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# Low cost urban housing – thermal efficiency

# Assessment and improvement of the thermal efficiency of standard low cost urban housing in Metroville – 1, Karachi

## GUIDELINES FOR IMPROVING THERMAL COMFORT IN EXISTING HOUSES; RECOMMENDATIONS FOR DESIGN OF NEW URBAN HOUSING IN KARACHI

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**Structural Engineer, Mrs Rahooja, is a Principal Scientific Officer with the National Building Research Institute, Karachi and with her colleages, Mr Muzaffar Hasan and Mr Tanveer Saleem, describes their study into the thermal efficiency of low cost housing in the warm, humid climate of Karachi, with mean outdoor summer temperatures of 35°C.**

Mrs Rahooja, ingénieur du bâtiment principal au National Building Research Institute de Karachi, et ses collègues, Mr Muzaffar Hasan et Mr Tanveer Saleem, décrivent leur étude sur l'efficacité thermique des maisons à faible coûr dans le climat chaud et humide de Karachi (température extérieure moyenne en été: 35°C).

## Introduction

Buildings have the primary function of shielding the occupants and their goods and possessions. As a rule,. they should be planned so that satisfactory indoor climate conditions can be obtained, which is better than the constantly changing outdoor climate.

### Basic shelter

Developing countries like Pakistan are faced with the problem of basic shelter and housing which is beyond the reach of the ordinary person. The cost of construction is the predominant factor in the design of low cost housing, whereas thermal comfort is recognized as a secondary factor. In such a case, emphasis on the building form, exploitation of design and proper choice of building materials can improve and control thermal performance by simple means, without the use of mechanical ventilation or heating and air-conditioning system.

The decisions on planning, design and method of construction for thermally efficient building requires accurate information of weather and climatic conditions of the environment, viz. air temperature, mean radiant temperature, air velocity and air humidity. The combination of these parameters, with personal factors of the occupants, also helps to predict optimal comfort for the inhabitants of buildings.

## Objectives

This research is directed towards recommending proposals for improving the thermal conditions of low cost urban houses in Pakistan. As an initial step, the scope of this study is limited within the Metropolitan City of Karachi and considers a standard low cost urban house in Metroville-I, constructed on 80 sq. yds. (see Fig. 1).

The purpose of this case study is to assess the thermal condition prevailing in the test model house due to various integrating parameters and then to check the thermal response of the same model house by suggesting various improvement measures. The study is based on an analytical approach and its theoretical considerations are described under 'theoretical considerations.'

The evaluation of the thermal efficiency of a house depends on the following factors:

- Metrological data of the environment under study.
- The acceptable limits of thermal comfort/comfort indices for urban houses.
- Allowable limits of U-values for different elements of a housing building.
- Thermal properties of various building materials.

## Theoretical considerations

### Thermal model equation

The design variables that affect the thermal performance of a building are shape, massing, orientation, window sizes, glass types, shading, surface finishes, material properties ventilation and nature of occupancy. Considering the above-mentioned variables, a model equation has been prepared which is capable of assessing the thermal response of any house under study.

$$\Sigma Q = Qc + Qv + Qc\phi + Qs + Q_I$$

where heat gained/loss due to various factors are as follows:

$Q_c$ = Conduction
$Q_v$ = Ventilation/Convection
$Q_c\phi$ = Radiation from opaque surfaces
$Q_s$ = Radiation from glass surfaces
$Q_I$ = Internal equipment
$\Sigma Q$ = Total heat gained/loss

### Thermal analysis on the test model house

The thermal model equation has been employed to assess the thermal performance of the test model house shown in Fig. 1. The total thermal load (in watts) has been calculated due to heat gain by conduction, convection and radiation from walls, roof, glass, surfaces and openings.

In the analysis of this test model house, heat gain due to internal heat has been ignored due to the variation of occupancy rates and use of domestic equipments which depends on the user's requirements, from one house to another. However, internal heat may be considered when analysing individual cases of different houses.

The mean outdoor temperature for this study has been assumed to be 35°C, which is the average summer temperature in July for Karachi.

For warm humid conditions like Karachi, in order to maintain the comfort level within a house without any auxiliary cooling, the mean indoor temperatures should lie between 27.2°C and 31.1°C. Thus, the total heat gained by the test model house should not exceed 4182 watts.

