Passive thermal design strategies for improved thermal comfort in schools in Pakistan

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This paper gives an account of a project to test the effectiveness of simple passive strategies to improve thermal comfort in Government Primary Schools in Pakistan.. Changes for improved thermal performance were carried out on five schools which were monitored both before and after modification. Schools are simple and minimally serviced. Improvements were controlled (as far as possible) to one strategy per classroom to make evaluation as straightforward as possible. An effectiveness score for a range of options has been developed.

1.Introduction

A range of factors, including concern over climate change, lack of user satisfaction with buildings that do not allow local control (Bordass, 1996, Rowe1994) and increasing acceptance of the Adaptive model (Nicols et al 1994) combine to increase interest in passive thermal design of buildings and make a study of this sort particularly relevant. The research is directed towards providing quantitative justification for the use of passive thermal techniques which could have positive impacts on comfort and fuel use in Pakistan and other countries with similar climates.

2. Background information about Peshawar.

Peshawar is in North West Frontier Province, on the north west edge of Pakistan, adjoining Afghanistan, close to the Kyber pass, see figure 1. The climate is composite, hot in summer with a short monsoon season and uncomfortably cold

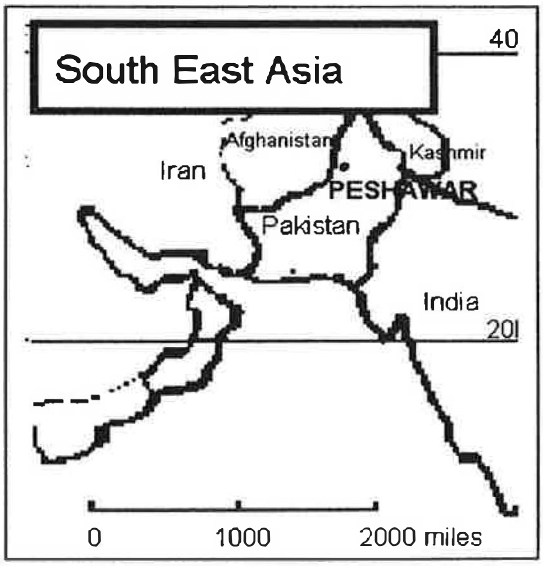


Figure 1 **Map to locate Pakistan and Peshawar (34degN)**

Humphrey's formula has been demonstrated to represent adult comfort temperatures in a free running building but no work has been done on child comfort temperatures. It has been established that air movement can effectively increase the onset of discomfort by 3 -4 K in summer conditions. In most of the classrooms there are two ceiling fans generating some modest amount of air movement for some of the children so the line plotted on the graph, figure 2, (May to October) represents an anticipated maximum comfort temperature in classrooms. In a free running building with no active thermal strategies, it is not possible to achieve an average temperature less than the monthly mean so achieving comfort conditions through the hottest months will rely on air movement.

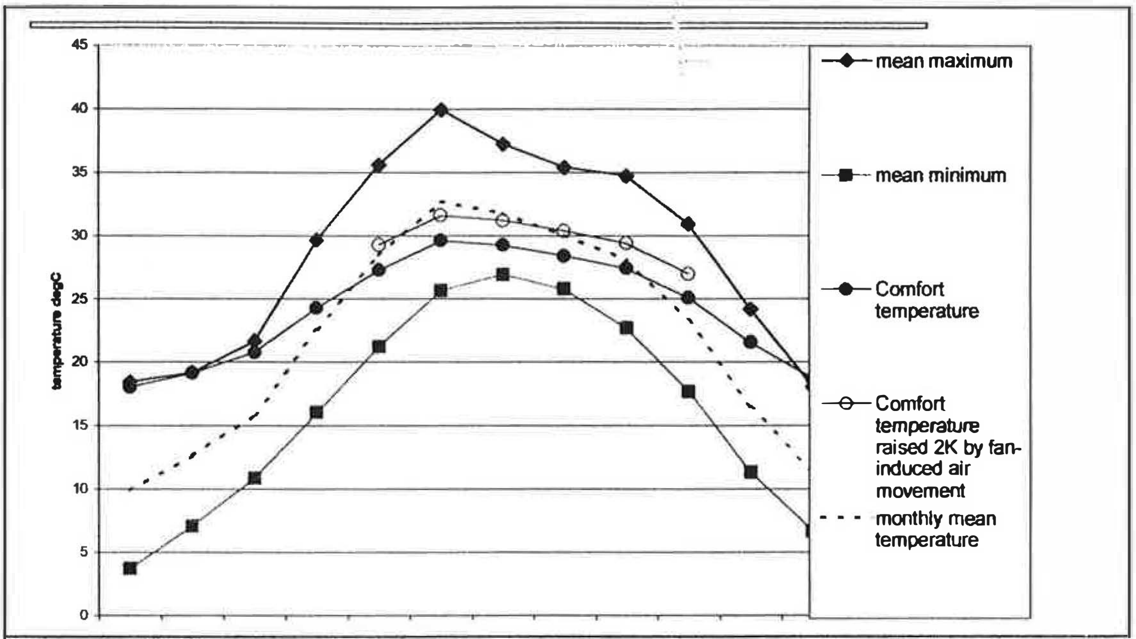


Figure 2 Peshawar; mean monthly maximum, minimum and monthly mean outdoor temperatures, 1986 data, plotted with indoor comfort temperatures

