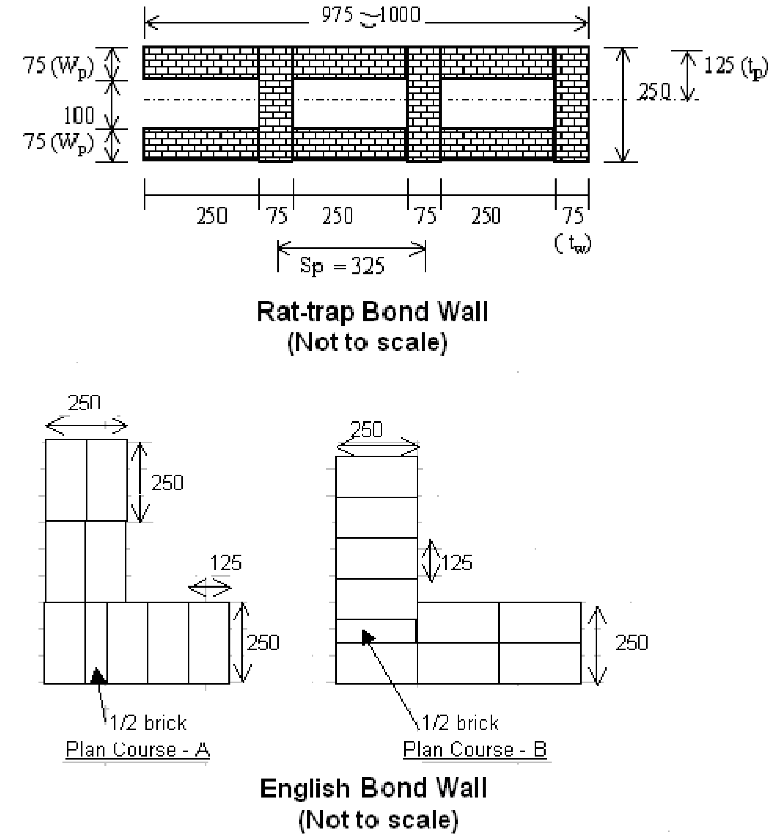

Fig.2: Cross-section of Rat-trap Bond Wall and English Bond Wall

Consider a central wall width of 1.0m

Loads:

a) Self weight of wall = 2 x {(1.0 x 0.25) - (0.1 x 0.25 x 3)} x 3.0 x 1900 kg/m^3 = 1995.00 kg

[3 cavities of size 0.1m x 0.25m in 1 m length to be deducted]

b) Dead load of floor and roof slabs =

2 x {0.15 x 1.0 x (3/2 + 3.7/2 + 0.25)} x 2400 kg/m^3 = 2592.00 kg

c) Live load of floor = 1.0 x (3.0 + 3.7)/2 x 200 kg/m^2 = 670.00 kg

d) Live load of roof = 1.0 x (3.0 + 3.7)/2 x 150 kg/m^2 = 502.50 kg

Total Load = a) + b) + c) + d) = 5759.50 kg

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Compressive stress developed at the base of the wall

= 5759.50/{(25 x 100 – (3 x 10 x 25)} kg/cm^2

= 3.29 kg/cm^2 = 0.329 N/mm^2

Assuming a crushing strength of 5.0 N/mm^2 and the wall is built using M2 type (1:6) cement mortar as per IS 1905-1987,

Basic compressive stress in masonry = σ_B = 0.44 N/mm^2 [Table-8, I.S. 1905 – 1987]

Clear wall height = 3.0 m

Effective wall height = 0.75 x 3.0 = 2.25 m [Table-4, I.S. 1905 – 1987]

Effective thickness = 2/3 x (0.75+0.75) x 2 (stiffness coefficient) = 0.2 m

[Clause 4.5.4, I.S. 1905 –1987]

Slenderness Ratio = 2.25m / 0.2 m = 11.25

Stress reduction factor for slenderness ratio 11.25 and eccentricity 1/12 (assumed) = 0.83

[Table-9, I.S. 1905 – 1987]

The permissible compressive stress may be increased by 25% as per clause 5.4.1.4 (a) of I.S.1905 - 1987

Permissive compressive stress = σ_B x k_s x k_p = 0.44 x 0.83 x 1 x 1.25

= 0.456 N/mm^2 > 0.329 N/mm^2 O.K.

Table-6 indicates the material consumption of both type of walls and the savings in the later.

