Do simple simulation tools improve design decisions in a hot climate? A comparison of simulated and monitored data at schools in Peshawar, Pakistan investigating problems in the use of simulation tools by architects at an early stage in design process.

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Summary
Architects often start design work with a relatively limited understanding of the site and its restraints. The design process is a learning process. Can simulation tools be used at an early stage, when precise climatic and performance data is not available, to help develop that understanding?
This paper evaluates the influence of a simple analogue model, 'Quick' in the refurbishment of a group of primary schools in North West Frontier Province, Pakistan.

Background information to the project in Pakistan

The project in Peshawar, which was funded by the Department for International Development (DFID), sought to demonstrate the effectiveness of a range of passive thermal techniques in improving thermal comfort[i] in primary school buildings[ii]. The project goal was to increase the use of passive thermal techniques to provide more comfortable conditions in a low cost way and to develop a methodology that might be replicable in other situations[iii]. A range of interventions for improved thermal performance were evaluated in simulation studies using the South African model 'Quick' and as far as possible these strategies were adopted in the modifications to the schools. Five schools were included in the project. Classrooms were monitored over a period of eighteen months, both before and after the introduction of low cost bioclimatic interventions.

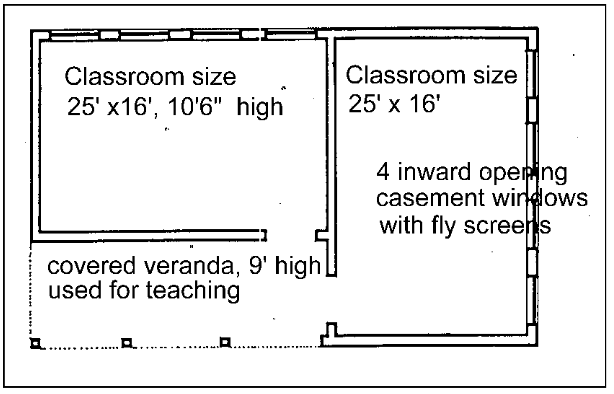


Figure 1 Plan of model school. Schools are brick built with reinforced concrete roofs

Government schools in Pakistan are usually built to a ‘model’ plan, illustrated in figure 1. Three of the five schools in the original study were built to this plan. The design is compact and therefore economical to construct. Not much thought appears to be given to thermal comfort, and the classrooms are variously orientated according to other constraints. The use of a standard classroom was helpful: size, height and construction are all standard. There are variations in orientation, location, (though all are within about 15 miles of Peshawar) and density of local development. The buildings are neither heated nor cooled. The school day runs from 8.00 a.m. - 1.00 p.m. in the summer with slightly later hours in the winter. Class sizes are nominally huge, a roll of 200 children in a two room school is not uncommon but experience gained from site visits to the schools seems to suggest that not everyone attends all the time. Much of the teaching in both summer and winter is in fact carried out outside because more comfortable conditions can be achieved.

Choosing Strategies for improved thermal comfort.

Modelling the classrooms and simulation of the changes was part of the strategy to develop a methodology for successful use of passive thermal design techniques and to decide which strategies might be the most effective in the refurbishment of the classrooms.

The first simulation exercises, at the start of the project, used the dos version of ‘Quick’[iv]. Architects are interested in evaluating the performance of their designs at a very early stage, so simulation tools of this sort, which can evaluate a design at the sketch stage, are attractive.

Inevitably at the start of a project, not much is known about the sites and so the data used in the preliminary simulation was fairly approximate. Examples of errors and uncertainties include:

1. Occupation of the classrooms was mostly overestimated (though girls are more inclined to stay in the classroom, even if it is very hot, boys and their teachers make more use of external spaces. I believe this is because of the cultural restrictions placed on women and girls.).
2. The model uses a standard metabolic rate for heat gain from adults, (the metabolic rate of children is not established so I rated them at two to an adult!) regardless of room temperature though when the temperature of the classroom approaches or exceeds skin temperature there would be no heat gains from building occupant. (their heat loss would be entirely achieved by perspiration.) This problem would tend to overestimate heat gains when the room temperatures are high (i.e. above about 32^0 C)
3. Ventilation rates and possible improvements were based on wind speeds recorded at the local airport; measurements later on the sites of the schools seemed to bear very little relation to that measured in the open conditions at the airport.
4. Solar radiation data was that measured in Capetown, South Africa, which is about the same latitude (-30^0) as no measured data was available for Peshawar.