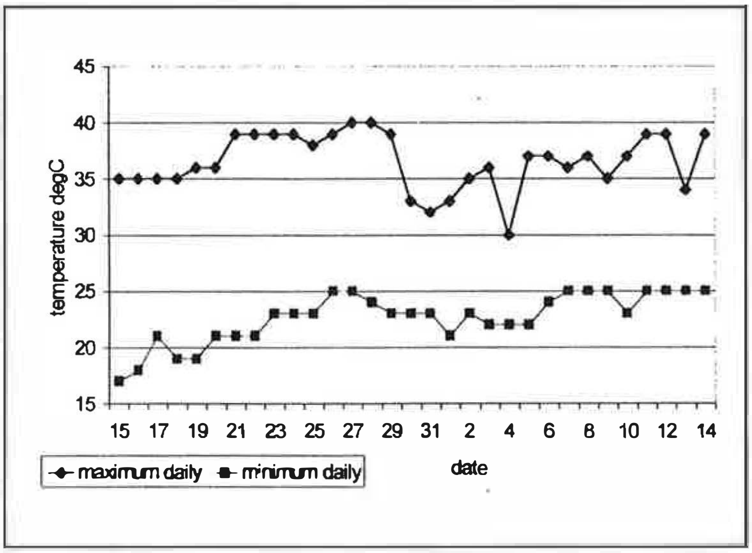
Comfort temperatures plotted on the graph, figure 2 (and subsequent graphs) are derived from the formula developed by Humphreys

$T_c = 12.1 + 0.534 \left(T_{\text{monthly mean max}} + T_{\text{monthly mean minimum}} \right) / 2$ (Humphrey 1978)

It was observed from Meteorological data that the largest diurnal variation occurs at times of maximum day time temperature.(see figure 3) This has encouraged investigation of the effectiveness of night time cooling.

Figure 3 Peshawar:

Met. Office data Mid May-Mid June 1997 At seasonal maximum the diurnal variation falls within range recommended by Givoni for night cooling



3. Background Studies

In 1995 a preliminary investigation of schools in Peshawar, funded by the British Council, established that classrooms deemed unsatisfactory by the teaching staff in summer conditions had common features

- windows facing east or west
- rooms immediately under a roof
- rooms without cross ventilation, even if fans were installed.

These points reinforced the traditional passive strategy of the importance of orientation. Rooms with east or west facing windows are difficult to shade from the sun's rays, because the sun is low in the sky; often the local choice is to draw the curtains (in one school to paint the window glass) and turn on the lights. Because the sun is high in the sky, the effect of roof insulation or shading is more significant than that of walls.

Ventilation with fresh air is important in these hot conditions where the rooms are crowded with children. Most of their heat loss at temperatures close to skin temperature would be achieved through evaporation of moisture from the skin.

4. Government schools in Pakistan

The construction costs of state schools in Pakistan are met by Government funds, but the site, specified to be a minimum of 1200 sq yds (1000 m^2) for a village school and half that for an urban school, has to be donated by the village. Thus the Education department have only a modest control over the choice of site (by power of veto) and it is not unusual for unfavourable sites- well away from the village centre or adjacent to graveyards etc to be adopted. Optimising the orientation of these buildings is not usually on the agenda.

There is an enormous programme to increase opportunities for education, particularly for girls, whose education has traditionally been very limited. Many new schools are currently planned or built, both Government and Aid funded.

Ventilation and daylighting levels are reduced by the almost inevitable location of the buildings tight on a boundary, to make the most use of the site area and its' development opportunities. The presence of fly screens and the lack of funding for school maintenance tends to further reduce daylighting and ventilation as poor maintenance leads to dust choked fly screens.

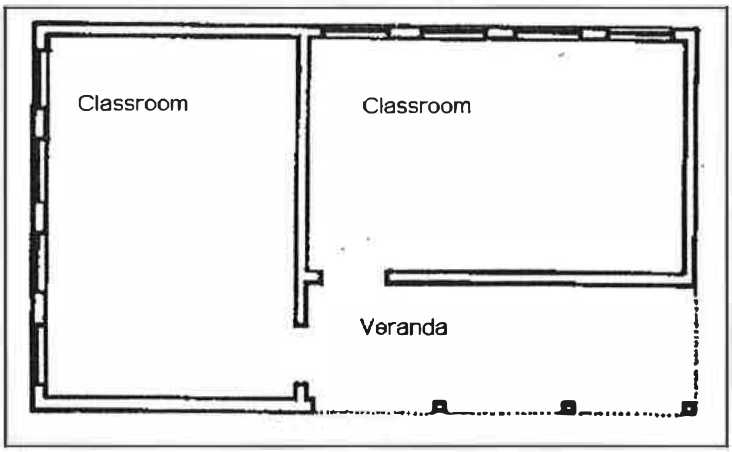


Figure 4 Plan of Model School. Orientation is not usually considered an issue in the siting of schools.

Many Government primary schools in Pakistan comprise two classrooms. Schools are built to a model plan (figure 4), each classroom is 16 x 25 ft (approximately 5 x 7.5 m), and 10'6" (3.2m) high. In the Peshawar area schools are generally brick built, with an external brick skin of approximately 9"(225mm) thick, plastered internally. The roof slabs are reinforced concrete, approximately 5" (125mm) thick, finished with either mud or bricks externally. The brick schools contrast with the surrounding village buildings which are usually made of mud. Schools have the advantage that they last longer: mud buildings require extensive maintenance immediately after each rainy season. The L-shaped plan seems an unfortunate choice for both orientation and ventilation; it was possibly adopted to minimize construction material used in building. This standardisation of design makes the buildings particularly suitable as test buildings and also means that any proven improvements in design strategy could be widely disseminated.

These two classroom schools cater for up to 200 children, divided into groups that are taught, some inside and some outside, by teachers and assistants. Conducting lessons outside is very common because conditions outside are often more comfortable than inside both in summer if shade under a tree is available (Kramer, 1960) and in winter when the thermal mass of the buildings tend to reduce temperatures, even when the sun shines. Children sit on the concrete floor, usually on hessian mats.

