Evaluation of the Thermal Performance of Low-Cost Tropical Housing

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Field measurements of the thermal performance of five low cost houses in Malaysia were carried out. Thermal simulation tests were performed on two of the houses, a traditional Malay village house, and a modern urban Cluster-Link house. The measured and the modelled results were found to agree, indicating a significantly higher overnight internal temperature in the modern house compared to the traditional house. The model was then used to predict the thermal performance of a new-design low cost house, which was shown to perform similarly to the traditional house type.

1. Introduction

The built form of the traditional Malaysian house (figure 1) is considered to be a prime example of environmental design in response to regional climate conditions. It has a low thermal mass, extensive solar shading, and a large number of ventilation openings. These features are well suited to the tropical climate of Malaysia, which exhibits high temperature and humidity with relatively small diurnal variations.

Yet, in general, modern low-cost housing in Malaysia (figure 2) has not followed the same design principles. In comparison with their traditional counterparts, they are of a relatively heavy-weight construction, they offer little solar shading or roof insulation, and they often suffer from low levels of natural ventilation. The environmental conditions produced by these types of housing are generally considered to be thermally unsatisfactory, and there has been a recent move towards the development of designs which offer the thermal performance of the traditional house, whilst using modern construction techniques and low cost materials.

This paper investigates the thermal performance of both traditional Malaysian and modern low cost houses, and assesses the extent to which traditional

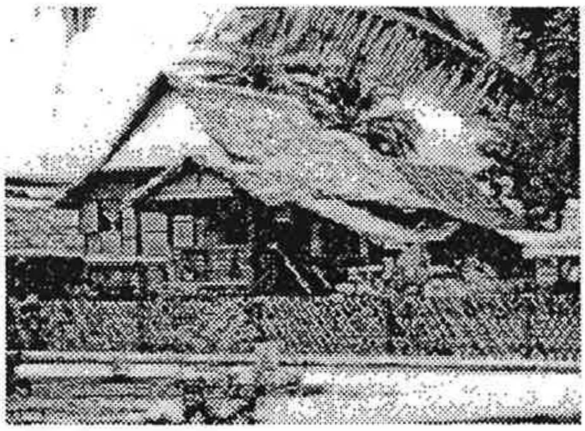

Figure 1 Traditional Malay House

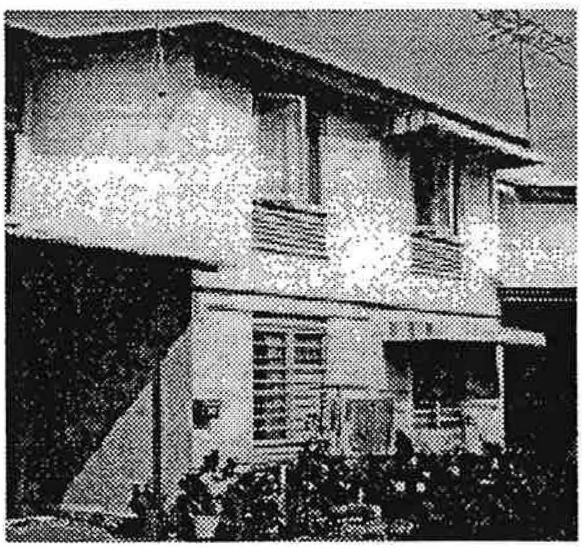

Figure 2 Modern Cluster-Link House

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climatic design principles can be successfully applied to modern low-cost housing.

The following method has been used in the study.

(i) the thermal performance of traditional and modern low cost housing has been monitored.
(ii) the building thermal model HTB2 has been used to simulate the performance of two houses, one traditional and one modern, and the results have been compared to measured data.
(iii) the thermal model has been used to assess the thermal performance of a newly designed low-cost house type, in which traditional environmental design principles have been applied.

This work has been carried out as part of a tripartite programme of work in Low Cost Housing, involving the Welsh School of Architecture, the Universiti Sians Malaysia, and the United Kingdom Building Research Establishment.

