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# A Critical Review of the Usefulness of Microcomputer Based Design Tools for Passive Solar Design of Low Cost Housing in Developing Countries

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*The popularity of micro-computer based tools for passive solar design of buildings is extending to developing countries and the low cost housing market. This paper discusses their effectiveness by evaluating the levels of expertise required to run a typical programme. Some of the shortcomings of computer design tools are identified with reference to validation studies in the literature and also some case studies in developing countries where the thermal comfort gains made through computer design are seen to be minimal and even trivial. In a situation where millions of poor households are informally providing their own homes, education awareness programmes would seem to be a far more effective and rewarding strategy to achieve greater thermal comfort and energy savings in this sector.*

## INTRODUCTION

PASSIVE solar design of buildings means a lot of different things to a lot of different people. To us it means climatic or environmental design—the climate determines the style of house. It is 'passive' in that instead of the building controlling the environment by mechanical or electrical means, the building conforms to the nature of the site and to diversities of climate.

As such it is not a new science. Indigenous and vernacular architecture are a direct result of adaptation to resource and environmental constraints and great architects have always preached and practiced these principles. Since the industrial revolution, the western world has relied more and more upon cheap (relative to income) and abundant, (relative to third world countries), electrical energy. Costs are rising as resources dwindle and so solar energy has become a science to the western world—baffling to the layman and increasingly specialized to the scientist. Passive solar design has followed suit. As the pace of research escalates, 'passive solar design' becomes less and less 'passive'. The state-of-the-art in the industrialized countries includes Trombe walls, greenhouses (or forms thereof), roof ponds with movable roof insulation, superinsulating glazing and all forms of superinsulating materials backed up by fans, ducting and electronic control systems.

Not surprisingly, passive solar design in the western world is expensive. To the western world, passive solar design of buildings means an increase in capital outlay, coupled with a decrease in energy requirements over the lifetime of the equipment installed. Passive solar design of buildings is an economical science as much as it is technical.

Microcomputer design tools for passive solar design of buildings, mean little to many people. To us, they are tools designed to prove scientifically that passive solar design can save you energy and to prove economically that free energy can save you money. Programmes use statistically compressed weather data and predict statistically, activity levels, clothing factors, humidity, radiation, air temperatures and air movement, and pop out the 'optimum' building design. There are few statistics relating to personal preferences, anthropological aspects, appropriateness of building material, or morals, so computers generally ignore these questions. To people who regard adobe building as being 'primitive' technology, microcomputer programmes are the gospel.

Low cost housing in the third world means many different things to millions of different people. To us there can never be one solution to many different problems. It is more appropriate to look at the obstacles which are keeping millions of people from carrying out millions of solutions. To us it is obvious that the best energy saver is the person who cannot afford wastage. The people most aware of the warmth given freely by the sun are the people who live in cramped, badly designed houses, or in shanties which provide little shelter from the cold, where there are no electrical plugs for 'domestic heat' and no money for scarce wood fuel. To many other people, low cost housing is a mathematical exercise in statistics—economical problems with economical solutions.

This paper is an overview of the appropriateness of microcomputer based design tools for passive solar design of low cost housing in developing countries.

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## PASSIVE SOLAR DESIGN BY MICROCOMPUTER

Imagine that we have a microcomputer based design tool for passive solar design of low cost housing. We shall call this programme DDM for convenience. DDM is special because it is designed for local climatic conditions (wherever local happens to be), and its library of building materials includes, in addition to more conventional building materials like brick, glass and galvanized steel, such appropriate materials as adobe, mud and wattle, stones packed between wire mesh and plastered with mud or sand/cement mixtures and the like. DDM does passive solar design of small residential buildings by means of simulation rather than correlation, and it models the thermal performance of the structure by a thermal network analysis.

Assume that we, as users, are aware of the basic principles of passive solar design. In winter, the objective is to keep the cold out, to let as much heat as possible in and then to avoid losing the heat gained to the outside. In summer, on the other hand, the objective is to keep the heat out and to retain the night cool as much as possible. We understand also, that in the southern hemisphere, in order to utilize the free heat of the sun in winter, most glazing should be exposed to the sun's low northern trajectory, but in summer, when the force of the sun is great, sufficient overhang should shade the glazing to avoid overheating. The purpose of DDM therefore, is to 'fine tune' the building design in order to optimize its thermal performance.