School are open in the morning, in winter from 8.30 - 1.00 p.m. and in summer 7.30 - 12.30 p.m. Culturally it is unacceptable to have mixed schools in Pakistan; the primary schools selected include two girl's schools(GGPS) and four boys (GBPS) The school year starts at the end of August, has a short break in December, extra holidays for Eid, and continues till the middle of June. If the weather is unusally hot (as has been the case in both 1996 and 1997) school will stop when the hot weather pattern is established (1996, mid May)

School	Description of school	Desc of classroom in programme	Passive thermal technique	Date.of compt of work
Behari Colony GBPS 230 pupils (1996) 270 pupils (1998) 5 teachers and assistants	Urban area school, 2 classrooms, south facing yard area with no shade so outdoor classes had to finish early in summer months, no latrines	Classroom with north facing windows	Roof awning and extract fans, secure fly screens. Enclosing wall to school that supported awning to external yard. Tree planting	May 1997 *Provision of ube well and latrines*
Saraband GBPS 200 pupils, 3 teachers	2 classrooms, both in programme., latrines, garden and vines providing shade to south facing veranda.	East facing classroom north facing classroom	insulated vertical fins that act as shutters 'air conditioning' tiles- a proprietary tile rec. by the army	February 1997 April 1998
Saraband GGMS 3 classrooms	3 classrooms, school office, teacher's latrine, large site including GGMS and GGPS (MS = Middle School)	south facing classroom	Clay pot roof insulation (replacement for roof at Sheikh Kali)	April 1998 *Provision of latrines*
Sheikh Kali GGPS, (MS on site) 250 pupils	2 classrooms	South facing classroom	Clay pot insulation (removed by over zealous building contractor) Terrazzo floor, reglazing	May 1997 *Four new classrooms built*
Mohib Banda 240 pupils 7 teachers and assistants	4 classrooms, forming an L shape. 3 face south but the windows are obscured by a 9ft wall across a 5 ft alleyway, no latrines	Classroom 1 Classroom 3 Generally	Screens and high and low level vents, and polystyrene 'warm' roof Polystyrene insulation internally Tree planting, refurbishing windows, security screens	May 1997 April 1998 April 1998 *Electricity supply and tube well*
Jogiyan 280 pupils (1996) 300 pupils (1998) 6 teachers (96) 7 teachers (98)	5 classrooms (2 when programme started) Original classrooms have cross ventilation, windows face east and west.	one classroom in programme	White painted roof	May 1997

Figure 5 Details of schools in refurbishment programme. Notes in *italics* indicate work completed during the course of this research with other funding sources, mainly local.
Schools were chosen from a selection offered by the Directorate of Primary Education,. see Figure5

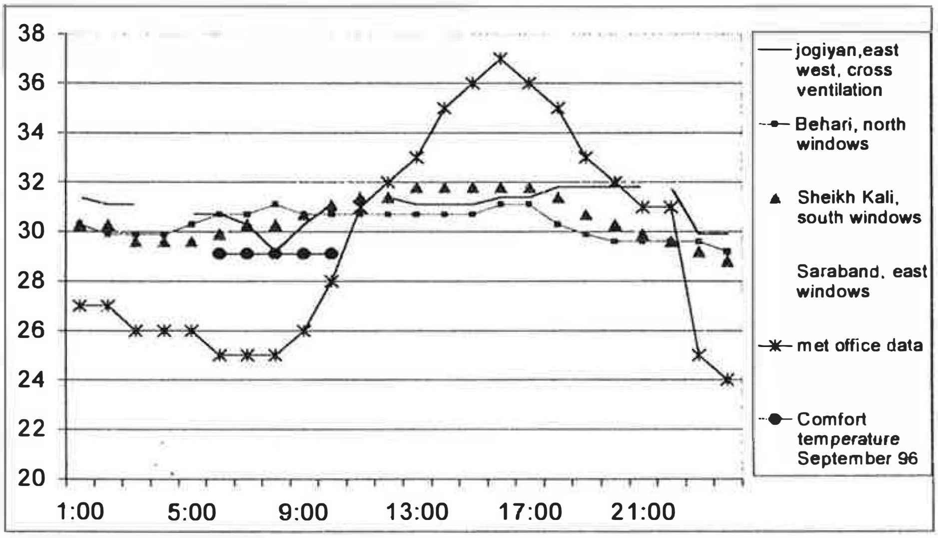


Figure 6 Classroom temperatures before refurbishment, September 17 '96
Comfort temperature is plotted for hours of school day and calculated from September temperatures.

It can be seen from figure 6 that comfort conditions would be within reach in September with the addition of effective air movement and some simple passive thermal strategies. Generally the east facing classroom (Saraband) is the hottest in school hours and the south facing classroom (Sheikh Kali) the coolest though this may be the effect of the damp floor. The classroom with cross ventilation (Jogiyan) seems to have benefited from cross ventilation in the early morning as the temperature drops sharply at the start of school.

