THERMAL PERFORMANCE AND ECONOMIC ASSESSMENT OF MASONRY BRICKS

by

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The objective of this study was to assess the thermal performance and economic assessment of different types of clay and concrete masonry brick wall samples used in building construction. In this study, eighteen types of clay bricks and two types of concrete bricks were analyzed for thermal performance. The bricks were classified and grouped based on the brick configuration, material, and size. The analysis of the results shows that the equivalent thermal conductivity does not depend only on the brick material and configuration but also on the brick thickness. The bricks having same configuration and size, the equivalent thermal conductivity variation is large depending on the type of material used, especially for concrete brick. In general, the brick with lesser thickness has lower conductivity as compared to those having higher thickness. However, the effect of brick length on equivalent thermal conductivity is insignificant. The economic analysis showed that the insulated clay brick type 16 is the most economical brick among the types of brick studied. Moreover, it is worthwhile to note that the net present value of normal concrete brick (type 19) is reduced by about 45% by making the concrete brick lightweight (type 20).

Key words: *thermal performance, thermal conductivity, concrete brick, clay brick, thermal insulation, net present value*

Introduction

The building industry is a major industry in Saudi Arabia. Both locally processed and imported building materials are used which range from simple building units (bricks & blocks) to complete housing units. Major building and construction projects were executed without having enough data on building materials and consequently some of them have already shown an alarming degree of deterioration within a short period of 10 to 15 years [1]. The testing and compilation of properties of building materials is a major requirement from structural and thermal point of view of building design. The building materials properties database will enable the designers to select the appropriate building materials and air-conditioning systems for the building design [2, 3]. In order to conserve electricity, thermally efficient building materials should be utilized in the construction industry. About 75% of the total electricity sold in Saudi Arabia is consumed in buildings [4], fig. 1. Available data show that the total energy consumption reached about 169,780 GWh in 2007. The annual increase in energy consumption averaged 5.8% between 2000 and 2007.

AI-Hazmy [5] studied the three different configurations for building bricks including a gas-filled and insulation-filled cavity. The results of the study showed that the movement of air

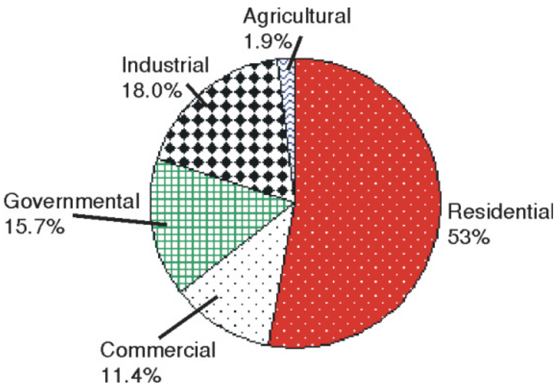

Figure 1. Energy consumption for different sectors in the Kingdom of Saudi Arabia

inside brick cavities causes significant contribution to the thermal load. However, the insertion of polystyrene bars inside the brick cavities caused reduction of heat transfer rate by a maximum of 36%. Del Coz Diaz *et al.* [6] studied the thermal transmittance coefficient of a walls made of Arliblock bricks. He carried out numerical study and compared the results with experimental values. A good agreement in numerical results was reported with the experimental ones. One important conclusion from his study was that the wall insulation decreases with corresponding increase in the mortar and material conductivities. Also, the alteration of brick configuration affects the heat transfer through the bricks.

Several research studies have been carried out in Saudi Arabia which is mainly concerned related to the measurement of thermal conductivity of locally manufactured thermal insulation [7-9]. The thermal conductivity measurement of masonry bricks is less commonly reported. Abdelrahman *et al.* [10] and Al-Hadhrami and Ahmad measured thermal conductivity of some of the commonly used bricks manufactured locally in Saudi Arabia using a guarded hot plate [3]. Al-Hadhrami and Ahmad reported that the use of insulating mortar in building walls increases the thermal resistance compared to that of the walls prepared with ordinary concrete mortar. The analysis of their results also showed that the addition of insulation material either within the masonry brick mix to make the brick more lightweight or through filling insulation material into the holes of masonry bricks increases the thermal resistance significantly.