Table 1 gives the details of the heat gained (in watts) by the individual rooms of the test model house due to various factors.

Table 2 shows the percentages of the heat gained by the test model house due to conduction, convection and radiation separately.

Similarly Table 3 gives the percentages of heat gained by the building elements, viz. roof, walls, glass surfaces and openings.

From these tables it is evident that almost 92% of heat is gained through roof and walls, due to conduction and radiation alone. Thus in order to improve the thermal efficiency of the test model house, it is imperative to improve the roof and walls by providing insulation or employing alternate and thermally efficient building materials.

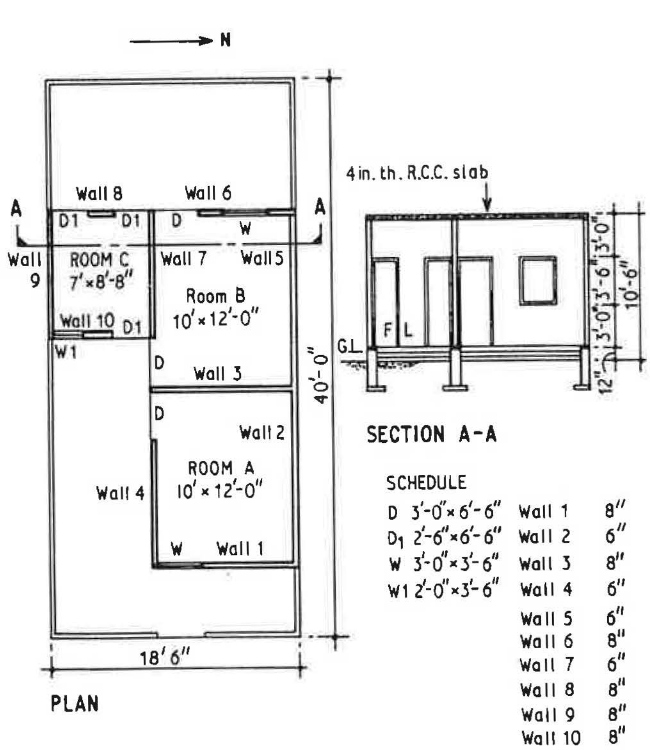


*Fig. 1a.* ***Test model house: a standard low cost urban house in Metroville, Karachi.***