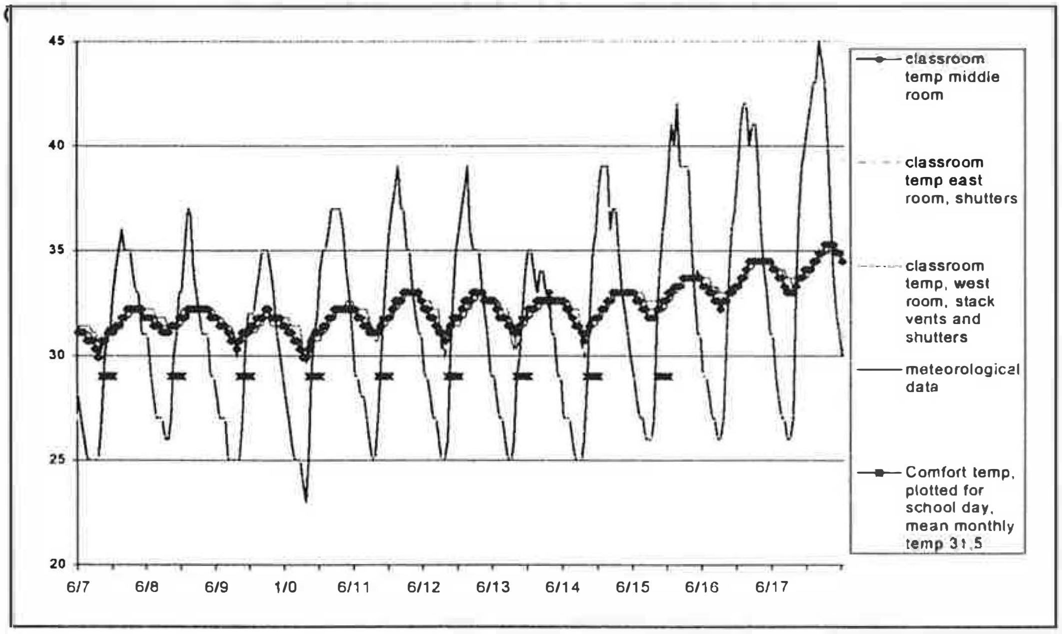


Figure 7 Temperatures in June 97 at Mohib Banda School

June temperatures in unmodified classrooms are only available for Mohib Banda where the roof insulation work was not completed until April 1998. Schools stopped for the summer holidays on 14 June 1997. It can be seen from the graph (figure 7) that the temperature after that date tended to rise as the external temperatures rose. Comfort temperatures are as plotted from Humphrey's formula and do not take into account air movement because fans are not usually used at Mohib Banda (electricity has only very recently been installed) and open windows do not generate any appreciable air movement in this school.. The heavy thermal mass of the building reduces the building cooling during the night but the time lag ensures that the school uses the building at the coolest time of day Electricity is now available at all the schools in the project and ceiling fans are used almost universally to increase thermal comfort in summer..

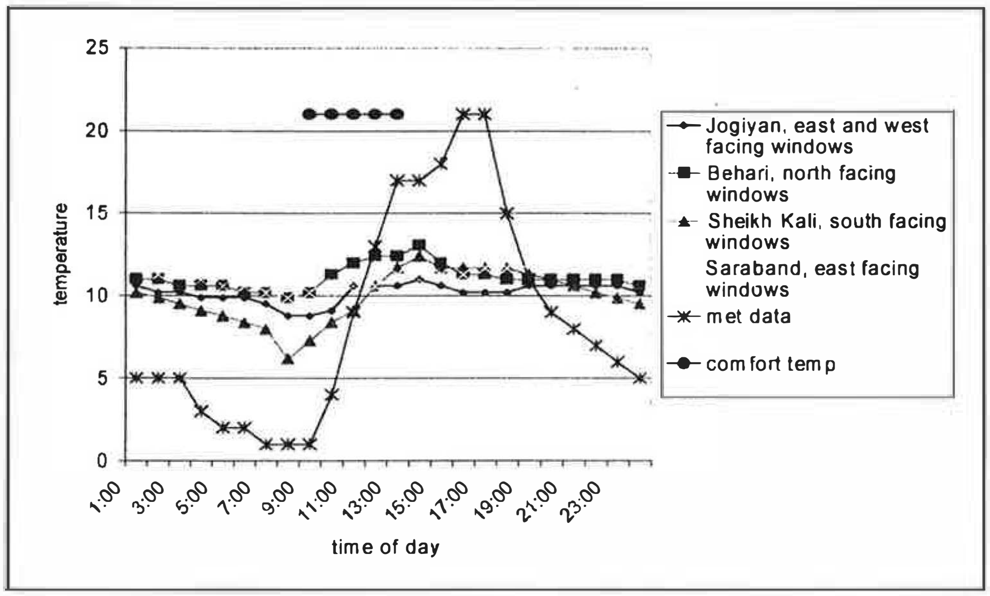


Figure 8 Temperatures inside classrooms on 10 December 1996, before modification

In the cold months of the year (figure 8) the temperatures in the classrooms are far from comfortable. Although the outside temperature remains low there is good solar radiation which means that outside conditions are comfortable. The schools perform much as the simulated data except that Sheik Kali, with its south facing windows, is the coldest in the school day. The floor at Sheikh Kali was extremely damp and it appears that any warmth in the classroom was lost in latent heat of evaporation.
Government schools do not have any heating devices. Most of the teachers regard the summer heat as a much worse problem than the winter cold: In winter several strategies are available to get warm- wearing more clothing, increased physical activity or going outside into the sun. By comparison the summer heat is relentless and inescapable.

5. Monitoring

The monitoring started at the beginning of September 1996, before any modifications were made to the schools; in this way 'before and after' temperatures were achieved.
Tiny Talk loggers were chosen. They were programmed to collect hourly data and therefore required down loading every three months. Down loading the loggers has proved quite difficult- the schools are spread over a wide area, lap top computers are not common in Pakistan and the act of downloading and restarting the loggers carries a certain amount of risk for the data.
Logger positions that would not inconvenience the class were chosen. The monitors were intended to remain in position for at least one year so it was important that they were well secured to the wall. For accuracy of results, it would seem more desirable to dangle the loggers in free space but in this position they would be too vulnerable for the months of logging that we expected to complete. (Finally the logging has stretched to nearly two years!) Two loggers were used per room, one at a height of one metre from the floor (head height for the children) and one at ceiling height. Cake tins were purchased in the bazaar and modified by a local trader, to include a hinge one side and a padlocked hasp the other, to conceal the internal loggers. The finished item was spray painted black! Generally the wall chosen for the loggers was that adjacent to the teacher's work position; this seemed to give some degree of protection but this restriction has resulted in a range of wall orientation for loggers including a mix of internal and external walls. Where this wall was a south-facing wall some attempt was made to insulate between the logger and the wall with glass fibre insulation

It was important to establish that the temperatures collected in the two points represented temperatures in the room and could be used as an indicator of comfort so a series of loggers were mounted in May 1997 to test classroom temperatures.