The present work is an extension of the previous work [3] carried out by the author for thermal performance assessment of the bricks. The purpose of the present study is to assess the thermal performance and economic assessment of locally manufactured masonry concrete bricks for the local environmental conditions. The assessment includes studying the effects of brick configuration, material, and size on equivalent thermal conductivity (k_{eqv}).

Brick testing procedure

Figure 2. Guarded hotplate thermal conductivity measuring equipment

The same brick testing procedure is followed as that reported in reference [3]. A guarded hot plate that conforms to ASTM Standard C177-85 [11, 12], shown in fig. 2, was used for the measurement of equivalent thermal conductivity under steady-state heat flow conditions. The thermal conductivity measuring equipment is suitable for testing non-homogeneous materials, *e. g.* concrete, masonry, wood products, cellular plastics *etc*. The accuracy of the test equipment is about

±4% of the true value of the thermal conductivity. The equipment is designed to carry two samples of maximum 15 cm thickness. Since samples had more than this thickness, a thin calibrated dummy sample was used on the upper side of the plate in order to accommodate test samples of larger thickness on the lower side of the plate.

The types of wall samples tested are shown in figs. 3-1 to 3-10. The test samples of dimensions 61 cm 61 cm were prepared in the same way as they are assembled on walls. The surfaces of the samples must be flat and parallel to minimize contact resistance between these two surfaces and the corresponding hot and cold plate surfaces. Due to the rough surfaces of the samples it was not possible to get the flat and parallel surfaces. An uneven surface would result in a significant temperature difference between the hot plate and the corresponding sample surface. To overcome this problem, the thermocouple wires were fixed on both sides of the sample and the

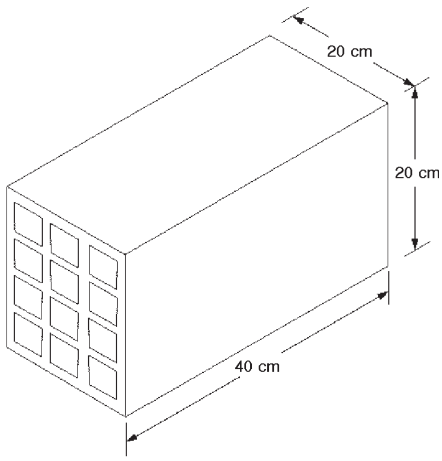

Figure 3-1. Figure of tested red clay brick types 1 to 3

Type 1: normal hollow red clay brick;
Type 2: Type 1 with body added polystyrene insulation;
Type 3: Type 1 with center holes filled w/polystyrene