5. The thermal transmittances of the building materials were presumed to be similar to materials available in South Africa and/or Great Britain (because no measured u-values are available for materials local to Pakistan.) Mud, which is frequently used as an insulating roof covering, had no European equivalent; thermally 'earth' was substituted.
6. Solar and light transmission of the glazing was probably overestimated as the windows were obscured by dusty fly screens.

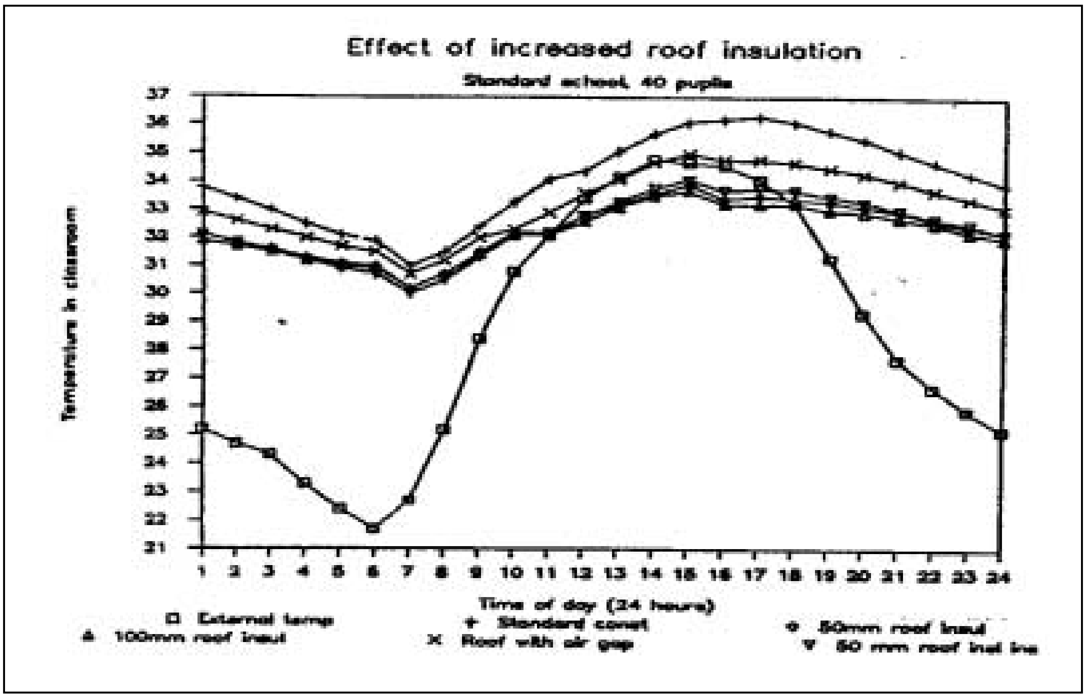


Figure 2 A range of insulation strategies for the roof of a typical classroom were simulated

The standard roof construction in the schools was 150 mm concrete and 50 mm mud. Strategies simulated included 50 mm and 100 mm polystyrene-type insulation, installed external to the main thermal mass, 50 mm polystyrene-type insulation installed internal to the thermal mass and a roof with an air cavity. It can be seen, figure 2 above, that all the refurbishment strategies were at their most effective in the late afternoon and that the insulation was least effective in the school day. The polystyrene type insulation, inside or outside the concrete slab performed better than the over roof. The results confirmed our expectations, conditioned by life in a temperate climate, that internal insulation would perform less well than external and that the cavity roof would not perform as well as the insulation. It was disappointing that the simulation seemed to show that the temperatures inside the building would generally exceed the external temperatures throughout the diurnal cycle. It seemed unlikely that anything approaching comfortable conditions could be achieved in the classrooms during the summer months.