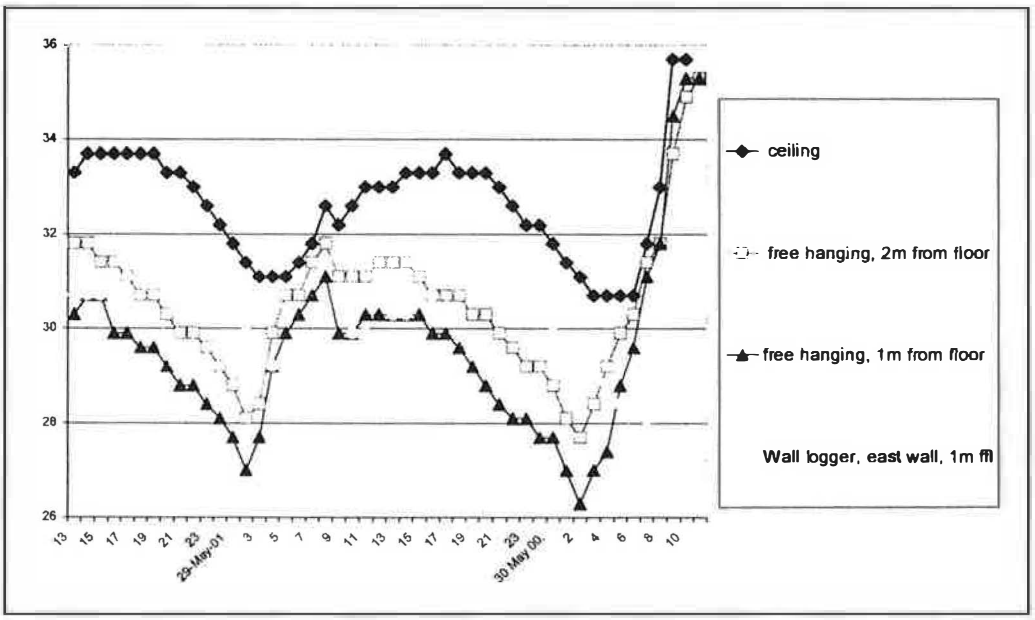


Figure 9 Comparison of wall and free hanging monitored temperatures in classroom at Sheikh Kali, 28-30 May 1997

It would seem from the graph (figure 9) that in the school day (7.30-12.30) the temperature difference between the wall logger and the free hanging one at the same height is small except early in the morning. The two temperatures at 1 metre from the floor are within 0.5K from 9.00-15.00hrs; establishing that, during school hours, wall temperatures are a reasonable approximation to the room temperature.

6.Methodology

6.1. Identification of suitable schools

Originally it was intended that passive design improvements be included at the design stage. At that time a wider range of options is presented, particularly orientation. The uncertainties of the Government building programme led us to reconsider this and to plan refurbishment of selected schools. Containing the research in refurbishment has the advantage that we have been able to identify the exact cost of any strategy and to control the programme. Modifications to a range of classrooms in the same school might have been desirable but this was not possible because the schools are small. Also because of the general shortage of money available for school improvements in Pakistan, it was thought fairer to share the available money round a number of schools. This strategy, though not part of the thermal strategy, has been effective and the interest and involvement has improved the schools in the programme far beyond the money spent. In total approximately Rs 20,000 (£3000) has been spent modifying the six schools.

6.2. Simulation

Schools were identified in August 1996 and simulation exercises, using the model 'Quick',(Matthews,1994) undertaken to guide the choice of strategies for practical testing. The model is intended for use as a design tool; information on climate (hourly temperatures and diffuse and direct radiation) occupancy and internal gains, construction, ventilation (an air change rate) can quickly be entered into the analogue programme. It calculates resultant temperatures for a typical hot or cold day for a single zone. This suits very well both this climate and building type.

No testing has been carried out on the thermal performance of construction materials in Pakistan; any values used were therefore based on information for similar materials in different climate conditions. Mud, which is frequently used as a roof insulation, was difficult to catalogue from a thermal point of view. Strategies of planting for increased comfort were not possible to simulate and their improvement in comfort conditions is likely to be too long term to register in the monitored data.

6.3. Techniques chosen

It was important that any strategy considered should be cheap to execute so a ceiling of 10 % of the classroom cost was imposed (around Rs 30,000 i.e. £500)

Refurbishment strategies have concentrated on improving roof performance and increasing ventilation rates. A range of six roof treatments have been investigated, one a simple painted coat, two using local materials (a canvas awning to shade the roof, and clay pots used locally for washing) and three using oil-dependant insulating materials. The first three are reported here and latter three will be reported at a later date.

In the simulation exercises increased ventilation was very effective at reducing room temperatures; however it has proved in practice quite difficult to achieve this increased ventilation. More windows to provide cross ventilation seemed an obvious first step in the schools but this has not been easy..

6.4 Practical refurbishment

Work was achieved in close co-operation with the caretaker at each school. Competitive prices were obtained where possible; in Pakistan everyone has a friend who could do the job so generally finding workman to execute the task was easy. Where the task was different from usual practice, for example insulating the roofs, careful supervision was required.

Roofs The simplest improvement was to paint the roof. Although the roof surface at Jogiyan was finished with cement render, problems were encountered with the porous roof surface which increased the cost of this option.