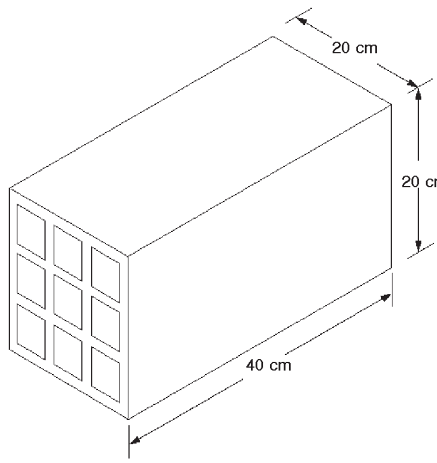

Figure 3-2. Figure of tested red clay brick type 4

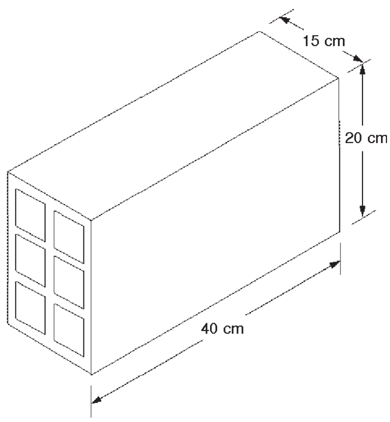

Figure 3-3. Figure of tested red clay brick type 5

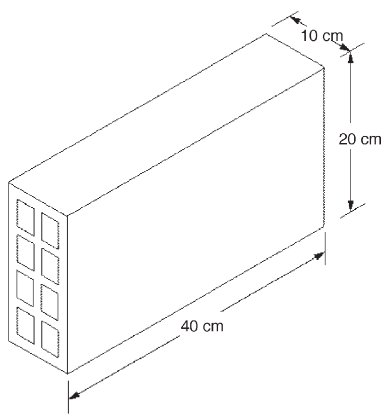

Figure 3-4. Figure of tested red clay brick type 6

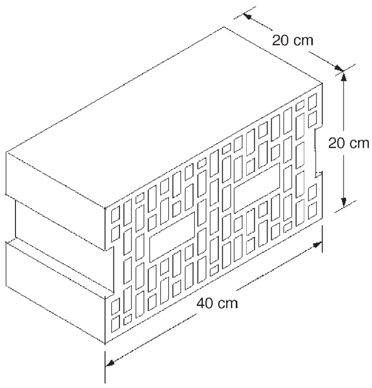

Figure 3-5. Figure of tested clay brick type 7

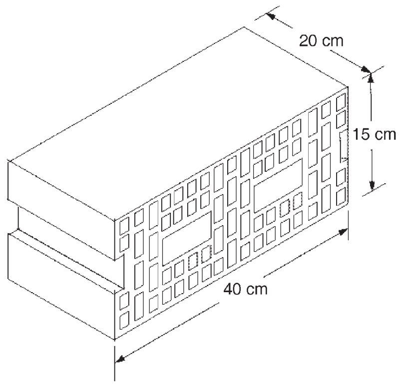

Figure 3-6. Figure of tested clay brick type 8

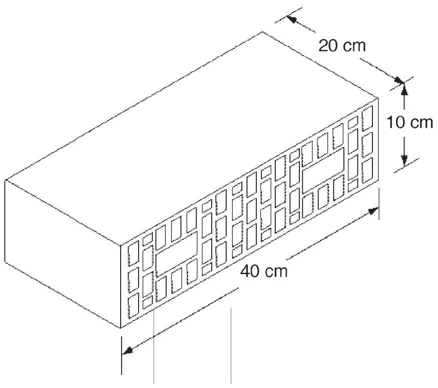

Figure 3-7. Figure of tested clay brick type 9

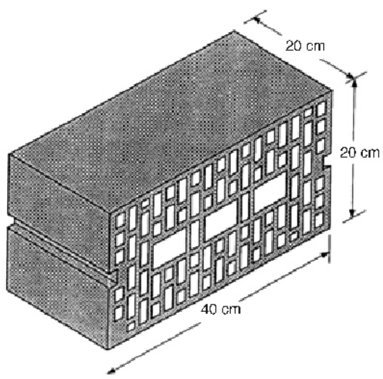

Figure 3-8. Figure of tested clay brick types 10 to 13 [3]

Type 10: Normal hollow red clay brick; ordinary concrete mortar;
Type 11: Type 10 with body added polystyrene insulation;
Type 12: Type 10 with body added perlite insulation;
Type 13: Type 10 with center holes filled w/polystyrene insulation

surface temperatures were monitored by a multi-channel programmable datalogger at hourly intervals. The arithmetic mean of the temperatures measured by these thermocouples on each side was used in calculation instead of those from hot and cold surfaces of the guarded hot-plate. The samples were covered with a blanket on both sides to have smooth contact with the plate surfaces. The sample temperatures were monitored till steady-state conditions were obtained. The equivalent thermal conductivity, k_{eqv}, for the test sample was calculated by the following equation:

$$k_{eqv} = \frac{(Q - Q_{ds})d}{A(T_h - T_c)}$$

where Q and Q_{ds} [W] are the heat flow through the main heater and dummy sample, respectively, d [m] – the thickness of the test sample, T_h and T_c [°C] – the hot side and cold side test sample temperatures respectively, and A [m^2] – the metered area of the heater.