As a simple example to illustrate the workings of DDM, a small traditional African hut is analysed. (A thermal network analysis of a similar building was carried out by Bahadori and Haghighat [1]. We shall cite their analysis in this example.)

The first requirement is to input the building topology. DDM is user-friendly, which means that current options are presented by menu hierarchy; all data input is prompted for; and error checking is carried out automatically for each input.

In order to carry out a passive solar analysis, DDM requires data regarding the peculiarities of the climate of the chosen building site.

Some data is readily known. Some can be measured or found in references, for example:

- Latitude: 22° south
- Mean monthly clearness index: 0.66
- Maximum temp of outside air: 40.4°C
- Minimum temp of outside air: 25.4°C
- Dew point temp: 8°C

Experts in the field can predict some factors:

- Thermal radiation shape factors
  floor to ceiling: 0.41
  floor to walls: 0.59
  roof to ground: 0.20
- Density of air: 1.12 kg $m^{-3}$
- Specific heat of air
  constant pressure: 1006 J $kg^{-1}$ °$C^{-1}$
  constant volume 718 J $kg^{-1}$ °$C^{-1}$.

But others are somewhat exasperating:

- Physical properties of adobe
  density: 1000 kg $m^{-3}$
  specific heat 840 J $kg^{-1}$ °$C^{-1}$
  thermal conductivity 0.25 W $m^{-1}$ °$C^{-1}$
  thermal diffusivity: 2.98 exp (−7) $m^2$ $s^{-1}$
- Thermal conductivity of ground: 0.55 W $m^{-1}$ °$C^{-1}$
- Absorptivity of walls, roof and ground: 0.55
- Absorptivity of floor: 0.7
- Emissivity of all surfaces: 0.9
- Transmissivity of windows and drapes: 0.4
- Deep ground temp: 17.5°C

Of course, you soon get the hang of this too.

- Convection heat transfer coefficients in W $m^{-2}$
  inside walls: 3.35
  4.35 (when ventilation >30 ac $h^{-1}$)
  floor: 1.25 (floor temp < inside temp); 4.3 (floor temp > inside temp)
  ceiling: 2.56 (ceiling temp > inside temp); 4.15 (ceiling temp < inside temp)
  outside walls: 15
  outside roof: 18
- Overall heat transfer coefficients in W $M^{-2}$
  single glazed windows: 2.75
  wooden door: 1.80
- Internal heat sources: 200 W from 8 am to 8 pm; 0 W from 8 pm to 8 am
- Ventilation rates: 3 ac $h^{-1}$ from 8 am to 8 pm; 30 ac $h^{-1}$ from 8 pm to 8 am.

Obviously we cannot expect this approach to produce the desired accuracy, and so what makes state-of-the-art software packages sophisticated is that they predict these values for us (or bypass the need for them empirically). But before investigating how these predictions are made, let us conclude this example. Eventually all data input will be completed and you finally hit the GO button. The disk light testifies to churning of figures and unimaginable complication in our analysis, but then DDM has a lot to do.

The science of passive solar design revolves around the study of heat flow within a building.

- Conductive heat flow occurs within a body from its hotter regions to its colder regions—the sun heats a wall surface and the heat is conducted through the wall, for instance.
- Radiative heat is given off when a body gains energy—the electrons of the atoms making up the body move to a higher energy state and in returning to a lower energy state, they 'radiate' heat. (Black surfaces radiate most heat.) Heat is constantly radiated from warmer objects to cooler objects.
- Convection is heat transfer by the movement of fluids—liquids and gases. The energy source may be the sun, or human activity, or what is called 'domestic heat',such as heaters, stoves and light bulbs.

In a building, these phenomena occur simultaneously and continuously, and are coupled with 'evaporative' heat transfer (in which a body loses heat to the surrounding air as a result of its losing molecules of high energy to the air). Any analysis of heat gained or lost is obviously very involved. Mathematical models have been derived to analyse these phenomena and mainframe computers are used to analyse single rooms in order to determine the thermal characteristics of various building materials subjected to various forcing functions (various climates).

