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Evaluation of Appropriateness of Rat-trap Bond Wall and Filler Slab Roof in housing sector in India

Nilanjan Sengupta
School of Ecology, Infrastructure and Human Settlement Management, Bengal Engineering and Science University, Shibpur, India-711103

Abstract

As housing demand in India is continuously growing, different government schemes are being implemented to cater to the need of mass housing for the poor and lower income group people. Use of Cost-effective Eco-friendly Construction Technologies (CECT) in housing sector in India has the potential to be the most appropriate in terms of economy and acceptability. The reduced cost of building, enhancement of comfort level and non-compromise on safety would decide choice of CECT, which will also act as a market force and demand for such technologies is expected to grow-up. This paper explored the acceptability and adaptability potential of different CECTs with special emphasis on Rat-trap Bond Wall and Filler Slab Roof, through literature study and technical calculations and tried to evaluate the appropriateness of those.

Keywords: Indian housing scenario, Cost-effective Eco-friendly Construction Technology, Rat-trap Bond Wall, Filler Slab, Safety, Comfort, Acceptability, Adaptability https://doi.org/10.36375/prepare_u.a16

1.0 Introduction – Housing Shortage in India

In order to meet growing demand of housing, Government of India has planned to provide shelter for every shelter-less people and also to build disaster-resistant housing in rural and urban areas. Different government schemes of mass housing are being implemented to cater to the need of housing. In India the buildings constructed under mass housing schemes are all low-energy buildings.

As per the Census reports of India 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. "Report of Technical Group on Urban Housing Shortage (TG-12)(2012-2017)" prepared by the National Building Organisation of India (Ministry of Housing & Poverty Alleviation 2012)[1] is the latest document available in this subject which have thoroughly investigated through primary survey, the rural to urban shift of labour resulting in shortage of dwelling houses in urban areas of India – particularly in the Lower Income Group (LIG) and Economically Weaker Section (EWS) segment. Draft prepared by the Working Group on Rural Housing, for the 12th Five Year Plan (Ministry of Rural Development, Govt. of India 2012)[2] has provided a detailed study and analysis on housing shortage in rural areas. Need of introduction and use of eco-friendly and cost-effective housing technologies were included in the document under clause 5.3.1(iii).

Indira Awaas Yojana – one of the flagship rural housing schemes, was launched in 1985-86 and guidelines were revised time-to-time with the latest issued in 2012 (Ministry of Rural Development, Govt. of India 2012)[3]. In its introduction in Page-1, the objective of the scheme was stated as "upgradation of unserviceable kutcha houses". In the same chapter emphasis was given on "use of cost affective, disaster resistant and environment friendly technologies in rural housing".

The following figures may be taken into consideration to assess housing shortage in India during its 12th Five Year Plan (2012-2017):

(i) Housing shortage in Urban Areas as assessed by Technical Group on Urban Housing Shortage of National Building Organisation - 18.78 million units of which 95.62% i.e. 17.96 millions belongs to Economically Weaker section and Low Income Group families

(ii) Housing shortage in Rural Areas as assessed by Working Group on Rural Housing, Ministry of Rural Development, Govt. of India for the 12th Five Year Plan - 48.81 million units of which 90% i.e. 43.93 million belongs to Below Poverty Level families

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. About 61.89 million units of residential houses for Economically Weaker Section and Low Income Group families will be constructed by 2017 to fulfill the declaration of “Housing for All” by the Government of India under the National Housing and Habitat Policy 1998.

If the said 61.89 million housing units have a minimum area of 25 square meters as per the standards of Indira Awaas Yojna scheme, a total of 1547.25 million square meter of built-up space is likely to be constructed by 2017. 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). Considering the growing concern about safety, quality and comfort, we may consider that that buildings will be built with masonry wall and R.C.C. roof to ensure durability, fulfill peoples’ perception and meet with the provisions in the Indian Standard Codes.

