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Evaluation of Building Techniques in Optimization of Materials: A Comparative Investigation in the Residential Architecture of Kerala

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Abstract

Sustainable utilization of resources means using resources in such a way that future generations do not have to compensate with their existing needs. Despite a number of cost-effective construction techniques, components and building materials developed through research, the residential sector have not seriously adopted or accepted these technologies in construction practice. Modern residential architecture of Kerala is passing through an important phase of application of new technologies and new materials. The authors have conducted an investigation and comparative analysis of the different systems of building construction in the residential sector of Kerala, constructed by adopting different construction technologies and materials. The study and its findings reveal that with suitable appropriate technologies for walls and roof construction, total materials for the building can be reduced without affecting climatic responsiveness and design efficiency.

Keywords: Kerala, Residential Architecture, Appropriate Technology, Optimization of Building Materials

1. INTRODUCTION

We live in an environment age where; valuable resources are further depleted and limits to growth are approached [1]. Natural resources are consumed by modifications of land, the manufacture of materials and systems, the construction process, energy requirements and waste products that result from operation, occupation and renewal [1]. Building and construction activities worldwide consume 3 billion tons of raw materials each year and represents 40 % of global use [2]. The manufacturing of many of the materials used in buildings requires the consumption of large amount of energy, derived from the fossil fuels and displacement of megatons of earth during the course of mining [2].

Almost half of the total world energy investments are oriented toward building sector, and the largest part of these activities, is related with the production and processing of raw materials, and of building materials and products [3]. Utilization of large quantity of natural resources for meeting the fast-growing building activities and generation of waste has exerted unavoidable pressures on natural environment [4].

The contribution of construction materials may account more than 50% of the project cost. Due to its major contributor to project cost, managing building materials become essential function in the construction project. Therefore, material management is an important element in project management [5]. While sustainable development is the need of the hour; we have to take lead in initiating activities that would minimize the exploitation of natural resources resulting in their effective utilization [6]. Optimization of the quantity of materials in the construction, to reduce the overall building mass, without compromising other requirements is an important aspect to achieve sustainability.

Technology is the principal instrument that will facilitate more rational use of resources during the entire life cycle of a building; through the phases of construction, use and demolition [7]. A clear understanding of different design principles, methods and techniques of construction employed and materials used in traditional architecture would be used in contemporary architecture by judiciously adopting them even while using suitable modern materials and modern technology [8-11]. Improved space efficiency also contributes to better material efficiency when assessing it in terms of functional units [12].

There is a great potential in the field of light weight building design, as the density optimization accompanied by intelligent integration allows the materials to be more easily maintained and recycled [13].

1.1 Present Scenario in Kerala

The climate of Kerala is characterized by heavy rainfall and relative humidity, and relatively moderate temperature [14]. Kerala, despite being blessed with immense natural resources, factors like population growth and urbanization demand a greater number of built structures and it puts more pressure on these resources.

The modernization of building process today opens up a new era of technology in the residential sector of Kerala, and it resulted in the vanishing of environment friendly architecture. The most adverse effect of this process is the excessive dependence of energy intensive materials and its overuse without any considerations to the need and structural efficiency.

Many of the construction technologies in the residential sector of Kerala today followed large building mass, which consumes large quantity of materials. This demands a detailed study of the different problems associated with overuse of materials, increasing the building mass and proper optimization techniques and guidelines to control the use of materials according to its need.

The most dominating proportion of middle-income sections of society are influenced by experimental construction technologies with depending factors of social acceptability, economic viability and environmental suitability. Material utilization of the residential structures for middle income sectors require a study and analysis to identify the importance of appropriate construction technology for optimization of materials and valuable resources.

2. METHODS

2.1. Case Studies

The authors have conducted a detailed comparative investigation and analysis of three different types of residences in Kerala, designed and constructed with different types of technologies and materials. The investigation focuses on the suitability of the technologies in optimization of building materials in the construction. Being representative of the typical type of construction, these buildings show significant differences regarding the construction technology, structural characteristics and materials used. Therefore, by adequate comparison and evaluation of relevant characteristics of technology and materials, the resource utilization characteristics can be evolved. Besides that, discussions have also been carried out on climate responsiveness, and design efficiency by utilization of spaces of these buildings.