Some patterns of heat gain or loss are predictable, for instance, it is predictable that at night , when the sun goes down, there will be no solar heat gain and, if it is cold outside, much heat loss. How much heat loss depends upon the wind, the humidity and the temperature difference between inside and outside. It also depends upon how much heat there was to loose in the first place, which in turn depends upon how much heat was gained previously and how much of this remains stored in the building's 'thermal mass'—its capacity to store heat. The thermal mass of the building accounts for the time lag between heat gain and heat loss and depends upon the interpositioning of its different building materials which have different thermal properties.

As Klein [2] says, the formulation of a general simulation programme for passive solar building is complex. Many heat transfer surfaces are involved. Geometric effects must be considered for calculation of both shortwave (solar) and longwave (thermal) radiation exchange. Beyond these complexities, major uncertainties in the form of unknown heat transfer parameters (particularly infiltration rates and ground properties), and the irregular behavior of weather, remain. In a passive solar building, both the heating load and the useful solar contribution are functions of solar radiation, ambient temperatures, wind direction and velocity, etc. These variables are neither random nor totally predictable both on a small (hourly) and large (seasonal) time scale. In general, solar energy systems exhibit a non-linear dependance on the weather which is further complicated by time lags introduced by thermal capacitance or storage effects.

*The error accumulation phenomenon*

As mentioned earlier, sophisticated software packages must predict local design parameters because it cannot be expected that this data is readily available to every user. Of course, all of these factors can be estimated, sometimes quite accurately in particular circumstances and on an individual basis. But when one approximation is added to the next, then multiplied by another and divided by yet another, the error accumulates.

Climatological data is the first area where estimation creeps into the passive solar analysis. Within the United States, for example, there are 35 sites where weather data, including solar data, have been taken and compiled by the U.S. Weather Service [3]. Then, based on correlations developed from this primary data set, hourly solar data sets have been generated for some 240 sites where hourly temperature and other weather data has been recorded. Most microcomputer based design tools then compress this data statistically, down to two pages or so. In particular circumstances, this data may be highly unreliable.

The physical properties of building materials is another area in which approximation is readily accepted. As an example, consider a sheet of glass. Since glass is generally quite thin and its thermal conductivity is relatively high, the resistance to heat flow of the glass is always quite small. Most of the resistance is offered by the processes needed to bring the heat to the warm surface and remove it from the cool surface. In other words, the resistance to heat flow of the glass depends more upon its environment than it does upon the material itself. Both radiation and convection are involved in these two processes but generally they are combined into a single 'surface coefficient' (designated as $h_o$ and $h_i$ for the outdoor and indoor surfaces respectively). Generally $h_i$ is assumed to be a constant and $h_o$ is estimated in a variety of ways.

The thermal properties of materials such as mud and wattle, adobe, stones packed between wire mesh and plastered with sand, clay and cement mixtures, etc., are even less predictable, because their thermal resistivity is related to their moisture content, their colour, their consistency and so on, all of which vary from one site to the next. The moisture content is in turn related to the air humidity and to whether it rained last night or not, or whether the windows are opened or not . . . need we go on?

Researchers found that to approach reality in their analysis of passive solar buildings they had to extend their studies to include, diffuse solar radiation, shading by overhangs, vegetation or surrounding buildings, and air movement between rooms. Different researchers defend different solutions, but the analysis is always approximation, or rather, it is a further approximation to add accumulative error to the already highly approximated analysis. What this all boils down to is the need for design tool validation.

*Validation of design tools*

Validation of passive solar simulation codes has proceeded in two ways. Firstly, comparisons were made between simulation results and experimental data from 'test cells', in which the thermal performance of particular building materials subjected to various forcing functions (those climates in which the test cells are built) are monitored under strictly controlled circumstances. A few careful measurements of energy flows in actual residences have also been compared with simulation results. Researchers validated their results against houses rigged with instrumentation and simulated occupancy of the houses using statistical norms pertaining to activity levels, hot water usage and the like. In general, however, the available experimental data useful for validating simulations is limited mainly because it is difficult to measure accurately the actual heat flows occurring in a building; but also because these experiments are expensive and time consuming.