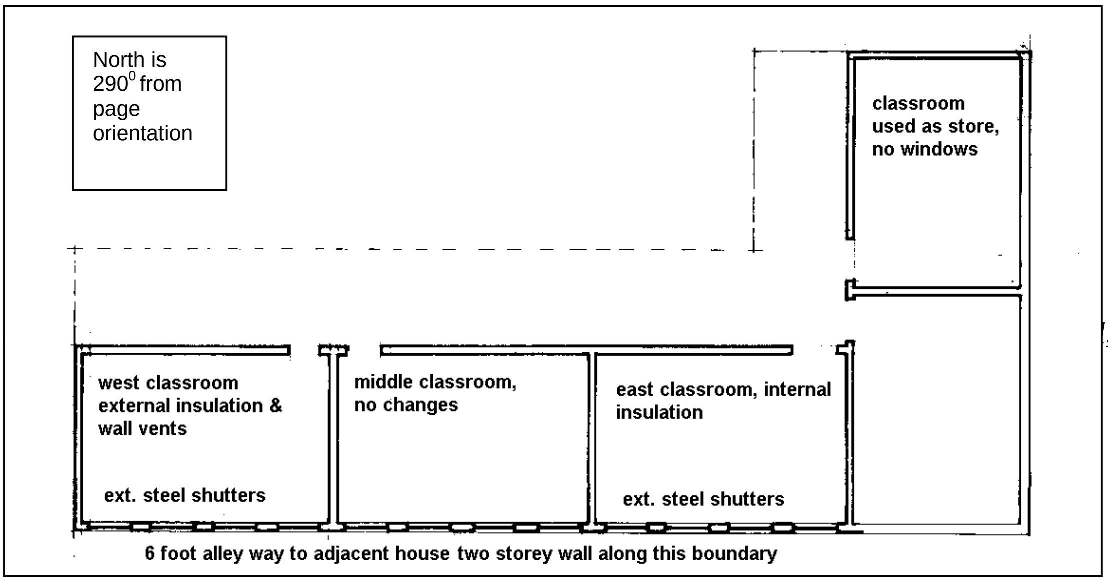
The range of roof strategies finally included in the schools included :

Mohib Banda Government Boys Primary School

- Insulating the roofs with polystyrene externally (a warm roof construction with 50 mm insulation)
- Insulating the roofs internally with polystyrene (50mm slabs attached to the underside of the concrete roof slab)

Behari Colony Government Boys Primary School

- Shading the roof with an awning which rested on the parapets to the roof..



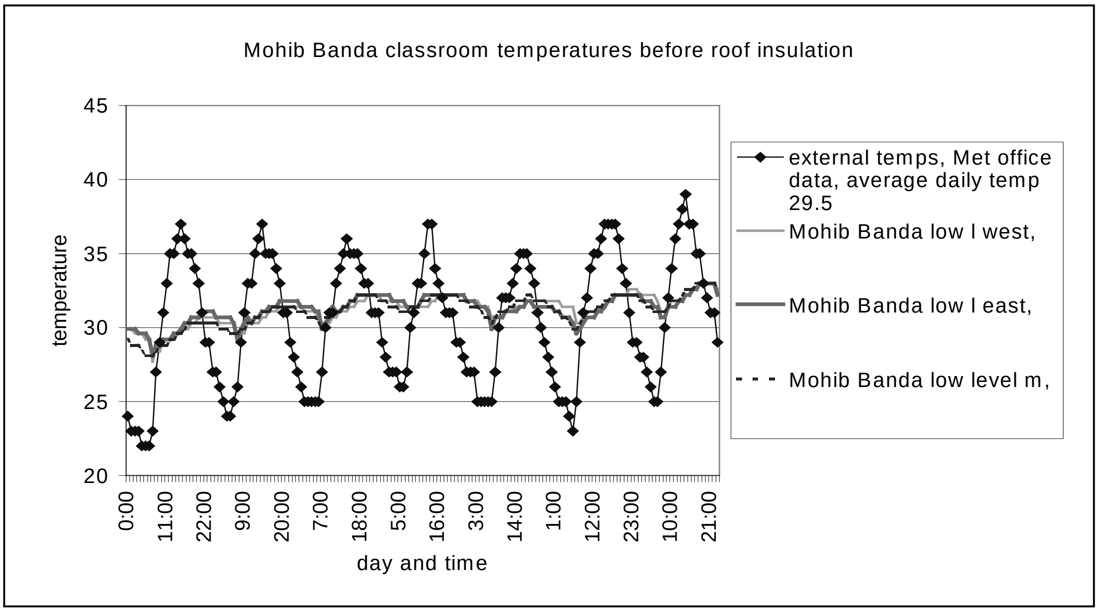


Figure 4 and 5 Mohib Banda School plan and monitored temperatures before intervention

It can be seen from figure 5 that the three classroom temperatures were very close in June 1997. The loggers were wall mounted 1 metre from floor level on the internal walls at the door (teachers) end of the room. The loggers were placed in black tins so that they were not in direct contact with the wall; it seems likely that the temperature measured would approximate to a resultant temperature.