Engineering Equation Solver software [13] was used to calculate the uncertainty in the equivalent thermal conductivity. The uncertainty in equivalent thermal conductivity lies in the

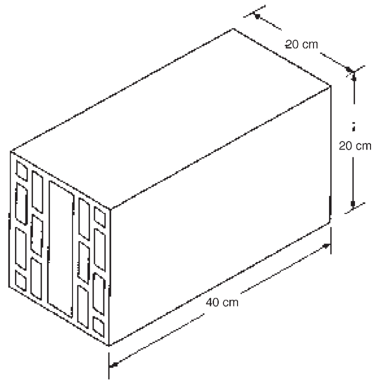

Figure 3-9. Figure of tested clay brick types 14 to 18 [3]
Type 14: Normal hollow red clay brick insulating mortar,
Type 15: Type 14 with center hole filled w/perlite+cement mix,
Type 16: Type 14 with center hole filled w/mineral wool insulation,
Type 17: Type 14 with center hole filled w/perlite+cement mix, ordinary concrete mortar,
Type 18: Type 14 with center hole filled w/mineral wool, ordinary concrete mortar

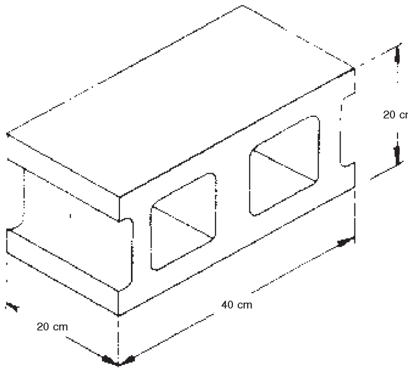

Figure 3-10. Figure of tested concrete brick types 19 and 20 [3]
Type 19: Normal hollow concrete brick, ordinary mortar,
Type 20: Type 19 with body added perlite insulation

range from ±4.06% to 5.65% of the tested brick samples. The total uncertainty in equivalent thermal conductivity of the tested samples lies in the range from 5.70% to 6.92%.

Results and discussions

The thermal performance assessment of the clay and concrete bricks, shown in fig. 3, is discussed in the present study in terms of configuration, material, and size on equivalent thermal conductivity. The tested bricks are classified into four groups details of which are presented in tab. 1. The criteria used for grouping the bricks were based on the configuration of the bricks, type of material used and size of the brick.

The equivalent thermal conductivity and thermal resistance values of the different types of tested clay and concrete wall samples are summarized in tab. 2. In the table, the results of our previous study [3] for clay and concrete brick types 10 to 20 are included to have comprehensive thermal performance analysis of the tested brick samples. The equivalent thermal conductivity of the tested brick wall samples varies between a minimum of 0.262 W/mK and to a

Table 1. Classification of bricks based on configuration, material and size

Group	Description	Brick types
1	Different configuration and size but same material	Clay brick types 4-9
2	Different configurarion and matertial but same size	Clay brick types 4, 7, 10-12, 14, 19 and 20
3	Same configuration and size but different materijal	Clay brick types 1-3, 10-13, 17 and 18; concrete brick types 19 and 20
4	Different configuraiton, size and mateial	Clay brick types 1, 4 and 8

Table 2. Thermal properties for the tested red clay and concrete brick wall samples