2. Thermal Performance Monitoring

The 'Welsh School of Architecture Environmental Logger' has been used to monitor the time varying thermal performance of five low-cost Malaysian houses (Rahman 1993). Two of these were traditional houses, one with a modern zinc roof, one with an attap (palm leave thatch) roof. The remaining three were modern houses, comprising a two story cluster house, a single story terrace house and a walk-up apartment.

In each house the Environmental Logger was used to monitor, in the main living area, the internal air and globe temperatures, relative humidity and lighting level. External air temperature was also recorded. The recorded data were supplemented with meteorological data recorded at a nearby station.

Each house was monitored for approximately one week. The measurements were carried out during the period 14th January - 19th February, 1991. The results of the measurements are summarised in Table 1.

In the three modern houses, measurement of infiltration rates were made through monitoring the decay of smoke which had been released into the interior space. Infiltration rates between 15 and 35 air changes per hour (Ac/h) were found.

In the traditional houses the measurement of infiltration rate was less successful, as it proved difficult to achieve the high initial concentration of smoke needed to reliably monitor a decay test, due to the very porous nature of the building envelope. The failure to provide the initial smoke concentration was an indication, however, of a lower bound for the ventilation rate for these houses, at approximately 30 air changes per hour.

The analysis of the measurements showed that during the daytime, for both the traditional and modern housing types, the internal air temperatures were higher than that of the outside, by up to 2.5°C. However, the thermal environments of the two types were significantly different at night, with the traditional houses cooling rapidly to near the external air temperature. The modern houses however retained a higher air temperature through the night, averaging about 2.5°C higher than outside temperature. This is illustrated in figure 3.

	Traditional Housing		Modern Housing		
	Zinc Roof	Attap Roof	Walk-up Flat	Cluster-Link	Terraced
Measurement Period	14/1 - 19/1	21/1 - 28/1	29/1 - 4/2	5/2 - 11/2	13/2 - 19/2
Global Hor. Solar (Wh/m2/day)	480	530	580	560	570
Mean External Temp (°C)	27.8	27.6	27.2	27.9	27.8
Mean Internal Air Temp (°C)	28.8	28.4	29.2	29.8	29.2
Max. External Temp (°C)	33.0	32.7	32.1	32.4	32.7
Max. Internal Air Temp (°C)	36.2	34.3	31.7	32.7	32.6
Max. Globe Temp (°C)	34.8	34.3	32.5	33.5	33.2
Min. External Temp (°C)	24.0	22.9	23.2	24.4	23.4
Min. Internal Air Temp (°C)	23.3	23.1	27.0	26.8	25.3
Max. Natural Light (Lux)	120	110	510	920	70
Measured Infiltration (Ac/h)	>30*	>30*	34	15	20

*estimated

Table 1 Measurement Results Summary

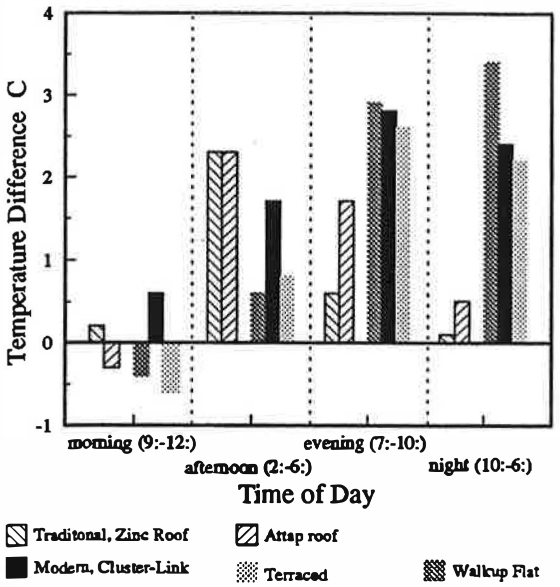

Figure 3 Period Average Inside to Outside Temperature Differences for the Measured Cases.

It was felt that this high night-time temperature was significant to the overall appraisal of the modern house type. Higher temperatures during the day could arguably be tolerated by occupants, but high temperatures at night could give over to feelings of discomfort.

3. Thermal Performance Modelling

In order to investigate further the differences in the thermal performance between the housing types, two houses, the traditional attap roof house and the modern cluster house, were chosen for modelling studies.