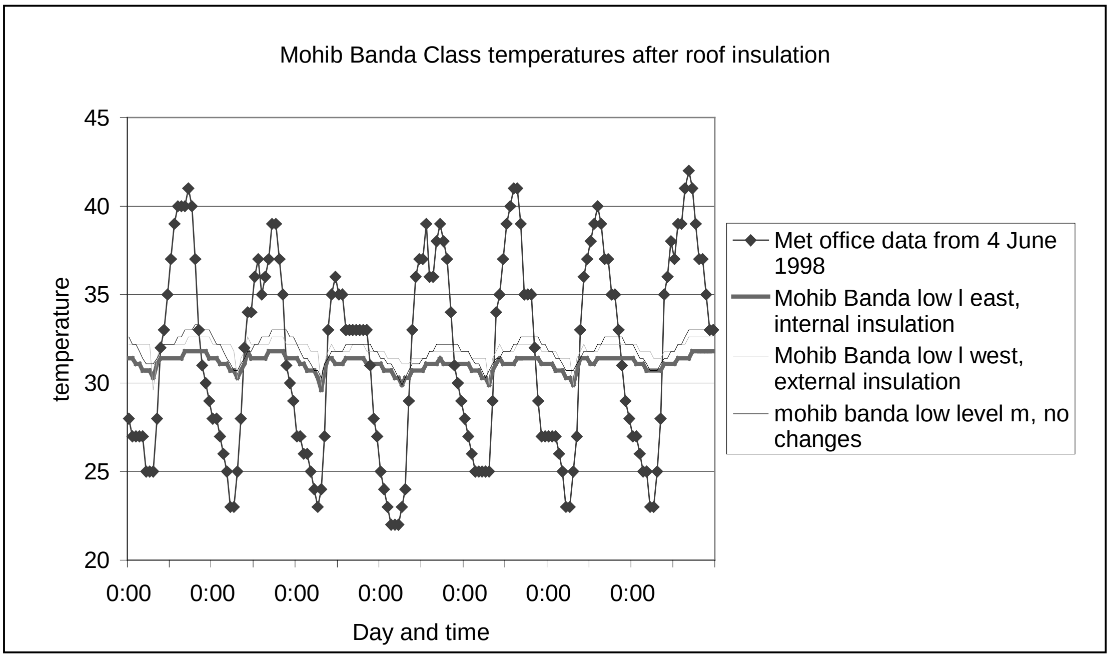


Figure 6 Classroom temperatures, same logging positions, internal and external insulation installed

In June 1998, see figure 6, when the roofs of the east and west classrooms had been insulated, neither of the classrooms were much improved during the school day though the temperature from late afternoon till early morning is lowest in the internally insulated classroom. The temperature is lowest in the internally insulated room because the insulation isolates the classroom from the hot roof slab yet allows unimpeded heat loss by radiation to the night sky.