Use of Cost-effective Eco-friendly Construction Technologies (CECT) to construct safe, durable, comfortable houses can bring down the cost of construction by reducing use of energy-consuming building materials. The cost of building which is expected to be reduced with adoption of CECT may also act as a market force and consequently demand for cost-effective technologies would grow-up.

The scope of the study is to examine, through literature review and computation, an appropriate CECT that will be acceptable to common people of India.

2.0 Assessing the Guiding Criteria for acceptability of construction technologies and building materials.

There are certain factors which decide the choice of building construction technologies for common people. Among those, Safety, cost of construction, maintenance expenses, availability of materials and artisans are the primary factors and comfort, aesthetics and societal status are secondary factors

Reddy (2004)[4] advocated some guiding principles for developing sustainable alternative building technologies. Those are (a) energy conservation, (b) concern for environment, (c) minimisation of transport and maximisation of locally available materials, (d) decentralisation of production and maximum use of local skills. Singh et al. (2007)[5] stated that there is an inseparable relationship between energy and architecture and indoor comfort. They have opined that though energy conservation is a necessity, but it should not be achieved at the cost of human thermal comfort. Gut et al. (1993)[6] have prescribed the following general guidelines for designing of climate-responsive building: (1) Minimisation of heat gains during daytime and maximisation of heat loss at night in hot seasons, and reverse in cold seasons, (2) Minimisation internal heat gain in the hot season, (3) Optimisation of building structure, (4) Control of solar radiation. They mentioned that walls and roof are the two important components of the building envelope that affect the thermal comfort of a building and roof has the strongest thermal impact of heat loss and gain as it receives most of the solar radiation. On choice of building materials and technologies they have cautioned against use of untested materials which may behave adversely under testing conditions like earthquake, flood, cyclone etc. and also which requires frequent maintenance. A combination of traditional knowledge with advanced technology has been preferred and they opined for use of local construction materials and recommended relying on technical ability of local builders.

Based on the literature review, it may be considered that in order to construct 61.89 million houses for below Middle Income Group, Capital Cost, Safety, Maintenance Cost, Local Availability of Materials and Workmen can be considered as the guiding criteria. Therefore, evaluation has been limited to those technologies, for mass housing schemes in India, which satisfies the above conditions.

3.0 Review of available CECTs in India and their appropriateness based on acceptance criteria

Some of the widely practiced CECTs in India are (i) Compressed Stabilised Earth Block (CSEB), (ii) Bamboo-Reinforced Cement Concrete (BRCC), (iii) Rat-trap bond Wall and Filler Slab. Several other technologies and alternate materials promoted by different research organisations including Central Building Research Institute are also capable to reduce cost in building construction. But their production and use require either special machinery or special craftsman. Those are, therefore, have very much limited use in different showcase projects at small pockets within the country. Society for excellence in Habitat development, Environment protection and Employment generation (2006)[7] has compiled the ‘Environment Friendly Indian Building Material Technologies for Cost Effective Housing’. The said document has discussed on 25 such materials/technologies, out of which 15 are for structural part of the building. Among those, except materials like CSEB, Clay Flyash Burnt Bricks, Marble Slurry Bricks, and technology like Rat-trap Bond Brick Masonry Wall, all other requires either special machinery or specially trained manpower for production and construction.

Compressed Stabilised Earth Block (CSEB) or Compressed Mud Block (CMB) is the most economic and energy-efficient building material having heat storage capacity is one of the highest and also has proven capability of control of humidity. Zami et al. (2008)[8] observed that Earth construction is energy saving and economically beneficial, requires simple tools and less skilled labour and it improves indoor air humidity and temperature which ensures thermal comfort, and the materials are readily available in large quantities in most regions. From the environmental point of view, emission of greenhouse gas from production of CSEB is about 7.9 times less than that of country-fired bricks. Maini (2005)[9] has stated that for production of good quality CSEB, top soil and soil with organic content should be avoided. It requires expertise and knowledge to choose the right soil and stabilizer for production of CSEB as per laid down standards. Hadjri et al. (2007)[10] have surveyed users’ perception on different type of constructions in Zambia, Africa and concluded that majority did not prefer buildings made of earth as it is a symbol of low societal status, culturally associated with poverty and there is a chance of decreased durability due to poor design and construction standards.