The monitoring project was intended as a means of investigating the thermal conditions in real buildings, not as a validation scheme for modelling and simulation. The modelling was seen as a way of investigating aspects of the buildings performance which were beyond the reach of the resources available to the field measurements.

The simulation code HTB2 (Lewis and Alexander 1991) was used for this study. HTB2 is a finite-difference dynamic thermal model, developed at the Welsh School of Architecture. It is able to assess the influence of fabric, ventilation, solar gains and shading on the internal thermal environment. It has been in use as a research tool in several institutions in the UK since 1985, and has been subjected to external appraisal and validation (Lomas etal 1991, Bloomfield et al 1993).

As a part of the tripartite research programme, the code was scrutinised and verified as suitable for use for tropical climates (Hanafi 1992). This involved, for instance, verifying the solar and geometrical algorithms for use near the equator, and collating appropriate material and construction properties. As part of this work a detailed solar radiation model (Hoyt 1978) was adapted, as being suitable for determining diffuse and direct beam components from measured global solar radiation under tropical sky conditions.

The available data on building constructions and dimensions were sketchy, as often the case in the simulation of real buildings. This work was therefore approached as the simulation of generic types. The description data for the simulations were therefore not highly detailed. For instance, only two zones were considered; the main living area where measurements were taken, and the rest of the building. Approximate wall areas and general material and construction properties were determined from notes, measurements and sketches made on site. Shading parameters were determined from the building geometry, and a high level of site obstruction (i.e. an effective horizon of 20°) was assumed. Fixed day-time ventilation rates were assumed from table 1, these were reduced at night to 5 air changes per hour to account for the closing of windows, shutters, and internal doors.

The results of the modelling are summarised in figures 4 and 5 for the traditional and modern houses respectively. These show both the individual day temperature cycles, and an "averaged" day, for the measured internal, simulated internal, and external air temperatures . The results show a reasonable agreement between the measured and modelled results, particularly in the light of the limited building data available. The divergence between the measured and modelled cases were typically less than 1°C. More importantly, the patterns of period averaged inside-outside temperature differences observed in the field measurements (figure 3) were also replicated in the simulation results, as shown in figure 6.

Beyond the simple agreement with the measurements, the modelling process also allowed the estimate of the energy pathways of the two house types. This is illustrated in figures 7 and 8, where the time-varying heat flows through the structure, and through ventilation and solar gains, are shown as heat gains to the space, for an averaged day.

As seen in these graphs, the energy flows overall were of a much lower level for the traditional house than those for the modern cluster house. It would appear that in the modern house the energy flows were driven largely by the solar gains to the interior. In the traditional house, the solar gains were calculated as being very much smaller than those of the modern house, indicating the efficacy of the shading of the traditional design. Sensitivity tests on the modelling results for the traditional house indicated that the measured temperature pattern could be replicated only if all direct solar gains were excluded from the interior, leaving only the ground reflected component. It was noted from the measurements that, indeed, the internal lighting levels for the traditional house were very much lower than those of the modern cluster