2.1.1. Selection of Buildings

Three Residential buildings, which have been selected for the study and analysis, with plinth area ranging from 200 to 330 Cu. M, are located in the Kollam district of Kerala. All the three buildings are designed for people belonging to middle income group, considering their economic affordability. These residential structures have considered various possibilities of construction technologies and materials, which are useful for the comparison on their appropriateness in a type of construction system, for the optimization of materials.

2.1.2. Case Study 1: Residence A

The first selected residential building for the study was at Ezhukone in Kollam district of Kerala, owned by Mr. Sudarsan. This residence was constructed in two floors in 2007, with a total floor area of 320 Sq. M.

Walls of this residence constructed with a technology of rat trap bond system using high quality bricks with an exposed brick work finish. Roofs are designed with a flat and sloping combination, adopting filler slab technology using RCC and Mangalore tiles.

Residence - A owned by Mr. Sudarsan

2.1.3. Case Study 2: Residence B

The second residence selected for the study was at Kunnikkode, in Kollam district owned by Mr. Riyas. This residence is constructed in two floors in 2018, with a total area of 272 Sq. M.

Walls of this residence constructed in a conventional Flemish bond brickwork and plastered on both surfaces. Roofs have adopted flat roof RCC construction for the entire area of the residence, providing an exposed flat terrace on top.

Residence - B owned by Mr. Riyas

2.1.4. Case Study 3: Residence C

The third selected residential building was at Paravur, in Kollam district owned by Mr. Biju Nettara. This residence also constructed in two floors in 2015, with a total area of 200 Sq. M. [15].

Walls of this residence constructed with hollow concrete

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blocks of varying thicknesses of 15 cm and 10 cm for ground floor and first floor respectively, and plastered on both sides. Ground floor roof of this residence adopted RCC conventional flat slab, while the upper floor roof is designed in a sloping pattern covering with algae resistant shingles, with wide overhangs. Framework of the roof is designed with G.I tubular truss and a false ceiling constructed below this level using gypsum board.

Residence - C owned by Mr. Biju Nettara

3. RESULTS

3.1 Construction Technology and Materials

Table 1: *Construction Technology & Materials*

Wall:		
Construction technology	**Residence A:**	Rat trap bond brick work- 23 cm construction for inner and outer walls for ground and first floor level. Exposed brick work with cement mortar construction.
Construction technology	**Residence B:**	Conventional 23 cm brick work in English bond for inner and outer walls and cement mortar plastering
Construction technology	**Residence C:**	Hollow concrete Brickwork for inner and outer walls with cement mortar plastering 15cm thick walls-Ground floor 10cm thick walls –First floor
Materials	**Residence A:**	First class wire cut bricks with dimensions of 22.9 x 11.4 x 7.5 cm and Cement sand mortar 1:6 composition
Materials	**Residence B:**	Ordinary wire cut bricks of dimensions 22.9 x 11.4 x 7.5 cm and Cement sand mortar 1:6 composition.
Materials	**Residence C:**	15cm x 20cm x 30 cm and 10cm x 20xm x 40cm hollow concrete blocks Cement mortar 1:6 composition
Roof:		
Construction technology	**Residence A:**	RCC slab with filler slab technology for flat and sloping roofs-12 cm thick.
Construction technology	**Residence B:**	RCC Flat slab -10 cm thick
Construction technology	**Residence C:**	Ground Floor- RCC flat slab – 10 cm thick First Floor- 4mm thick algae resistant shingles on top of cement board and steel framework
Materials	**Residence A:**	RCC construction with cement concrete 1:2:4 composition Mangalore tiles as filler material
Materials	**Residence B:**	RCC slab with 1:2:4 cement concrete composition.
Materials	**Residence C:**	RCC slab with 1:2:4 cement concrete proportion for the ground floor roofing. 4 mm thick shingles, cement board, steel frame work and gypsum board for false ceiling for first floor roofing.

