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Name Prof. Pablo Miguel La Roche

Passive Cooling Systems for Sustainable Architecture in Warm Developing Countries

Pablo La Roche

University of California Los Angeles / Universidad del Zulia

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Introduction

People in developing countries generally have a lower quality of life than those of developed countries. Thermal conditions inside most unconditioned dwellings, formal or informal are worse than outdoors due to bad design or inadequate selection of materials, and families that can afford mechanical cooling systems spend a large amount of their income in electrical bills. This paper presents some ideas on how Passive Cooling Systems (PCS) can improve the quality of life of people in developing countries.

Vernacular Architecture

In most developing countries there are excellent examples of vernacular architecture, where man has traditionally adapted buildings to climate in order to be more comfortable. In these buildings they implemented local traditions of craftsmanship using indigenous materials and in organic relationship to the site and climate. The extreme heat in the deserts led to the construction of massive structures that modulated outdoor conditions, while in warm and humid climates building structures were generally open to the wind to promote evaporative cooling from the skin, while blocking the sun. Traditional dwellings in these warm climates were better adapted to climate than most current buildings in the same countries and many lessons can be learned from their design.

Passive Cooling Systems

Some architects have rediscovered and further advanced these design principles that have been applied for centuries by "non architects". These are now called bioclimatic or passive design principles and they apply appropriate building design to capture and process available solar energy to reduce consumption of natural resources and fuels and improve indoor thermal comfort.

The evolution of the *bioclimatical* or *passive solar* approach has led to the current and broader concept of "sustainable architecture", which describes a broader energy and ecologically conscious approach to the design of the built environment.

Passive cooling systems are space-conditioning systems that are driven primarily by natural phenomena and are capable of transferring heat to various natural heat sinks, reducing indoor air temperature.

Importance of Passive Cooling Systems in Developing Countries

Most of the research in architectural sustainability is directed towards developed countries because they are the main consumers of energy. But sustainable architecture is also a very important issue in developing countries for several reasons that are explained in the following paragraphs.

1. Changing patterns in energy consumption. Energy consumption is a function of economic growth and the development level of a country, so it is distributed unequally in the world. Developed market economies, which constitute one fifth of the world's population, consume almost 60% of the world's primary energy. But this proportion is changing and as a consequence of development and the rapid replacement of traditional energy sources by commercial (mainly fossil) sources, some regions of developing countries already have consumption patterns similar to those of developed countries.

2. Development differences inside countries. Because of political, industrial or economical factors, some regions in a country might have a better life quality, with higher per capita energy consumption than the rest of the country and even than other developed countries.

3. Population growth in developing countries is higher than in developed countries. While developed countries grow at an average rate of 0.4% per year, developing countries grow at a rate of 1.4% and the least developed countries at a rate of about 2.4% per year (United Nations Human Development Report 2000). The population of the developed countries is about 1.2 billion and expected to change little in the next 20 years (UN Population Division 2000) while the population of the less developed regions is expected to rise steadily from the current 4.9 billion to somewhere between 8.2 billion (medium variant) and 11.9 billion.

4. Social and economical inequalities. In most developing countries there are important differences in income levels, which are expressed in many ways, including housing. The richer segment of the population has better houses, but because of the lack of energy codes and warmer climates they use a very large amount of energy for cooling. The poorer segments of the population, not only live in housing that is of inferior quality but do not have access to mechanical cooling systems, making their life very uncomfortable.

5. Improvements in the quality of life of developing countries. As life quality improves in developing countries and developed countries implement conservation measures, developing countries will approach the consumption levels of developed countries, and even if they develop very slowly, by simple population growth their share in world energy consumption will probably increase.

The Opportunity: Passive Cooling Systems in Developing Countries.

The design of heating, cooling and lighting of buildings is proposed in three tiers as in (Lechner, 2001). In warm climates, the first tier is the architectural design of the building itself to minimize heat gain in the summer and to use natural light efficiently. The second tier involves the use of natural energies through passive cooling and daylighting systems. Tier three consists of the design of the mechanical equipment to reduce the thermal loads that remain after tiers one and two have reduced them as much as possible.

Depending on available resources, the first, second or third tiers would be achieved. With a limited budget there would only be a good first tier design (reduction of heat gains and efficient use of natural light), but with the possibility of integrating passive cooling systems as the families can afford other mechanisms to improve thermal comfort. The fact that many families are improving their standards (e.g. houses) at a slow but consistent phase is a good opportunity to implement passive cooling systems, instead of conventional mechanical systems. Air conditioning in the third tier could be implemented when a larger budget is available or if the building requires it.

Currently, the cities of developing countries are economically and socially divided in a formal and an informal sector. The buildings in the informal sector are generally self-built or built by local workers without construction documents or codes, while the buildings in the formal sector are built according to codes, but not necessarily with high design standards. Because of this differentiation, the strategies for the implementation of passive cooling systems should be different depending on whether they are directed to the formal or informal sector. For example, in the informal sector PCS can be simple and economical and could satisfy basic cooling needs, while in larger buildings they could be more complex and work together with conventional mechanical cooling systems to reduce energy consumption. Acceptance is a key factor for the implementation of PCS. Two advantages of PCS that would help to generate their acceptance are:

1. Low initial and operating costs. In many developing countries air conditioners are expensive and are out of reach of low income and even many mid-income families. For the middle class that does have an air conditioner, the operating cost for cooling is such a big expense that sometimes they cannot turn them on, or maintain them, making them inoperative. Passive cooling systems are much more affordable and use a fraction of the energy used by conventional mechanical systems.