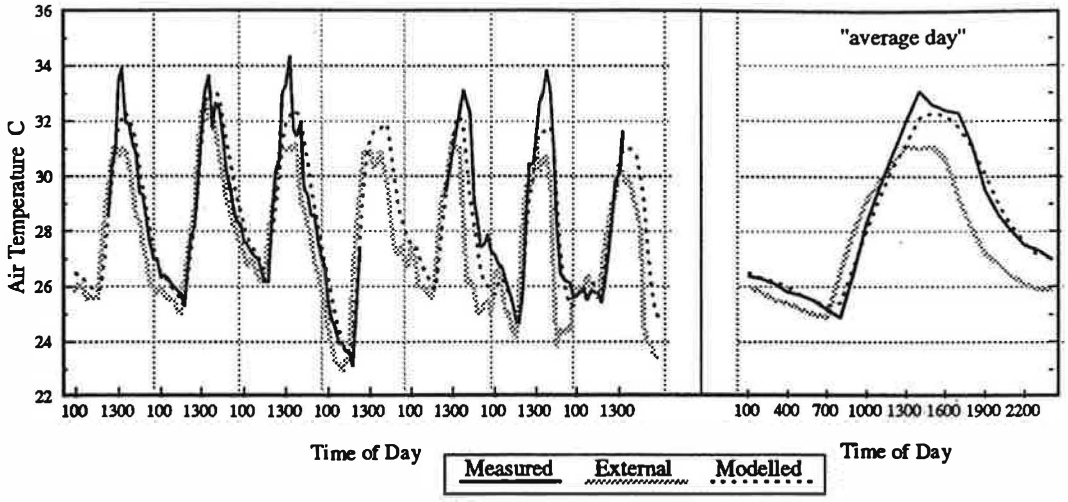

Figure 4 Comparison of Measured and Modelled Air Temperatures in Main Living Space; Traditional Attap Roof House

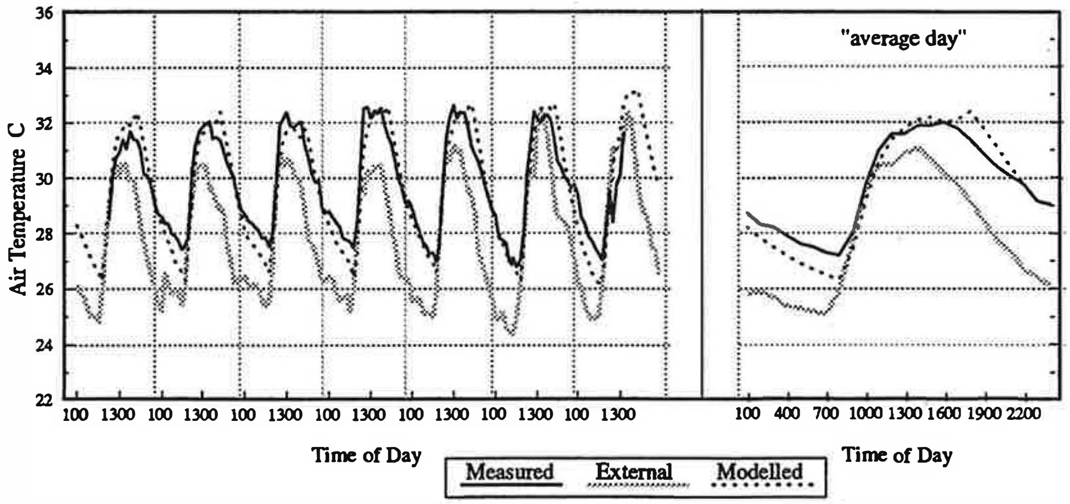

Figure 5 Comparison of Measured and Modelled Air Temperatures in Main Living Space; Modern Cluster-Link House

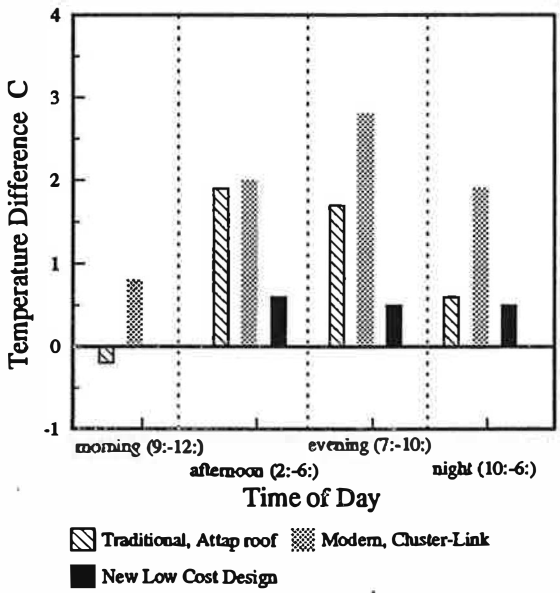

Figure 6 Modelled Period Average Inside to Outside Temperature Differences

house (table 1), underlining the effectiveness of the shading in practice.

The simulation results also highlight the effect of the different constructions between the two houses. In the traditional house, the lightweight floor played little part in the overall energy flows. The attap roof of the traditional house appeared to isolate well the interior from indirect solar gains, insulating and absorbing the solar radiation, re-radiating to the night sky and only admitting a small amount into the building after a few hours delay. The lightweight walls admit energy during the day, but store little energy for later release to the interior at night.