3.2 Quantity of Materials

Table 2: Final Quantity of materials consumed by each Residence for the construction of Walls and Roof

Particulars	Residence A	Residence B	Residence C
Walls (including plastering)			
Bricks (23 x 11.5 x7.5 cm) (Nos.)	37011	44944	
Hollow concrete blocks (15 x 20 x 30 cm) (Nos.)			1878
Hollow concrete blocks (10 x 20 x 40 cm) (Nos.)			922
Sand (Cu. M)	24.67	51.12	12.82
Cement (Cu. M)	4.19	8.17	1.99
Roofs (including ceiling plastering)			
Coarse aggregate (Cu. M)	34.6	28.17	5.76
Sand (Cu. M)	24.98	19.96	4.1
Cement (Cu. M)	9.8	7.92	1.63
Steel reinforcement (Kg)	266	2513	514
Mangalore tiles (as filler material) (Nos.)	2883		

4. ANALYSIS AND DISCUSSION

4.1. Material Consumption

Based on the results and calculations of the materials consumed by each residence for the construction of walls and roof, comparative charts and diagrams have been prepared to show the quantity of each material, consumed by Residences for 1 sq.m area of the residence. This will give a clear indication of the material consumption of each residence for the total construction.

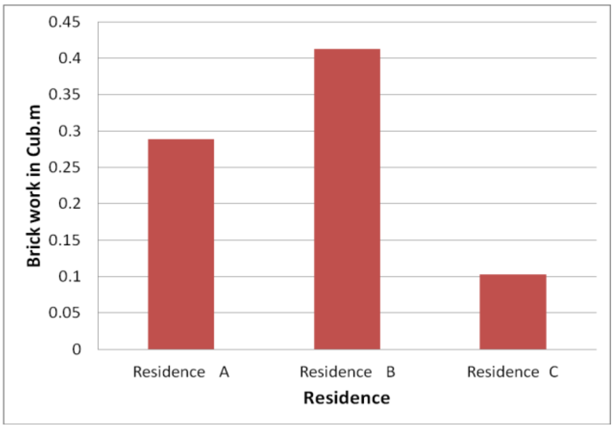

***Figure1.** Comparative analysis of quantity of brickwork needed per sq.m area of each residence*

Comparative analysis of the quantity of Brickwork needed for 1 sq.m. area of the residence (Figure 1), shows that Residence B consumed maximum quantity of brickwork (0.289 Cu. M), as it applied conventional English bond system and 23 cm walls for the two floors of construction. Residence A, consumed lesser brickwork (0.413 Cu. M) compared to Residence B, as Residence A applied rat trap bond system for the wall construction; as it consumes 25% less brick for the walls. Residence C consumed least quantity of brickwork (0.103 Cu. M) with hollow concrete block system, and with application of light weight construction with 15 cm and 10 cm thick walls for the lower and upper floors respectively.

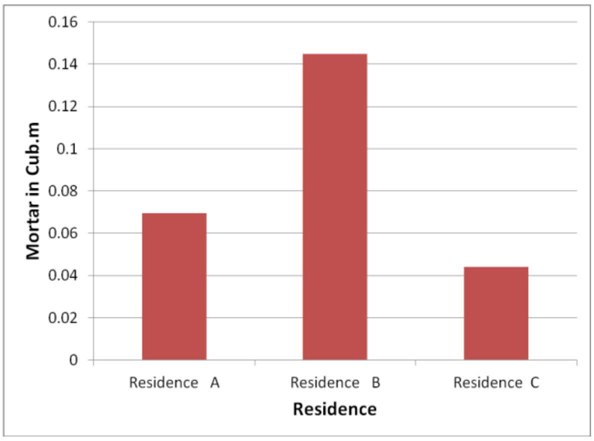

***Figure 2.** Comparative analysis of quantity of cement sand mortar used for brickwork and wall plastering per Sq.M area of each residence*

Analysis of the usage of Cement sand mortar for 1 sq.m area of each residence (Figure 2) shows that Residence B consumed maximum quantity of Cement sand mortar (0.145 Cu. M) , for masonry work of the walls and wall plastering, and Residence C consumed least quantity of mortar (0.044 Cu. M) due to reduced wall thickness. Residence A consumed medium quantity of mortar (0.0694 Cu. M), as the wall construction adopted exposed brickwork system with no plastering.