*Fig. 1b*

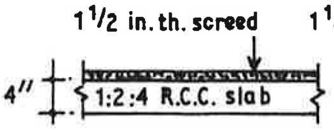


*Fig. 2*

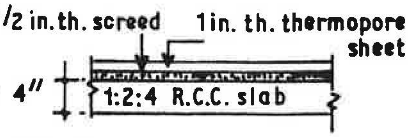


*Fig. 3*

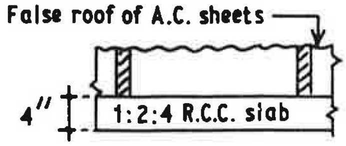


*Fig. 4*

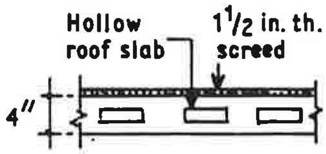


*Fig. 5*

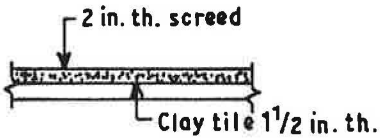


*Fig. 7*

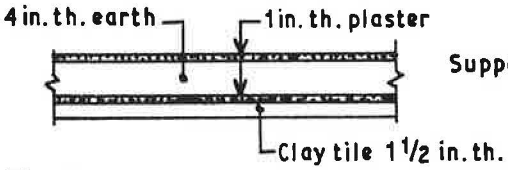


*Fig. 6*

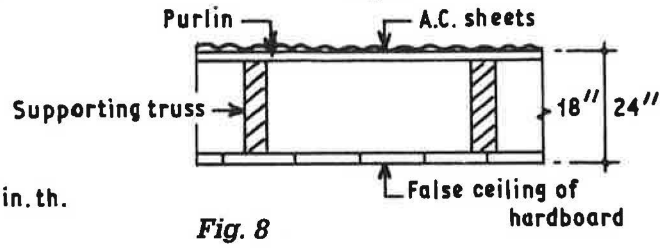


*Fig. 8*

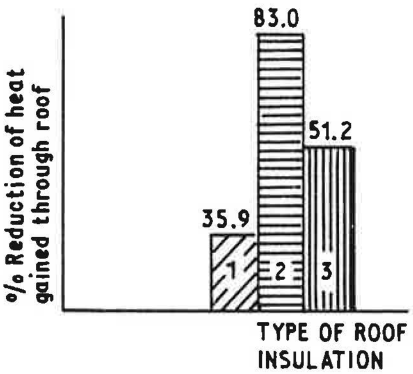


*Fig. 9*

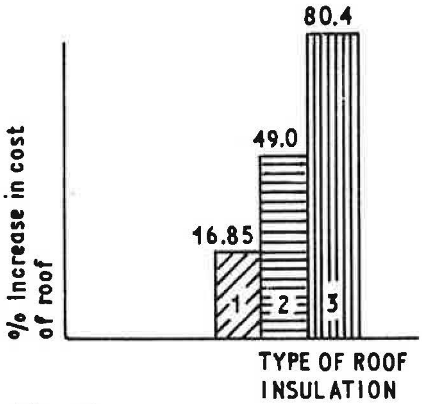


*Fig. 10*

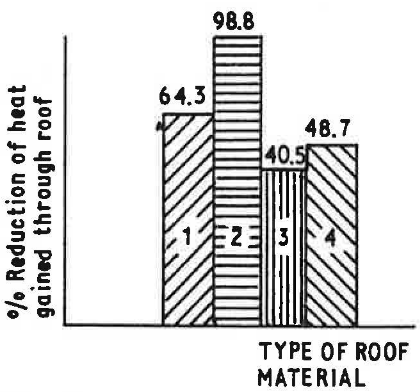


*Fig. 11*

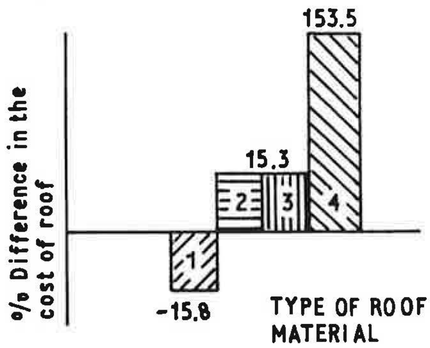


*Fig. 12*

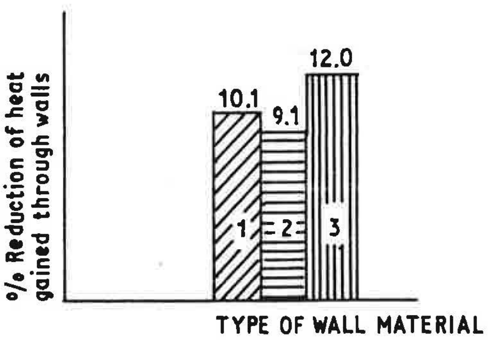


*Fig. 13*

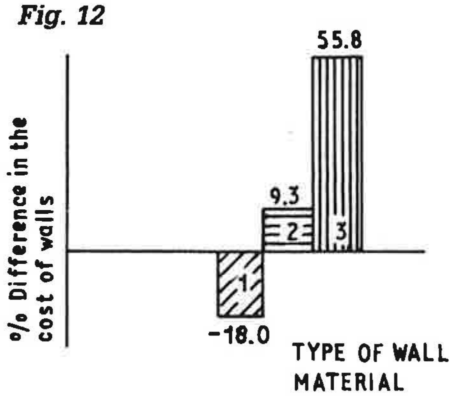


*Fig. 14*

*Table 1.*

| Room No. | Conduction $Q_c$ | | Convection $Q_v$ | Radiation $Q_c\phi$ | | Radiation $Q_s$ Glass | Total heat $\Sigma Q = Q_c + Q_v + Q_c\phi + Q_s$ |
|---|---|---|---|---|---|---|---|
| | Walls | Roof | | Walls | Roof | | |
| A | 623.26 | 436.5 | 132.5 | 743.14 | 1063.3 | 87.69 | 3086.39 |
| B | 498.65 | 523.91 | 159.02 | 607.25 | 1276.2 | 87.69 | 3152.72 |
| C | 460.10 | 274.9 | 83.46 | 578.44 | 669.6 | 58.50 | 2125.00 |
| Σq | 1582.01 | 1235.31 | 374.98 | 1928.33 | 3009.1 | 233.8 | 8364.11 |
| p | 18.9 | 14.00 | 4.48 | 23.06 | 36.0 | 2.8 | 100 |