Simulations have also been validated in a second way—by comparing the results of different programs. One example is a study in which short and long term results from FREHEAT, SUNCAT, PASOLE/SUNSPOT, TRNSYS and DOE-2 were compared for collector storage walls and direct gain buildings. Regarding this study, Klein [2] says that: '*After initial discrepancies caused by unclear or insufficient problem specification were eliminated, these programs showed excellent agreement (differences of less than 4%) in their estimates of annual auxiliary heating loads. However, much larger discrepancies (up to 40%) were observed in their cooling load estimates. DOE-2, BLAST, SUNCAT and DEROB were compared in a similar study, the results of which are inconclusive . . . after a few problems in the simulation* *codes where identified and corrected . . . the annual heating loads predicted by three of the codes agree reasonably well, while the cooling load estimates posed a problem.'*

Balcomb [3] explains these discrepancies: *'Natural cooling is perhaps the most complex passive research area because the building is thermally opened to the surroundings at times to encourage rejection of heat. Night ventilation of the building is usually the most important passive cooling strategy and the one least tractable to analysis. Radiation cooling is analysed more easily and has been more carefully researched. Earth contact cooling, although of minor importance, has also been the subject of much investigation.'*

Considering all this, it would obviously be of interest to take a look at some results. In analysing the little adobe hut, Bahadori and Haghighat [4] determined 29 differential equations (which must be solved simultaneously) to simulate the thermal response of the building, they then made the following observations from results:

*'(1) The temperature of the internal surfaces (adobe or brick) can be reduced appreciably when these surfaces are kept moist and evaporatively cooled at all times. When the ventilation rates are high, the room air does not become humid.*

*'(2) Depending on the ambient air temperature, solar radiation, wind velocity, etc., the building occupants can maintain a thermal comfort by controlling the following factors: (a) the total area of the internal surfaces which are kept moist; (b) the duration or period that these surfaces are kept moist; (c) the rate of natural ventilation through the building. The building occupants will learn quickly as to how to control the above factors to provide thermal comfort for themselves.*

*'(3) Air flow rate in the building has a significant contribution on the room air temperature. The best strategy to achieve the lowest temperature is to circulate as much air through the building as possible when the outside air temperature is below the comfort level, and reduce it to a minimum when the temperature is above this level.'*

Isn't all this obvious? Take a simple structure, conduct a highly complicated analysis of its thermal performance using approximation for all boundary conditions, in order to 'prove' what is common sense? In our opinion, microcomputer based design tools cannot be relied upon as design tools for optimization (fine-tuning requires precision). DDM stands for Doesn't Do Much—it is state-of-the-art software.

## PASSIVE SOLAR DESIGN OF LOW COST HOUSING

*Traditional low cost housing*

Traditionally, indigenous people were admirable architects. Their architecture is adaptive and it evolved by way of a combination of cultural and natural selection, in response to peculiar environmental conditions. They designed intuitively, and as a result their houses conform to the nature of the site and to diversities of climate. Consider for example an ovaHerero hut. (The ovaHerero are people of the Okavango district in Botswana. This example was selected because the design has been retrofitted by American experts in passive solar design, with some interesting results which are discussed later.)

Anybody who has been to the Okavango swamps will understand that in this region, the priority is for natural cooling. The early morning chill is a relief from the intense heat of the afternoon, even in winter. The ovaHerero people build round huts of thick clay walls, thatch roofing with ample overhang and thin slits for windows. They leave a gap between wall and roof for ventilation, and they cover the entire hut with a stark white paint-like substance to reflect the intense direct and diffuse solar radiation.

These huts are amazingly cool in a hot region. Apart from strategies for keeping the heat out, these huts use natural ventilation, night-time cooling and ground cooling as passive cooling strategies—precisely those strategies which are least tractable to analysis.

Passive solar design is not new in concept. Throughout developing countries architectural examples of adaptation to resource and environmental constraints can be found. (Fuggle [4] relates the significance of the siting of Basuto dwellings in Lesotho, whilst Siegfried and Hough [5] studied the adaptive significance of indigenous hut architecture in Transkei in South Africa.) The Roman architect and educator Vitruvius [6] speaks at length on climate as determining the style of house. In fact great architects have always preached and practiced these principles. But increasingly passive solar design has become an overcomplicated and inaccessible science.

