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Energy efficient choice of brick façade in Kolkata, India

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Abstract

The standard practice for façade in Kolkata, India is with 250mm thick traditional burnt clay brick wall and 6mm glazing fitted to aluminium window shutters. In the present study, the embodied energy of traditional brickwork and cumulative cost throughout its lifecycle in a conditioned space has been estimated. The impact on operational energy of such brickwork is also estimated through energy simulation. Variations of the present specifications using varying thickness of fly ash bricks and window glazing have been considered and the cost impacts are estimated. Fly ash brickwork of 300mm thickness and single layer 6mm glazing for window glass is proposed as the optimum façade specification.

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Keywords: Burnt clay brick; Fly ash brick; Embodied energy, Operational energy, Energy simulation; Benefit-cost ratio

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1. Introduction

The population in Kolkata, India is increasing rapidly like other cities in developing countries which has created a colossal demand for affordable housing. It has increased the demand for clay bricks in turn. Raw materials for clay bricks are mainly clay and coal and the easy availability of raw materials has made the clay bricks popular. However, its large scale production is environmentally unsustainable because of its high embedded energy, release of greenhouse gases and loss of fertile agricultural land. The brick use patterns in building industries in Kolkata requires re-examination in the light of sustainability.

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Any revision for improvement of a construction work should consider the existing practice before prescribing any change. India is a developing country and as a part of an aspiring nation the requirements and expectation of the people in Kolkata is increasing rapidly. For example, more and more people are opting for air conditioners in their homes. Most of the new offices are now centrally conditioned [1]. Apart from the costs to the consumer it has a negative impact on the green house gases and sustainability. Life cycle costs of brick work and its impact on sustainability have been studied in this light.

The embodied energy in brick façade as commonly done in Kolkata has been estimated. The cumulative cost of such brick façade throughout its lifecycle in a conditioned space has been calculated. In the process, the impact on operational energy of such brick façade has been estimated from energy simulation. Variations of the present specifications have been considered and its cost impacts are estimated. The optimum specification for brickwork and window glazing is then proposed.

2. Brick Façade

2.1. Products

In absence of stones in Kolkata area, clay bricks or its derivatives are the only major source of building materials since the middle age. The English rulers at the time standardized the clay bricks to a size of 230mm x 115mm x 65mm. Later, Indian standards codes have proposed the metric measurement of 190x90x90 [2]. However, the traditional dimension of 'English' brick is still followed for clay bricks in Kolkata area.

The traditional clay bricks as used in Kolkata are no longer sustainable. On the other hand, the ash from the coal fired power plants is abundantly available. The ash is a by product of power plants and does not have inherent embodied energy as a building material. In 2003 the central government of India notified that the buildings located within hundred miles of a power plant should use fly ash bricks. [3]. Bricks made of fly ash are now available around Kolkata. The sizes of these bricks are 190x90x90 [2].

The glazing is traditionally used as filler material for timber shutters. Presently, the timber has become scarce and expensive. Glazing is now fixed to aluminium shutters [2] in most of the buildings.The material properties of the façade items are detailed in Table 1 [4, 5, 6].

Table 1. Details of the façade material properties

Material	Density (kg/m^3)	Specific Heat (J/kg.K)	Thermal Conductivity (W/m.K)	Embodied Energy
Burnt Clay Bricks	2000	836.8	0.711	4.50MJ/Brick
Fly Ash Bricks	1700	857.0	0.360	2.32MJ/Brick
Window Glass	2300	836.8	1.046	25.30MJ/kg

2.2. Options

The standard practice for façade in Kolkata is one brick thick wall with traditional bricks and 6mm glazing fitted to aluminium window shutters considered as the 'Base' in the present analysis. Six additional options with combination of varying thickness of fly ash bricks in place of burnt clay bricks along with single or double glazing are also considered. Details of these options are specified in Table 2. The energy and cost performance of different options are studied for a four storey sample building.The boundary conditions of the considered rooms are presented in Table 3.