At Behari Colony a covering to shade the roof was proposed. The roof has a parapet and so it was fairly simple to lay an awning across the roof, held off the roof by the parapet and as necessary at mid span with loose bricks. This has proved very effective, particularly as in the project an awning for the open yard was also provided, cooling the air immediately in front of the building and providing shelter for the junior classes who had previously had to go home early on the hottest days.

The Girls school at Sheikh Kali was insulated with a roof of upturned washing pots. The pots, which are about 125mm deep and 450mm diameter, were made by the local potter as washing bowls. They have the disadvantage that they are heavy and quite difficult to transport. It was disappointing that the bowls cost about the same as a 50mm polystyrene layer for a similar roof, particularly as they were removed from the roof by a local contractor after only a few weeks of monitoring. A second school is now proceeeding with the testing of this option.

Ventilation Contract supervision in school building in Pakistan is not good and therefore, although a ring beam surrounds the building at window head height, local people were not happy to make any large holes in the building fabric for the proposed windows. Three other options were tested for ventilation.

High and low level vents (brick sized and made of steel sheet, with a fly screen and a closing panel) were introduced at Mohib Banda to encourage stack ventilation as there is very little wind driven ventilation available in the rather tightly packed village buildings.

Extract fans were installed at Behari Colony to pull air through the building.

Secure fly screens were installed at Behari Colony and Mohib Banda to encourage the caretakers to leave the windows open at night. (sealing up the building when the children leave at lunch time until the following morning is regarded as good practice from a security viewpoint but tends to prevent any night time cooling.)

The ventilation options have not been installed for long enough to report on their effectiveness but teachers report that the high and low level stack ventilation openings work well.

Maintenance. work was also required at some schools

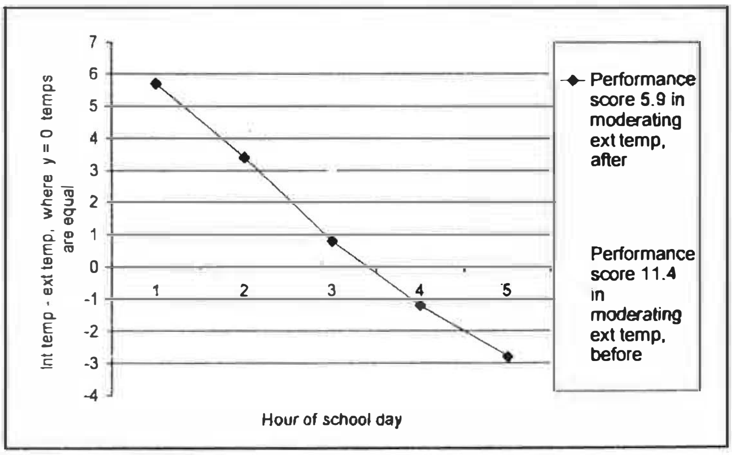
Behari Colony School, a town school was in fairly poor repair. An enclosing wall to reduce distractions and to keep out passing oxen was urgently required by the teachers. This was provided in the thermal work; it acted as a support for the awning which shades the yard, and also improved security. The school installed a tube bore water pump in the autumn of 1997; this is a huge improvement because plants are now growing and improving the harsh environment round the school and also because it has now been possible, through a special environmental grant, to install pour- flush latrines.

Sheikh Kali, in Charsada, was also in poor repair. The floor in the classroom was very damp and the hessian mats smelt unpleasant. The floor was replaced with a terrazzo floor with damp proof membrane; this gives satisfaction to the teachers but probably increases summer temperatures. Glazing was replaced (helpful in the winter but less so in the summer if teachers do not open windows)

7. Results

The research has been carried out with the intention of increasing the use of effective passive strategies in a country where comfort conditions are difficult to achieve in a significant part of the year. Disseminating the information to people not interested in making thermal calculations is important. A simple effectiveness rating has been developed. The rating is at present based only on monitored data. Using this rating it is possible to compare the effectiveness of a range of strategies and optimise strategies for new building or refurbishment in the area of Peshawar. The simple evaluation tool, effectively a degree hour measurement, scores how effective a range of passive techniques have been in comparison with each other. Temperatures inside the classroom are compared to external temperatures on similar days both before and after the refurbishment, considering just the hours of the school day. An effectiveness score is achieved by summing the degree-hour scores for the hours of the school day. For a different building type, such as a hospital or home, the effectiveness score would change. Averaging the temperatures over a range of days, say 7 or 14 days, is expected to improve the accuracy of the evaluation by averaging variables not easily quantifiable, such as solar radiation changes day to day or more children in class, and is proposed when more data is available.

Figure 10 Jogiyan School: developing effectiveness score



Two monitored days were chosen to be as similar as possible, one before and one after the refurbishment work. The Performance score, see *figure 10*, is calculated as the sum of the hourly difference between inside and outside temperatures during the school day. For example, before the roof was painted white at the start of the school day the wall logger temperature registered 4K hotter than outside. After one hour the difference was about the same but by the end of the morning it was slightly hotter outside than in (i.e. -0.6) and the performance score totals 11.4. After white paintingthe roof the room scored better ,that is the temperature inside tended to be lower than outside for more hours of the school day. At the start of the school day it was 5K hotter in the classroom than outside but by mid morning there was very little difference(0.8 hotter inside) By the end of the morning the internal temperature was considerably less than that outside The performance score for the five hours totals 5.9.(A smaller score indicates less time when the inside temperature was higher than outside.) The effectiveness score is the difference between these two values, the improvement in building performance, i.e.about 5.5.