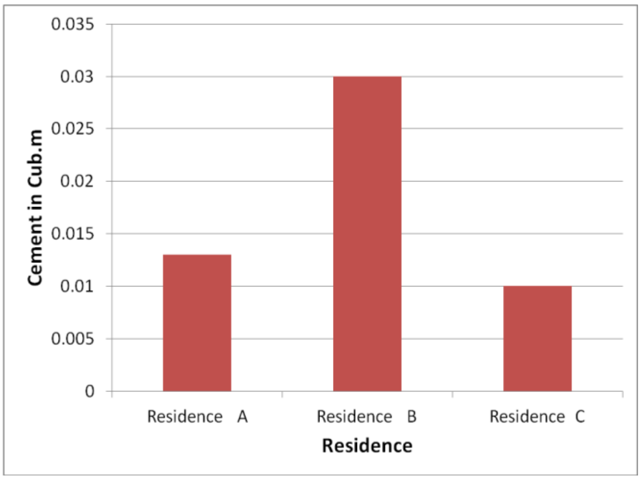

Figure 3. *Comparative analysis of quantity of cement used for brickwork and plastering per sq.m area of each residence*

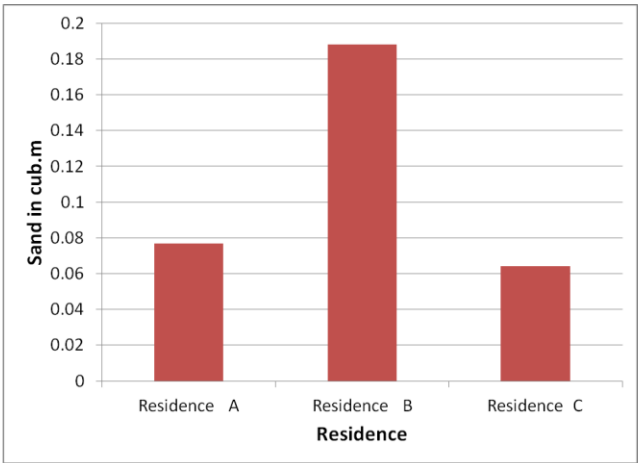

Figure 4. *Comparative analysis of quantity of sand used for brickwork and plastering per sq.m area of each residence*

Comparative analysis of consumption of cement and sand for the wall construction (Figures 3 and 4) including plastering for 1 sq.m. area of each residence shows that, Residence C consumed least quantity of cement (0.01 Cu. M) and sand (0.064 Cu. M) and Residence B needed maximum amount of cement (0.03 Cu. M) and sand (0.188 Cu. M), and Residence A consumed slightly higher quantity of cement (0.013 Cu. M) and sand (0.077 Cu. M) than Residence C.

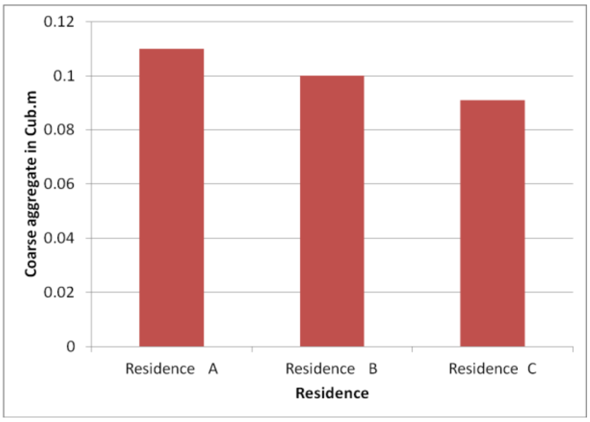

Figure 5. *Comparative analysis of quantity of coarse aggregate used for roof work per sq.m area of each residence*

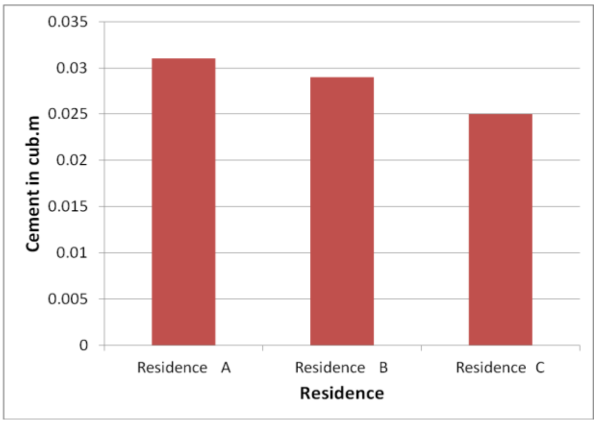

Figure 6. *Comparative analysis of quantity of cement used for roof work per sq.m area of each residence*