Table - 6 : Material Consumption in Conventional Masonry Wall and Rat-trap Bond Wall
(For 1 cu.m. of brickwork)

Sl.	Item	Conventional Wall (with 1:4 Cement:Sand mortar)	Rat-trap Bond (with 1:4 Cement:Sand mortar)	Savings
1	Brick	389	280	28%
2	Cement	2.39 bags (119.5 kg.)	1.5 bags (75 kg.)	37%
3	Sand	12 cu.ft. (0.34 cu.m.)	7.2 cu. ft. (0.20 cu.m.)	40%

ANNEXURE – II

Comparison between Foundation of Common Masonry wall and Rat-trap Bond wall

Considering:

Bearing Capacity of Soil (P) = 6000 kg/cm^2

Unit weight of soil = 1600 kg/cu.m.

Angle of Repose Φ = 33^o

$\{(1-\sin\Phi)/(1+\sin\Phi)\}^2$ = 0.087

Minimum depth of foundation (h) based on Rankine's formula applicable to loose soils

= P/w x $\{(1-\sin\Phi)/(1+\sin\Phi)\}^2$ = 0.326 m

Let us provide depth of foundation as 0.6 m or 600 mm. below ground level.

Common Masonry Wall

Load at base of wall (i.e. top of foundation) = 6614.5 kg (from Annexure I)

Add 15% for weight of foundation = 992.2 kg

Total weight at base of foundation = 7606.7 kg say 7610 kg

Width of foundation = 7610 /6000 m = 1.27 m say 1.3 m

A typical cross section of the foundation and plinth is shown in Figure-4.

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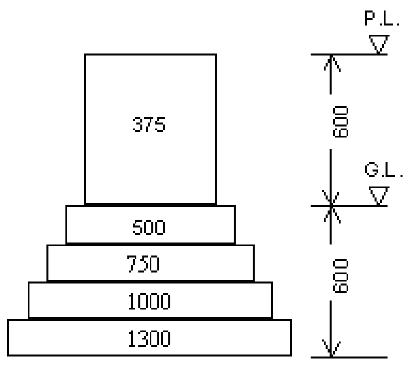

Fig.4: Foundation and Plinth for ordinary masonry wall (Not to scale)

Bricks required in per 1m length of foundation and plinth
= 0.7575 cu.m. x 389 = 295 nos.

For Cement Mortar (1:6) per cu.m. of brickwork
Cement required @ 79 kg (1.58 bags) per cu.m. = 0.7875 cu.m. x 79 = 60 kg
Sand required @ 0.34 cu.m/ cu.m = 0.7875 cu.m. x 0.34 = 0.26 cu.m.

Rat-trap Bond Wall

Load at base of wall (i.e. top of foundation) = 5759.5 kg (from Annexure I)
Add 15% for weight of foundation = 863.9 kg
Total weight at base of foundation = 6623.4 kg say 6630 kg
Width of foundation = 6630 /6000 m = 1.105 m say 1.2 m
A typical cross section of the foundation and plinth is shown in Figure-5.

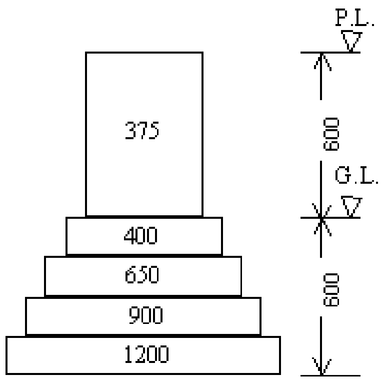

Fig.5: Foundation and Plinth for Rat-trap Bond Wall (Not to Scale)

Bricks required in per 1m length of foundation and plinth
= 0.6975 cu.m. x 389 = 271 nos.

For Cement Mortar (1:6) per cu.m. of brickwork
Cement required @ 79 kg (1.58 bags) per cu.m. = 0.6975 cu.m. x 79 = 55 kg
Sand required @ 0.34 cu.m/ cu.m = 0.6975 cu.m. x 0.34 = 0.24 cu.m.

Table-7 indicates material consumption in foundation and plinths for two types of walls and savings in the later.

Table - 7 : Material Consumption in Foundation and Plinth for Conventional Masonry Wall and Rat-trap Bond Wall (For 1 m length of wall)				
Sl.	Item	Conventional Wall (with 1:4 Cement:Sand mortar)	Rat-trap Bond (with 1:4 Cement:Sand mortar)	Savings
1	Brick	295	271	8%
2	Cement	1.2 bags (60 kg.)	1.1 bags (55 kg.)	8.33%
3	Sand	9.2 cu.ft. (0.26 cu.m.)	8.5 cu. ft. (0.24 cu.m.)	7.7%

ANNEXURE – III

Comparison between Ordinary R.C.C. Slab and Filler Slab

Let us compare a filler slab with an ordinary R.C.C. slab having same size of 3.0m x 3.7m with two adjacent edges discontinuous and the corners are prevented from lifting.