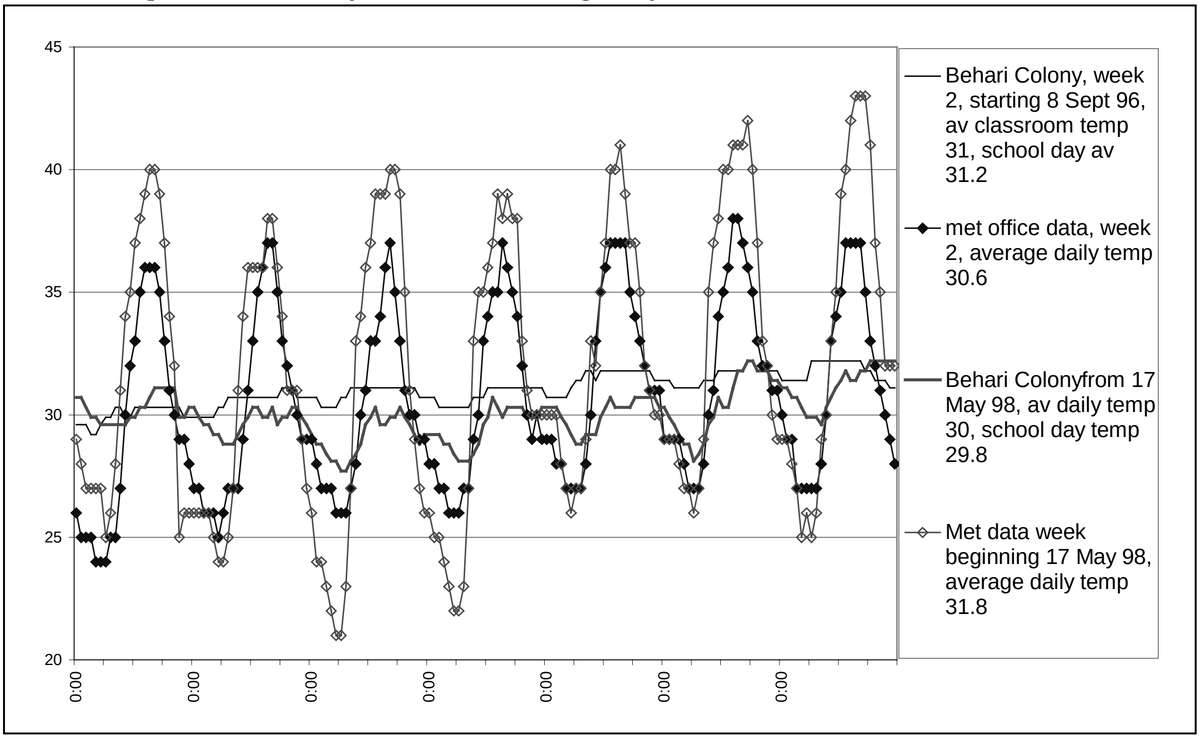


Figure 7 Temperatures at Behari Colony, north facing classroom before and after awning

The plan of the school at Behari Colony is shown at the beginning of the paper. The logger was attached to the internal wall between the two classrooms. It can be seen from figure 7 above that the classroom temperatures at Behari were considerably improved by the addition of the awning which stretched over the classroom roof. A second awning was also used which shaded the yard area south of the classroom but as the classroom south wall was already shaded by the veranda would not have directly reduced the sun on the classroom wall though it would have reduced reflected solar radiation.

Interim conclusions.

At the end of the monitoring it was observed that the information obtained from the sketch proposal modelling and simulation at the start of the project showed some divergence. The internal insulation performed better than the external insulation, though neither made very much difference. The awning performed much better than expected from the simulation results. This threw doubts on the way the modelling had been carried out.

Further simulation work was carried out when this problem with the results emerged. In 1999 the model school was simulated at Brookes by an experienced modeller, using the model TAS. A new 'windows' version of 'Quick', called 'Building Toolbox' was also used.

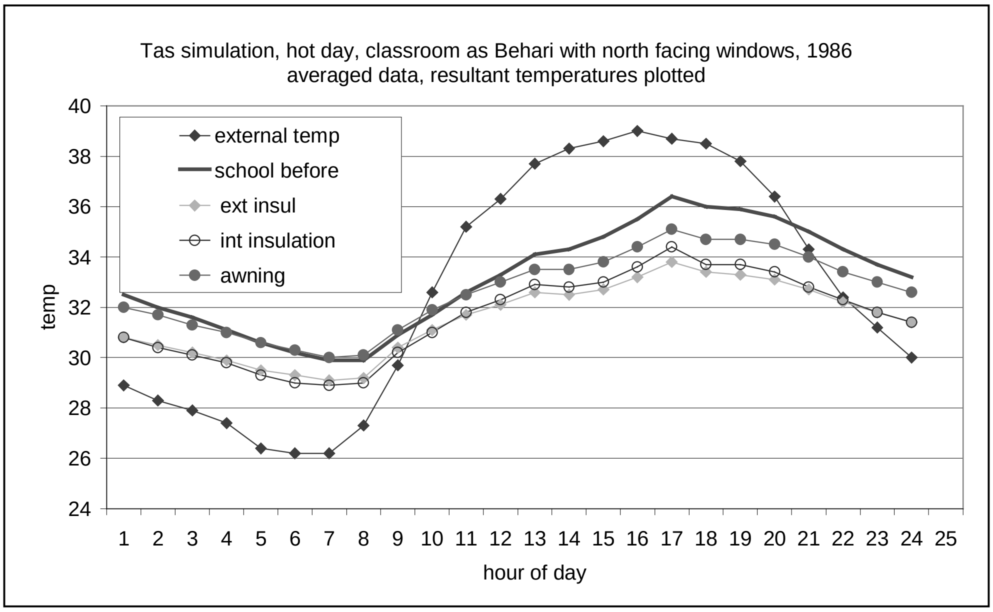


Figure 5 TAS Simulation of north facing classroom at Behari Colony

The TAS simulation, although carried out with solar radiation data from the TAS Oman weather file, (as no solar radiation data was available for Peshawar) showed a better temperature match between monitored and simulated data. TAS is a more sophisticated model than Quick so more data was required; omissions in the data were resolved by the inclusion of informed guesses. Ground reflectivity was set at 0.1, solar transmittance of the windows at 19%. The model shows the external insulation performing better than either the internal insulation or the awning.