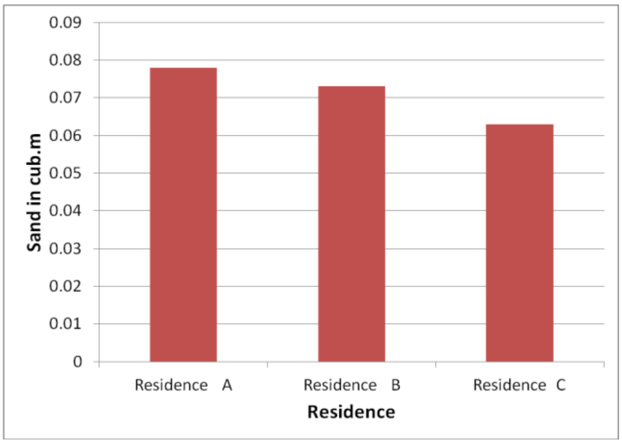

Figure 7. *Comparative analysis of quantity of sand used for roof work per sq.m area of each residence*

Comparative study and analysis of the consumption materials for the roof work including beams (Figures. 5, 6 and 7), for 1 Sq. M. area of the residence shows that, Residence A consumed maximum quantity of coarse aggregate (0.11 Cu. M), cement (0.031 Cu. M) and sand (0.078 Cu. M) for the roof construction. This is due to the additional thickness of the roof to accommodate the filler material, and sloping profile of the roof system in half portion of the upper floor roof. Residence C consumed least quantity of coarse aggregate (0.091 Cu. M), cement (0.025 Cu. M) and sand (0.063 Cu. M) with minimum slab thickness and less usage of beams, with the design and construction technology. Analysis also shows that Residence B, adopted a flat slab roof system, consumed slightly less materials than Residence A, and slightly more materials than Residence C, with consumption of Coarse aggregate (0.1 Cu. M), cement (0.029 Cu. M) and sand (0.07 Cu. M)

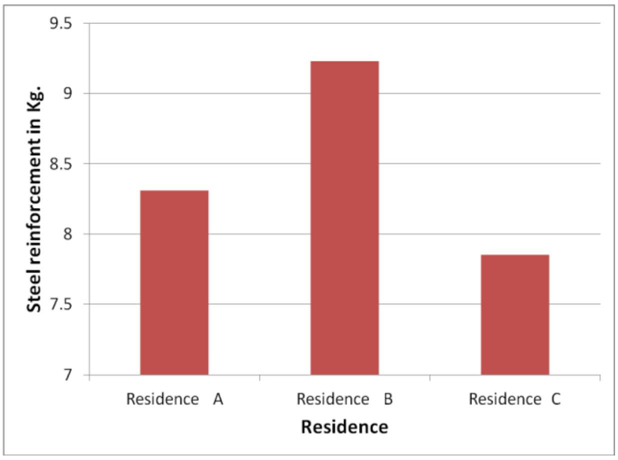

Figure 8. *Comparative analysis of quantity of steel reinforcement used for roof work per sq.m area of each residence*

Comparative analysis of the consumption of steel reinforcement for the roofs and beams for unit area of the residences (Figure 8), reveals that, Residence B utilized maximum steel reinforcement (9.23 kg.), as it adopted a conventional slab system with a greater number of beams for structural stability. Residence A consumed comparatively less amount of steel reinforcement (8.31 kg.), as it adopted filler slab technology with less steel reinforcement, compared to a conventional roof. Residence C consumed least amount of steel reinforcement (7.85 kg.), as the additional requirements of beams are minimum in this residence.