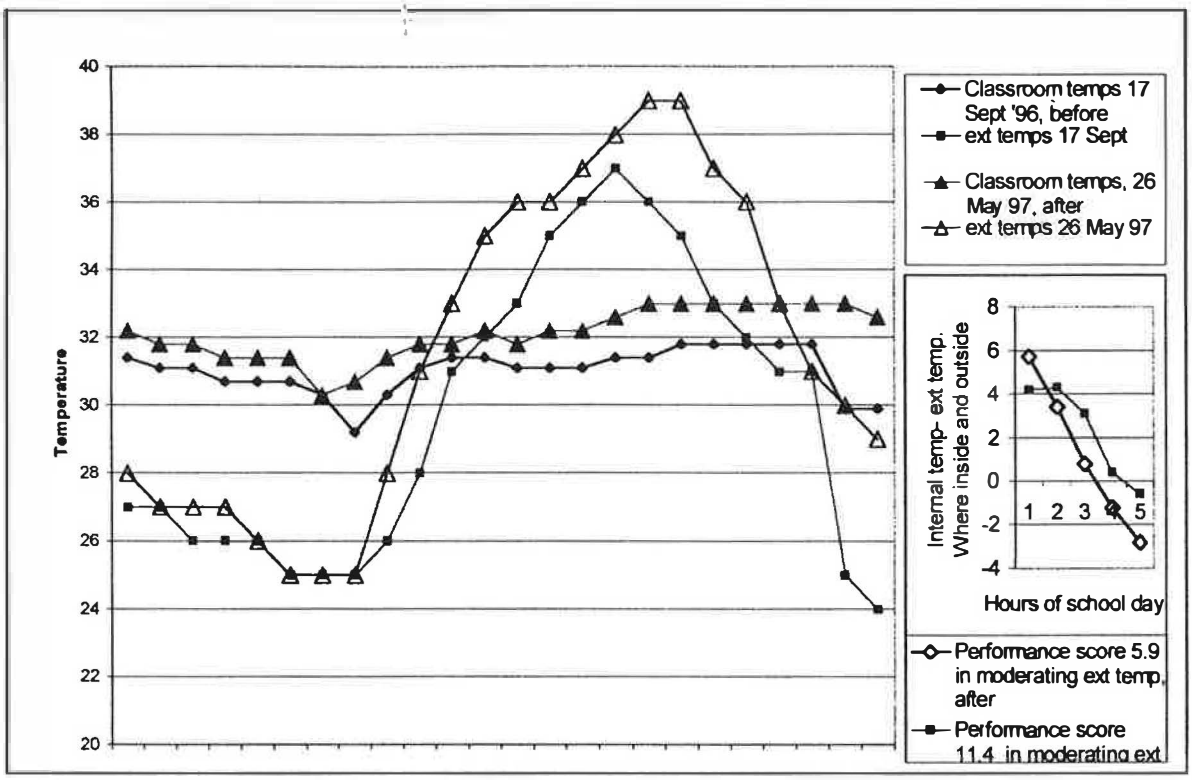


Figure 11 Evaluation of white painting roof at Jogiyan

Painting the roof presented considerable problems as the brick surface finish was not very stable. It used a lot of paint and was therefore more expensive than had been expected. Only the area immediately over the classroom was painted (not including the veranda)

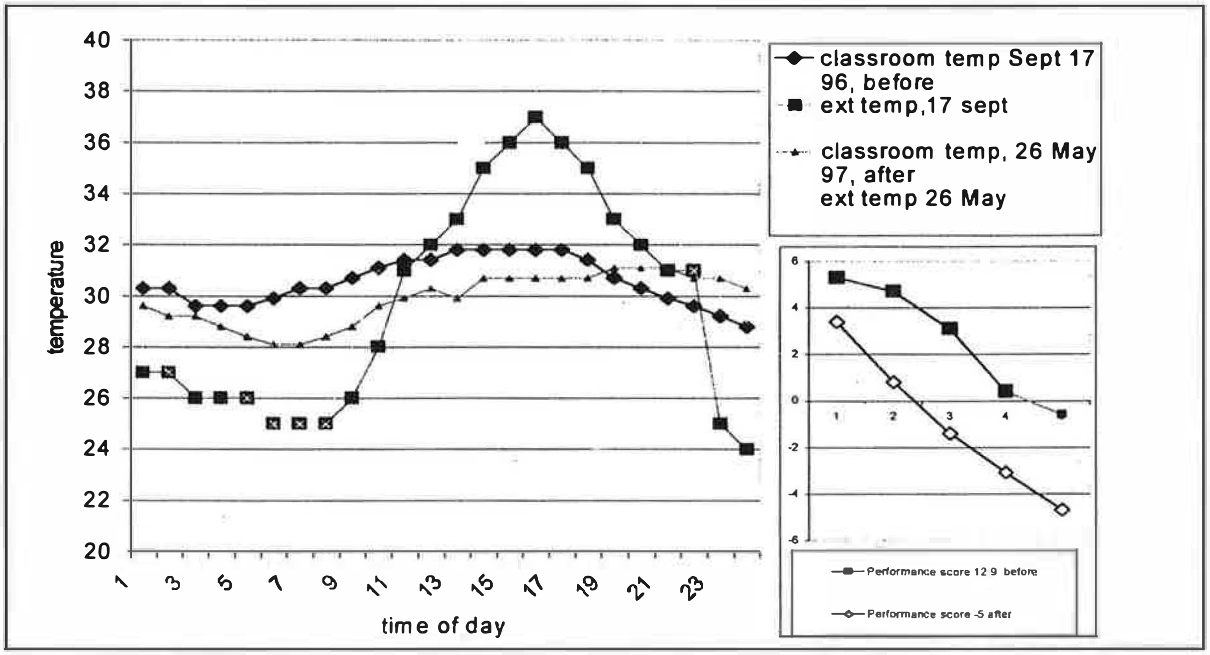


Figure 12Evaluation of clay pots, Sheikh Kali

Clay washing pots were purchased from the local potter and placed on the roof, inverted to hold a cushion of air. The pots are stronger and heavier than is required for purposes of insulation- though they were easily available. The apparent effectiveness of the insulated roof at Sheikh Kali must be adversely affected in summer conditions by the new dry floor.