CSEB has failed to get wider social acceptability in India because (a) people who aims to improve their dwelling prefers ‘pucca’ or permanent construction materials and mud or earth is still considered as a non-durable and poor man’s material, (b) technical and scientific expertise for this technology is not easily available, (c) composition and strength of production of CSEB varies on location, type of available earth and type of stabilisers, thus making it difficult to convince common people and local artisans.

Bamboo-reinforced Cement Concrete (BRCC) has also been considered as a low-cost building material, but its use is very much limited to the bamboo-producing zones of the country and where trained personnel are available for such technology. Maiti et al. (2009)[11]

have worked with BRCC as a cheap and energy-efficient building material. Bamboo should be treated immediately when cut at the bamboo grove. There are tendencies to develop crack along cleavage due to low strength along fibres of bamboo and also strength varies from species to species. The alkaline property of concrete may also have adverse effect on bamboos embedded in concrete. However, cost effectiveness, eco-friendliness, light weight, shock absorbing capacity during earthquake advocate the use of bamboo as an alternate building material and an alternative to steel in reinforced cement concrete. Building Materials and Technology Promotion Council of India[12] has promoted bamboo as a material for cost-effective and disaster resistant housing. They said that bamboo is a renewable raw material having a life span of 30 – 40 years, but the natural durability depends upon the species and type of treatment carried out on that material. In hilly areas and bamboo-producing zones these technologies are used by local people, but country-wide acceptability of the same is very poor.

The report of National Disaster Management Division, Ministry of Home Affairs, India[13] has indicated that houses built with mud, unburnt brick and mud mortar become vulnerable due to their loss of strength in submerged condition during flood and houses made from light weight materials like GI or other metal sheets or grass, leaves, bamboo etc. easily float away as soon due to uprooting of their holding down ports by the flowing water. Buildings constructed with lighter materials such as metal sheets and bio-mass materials are not much affected during earthquakes, but can be blown away under the storm winds. But those constructed using heavy materials will be totally destroyed under earthquake conditions endangering life and property. It has been recommended that the plinth should be high enough and must be made of non-erodible material, the superstructure walls must be made stable under earthquake as well as under strong wind conditions, and the wall material should not become soft and dissolve under water. As per the recommendations given by the National Disaster Management Authority of India it is required that the houses in the flood prone areas should be made with flat horizontal roofs which could be used as the shelter by the family during flood. The instant study has been carried out to find out the most appropriate CECT that will conform to all the guiding criteria as perceived by common people as well as will meet the stipulations laid down by the national authorities of India like Bureau of Indian Standards, National Disaster Management Authority etc.

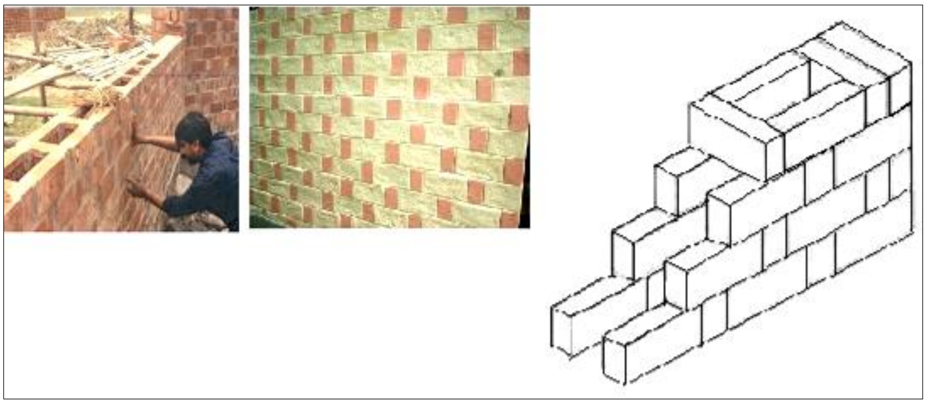

Figure – 1: Rat-trap Bond Masonry Wall

Rat-trap bond is a type of masonry bond of 250mm (10”) thick brickwork laid by placing the bricks on their sides having a cavity of 100mm (4”) with alternate course of stretcher and headers (Figure - 1). The headers and stretchers are staggered in subsequent layers to give more strength to the walls. 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. Structurally Rat-trap bond wall is an improved form of masonry cavity wall.