Ordinary R.C.C. Slab

Slab size: 3.0 m x 3.7 m
As per I.S. 456 – 2000, depth of slab = 3000 / 35 = 85.70 mm [Clause 24.1, I.S.456 - 2000]
M200 concrete (σ_{cbc} = 70 kg/cm^2) and high yield strength deformed bar (conforming to Fe 415) having permissible tensile stress (σ_{st}= 2300 kg/cm^2) are used
Let us use 110 mm overall depth and 8 mm diameter tor-steel bars as reinforcement
Effective depth = 110 – 15 – 4 = 91 mm
L_y / L_x = 3.7 / 3.0 = 1.23 So it is a slab spanning in two directions.
$M_x = 0.0615 \times W \times L_x^2$ [Table 26, I.S.456 – 2000]
$M_y = 0.0462 \times W \times L_y^2$

Load Calculation:
Dead Load = 0.11 x 2500 kg/m^2 = 275 kg/m^2
Floor finish (40 mm thick) and Ceiling finish (6 mm thick) = 0.046 x 2000 = 92 kg/m^2
Live Load as per I.S. 875 = 200 kg/m^2
Total Load = 567 kg/m^2
$M_x = 0.0615 \times W \times L_x^2 = 0.0615 \times 567 \times 3.0^2$ Kg.m. = 314 Kg.m. = 3.14x10^6 N.mm
$M_y = 0.0462 \times W \times L_y^2 = 0.0462 \times 567 \times 3.7^2$ Kg.m. = 359 Kg.m. = 3.59x10^6 N.mm
d = √{(3.59x10^6)/0.91x1000)} = 62.80 mm < 91 mm O.K.
Area of steel in X direction = $M_x / (\sigma_{st} \times j \times d)$ = 314 x 100 / (2300 x 0.9 x 9.1) = 1.667 cm^2
Area of steel in Y direction = $M_y / (\sigma_{st} \times j \times d)$ = 359 x 100 / (2300 x 0.9 x 8.3) = 2.089 cm^2
Spacing of 8 mm dia tor-steel bars in X direction = 0.503 x 1000 / 1.667 = 30.17 cm
Spacing of 8 mm dia tor-steel bars in Y direction = 0.503 x 1000 / 2.089 = 24.08 cm
Let us provide 8 mm dia tor-steel reinforcement @ 300 mm along the long direction and 8 mm dia tor-steel reinforcement @ 240 mm along the short direction (maximum permissible spacing as per I.S.456-2000 is 300mm)

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R.C.C. Filler Slab

Slab size: 3.0 m x 3.7 m

As per I.S. 456 – 2000, depth of slab = 3000 / 35 = 85.70 mm [Clause 24.1, I.S.456 - 2000]

M200 concrete (σ_{cbc} = 70 kg/cm^2) and high yield strength deformed bar (conforming to Fe 415) having permissible tensile stress (σ_{st}= 2300 kg/cm^2) are used

Let us use 110 mm overall depth and 8 mm diameter tor-steel bars as reinforcement

Effective depth = 110 – 15 – 4 = 91 mm

So depth of neutral axis = 0.29 x 91 = 26.39 mm

Since the resistance of concrete in tension has to be neglected, concrete area below the neutral axis is not considered in finding out total tension. So this area may be replaced with non-concrete low-cost filler materials like earthen or burnt clay tiles.

Hence the depth of 83.61 mm (110 mm – 26.39 mm) between two reinforcement bars (keeping adequate cover) is filled up with 2 nos. burnt clay tiles of size 250 mm x 250 mm x 25 mm thick placed one on another with 30 mm thick spacer blocks and sides blocked with cement or clay mortar to maintain the in-between air gap as shown in Figure-3.