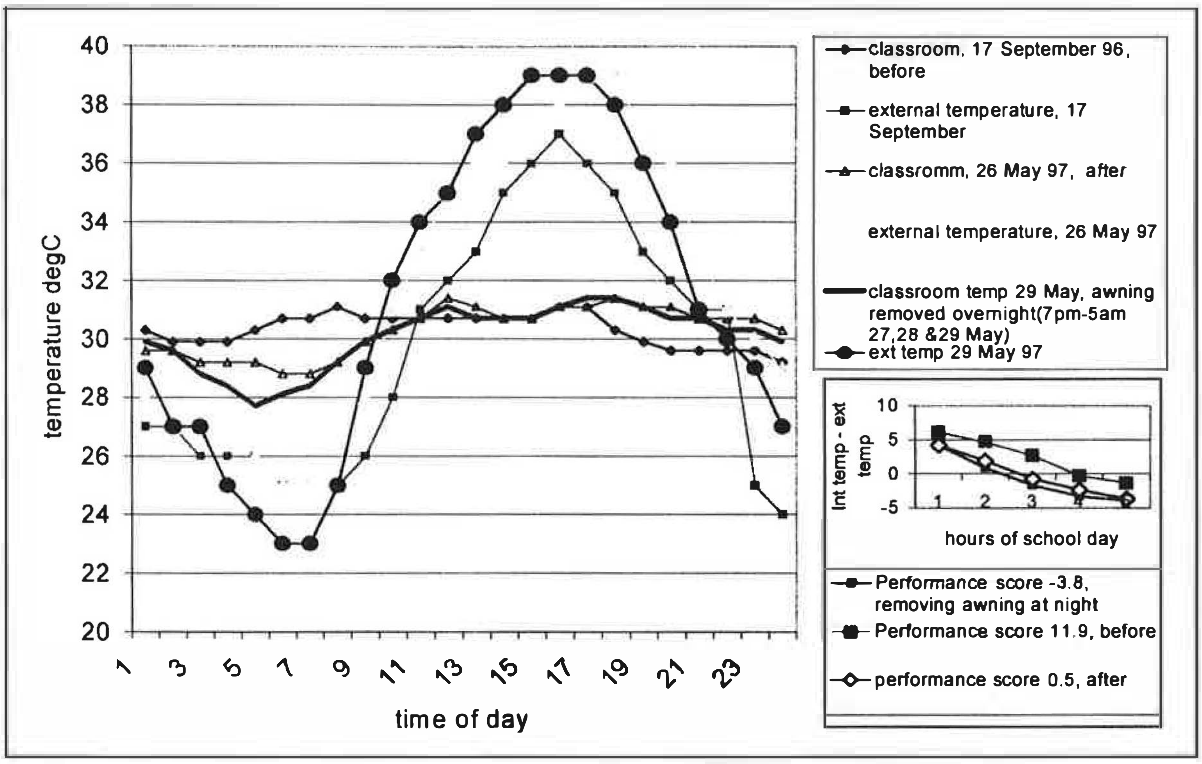


Figure 13 Evaluation of Awning, Behari Colony

The awning at Behari Colony has generally been a great success, particularly as an awning to shelter the school yard was also provided (it was clear that the roof awning might be otherwise appropriated as it was needed to shelter the children). It is interesting to see how effective removing the awning at night, has been, taking full effect of the radiation to the night sky of the heat on the roof. This moving of the awning was quite labour intensive and was only achieved on three nights. Generally the awning has remained on the roof through summer and winter except when conditions are stormy and the caretaker fears it may blow away (as it did once before).

8. Conclusions

The results so far are summarised in the table below (figure 13) It appears that the three strategies evaluated, and given an effectiveness score, offer about the same value for money.

The cost of the techniques is slightly misleading; although these are the costs, in almost all schools other work that contributed only marginally to the exercise had to be completed (see schedule of work, figure) These maintenance jobs increased the cost of the project but were not directly attributable to the improved thermal performance. Tree planting, to improve air quality and provide future shade has been carried out at two schools; this does not yet have a measurable effect on the thermal performance but it has considerably improved the quality of environment in the vicinity of the school. In a composite climate some strategies, such as replacing a damp floor or mending the glazing have a helpful effect in one season but not the other.

It appears that a ranking of the effectiveness of these measures (a summer and a winter effectiveness score) can be achieved and could be a useful tool in encouraging wider use of passive strategies in these school buildings.

School	Original performance rating (ext temp-int temp)	Modified performance rating	Effectiveness score	Cost of modification
JogiyanWhite painting classroom roof	11.4	5.9	5.5	Rs 2,715
Sheikh Kali Installation of clay pot insulation on roof, reglazing windows, new	12.9	-5	17.9	Rs 4,780 (clay pot roof)

floor				
Behari Colony Awning over classroom roof, fans for night cooling (not evaluated in this exercise)	11.9	0.5 (-3.8 removing awning at night)	11.4 (or 15.2 removing awning at night)	Rs 4000 (awning to roof only)

Figure 14 Comparison of hourly performance rating (effectiveness score) and cost of modification

9. Acknowledgements

The research was funded by the Overseas Development Administration (now DFID) Funding for the background study was provided by the British Council. Gul Najam Jamy, previously of ENERCON and now of IUCN in Peshawar, provided much needed support and local knowledge in Pakistan.

I am grateful for the co-operation of the Directorate of Education in Peshawar, partciularly Fazil Manan, deputy director, and of the teachers, pupils and caretakers in the schools who have been extremely supportive.

Dr Qamur uz Zaman, Director -General of the Pakistan Meteorological office kindly provided hourly temperature data.

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