In the modern house however, the heavier thermal weight of the walls and floor absorb the extra solar radiation during the day, and then release much of it back into the space at night. This would appear to be the dominant factor in keeping night-time temperatures high. The modern house is a two-story design, so that the roof has no direct role in the ground floor space. The upstairs however is heated considerably by

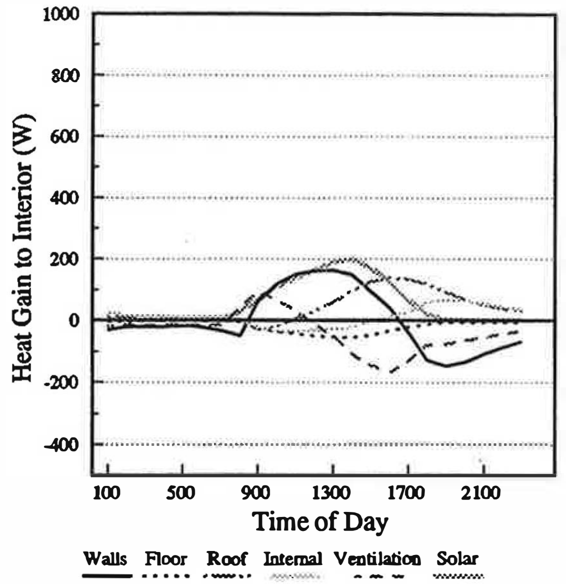

Figure 7 Modelled Energy Flows for Average Day, Traditional Attap Roof House, Main Living Space.

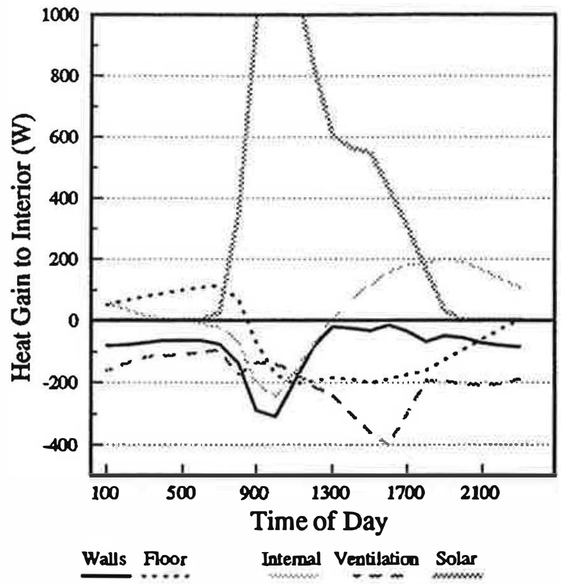

Figure 8 Modelled Energy Flows for Average Day, Modern Cluster-Link House, Ground Floor.

the roof, and this excess heat does filter down, through the structure and through inter-zone air movement, again warming the spaces at night.

4. Thermal Performance Modelling of a New Design House

As part of the tripartite project, the design principles of traditional housing have been researched and investigated. These investigations have identified a number of design features that act to reduce internal temperatures and direct solar gain (Hanafi 1992).

A modern low cost house was designed to accommodate the following features in order to reduce internal air and radiant temperatures. These features included:

- large amounts of solar shading,
- an insulated roof structure, incorporating a ventilated air cavity,
- the use of relatively low thermal mass constructions, i.e. ferro-cement walls,
- a good distribution of openings, allowing high ventilation rates to be achieved.

It was required, on the grounds of cost and conservation, that these features were to be provided using modern materials and construction techniques. Whilst the traditional design may be a paragon, its' reliance on now scarce natural resources make it inappropriate for mass replication.