Sample type(1)	Description	Equivalent thermal conductivity(2) [$Wm^{-1}K^{-1}$]	Thermal resistane [m^2KW^{-1}]	Comments
Type 1 (clay)	Normal hollow red clay brick with ordinary concrete mortar	0.495	0.404	Current experimental data
Type 2 (clay)	Type 1 with body added polystyrene insulation	0.473	0.423	
Type 3 (clay)	Type 1 with center holes filled w/polystyrene insulation	0.419	0.477	
Type 4 (clay)	Normal hollow red clay brick with ordinary concrete mortar	0.504	0.397	
Type 5 (clay)	Normal hollow red clay brick, ordinary concrete mortar	0.400	0.375	
Type 6 (clay)	Normal hollow red clay brick, ordinary concrete mortar	0.338	0.296	
Type 7 (clay)	Normal hollow red clay brick, ordinary concrete mortar	0.452	0.442	
Type 8 (clay)	Normal hollow red clay brick, ordinary concrete mortar	0.378	0.397	
Type 9 (clay)	Normal hollow red clay brick, ordinary concrete mortar	0.402	0.249	
Type 10 (clay)	Normal hollow red clay brick, ordinary concrete mortar	0.382	0.524	Data taken from previous study [3]
Type 11 (clay)	Type 10 with body added polystyrene insulation	0.330	0.606	
Type 12 (clay)	Type 10 with body added perlite insulation	0.348	0.575	
Type 13 (clay)	Type 10 with center holes filled w/plystyrene insulation	0.339	0.590	
Type 14 (clay)	Normal hollow red clay brick, insulating mortar(3)	0.347	0.576	
Type 15 (clay)	Type 14 with center hole filled w/perlite+cement mix	0.316	0.633	
Type 16 (clay)	Type 14 with center hole filled w/mineral wool insulation	0.262	0.763	
Type 17 (clay)	Type 14 with center hole filled w/perliete+cement mix, ordinary concrete mortar	0.389	0.452	
Type 18 (clay)	Type 14 with center hole filled w/mineral wool, ordinary concrete mortar	0.382	0.378	
Type 19 (concrete)	Normal hollow concrete brick, ordinary concrete mortar	0.976	0.402	
Type 20 (concrete)	Type 19 with body added perlite insulation	0.489	0.409	

(1) See fig. 3 for graphical description of different types of brick; (2) Uncertainty lies in the range from 5.70% to 6.92%;
(3) Samples were prepared with insulating mortar

maximum of 0.976 W/mK, tab. 2. The brick sample with center holes filled with mineral wool insulation sheet (type 16) has the lowest equivalent thermal conductivity whereas the normal hollow concrete brick sample (type 19) has the highest equivalent thermal conductivity.

Effect of brick size and configuration on equivalent thermal conductivity

The effect of brick size and configuration on equivalent thermal conductivity of different types of brick samples having same material is presented in fig. 4. The figure shows two sets of equivalent thermal conductivity data for different brick material. The clay brick types 4, 5, and 6 are having same brick material 1 whereas the brick types 7, 8, and 9 have the same material 2 but different from that of the material 1. It can be seen from the figure that the equivalent thermal conductivity decreases with thickness for brick material 1. However, for brick material 2, the thermal conductivity for 10 cm thick brick is higher than the 15 cm thick brick. Hence, the bricks of thickness 20 cm and 15 cm belonging to material 1 have higher thermal conductivity as compared to the bricks belonging to the material 2. The 20 cm thick brick of material 1 has 11.5% higher thermal conductivity as compared to that of the material 2 brick (of same thickness). This analysis shows that the thermal conductivity does not depend only on the configuration of the brick but also on the material used for brick manufacturing.

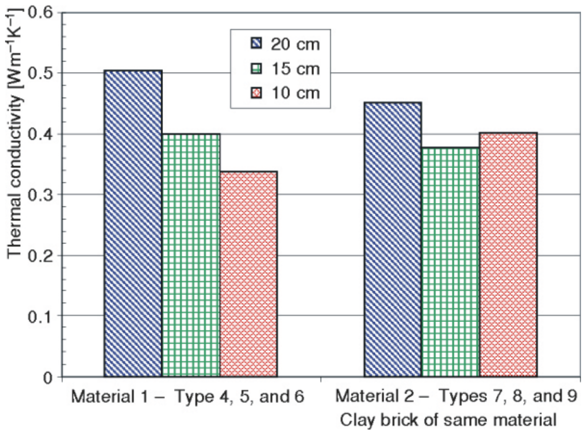

Figure 4. Equivalent thermal conductivity of clay brick samples having same material but different configuration and size