Figure – 2: Single-storied building with Rat-trap Bond Wall

There is 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, good quality brick possess very low moisture movement of 0.002% to 0.01%[14] and use of the material does not call for much precaution. In India and abroad, buildings with exposed brickwork in cement sand mortar and 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 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 walls are: (a) Strength is equal to standard 250mm thick brick wall, but savings in consumption of brick, cement and sand are 28%, 37% and 40% respectively (Table - 1). The overall saving on cost of materials used for construction compared to the traditional 10" wall is about 20% (b) 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 India, (d) 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 aesthetically appealing from both inside and outside (Figure - 2), (e) Buildings up to two stories can easily be constructed with this technique (f) In R.C.C. framed structures, the filler walls can easily be made of rat-trap bond, (g) Due to reduced load on the base of the walls, the width of foundation is also decreased, resulting in a saving of about 8%, 8.33% and 7.7% respectively on use of bricks, cement and sand in foundation and plinth for small dwellings.

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	119.5 kg.	75 kg.	37%
3	Sand	0.34 cu.m.	0.20 cu.m.	40%

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

Earlier work shows that demolition projects in USA have revealed that cavity walls were built in the country 60 or more years ago[15]. From this fact it is evident that cavity walls were in use in United States since early 20th century and the U.S. Army has adopted the technology to build their barracks, officers' mess etc. since middle of the 20th century. Zackirson Sr. reported that performance of those constructions was reported to be very good in terms of maintenance and thermal insulation[16].

RCC Filler Slab is basically a normal R.C.C. slab where concrete in the tension zone i.e. bottom of the slab, is replaced by light-weight filler materials such as bricks, tiles etc (Figure – 3). These filler materials are so placed as not to compromise with structural strength.

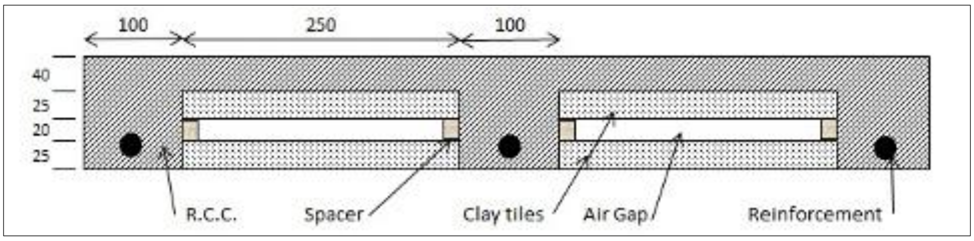

Figure – 3: Cross-section of a typical RCC Filler Slab

The main features of Filler Slab are: (a) Consumes less concrete and steel due to the reduced weight of the slab achieved by replacing a portion of concrete with light-weight filler materials, (b) Slab thickness minimum 110 mm. Reinforcements are placed in between the filler materials, (Figure - 4) (c) Reduces heat flow through roof in the building due to heat resistant qualities of the filler materials and the gap between two burnt clay tiles. (d) Reduction in volume of concrete results in reduction of consumption of cement, sand & crushed stonechips by about 49%, whereas use of steel is reduced by about 13% (Table - 2), (e) Cost saving of about 23% in comparison with normal RCC slab, (f) produces a good aesthetic if plastering is done only on concrete surface of the ceiling (Figure - 5).