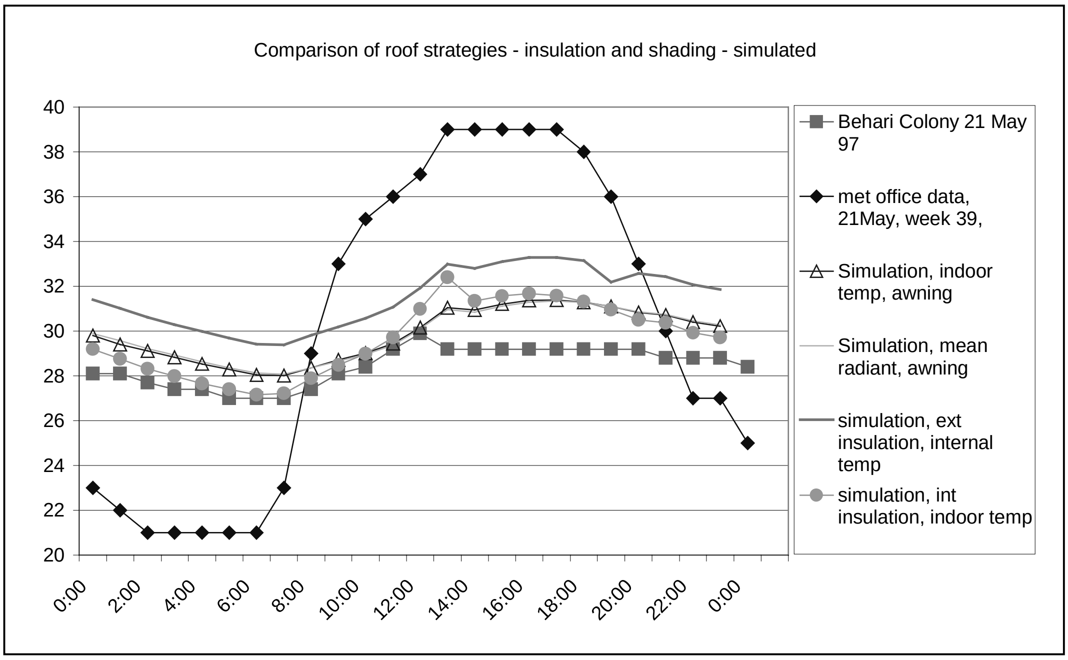


Figure 8 Simulation of model classroom using the simulation tool 'Building Toolbox'

Further simulation studies were carried out using a new version of 'Quick', 'Building toolbox'. Building Toolbox simulates the building performance from a very limited range of inputs. (orientation, percentage of glazing, approximate amount of shading, type of construction for walls, roof and floor, use of building)

Solar radiation data for Cape Town was used, matched to temperatures recorded on May 21 1997. Thermal performance of building materials was modelled using the South African data base. This simulation gave ranking of strategies and temperatures very similar to that measured in the classroom.

Final Conclusions

There were varying degrees of success with the simulation models. Variations between simulated and monitored data could be attributed to:

- Inexperience running the model and actually misusing it. This might be a general criticism as architects using the models for design purposes might very well use (and misuse) the models in the same way.
- The data, particularly solar radiation, surface reflectances and the thermal performances of the building materials, is so inaccurate as to make the modelling and simulation unrealistic. The data

used was based on European and South African thermal performances of the building materials as data is unavailable for local materials used in Peshawar.

- It seems likely that the models might perform better when the temperature differences are bigger, and the heat flows only in one direction, say in a heated building.
- Perhaps the models are more designed to predict energy flows than temperatures.
- Over expectation of the results- perhaps in trying to use the models to simulate and influence relatively small design decisions one is using the model at a scale that was not intended.

Architects need to use caution in the application of design advice obtained from simple simulation tools. It is understood that the errors are most likely associated with the worker and not the tool but appreciating errors and inadequacies in the inputs is most easily perceived at the end of the job!
Two out of three models returned advice that was not sufficiently accurate to help the design process.

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[i] Thermal Comfort in Pakistan, Fergus Nicol et al, 1994
[ii] Final report to DFID project R6478 'Improving Thermal Comfort by Passive Thermal Design' Mary Hancock 1999
[iii] Passive thermal design strategies for improved thermal comfort in schools in Pakistan, Mary Hancock, CIBSE National Conference 1998
[iv] Quick – developed by Prof Edward Matthews at the University of Pretoria