Effect of brick configuration and material on equivalent thermal conductivity

The effect of brick configuration and material on equivalent thermal conductivity of different types of brick samples having same size is investigated and the results are presented in fig. 5. The analysis is carried out for normal and lightweight clay bricks. The figure shows two sets of equivalent thermal conductivity data for normal clay brick types 4, 7, 10, and 14 and lightweight clay brick types 11 and 12. It can be seen from the figure that the equivalent thermal conductivity for the normal clay brick lies in

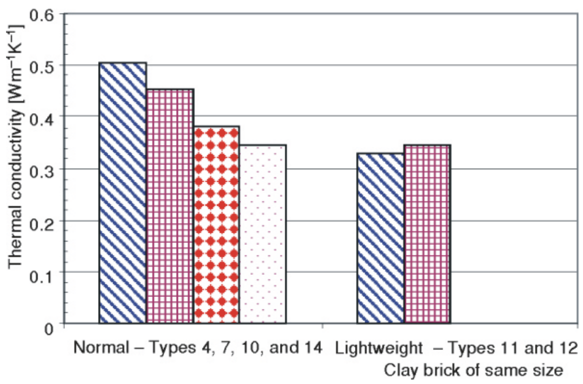

Figure 5. Equivalent thermal conductivity of clay brick samples having same size but different configuration and material

the range from 0.347 to 0.504 W/mK with an average value of 0.421 W/mK whereas for the lightweight clay brick it varied between 0.330 and 0.348 W/mK with an average value of 0.339 W/mK. The results show that there is large variation in the thermal conductivity values of the normal clay brick types. However, lightweight clay brick types have little difference in their thermal conductivity values. It is also interesting to note from the fig. 5 that the normal clay brick type 14 (with insulating mortar) is as good as the lightweight clay brick (types 11 & 12) from thermal consideration point of view. This analysis shows that the thermal conductivity depends on the configuration and material even though the size (thickness) of the brick is the same.

Effect of brick material on equivalent thermal conductivity

The equivalent thermal conductivity of different types of brick having same configuration and size but different brick material for clay and concrete bricks have been studied and presented in fig. 6. The figure shows three sets of equivalent thermal conductivity data for clay brick samples and one set for concrete brick samples. Each set of data is for bricks having same configuration and material. The analysis of the results shows that making the brick lightweight through the process of body-addition of insulating material in the brick causes reduction in equivalent thermal conductivity. Furthermore, insulating the brick through insertion of insulation material into the holes of the bricks also reduces the thermal conductivity and is more effective than the body-addition of insulating material in the brick as evident from the fig. 6 for first set of thermal conductivity data for clay brick. The type of insulating material used inside the holes of the brick does not have significant effect on the thermal conductivity as evident from the third set of clay brick data. However, significant reduction in thermal conductivity is observed for making the concrete bricks lightweight through the process of body-addition of insulating material. The thermal conductivity of lightweight concrete brick is reduced by about one-half of the normal concrete brick. This analysis shows that the bricks having same configuration and size, the thermal conductivity variation is large depending on the material used especially for concrete brick.

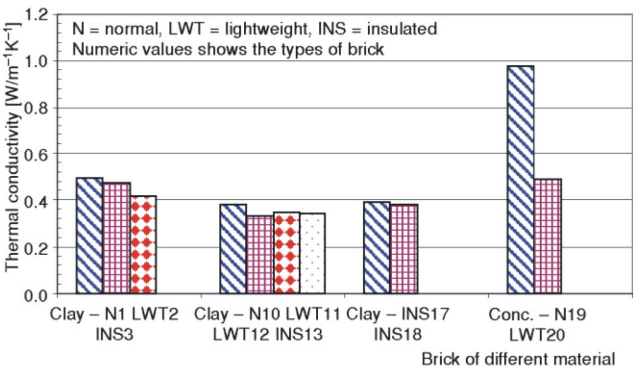

Figure 6. Equivalent thermal conductivity of clay and concrete brick samples having same configuration and size but different material