Figure – 4: RCC Filler Slab during casting

Figure – 5: View of ceiling of RCC Filler 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 0.11 = 1.221 cu.m.	1.221 – (120 x 0.25 x 0.25 x 0.08) (120 pair of tiles of size 0.25 m x 0.25 m x .025 m with .030 m thick spacer blocks) = 0.621 cu.m.	
1a)	Cement @ 0.286 cu.m./cu.m. of concrete	0.35 cu.m.	0.178 cu.m.	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%

Table - 2: Material Consumption in Ordinary R.C.C. Slab and Filler Slab
(for a 3.0m x 3.7m x 0.11 m thick slab)

Sengupta[17] has designed the Rat-trap Bond Wall, Filler Slab and Foundations for buildings built with these two technologies. Computation of strength of the 0.25 m thick rat-trap bond masonry wall on the basis of available Indian Standards has revealed that it is safe to construct walls for two-storied buildings with this technology. Design of roofs of size 3m x 3.7m, which is a very common size for small residential houses, as filler slab roof has also revealed that it is safe for such houses. However, disaster-resistant arrangements like providing RCC bands at sill level and vertical reinforcing bars at centre of masonry columns as suggested by the engineers are to be adopted. This is irrespective of any type of technology or material for construction. He has inferred that both Rat-trap Bond Wall and RCC Filler Slab are safe for construction of small residential buildings up to two floors.

After safety, the next concern for common people is obviously the cost of the building. In a developing country like India, the trend of building technology is inclined towards low-cost locally-available materials and workmen. A balanced approach should be made to construct buildings with minimum cost, maximum safety and moderate level of comfort for users.

Sengupta[17] has compared the cost of the basic structure built with conventional and alternate technologies and concluded that small buildings of size 25 sq.m., which is a standard for mass housing projects under different housing schemes in India, 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. This aspect will act as an added advantage to the acceptability of these technologies by common people.

Thermal comfort, though not in the top priority of the guiding criteria, may not be ignored also to ascertain acceptability of CECTs among common people.
Parsons[18] has defined thermal comfort as that condition of mind, which derives satisfaction from the thermal environment. It is rather a psychological phenomenon rather than a physiological state. It is influenced by individual differences in mood, personality, culture and other individual, organizational and social factors. Therefore predicting thermal comfort will never be perfect.

In most of the parts of India which are warm and humid, in dwelling houses belonging to middle income group and below i.e. which do not have any provision for artificial cooling, the windows are normally operated in following sequence: (a) In summer, windows are generally closed between 10 A.M. and 5P.M., when solar incidence is maximum, to reduce inflow of heat from outside into the rooms and those are kept open between 5P.M. to 10 A.M. to facilitate circulation of air inside the room and dissipation of the accumulated internal heat, (b) In winter windows are generally kept open from 7A.M to 5P.M. to get maximum warmth from sunlight and kept closed between 5P.M. to 7A.M. to reduce loss of heat from inside of the room and protect the interior from rapid cooling. To coincide with the practice, it would be appropriate to construct the buildings with such materials or technologies which are capable of reducing convection of heat through building envelop.

Heat transferred through per square meter of 0.25 m thick rat-trap bond masonry walls in still air condition and for a temperature difference of 5^o is approx. 5.93 W (Appendix – 1) compared to that of a solid 0.25 m thick masonry wall as 13.84 W (Appendix - 2). In Rat-trap bond the air gap between the two wythes of bricks provide the necessary barrier for heat transfer. Similarly it can be calculated that heat transferred through per square meter of 0.11 m thick R.C.C. filler slab in still air condition and for a temperature difference of 5^o is approx 16.50 W and that for a solid 0.11 m thick R.C.C. slab is approx. 25.91 W. This is due to the two layers of clay tiles at the bottom of the slab and the air gap between them.

These properties of rat-trap bond wall and filler slab result in reduction of heat flow through the wall surface and roof and thus ensure more comfort for the inhabitants and reduction in use of air circulators or air coolers during summer time and heating requirements during winter.