4.2. Response to climate

Design of Residence A with exposed brick work, is not a perfect construction system for the walls, as this required suitable protections from intensive rain in Kerala climate. Wide overhangs of sunshades and roofs required for this protection and it consume large amount of materials finally. Combination of flat and slope roofing system with filler slabs technology, for this residence is a moderately good solution considering the climatic features of summer and rainy seasons of Kerala.

Design of residence B, using totally flat exposed top roof is directly transferring heat energy in to the interior spaces of the building, and caused an uncomfortable living condition inside. Absence of wide overhangs exposed the external walls of this building to direct sun light and enhanced the absorption of heat energy in summer seasons.

Design of residence C used a sloping roof construction over the upper floor of the building, with a much lighter materials and technology. Wide overhangs on all sides, moderate sloping roof profile, shingles roof finish over steel framework, flat ceiling below the sloping roof with ventilated space between roof and ceiling provide a much better condition inside the interior spaces.

5. CONCLUSIONS

5.1 Quantity of Materials and Resources

5.1.1 Brickwork

Comparative analysis of quantity of materials consumed by each Residence for the brickwork of walls shows that, Residence B consumed maximum quantity of brickwork, cement mortar, cement and sand for 1 Sq. M area of the Residence compared to Residences A and C. Residence C utilized minimum quantity, while Residence A consumed moderate quantity of materials.

The differences in construction technology clearly influenced the quantity of brickwork and materials for all the residences. Residence A adapted rat trap bond system for wall construction without any plastering on walls. Though this technology comparatively reduced the quantity of materials compared to conventional brick bond system for walls, its structural stability and aesthetics aspects have different opinions.

Residence B used a conventional brickwork system with 23 cm wall construction with plastered inner and outer walls of the residence. Though its structural stability is good, compared to other residences, it consumed maximum quantity of materials for walls, compared to other two buildings.

Residence C adopted an innovative light weight construction system, with minimum thickness for the walls using hollow concrete blocks. As this technology consumed minimum quantity of brickwork, its usage of all materials is minimum.

5.1.2 Roof work

Comparative analysis of the materials consumed by three residences shows that, they adopted different technologies for the constructions, which influenced the quantity of materials. Residence A consumed maximum quantity of RCC work with coarse aggregate, cement and sand with steel for the construction of roof, considering the materials for 1 sq.m area of the residence. Though this residence used filler slab construction system for reducing quantity of materials, the sloping roof system with complications, in the upper level of the building, utilized additional materials and thus increased the total quantity per unit area.

Residence C consumed minimum amount of coarse aggregate, cement and sand for the roof system, considering materials for 1 sq.m area of the residence. This is because of minimum usage of additional beams as a structural element, with compact design solutions and optimum room design. Residence B adopted conventional RCC construction and consumed more materials than Residence C, but fewer materials than Residence A.

5.2 Material Consumption

A detailed comparative analysis of materials consumed by each residence for the construction of walls and roofs based on materials for 1 Sq. M area of residence, revealed the following conclusions after analysis and discussions.

1. Residence C consumed minimum quantity of materials for the walls and roof, with light weight construction systems, and compact design solutions with optimization of area according to functions.
2. Residence A consumed maximum quantity of all materials for roof system, but fewer materials for walls compared to Residence B.
3. Residence B consumed maximum quantity of materials for wall construction, but fewer materials for roof construction compared to Residence A.

So, it can be concluded that, with suitable appropriate technologies for walls and roof construction, total materials for the building can be reduced without affecting climatic responsiveness and design efficiency.

5. 3 Climate Responsiveness

Protection against extreme solar radiation and heat energy in hot seasons, and rainfall in monsoon and rainy seasons are important aspects to be considered during the total design of a buildings in Kerala. Reducing the quantity of materials for the construction with a proper response to the positive and negative features of the climate is a challenging task to achieve sustainability in construction.

Comparative analysis of three residences on its response to climate shows that, Residence A, due to its exposed construction technology in wall construction, required wide overhangs for its protection form rainy seasons.

Flat roof design of the Residence B, directly transferred the heat energy in to the interior spaces of the building during summer seasons and it require mechanical systems for controlling the thermal comfort levels.

Residence C, with its innovative sloping roof system with wide overhangs and a false ceiling system below the roof level, with a ventilated space between roof and ceiling provide comfortable condition inside the room spaces.

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