A plan and section of the proposed design are shown in Figure 9. A summary of results of the simulation tests on that design are shown in Figures 10 and 11, as

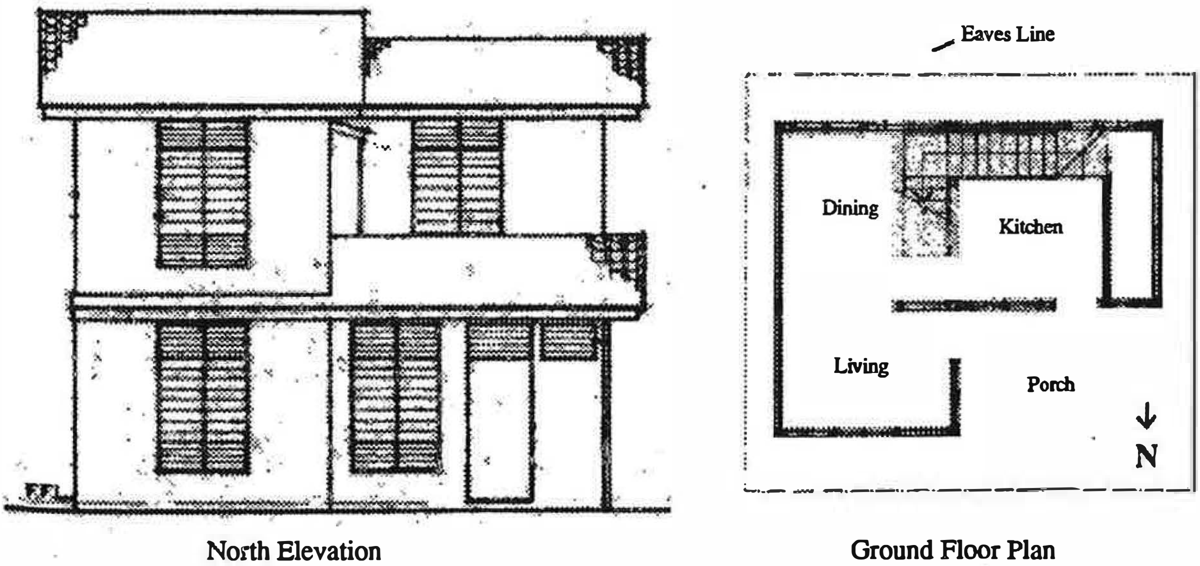

Figure 9 Proposed Low Cost Housing Design (Universiti Sians Malaysia 1992)

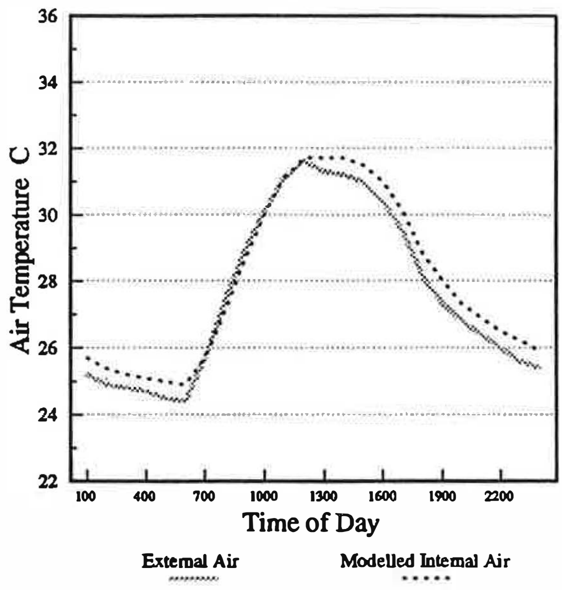

Figure 10 Modelled Air Temperatures for Average Day, Proposed Low Cost House, Ground Floor.

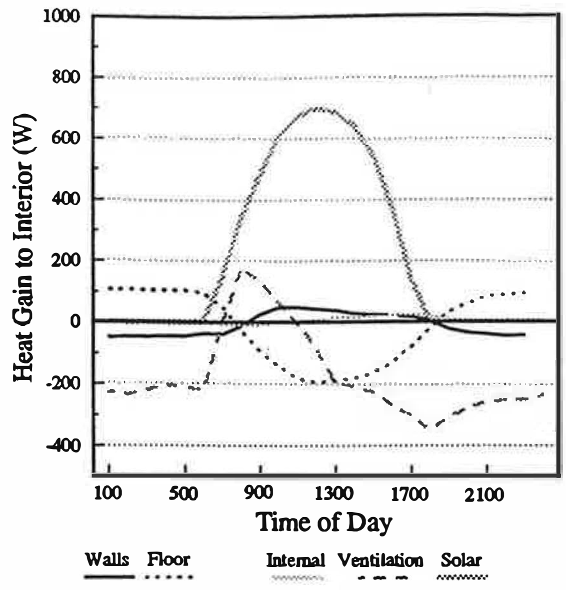

Figure 11 Modelled Energy Flows for Average Day, Proposed Low Cost House, Ground Floor.

averaged day temperature and heat flow profiles for the main living area, for a January-February period.