Conclusion

From the above study and analysis it can be concluded that while there are various CECTs are available for construction of dwelling houses in India, Rat-trap bond wall and Filler Slab roof would be one of the most appropriate and acceptable CECT among people belonging to Middle Income Group and below in India as they are satisfying all their guiding criteria and capable of providing the following advantages:

(i) Reduction of Cost of Construction by about 17%
(ii) Use of locally available traditional materials and can be used by local artisans,
(iii) Much cheaper than presently-followed type of construction of permanent buildings,
(iv) Safe as per Indian Standards,
(v) Comfortable in all weather, and
(vi) Aesthetically pleasant.

To sensitise people to adopt these technologies, respective government departments have to undertake awareness generation programmes among the users, training of masons, creation of pool of architects and engineers, establishment of building guidance centres etc. The policy makers of the country should also realise the efficacy of adoption of CECT's like Rat-trap Bond Wall and Filler Slab roof as it would not only reduce the cost but also enhance comfort level of the users and reduce greenhouse gas emission from building construction sector [Sengupta[19]]. Once accredited by the government department and agencies, the acceptance of people and the market force created out of that will accelerate use of these methods of building construction.

Acknowledgement

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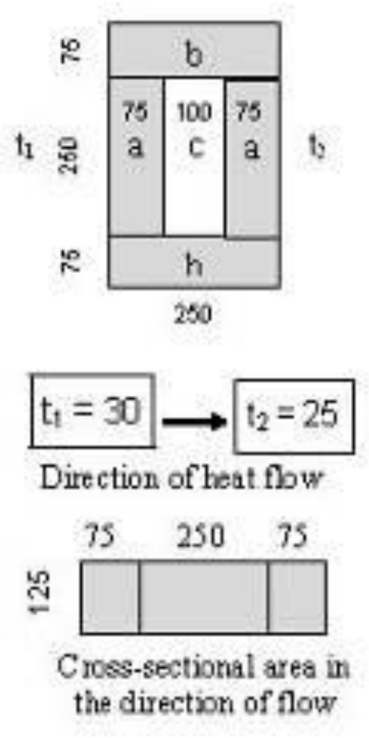
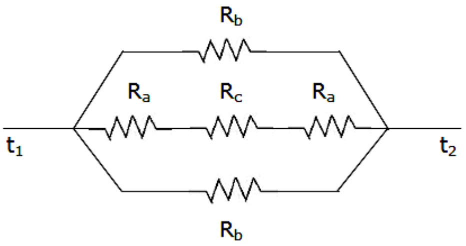
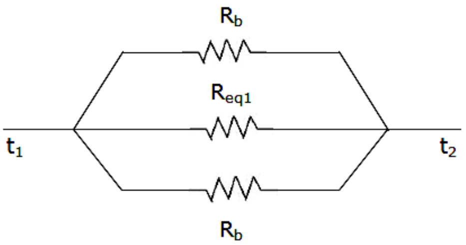
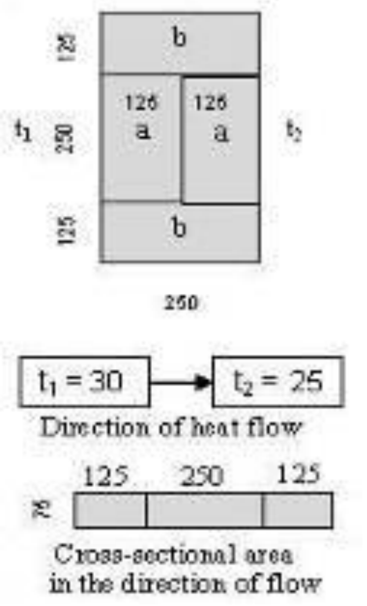
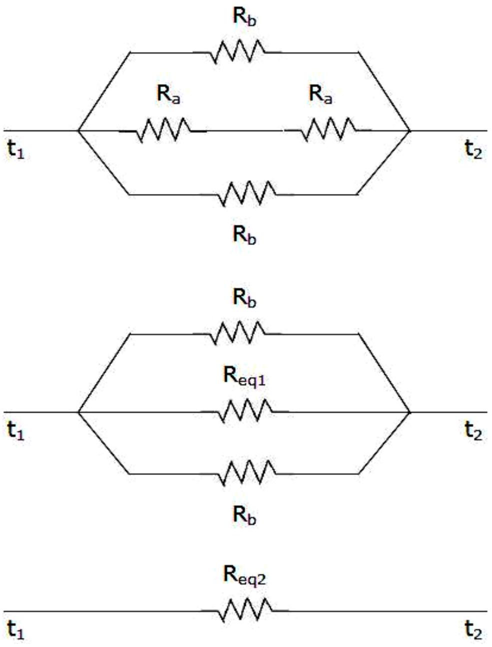
Appendix – 1: Calculation of Equivalent Resistance and Heat Transfer rate for Each unit of Rat-trap Bond