where
Σq = Summation of heat gain
p = Heat gain wrt total heat gain

*Table 2.*

| % heat gained due to: | |
|---|---|
| Conduction | = 33.67% |
| Convection | = 4.48% |
| Radiation | = 61.86% |

*Table 3. Percentage heat gained by building elements*

| | |
|---|---|
| Roof | = 50.8% |
| Walls | = 42.0% |
| Glass surfaces | = 2.8% |
| Openings | = 4.48% |

## Thermal response of the test model house by improvement of the building elements

### Improvement of roof

The roof of the test model house is constructed with 4'' reinforced concrete 1:2:4 mix. As shown in Table 3, the heat gained by the roof alone is 50.8% of the total heat gain by the model house. To reduce this the thermal response of the roof has been studied by considering the following two cases:

*Case A*: By providing low-cost locally available insulation on the roof.

*Case B*: By employing alternate low cost roofing materials instead of the conventional 1-2:4 R.C. slab, as provided in the test model house.

### Case A:

The following types of insulation on the bare, 4" thick R.C. slab were tried for the study of this case (see Figs 2 to 4).

- 1½" thick screed on the 4" thick R.C. slab.
- 1½" thick screed and 1" thick thermopore sheets on the 4" thick R.C. slab.
- False roof of A.C. sheets on the 4" thick R.C. slab.

The thermal response by providing different types of insulation is shown diagrammatically in Fig. 5.

The extra cost required for providing different insulation on the roof is shown in Fig. 6.

### Case B:

The following alternative low-cost roofing materials were selected for the comparison of their thermal response, with the conventional roof slab of the model house (see Figs 7 to 10).

- 4" thick hollow roof slab (25% cavitation) with 1½" thick screed.
- Clay tiles 1½" thick with mud insulation.
- Clay tiles 1½" thick with 2" thick conventional screed.
- Trussed roof (steel) with asbestos cement roof cladding sheets and false ceiling of hardboard.

The thermal response by varying the roofing materials is shown diagrammatically in Fig. 11.

The cost of roof expressed in percentage increase or decrease, as compared to the cost of the basic roof slab of the model house, is shown in Fig. 12.

### Improvement of wall

The external walls, of the test model house are constructed with 6" and 8" thick solid block masonry (see Fig. 1a). As shown in Table 3, the heat gained by the external walls alone is 42.0% of the total heat gained by the model house. To reduce the total heat gain of the model house through the external walls, the following alternative types of wall materials were selected for comparison for their thermal response.

- Hollow block masonry 6" and 8" thick.
- Cavity brick masonry 11" thick (2" thick cavity).
- Cavity brick masonry 15½" thick (2" thick cavity).

The thermal response by varying the materials for the external walls of the model house is shown diagrammatically in Fig. 13.

Comparison of the cost of construction for different types of the external walls is shown in Fig. 14.

(Solid brick masonry 9" and 13½ thick have been ignored because the total heat gained increases as compared to the 6" and 8" solid block masonry external walls.)

### Combination of different roof types with different types of external walls

The descriptions of different roof types which have been combined with the various types of external walls are as follows:

- 4″ thick R.C. slab with 1½″ thick screed Fig. 2.
- 4″ thick R.C. slab with 1½″ thick screed and 1½″ thick thermopore sheets Fig. 3.
- 4″ thick R.C. slab with a false roof of asbestos corrugated sheets Fig. 4.
- 4″ thick hollow roof slab with 1½″ thick screed Fig. 5.
- Clay tiles 12″ × 6″ × 1½″, with mud insulation Fig. 6.
- Clay tiles 12″ × 6″ × 1½″, with conventional screed 2″ thick Fig. 7.
- Steel trussed roof with asbestos sheets as roof cladding and false ceiling of hardboard Fig. 8.