The simulation for these tests was carried out using the same nominal location and level of detail as for the previous two cases. The daytime infiltration rate was thought likely to fall between the very high levels of the traditional house, and the low levels of the cluster house; 20 air changes an hour was assumed.

Analysis of the simulation results, in comparison to the results for the traditional and modern houses, show that the new design house has indeed followed the performance characteristics of the traditional house, in particular with respect to cooling at night. Thus it was considered that this design should allow good thermal performance whilst allowing the use of modern materials and techniques. Whilst there is a greater thermal mass in this design than in the traditional house type, the effect of increased shading and ventilation rates (as compared to the modern house) has reduced the adverse effect of that thermal mass during the night period.

This new design, and the Cluster-Link house, are two story houses; the sleeping areas are upstairs. Due to heat gains through the roof structure, these upstairs spaces may have higher temperatures than those on the ground floor. Figures 12 and 13 show the modelled averaged day air temperatures for the upstairs rooms for these two houses. The modelled air temperature for the ground floor space are also in-

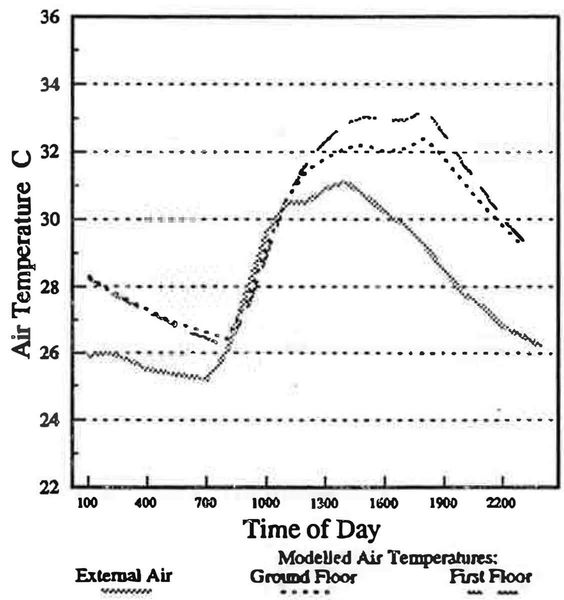

Figure 12 Modelled Air Temperatures for Average Day, Cluster-Link House, Showing Upstairs Rooms.

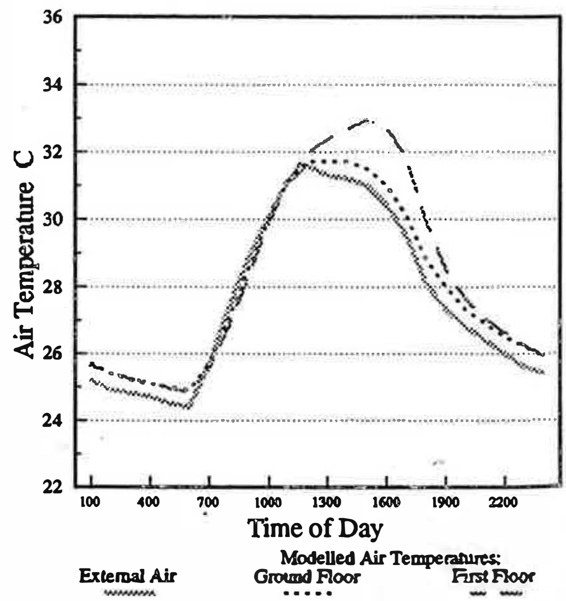

Figure 13 Modelled Energy Flows for Average Day, Proposed Low Cost House, Showing Upstairs Rooms.