Table 2. Details of the façade construction options

Options	Brickwork of the External Wall			Window Glass		
	Brick Material	Thickness (mm)	Cost (INR/m^3)	Glass Material	Thickness	Cost (INR/m^2)
Base	Burnt Clay Bricks	250	4500.00	Clear Glass	6mm Single	5200.00
1	Fly Ash Bricks	200	4700.00	Clear Glass	6mm Single	5200.00
2	Fly Ash Bricks	200	4700.00	Clear Glass	6mm Double	11000.00
3	Fly Ash Bricks	300	4700.00	Clear Glass	6mm Single	5200.00
4	Fly Ash Bricks	300	4700.00	Clear Glass	6mm Double	11000.00
5	Fly Ash Bricks	400	4700.00	Clear Glass	6mm Single	5200.00
6	Fly Ash Bricks	400	4700.00	Clear Glass	6mm Double	11000.00

Table 3: Boundary conditions of the studied rooms

Room Mark	Floor Area (m^2)	Floor Level	Sides Exposed			
			North	East	South	West
R1	66.60	Ground	No	No	Yes	Yes
R2	67.34	Ground	No	Yes	No	No
R3	66.60	Top	No	Yes	No	No
R4	66.60	Top	No	Yes	Yes	No

3. Embodied energy

3.1. Building materials

The embodied energy in a building material is the amount of energy required to produce and bring that material to work site. High embodied energy would also mean additional green house gases. Efforts are therefore required to minimize embodied energy for sustainability. Its importance has been recognized by the scientist since the early days of the movement for sustainable homes [7]. International green building ratings like LEED does not have a specific advice for lowering embodied energy. The Indian green building standard GRIHA offers credits for minimizing embodied energy in criteria 16 It also designates a specific credit for using fly ash in criteria 15 [8]. The NIST, a US government organization has developed BEES, an online system for estimating embodied energies of building materials [9].

3.2. Brickwork and glazing

The fly ash is a by product of power plants and does not have inherent embodied energy as a building material. The output of the BEES software shows that the embodied energy in a fly ash brick of ASTM C216 specification is about 0.89 MJ compared to that of a clay brick which is about 9.3MJ [10]. For Indian condition, the values have been estimated as 4.5 MJ for clay bricks and 2.32MJ for fly ash bricks [5]. The embodied energy of glass has been estimated as 25.8MJ/kg for Indian conditions [4].

3.3. Embodied energy estimate

The embodied energy of the façade materials are estimated for the four rooms specified in Table 3 for the considered options. The quantities of brickwork and window glass for the rooms are multiplied by the corresponding embodied energy coefficients as detailed in Table 1. The total embodied energy thus obtained is divided by the floor area to get the embodied energy of unit area. The savings in embodied energy for the six considered options over the baseline building has been reported in Table 4.

Table 4: Details of embodied energy and heating-cooling energy estimates

Option	Embodied Energy (kWh/m^2)					Heating Cooling Energy Consumption (kWh/m^2/year)				
	R1	R2	R3	R4	Average	R1	R2	R3	R4	Average
Base	152.77	124.79	126.18	152.77	139.13±15.76	5.52	5.13	6.53	6.82	6.00±0.81
	Savings over Base Building S_{EE} (kWh/m^2)					Savings over Base Building S_{OE} (kWh/m^2/year)				
1	71.56	60.83	61.51	71.56	66.37±6.01	0.12	0.14	0.15	0.12	0.13±0.02
2	57.31	53.78	54.38	57.31	55.70±1.88	0.37	0.27	0.28	0.37	0.32±0.06
3	50.02	51.44	52.02	50.02	50.88±1.02	0.55	0.62	0.69	0.55	0.61±0.07
4	35.77	44.39	44.89	35.77	40.21±5.13	0.79	0.75	0.81	0.79	0.79±0.03
5	28.48	42.05	42.52	28.48	35.38±7.97	0.69	0.79	0.87	0.69	0.76±0.08
6	14.23	35.00	35.39	14.23	24.71±12.11	0.93	0.91	0.98	0.93	0.94±0.03

4. Operational energy demand

The embodied energy invested to the brickwork and glazing has a significant role in minimizing the operational energy demand of buildings. After the impacts of economic liberalization, the Indian air conditioning industry is on a high growth trajectory with an overall volume growth rate of 20–25 percent per annum in last few years [11]. The growth rate in domestic sector is about 20% and private business sector is about 25% [12]. This high growth rate is increasing the demand for power which could be minimized by a thicker façade wall. Thicker brickwork with traditional clay bricks would cause more energy demand but would reduce the operational energy demand significantly in future in an air conditioned habitat. If the traditional clay bricks are replaced with fly ash bricks the initial investment of embodied energy would be reduced and the total energy impact for the building would be optimized.