Effect of brick configuration, size, and material on equivalent thermal conductivity

In this section, the equivalent thermal conductivity of different types of clay brick having different configuration, size, and material is discussed in details. The equivalent thermal conductivity of different types of clay brick is presented graphically in fig. 7. The figure shows three types of clay brick *i. e.* type 1 (length = 30 cm, thickness = 20 cm), type 4 (length = 40 cm, thickness = 20 cm) and type 8 (length = 40 cm, thickness = 15 cm). The results show that the brick having different length but same thickness have almost the same thermal conductivity although the brick configuration and material are different. However, the 15 cm thick brick has lower thermal conductivity as compared to 20 cm thick brick. In general, the analysis of the results shows that the brick with less thickness has lower conductivity as compared to those having higher thickness. However, the effect of brick length on equivalent thermal conductivity is insignificant.

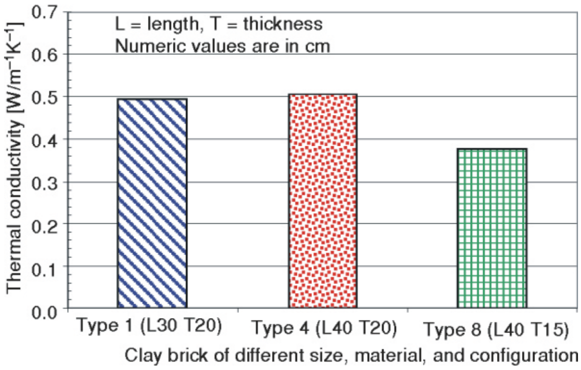

Figure 7. Equivalent thermal conductivity of clay brick samples having different configuration, material, and size

Life cycle cost analysis

An economic analysis has been carried to select the thermally efficient brick. The electrical energy used (E) by the air-conditioning equipment to meet the wall thermal transmission load is calculated by the procedure described in details in the literature [3, 14]. The following equation [3] is used to calculate the net present value (NPV) per square meter of brick surface area:

$$NPV = E \cdot PWF \cdot EC + BC \ \$/\mathrm{m}^2$$

where E [kWhm^{-2}] is the annual energy consumption, EC – the energy cost (4 cents/kWh), PWF – the present worth factor, and BC – the brick cost.

The following equation [15] is used for calculation of the present worth factor, PWF:

$$PWF = \frac{1}{i - e}\left[1 - \left(\frac{1 + e}{1 + i}\right)^n\right] \quad \text{for } e \neq i$$

$$PWF = n(i + e) \quad \text{for } e = i$$

where e is the energy inflation rate (3%), i – the discount rate (6%) and n – the lifetime of the brick (30 years). The parameters used in the calculation of PWF are the same as that reported in the previous study [3].

The NPV approach is used in the present study for economic analysis as the simple payback period ignores the influence of discount rate and cost escalation. The NPV for the tested brick samples are presented in tab. 3. The data for brick sample types 11 to 20 are taken from the previous study [3]. The purpose of inclusion of the previous data in the present study is to look at the performance of bricks in totality. It can be seen from the table that the NPV lies in the range from 36.9 \$/m^2 (clay brick type 16) to 97.8 \$/m^2 (concrete brick type 19). The economic analysis shows that the insulated clay brick type 16 (with center holes filled w/mineral wool insulation) is the most economical brick among the types of brick studied. Moreover, it is worthwhile to note that the normal concrete brick type 19 has NPV of 97.8 \$/m^2. Making the normal concrete brick lightweight (type 20), the NPV is reduced to a values of 53.7 \$/m^2 *i. e.* reduction in NPV by about 45.1%. This shows that the reduction in NPV of a normal concrete brick is very significant by making the brick lightweight.