	a: Brick on edge. δ_a = thickness normal to direction of flow = 75mm = 0.075m, A_a = Area normal to direction of flow = 0.25 x 0.125 = 0.03125 sq.m. b: Brick on edge δ_b = thickness normal to direction of flow = 250mm = 0.25m, A_b = Area normal to direction of flow = 0.075 x 0.125 = 0.009375 sq.m. c: Air gap δ_c = thickness normal to direction of flow = 100mm = 0.1m, A_c = Area normal to direction of flow = 0.25 x 0.125 = 0.03125 sq.m. $k_a = k_b$ = Thermal Conductivity of burnt clay brick = 0.692 W/^{0}C.m k_c = Thermal Conductivity of air = 0.025 W/^{0}C.m t_1 = Outside temperature = 30^{0}C (considered) t_2 = Inside temperature = 25^{0}C (considered) A_{xu} = Cross-sectional area in the direction of flow = 0.05 sq.m.

  	$R_a = \delta_a/(k_a x\ A_a) = 3.468$ deg/W $R_b = \delta_b/(k_b x\ A_b) = 38.536$ deg/W $R_c = \delta_c/(k_c x\ A_c) = 128.0$ deg/W As R_a, R_c and R_a are in series $R_{eq1} = R_a + R_c + R_a = 134.94$ deg/W As R_b, R_{eq1} and R_b are in parallel $1/R_{eq2} = 1/R_b + 1/R_{eq1} + 1/R_b = 0.0593$ $R_{eq2} = 16.86$ deg/W So Heat Transfer rate per unit of rat-trap bond = Q_{xu} = $(t_1 - t_2)/R_{eq2}$ = 0.296 W So Heat Transfer rate per sq.m. = Q_{xu} / A_{xu} = 5.93 W

Appendix – 2: Calculation of Equivalent Resistance and Heat Transfer rate for Each unit of Flemish Bond masonry wall.

	a: Brick flat. δ_a = thickness normal to direction of flow = 125mm = 0.125m, A_a = Area normal to direction of flow = 0.25 x 0.075 = 0.01875 sq.m. b: Brick flat δ_b = thickness normal to direction of flow = 250mm = 0.25m, A_b = Area normal to direction of flow = 0.075 x 0.125 = 0.009375 sq.m. $k_a = k_b$ = Thermal Conductivity of burnt clay brick = 0.692 W/^{0}C.m t_1 = Outside temperature = 30^0 (considered) t_2 = Inside temperature = 25^0 (considered) A_{xu} = Cross-sectional area in the direction of flow = (.25+.125x2)x.075 = 0.0375 sq.m.

	$R_a = \delta_a/(k_a \mathrm{x}\ A_a) = 9.634$ deg/W $R_b = \delta_b/(k_b \mathrm{x}\ A_b) = 38.536$ deg/W As R_a, and R_a are in series $R_{eq1} = R_a + R_a = 19.268$ deg/W As R_b, R_{eq1} and R_b are in parallel $1/R_{eq2} = 1/R_b + 1/R_{eq1} + 1/R_b = 0.1038$ $R_{eq2} = 9.634$ deg/W So Heat Transfer rate per unit of rat-trap bond = $Q_{xu} = (t_1 - t_2)/R_{eq2} = 5/9.634 = 0.519$ W So Heat Transfer rate per sq.m. = $Q_{xu} / A_{xu} = 13.84$ W