The thermal response of the model house has been studied for different combinations of roof/wall types. The percentage reduction in total heat gain and the mean indoor temperatures attained in the model house have been determined and are summarized in Tables 4, 5 and 6.

## Conclusion and summary of results

The description of the ideal combinations of different roof/wall systems are summarized in Table 7. It was

***Table 4. Different roofs with 6″/8″ thick solid block masonry***

| S. No. | Roof types | % Reduction in ΣQ | Mean indoor temp °C |
|---|---|---|---|
| 1. | Fig. 2 | 18.22 | 33.57 |
| 2. | Fig. 3 | 42.15 | 31.71 |
| 3. | Fig. 4 | 25.98 | 33.00 |
| 4. | Fig. 5 | 32.64 | 32.45 |
| 5. | Fig. 6 | 50.15 | 31.08 |
| 6. | Fig. 7 | 20.6 | 33.4 |
| 7. | Fig. 8 | 24.7 | 33.07 |

***Table 5. Different roofs with 6″/8″ thick hollow block masonry***

| S. No. | Roof types | % Reduction in ΣQ | Mean indoor temp °C |
|---|---|---|---|
| 1. | Fig. 2 | 28.32 | 32.8 |
| 2. | Fig. 3 | 52.25 | 31.0 |
| 3. | Fig. 4 | 36.04 | 32.8 |
| 4. | Fig. 5 | 42.74 | 31.67 |
| 5. | Fig. 6 | 60.25 | 30.3 |
| 6. | Fig. 7 | 30.7 | 32.6 |
| 7. | Fig. 8 | 43.8 | 31.58 |

***Table 6. Different roofs with 11″ thick cavity brick masonry***

| S. No. | Roof types | % Reduction in ΣQ | Mean indoor temp °C |
|---|---|---|---|
| 1. | Fig. 2 | 22.02 | 33.28 |
| 2. | Fig. 3 | 45.95 | 31.4 |
| 3. | Fig. 4 | 29.78 | 32.68 |
| 4. | Fig. 5 | 36.44 | 32.16 |
| 5. | Fig. 6 | 53.95 | 30.8 |
| 6. | Fig. 7 | 24.39 | 33.1 |
| 7. | Fig. 8 | 28.52 | 32.77 |

***Table 7. Different roofs with 15½″ thick cavity brick masonry***

| S. No. | Roof types | % Reduction in ΣQ | Mean indoor temp °C |
|---|---|---|---|
| 1. | Fig. 2 | 23.25 | 33.18 |
| 2. | Fig. 3 | 47.2 | 31.31 |
| 3. | Fig. 4 | 31.0 | 32.58 |
| 4. | Fig. 5 | 37.7 | 32.06 |
| 5. | Fig. 6 | 55.2 | 30.7 |
| 6. | Fig. 7 | 25.6 | 33.0 |
| 7. | Fig. 8 | 29.74 | 32.68 |

*Table 8.*

| S. No. | Description of roof/wall systems | q | c |
|---|---|---|---|
| 1. | Clay tiles 1½" thick with mud insulation and 6"/8" thich hollow block external walls. | 60.25 | 9.27 |
| 2. | Clay tiles 1½" thick with mud insulation and 15½" thick cavity brick external walls. | 55.2 | 44.9 |
| 3. | Clay tiles 1½" thick with mud insulation and 11" thick cavity brick external walls. | 54.0 | 22.5 |
| 4. | 4" thick RCC slab with 1½" thick screed and 1" thick thermopore, with 6"/8" external walls. (hollow b.m.) | 52.3 | 16.57 |
| 5. | Clay tiles 1½" thick, with mud insulation and 6"/8" solid block external walls. | 50.2 | 18.0 |

where: q = % reduction in total heat gain
c = Increase in the cost of roof and walls

determined that with these roof/wall combinations, the mean indoor temperature does not exceed the acceptable limits for comfort, i.e. 31.1°C for warm and humid climatic conditions prevailing during summers in Karachi. Table 7 also summarizes the percentage reduction in the total heat gain and the extra cost required for the construction of different roof/wall systems for the test model house, to make it into a more comfortable and thermally efficient dwelling.

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