Members of the Berkeley Solar Group were involved in retrofitting traditional huts in Botswana for passive solar design. Hamilton and Sachs [7] discuss the passive solar features used: *'One rondavel was retrofitted with a plastic air barrier and a second layer of thatch on the roof, and the gap between the top of the wall and roof was sealed in order to reduce infiltration. The north face of the rondavel was painted a dark colour and a large window was added on the north side to increase solar heat gain in winter.'*

These are all noble strategies for passive winter heating, but what will happen in summer? The large windows are now exposed to intense diffuse solar radiation (there is little vegetation), and regarding ventilation, the same experts present the following general guidelines for passive solar design in Botswana: *'The dominant load in buildings is cooling. . . . Wind driven ventilation is the key passive cooling concept and windows should be designed and located to take advantage of it. . . . Site planning to allow proper orientation of buildings is an important goal. Again, design with respect to cooling (i.e. wind driven ventilation) is at least as important as solar access.'*

So what has been achieved? Are these retrofitted huts better designed, or are they modernized only in that they now cost money (for window frames, glazing and plastic insulation), and they require 'high tech' design methods?

*Thermally comfortable urban low cost housing*

Nowadays in developing countries, urban low income housing is generally void of any good architectural awareness of the principles of climatic design. If tin roofs were painted white and ventilated; if glazing were exposed to the winter sun and shaded in summer; if houses were insulated at all, the thermal comfort of these houses would improve drastically. The 'fine tuning' can then be left to the occupants, assuming of course that the occupants are motivated towards improving their living conditions. In a recent major study of 16 cities in eight developing countries undertaken by researchers for the World Bank [8], the researchers found that the best solution for the poorest areas can be the upgrading of existing slums and squatter settlements. This reaches the largest number of poor people at the lowest cost. They say: *'It is important to regularize the rights of owners and tenants in unauthorized settlements that have spread like wildfire in many cities. Uncertainties over rights inhibit investment in and the availability of housing. Studies show that once legal title is given to squatters, there is a big jump in the investments they make in expanding and improving housing. Secure rights help the poor more than the better-off, large families more than small ones, new settlements more than old ones. Thus they promote equity.'* Once this is done, poorer people have a far stronger motivation for energy conservation than do rich people.

In a free society, people will build their own homes, either with their own hands or with their own money. They will have their homes designed or they will design them themselves, but either way their designs will conform to personal preferences within the constraints of individual circumstance. Aware people will demand good building practice. It is a question of awareness through education.

*Awareness through education*

If we are honest in our desire to improve the living standards of the millions of deprived people in the third world, then we must first determine whether our advice is truly appropriate—we must determine the real need. Obviously, there can never be one solution to millions of different problems. What is appropriate to one community is not necessarily appropriate to the next, and so the best solution is to remove the obstacles which prevent millions of people from carrying out millions of solutions, and then to advise. We need to seek solutions unique to our environment and our society. We need to throw open the doors to allow widespread intuition. Ideas would be plentiful and truly appropriate to individual circumstance, and the knowledge of our ancestors would not be brushed off in the wake of 'high tech'. There is no lack of innovative thinking when millions of people apply their minds to a problem, the solution to which is not stipulated. Since humans are of an imitative and teachable nature, they would daily point out to each other the results of their building, boasting of the novelties in it; and thus, with their natural gifts sharpened by emulation, their standards would improve daily.

Widespread awareness of passive solar design principles will only come through education—newspaper and magazine articles, booklets, video and film shows, workshops, schooling, or . . . microcomputer based design tools for passive solar design?

To us, the best form of education is 'active education' in which the students are actively involved in the lesson:

When you hear it you forget.
When you see it you remember.
When you *do* it, you *know*.

Computers, as education tools, firstly restrict innovation because they baffle rather than educate, (students learn which buttons to push and go away knowing nothing of the concepts and principles involved), and secondly, they reflect the ideas of a privileged few and students do not learn to think for themselves.

If we, as scientists, keep insisting that climatic design is a baffling science, full of complicated analysis and so involved that only computers can attempt to do it; then in the third world, passive solar design and thermally efficient buildings will never be a widespread (and accepted) practice.

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