4.1. Energy simulation

Estimating operational energy requirements by computation has become a routine practice. Standard energy simulation software are available for computing the operational energy requirements of a building. In the present study, Ecotect [13] is used as the energy simulation software to calculate the annual heating cooling energy consumption of the four storey sample building in Kolkata. The weather file used for the study is “IND_Kolkata_ISHRAE.epw” which was converted to Ecotect compatible format before use.

4.2. Simulation efficiency

The efficiency of the Ecotect software has been studied in a four storey sample building in Kolkata. The configuration of the building is presented in the Ecotect model as shown in Fig. 1 (A). The temperature variations have been modelled for four typical rooms of the buildings shown in Table 3. Data loggers made by HTC (Model: Easy Log) capable of temperature measurement with resolution 0.1°C have been placed in these rooms for recording actual temperatures. The scatter plot arising out of the model and actual temperatures as presented in Fig. 1 (B) shows significant correlation (R^2=0.6065).

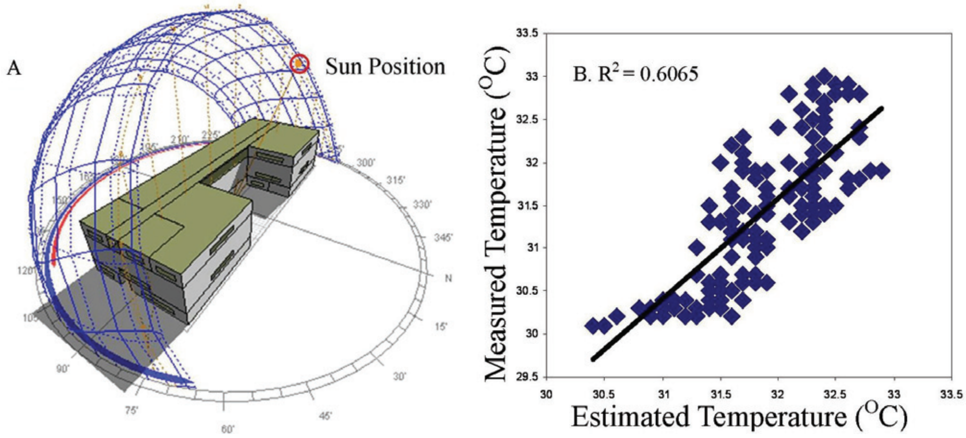

Fig. 1. (A) Configuration of the rooms in Ecotect model; (B) The scatter plot

Typical comparisons of model and actual temperatures for two of he studied rooms are presented in Fig. 2. A calibration coefficient (CF), which is the ratio of the actual and model predicted temperature, has been estimated from the data presented and found to be very close to unity for all the four rooms. It confirms the efficiency of Ecotect in Kolkata's climate for accurate estimation of heating-cooling energy.