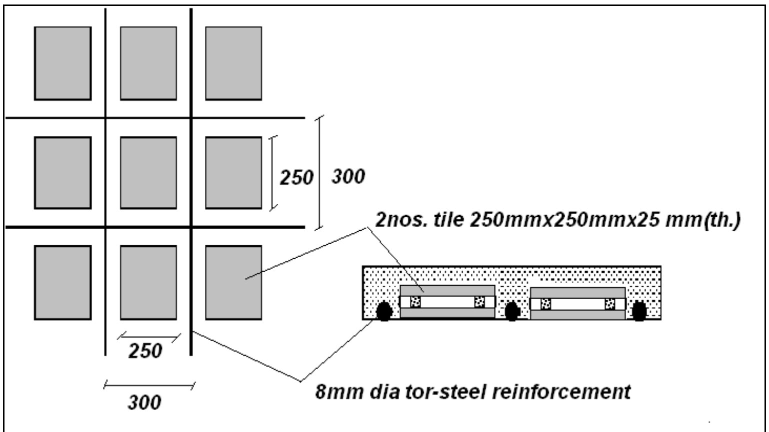

Fig.3 : Plan and section of Filler Slab (Not to Scale)

L_y / L_x = 3.7 / 3.0 = 1.23 So it is a slab spanning in two directions.

M_x = 0.0615 x W x L_x^2 [Table 26, I.S.456 – 2000]

M_y = 0.0462 x W x L_y^2

Load Calculation:

Two nos. burnt clay tiles of 250 mm x 250 mm x 25 mm(thick) weighs 2.5 kg

Weight of equivalent area of R.C.C. = 12.5 kg (.25 x .25 x .08 x 2500)

In the grid of 300 mm x 300 mm of the 110 mm thick filler slab (having 2 nos. filler tiles), weight of slab = (0.3 x 0.3 x 0.11 x 2500) – 12.5 + 2.5 = 14.75 kg i.e. 1490 kg/ m^3

Dead Load =	0.11 x 1490 kg/m^2	= 164 kg/m^2
Floor finish (40 mm thick) and Ceiling finish (6 mm thick) = 0.046 x 2000		= 92 kg/m^2
Live Load as per I.S. 875		= 200 kg/m^2
Total Load		= 456 kg/m^2

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$M_x = 0.0615 \times W \times L_x^2 = 0.0615 \times 456 \times 3.0^2$ Kg.m. = 253 Kg.m. = 2.53 $\times 10^6$ N.mm
$M_y = 0.0462 \times W \times L_y^2 = 0.0462 \times 456 \times 3.7^2$ Kg.m. = 288 Kg.m. = 2.88$\times 10^6$ N.mm

Using M200 concrete (σ_{cbc}= 70 kg/cm^2) and high yield strength deformed bar (conforming to Fe 415) having permissible tensile stress (σ_{st}= 2300 kg/cm^2)
d = $\sqrt{(2.89\times10^6)/0.91\times1000)}$ = 56.35 mm < 91 mm O.K.

Area of steel in X direction = M_x / (σ_{st} x j x d) = 253 x 100 / (2300 x 0.9 x 9.1) = 1.343 cm^2
Area of steel in Y direction = M_y / (σ_{st} x j x d) = 288 x 100 / (2300 x 0.9 x 8.3) = 1.676 cm^2
Spacing of 8 mm dia tor-steel bars in X direction = 0.503 x 1000 / 1.343 = 37.45 cm
Spacing of 8 mm dia tor-steel bars in Y direction = 0.503 x 1000 / 1.676 = 30.01 cm
Let us provide 8 mm dia tor-steel reinforcement @ 300 mm both ways (maximum permissible spacing as per I.S.456-2000 is 300mm)

Table - 8 compare the material consumption by two types of slab and the savings in the later.

(In many areas of India, where burnt clay tiles of size 275mm x 425mm are widely available, the reinforcements are placed at 375mm c/c and 525mm c/c, which does not conforms to clause 26.3.3 of IS456-2000 on maximum distance between the bars in tension. But the method is time-tested and based on field experience. This can result upto 20% saving in steel consumption if found safe and sound after recommended tests)

Table - 8 : Material Consumption in Ordinary R.C.C. Slab and Filler Slab
(for a 3.0m x 3.7m x 110 mm thick slab)

Sl.	Material	Ordinary Slab	Filler Slab	Savings in filler slab
1.	Concrete (M20 grade of standard mix 1:1.5:3)	3.0 x 3.7 x .11 = 1.221 cu.m.	1.221 – (120 x 0.25 x 0.25 x 0.08) (120 pair of tiles of size 250 mm x 250 mm x 25 mm with 30 mm thick spacer blocks) = 0.621 cu.m.	
1a)	Cement @ 0.286 cu.m./cu.m. or 8.24 bags/cu.m.	0.35 cu.m. or 10 bags or 500 kg	0.178 cu.m. or 5.12 bags or 256 kg	49%
1b)	Sand @ 0.43 cu.m./cu.m.	0.53 cu.m.	0.27 cu.m.	49%
1c)	Stonechips @ 0.86 cu.m./cu.m.	1.06 cu.m.	0.54 cu.m.	49%
2,	Burnt clay tiles of size 250mmx250mmx25mm	Nil	240 nos	
3.	Steel	41.4 kg	36 kg	13%