Table 3. Net present value (NPV) for the tested brick samples

Sample type	Description	Annual energy [kWhm^{-2}]	Annual energy cost [\$m^{-2}]	Annual energy saving$^{(1)}$ [\$m^{-2}]	Brick cost [\$m^{-2}]	Increase in brick cost$^{(1)}$ [\$m^{-2}]	$NPV^{(2)}$ [\$m^{-2}]	Comments
Type 1 (clay)	Normal	60.09	2.40	2.33	8.25	1.63	54.5	Current study data
Type 2 (clay)	Body added insulation	57.39	2.30	2.44	10.75	4.13	54.9	
Type 3 (clay)	Insulated	50.90	2.04	2.70	11.50	4.88	50.7	
Type 4 (clay)	Normal	61.15	2.45	2.29	8.25	1.63	55.3	
Type 5 (clay)	Normal	64.74	2.59	2.15	6.75	0.13	56.6	
Type 6 (clay)	Normal	82.02	3.28	1.46	5.38	–1.25	68.5	
Type 7 (clay)	Normal	54.93	2.20	2.54	8.25	1.63	50.5	
Type 8 (clay)	Normal	61.15	2.45	2.29	6.75	0.13	53.8	
Type 9 (clay)	Normal	97.50	3.90	0.84	5.38	–1.25	80.4	
Type 10 (clay)	Normal	46.33	1.85	2.88	8.25	1.63	43.9	Data taken from previous study [3]
Type 11 (clay)	Body added insulation	40.06	1.60	3.13	9.38	2.75	40.2	
Type 12 (clay)	Body added insulation	42.22	1.69	3.05	10.75	4.13	43.3	
Type 13 (clay)	Insulated	41.15	1.65	3.09	11.50	4.88	43.2	
Type 14 (clay)$^{(3)}$	Normal	42.15	1.69	3.05	9.13	2.50	41.6	
Type 15 (clay)$^{(3)}$	Insulated	38.35	1.53	3.20	12.38	5.75	41.9	
Type 16 (clay)$^{(3)}$	Insulated	31.82	1.27	3.46	12.38	5.75	36.9	
Type 17 (clay)	Insulated	47.23	1.89	2.85	11.50	4.88	47.9	
Type 18 (clay)	Insulated	46.33	1.85	2.88	11.50	4.88	47.2	
Type 19 (concrete)	Normal	118.43	4.74	–	6.63	–	97.8	
Type 20 (concrete)	Body added insulation	59.36	2.37	2.36	8.00	1.38	53.7	

(1) Energy saving and increase in brick cost are obtained with reference to the noraml concrete brick (type 19) values. Energy cost is taken as 4 cents/kWh. Also, the energy and cost values are normalized to brick wall surface area

(2) *NPV* – Net present value or the total discounted cost (discount rate, $i = 6\%$; eneryg inflation rate, $e = 3\%$) over the lifetime of the brick ($n = 30$ years) [3]

(3) Brick samples were prepared with the insulating mortar

Conclusions

The thermal performance assessment of the clay and concrete bricks is discussed in the present study in terms of configuration, material, and size. The results of the previous study [3] for clay and concrete brick types are included in the present study to have comprehensive thermal performance analysis of the tested brick samples. The following conclusions can be drawn from the present study.

The equivalent thermal conductivity does not depend only on the brick material and configuration but also on the brick thickness.
The bricks having same configuration and size, the equivalent thermal conductivity variation is large depending on the type of material used, especially for concrete brick.
In general, the brick with lesser thickness has lower equivalent thermal conductivity as compared to those having higher thickness. However, the effect of brick length on thermal conductivity is insignificant.
The economic analysis showed that the insulated clay brick type 16 is the most economical brick among the types of brick studied. Moreover, it is worthwhile to note that the net present value (*NPV*) of normal concrete brick (type 19) is reduced by about 45% by making the concrete brick lightweight (type 20).

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