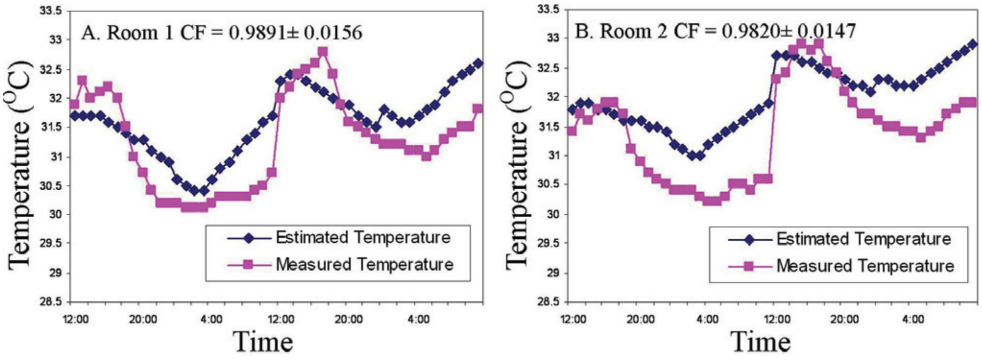

Fig. 2. Comparisons of estimated and measured temperature for Room 1 and Room 2

4.3. Operational energy estimate

The annual heating and cooling energy demand for the four studied rooms are obtained through energy simulation by Ecotect. Considering Kolkata's climate, cooling energy consumption is estimated by setting the upper band of thermostat (cooling set point) at 24°C. The unit area cooling energy demand for each option is obtained by averaging the same for the individual rooms. The savings in cooling energy for the six considered options over the baseline building has been reported in Table 4.

5. Optimization

5.1. Estimation of cost

The cost of each of the options considered in the present study essentially has two components viz. the initial investment in construction and the recurring expenditure in the account of operational energy consumption over the useful life span of the building. The unit rate of initial investment for each of the options are estimated by multiplying the estimated quantity of brickwork and window glass by their prevailing market rates and dividing the results by the floor area. The values are depicted in Table 6 as initial investment (*A*). In order to calculate the recurring expenditure in the account of operational energy consumption, the unit rate of yearly consumption of heating cooling energy has already been estimated through energy simulation as reported in Table 4. Multiplying the same with the unit price of electricity in Kolkata (INR 2.70/kWh) the unit rate of yearly expenditure in this account is estimated and reported in Table 6 as operational energy cost (C_{OE}).

The investments are discounted to its present value for normalizations of cash flows in different time factors. Several issues namely, project life span, inflation and discounting factor are particularly relevant in this regard. The service life (*t*) generally expected from a standard RCC building is about 75 years [14] which has been used for the present life cycle analysis. Inflation has almost become an integral part of the economic estimates. In India, the inflation phenomena are observed by Reserve bank of India (RBI) and are published sector wise in their bulletins. In this study, consumers' price index as reported in RBI bulletin [15] has been used for inflation (*r*). These values are used for projecting the future inflation. The discount rate is used to compress a stream of future benefits and costs into a single present value amount. The discounting rule for public projects is based on the Social Time Preference Rate (STPR). Boscolo et al. [16] presented a list of discount rates used in many countries for environmental control project. A rate of about 6 to 7% was selected in most of these studies. The rate of STPR for the present study (*i*) is also taken as 7%.

The present value of cost of the project is estimated using the relationship expressed in Equation (1). The results for each of the options are reported in Table 6 as present value of cost (*C*).

$$C = A + \sum_{t=0}^{t} \frac{C_{OE}(1+r)^t}{(1+i)^t} \tag{1}$$

5.2. Estimation of total energy savings over the life cycle

In order to reduce the operational cost for air conditioning proper insulation of facade walls is a common practice that requires additional initial costs. Several options using fly ash bricks as considered in the present study can provide energy efficient alternatives. These options are based on the study of construction history of Kolkata as outlined here and are practical methods by all means. The additional costs of the options, if any, would reduce the operational costs of air conditioning and would also reduce the total energy expense of its life cycle. Total energy savings over the base for the expected service life of the building is considered as the benefit of the investment estimated in the previous section. The benefit part of the six considered options as reported in Table 5 is estimated using Equation (2) as follows:

$$S_T = S_{EE} + S_{OE} \times t \tag{2}$$

Table 5. Details of cost and benefit

Options	Operational Energy Cost C_{OE} (INR/m^2/year)	Initial Investment A (INR/m^2)	Present Value of Cost C (INR/m^2)	Life cycle energy savings S_T (INR/m2)	Benefit Cost Ratio BCR (kWh/INR)
Base	16.20±2.19	1644.86±315.61	-	-	-
1	15.85±2.19	1466.65±299.48	1478.34±299.49	76.12±6.21	0.0539±0.0138
2	15.34±2.13	2092.53±542.15	2103.88±542.19	79.70±4.87	0.0413±0.0195
3	14.55±2.19	1692.59±401.37	1703.33±401.30	96.63±5.36	0.0607±0.0194
4	14.07±2.13	2318.47±644.04	2328.87±644.07	99.46±5.61	0.0475±0.0318
5	14.15±2.19	1918.53±503.26	1928.99±503.33	92.38±9.96	0.0520±0.0317
6	13.69±2.13	2544.40±745.94	2554.49±745.96	95.21±12.32	0.0420±0.0411

5.3. Simulation of Benefit cost ratio

The benefit cost ratio represents the total energy saved per INR of the investment for each of the considered options. It is estimated for the six considered options using Equation (3) as follows:

$$BCR = \frac{S_T}{C} \tag{3}$$

The inputs for calculation of present value of cost, total energy savings (ST) and benefit cost ratio are stochastic in nature which is responsible for the risk or variation in the outputs. Monte Carlos simulation has been used to estimate the risk profile of the said parameters using the @Risk simulation tool [17]. In each case the simulation was run for 10000 times. The maximum benefit cost ratio is observed for option 3. The mean, standard deviation and the distribution of the same is presented in Fig. 3 (A). The sensitivity of the benefit-cost ratio on different stochastic input parameters are shown in the tornado diagram presented in Figure 3 (B) and the parameter is found to be most sensitive on initial investment.

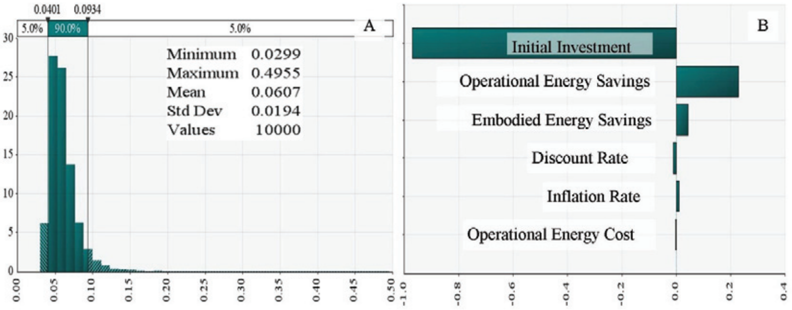

Fig. 3. Benefit-Cost ratio for optimum option (A) Distribution (B) Tornado diagram of Spearman rank correlation coefficients

The benefit cost ratio for each of the considered options is reported in Table 6. A review of Table 6 would indicate that the benefit cost ratio of option 3 is 0.0607 for each Indian rupee (INR). Since this option that is a façade with 300mm (one and half fly ash brick) fly ash brick work and 6mm single window glazing provides the maximum benefit for each Indian rupee it should be adopted for constructions in Kolkata.

6. Discussion and conclusion

In the present paper an attempt has been made to make an optimum choice of the building façade materials like brickwork and window glass from the viewpoint of energy and cost. The 250mm thick burnt clay brick wall and 6mm thick single layer clear window glazing as commonly done in Kolkata is considered as the baseline option. Six other options with different combinations of fly ash brickwork and window glazing are also considered and compared with the baseline.

In order to evaluate the energy performance of the selected options the energy savings for the considered options are calculated over the base line option for both of the embodied energy and heating-cooling energy and ultimately represented in terms of the total energy saved (S_T) in Table 6 over the entire life cycle of the building. To evaluate the cost performance of the selected options, present value of cost for the façade materials for each option was calculated. The initial cost constituted the construction cost of the selected options. The cost cash flow over the lifecycle constituted the cost of the heating cooling energy.

Finally for each of the selected options the benefit cost ratio is calculated and presented in Table 6. A review of Table 6 would indicate that the maximum energy savings over the baseline for each Indian rupee (INR) is observed for option 3. Since this option that is 300mm fly ash bricks with single glazing provide the maximum benefit for each Indian rupee it becomes the optimum choice of façade in Kolkata.

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