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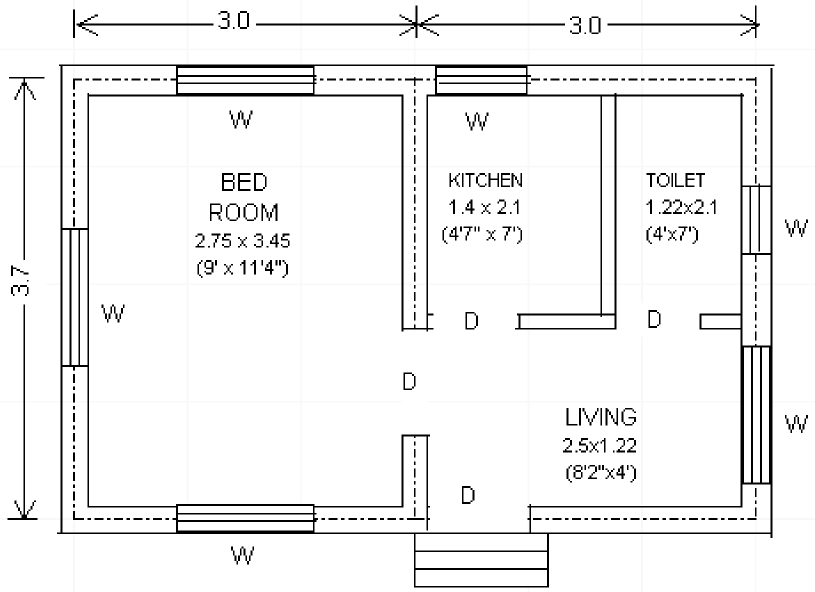
ANNEXURE – IV

Houses for Economically Weaker Section – Comparison of requirement of Building Materials for ordinary house and house built with cost-effective construction technology

Figure 6 shows a typical plan of a house of area 25 sq.m. (approx) for Economically Weaker Section.



Height of Rooms: 3.05 m (10 feet)
Built-up area: 24.69 sq.m. (266 sq.ft.) Main walls are 250 mm. thick

Fig. 6: Typical Plan of a House for Economically Weaker Section (Not to scale)

Deductions for doors, windows and addition for 125 mm thick partition walls and stair have not been considered in the estimate, as they will almost compensate each other. Lintels and chajjas have not been considered, as those will be same for both type of construction.

Total length of 250 mm thick wall (along Centre Line) = 23.1 m
Volume of brickwork in Superstructure = 23.1 x 3.05 x 0.25 = 17.614 cu.m.
Consumption of building materials like Brick, Cement, Sand, Stonechips and Steel Reinforcement (without taking into account for lintels and chajjas) in basic structure of the building i.e. foundation, superstructure and roof have been calculated in Table – 9.

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Table - 9: Consumption of basic building materials in foundation, superstructure and roof of a 25 sq.m. residential house

	Material	Common Masonry wall and ordinary R.C.C. Slab	Rat-trap Bond masonry wall and R.C.C. Filler Slab
Foundation and Plinth with masonry brickwork in 1:6 mortar (Refer Annexure – II)	Brick	6815 Nos.	6261 Nos.
	Cement	1386 kg	1270.5 kg
	Sand	6.70 cu.m.	5.55 cu.m.
Superstructure with masonry brickwork in 1:4 mortar (Refer Annexure – I)	Brick	6852	4932
	Cement	2105 kg	1321 kg
	Sand	6.0 cu.m.	3.5 cu.m.
Roof – 110 mm thick R.C.C. Roof (Refer Annexure – III)	Cement	1000 kg.	512 kg.
	Sand	1.06 cu.m.	0.54 cu.m.
	Stonechips	2.12 cu.m.	1.08 cu.m.
	Steel	82.8 kg.	72 kg.
	Tiles	NIL	480 nos.
SUMMARY	**Brick**	13667 Nos.	11193 Nos.
	Cement	4491 kg.	3103.5 kg.
	Sand	13.76 cu.m.	9.59 cu.m.
	Stonechips	2.12 cu.m.	1.08 cu.m.
	Steel	82.8 kg.	72 kg.
	Tiles	0 Nos.	480 Nos.