2. Generation of local income. Because of their simple design and use of materials, passive cooling systems offer the opportunity to be built at lower costs and using local labor and resources, generating the possibility of additional income for local entrepreneurs rather than large global corporations.

The Passive Cooling Systems

Three Passive Cooling systems that would improve thermal comfort and/or energy consumption at a low cost are very briefly mentioned in the following sections.

Selective Ventilation

This is more commonly known as nocturnal ventilative cooling or night flushing and consists of cooling the structural mass of the building interior by air movement from the cooler outside air, generally during the night, and closing the building to the warmer outside air, usually during the daytime. Together with comfort ventilation, this is the simplest and most economical passive cooling strategy. It only requires establishing with windows and /or fans, a connection between the inside and the outside of the building, external insulation, some mass inside the building, and a diurnal temperature range above 8 ºC. In many developing countries brick and concrete are common (mass) but insulation is not commons, so should be added, preferably with local materials.

To increase the application of selective ventilation, an intelligent control system has been designed at UCLA that manages airflow according to cooling needs in a building and resources in the environment. This system is a microcomputer-controlled thermostat with both indoor and outdoor temperature sensors that can control a whole-house fan, in addition to a furnace and air conditioner. No such thermostat is currently available commercially. The rules for various control strategies have been programmed and tested using two slab floor test cells and the system has proven effective in reducing both the maximum temperature and the number of overheated hours in the test cell compared to the control cell.

Passive Evaporative Cooling

In the broadest sense, the term "evaporative cooling" applies to all processes in which the sensible heat in an air stream is exchanged for the latent heat of water droplets or wetted surfaces. Evaporative air cooling equipment may be characterized as direct, when the air stream comes into direct contact with liquid water, and indirect when the air is cooled without addition of moisture by passing through a heat exchanger that uses a secondary stream of air or water that has been evaporatively cooled. A direct evaporative cooling system is more appropriate for a warm and dry climate, because the additional moisture increases comfort, while an indirect evaporative cooling system is more appropriate for a warm and humid climate because there is no moisture added to the air.

Two indirect evaporative cooling systems, using a pond and a shower have been built at UCLA with discarded metal bookshelves as the main structural frame, insulation panels, nuts and bolts, a plastic liner, a pump and flexible hoses, all of which were bought in a hardware store. These cool the ceiling of a test cell that serves as its heat sink. These systems can be used in more consolidated buildings with the piping embedded inside the walls or roofs.

Radiant Cooling

Any ordinary surface that "sees" the sky looses heat by the emission of long wave radiation toward the sky and can be regarded as a heat radiator. Radiant cooling has the least thermal impact on the immediate exterior environment; all that is needed is an exterior environment that does not block the clear view of the sky.

Most of the housing in informal settlements is generally built in stages using available materials and resources. A common initial stage of these dwellings is to use metal sheets for the walls and roofs or to build brick walls with the metal sheets placed directly above them. In hot climates the temperature inside these dwellings reaches values high above the outdoor dry bulb during the daytime, especially on sunny days, but these values drop rapidly at nighttime, until they are close to outdoor conditions.

In 1996 a system that could be adapted to these low cost dwellings was developed at UCLA (Givoni et al, 1996). In this cell the roof acts as a nocturnal radiator; and below it are centrally hinged, lightweight and operable reflecting panels. During the daytime these panels are in a horizontal position (closed), creating a continuous insulation under the roof, reducing the heat flow into the interior space. During the night, the plates are turned into a vertical position, enabling radiant and convective heat flow from the interior space to the metal ceiling, which is cooled by long wave radiation to the sky. The rotation of the insulating ceiling panels between the horizontal and vertical positions is achieved by an electro mechanical system. Under computer control, the panels are opened at sunset and closed at sunrise, according to a prescribed action schedule calculated for the longitude and latitude of Los Angeles. In a real home the panels can be controlled manually, e.g. by a rope and since interior operable insulation plates are not exposed to the wind and the rain they can be simpler in construction, lighter and much less expensive than external operable panels.

The main features of these three PCS are presented in table 1. All have advantages and disadvantages. Selective ventilation is probably the easiest and most economical to implement in any building and can be easily combined with other strategies. Passive indirect cooling with the pond requires a large surface but the water can be used for other purposes. The shower uses less space and water than the shower and could be integrated in the balcony of a small building or apartment. The radiant roof has the advantage that it could be implemented in the large stock of metal roofs in these countries. Furthermore, some PCS might be effective during some parts of the day or year, so it might be useful to combine several PCS in a single building using an intelligent thermostat such as the one developed for selective ventilation. All of these systems need little energy to operate, basically pumps or fans, and all can be built with many different materials as long as they don't affect the physics of the systems, permitting the use of locally available materials and components.

Table 1: Synthesis of Passive Cooling Systems

Passive Cooling System	Heat Sink	Climatic Range	Physiological effect	Dominant Building Element
Nocturnal Ventilative Cooling	Air	Diurnal range > 8 K Min DBT < 20 C Max DBT < 36 K	Decreases surface temperature of interior walls	Internal mass with external insulation. Operable windows and fans.
Radiant Cooling	Space or upper atmosphere	Clear nights Humidity and temperature are not as important	Reduces air temperature and MRT of interior walls	Roof surface must be exposed to the sky.
Evaporative cooling: Direct and Indirect	Air but uses water as transport (direct) and heat sink (indirect)	WBT < 24 C DBT < 44 C WBT < 25 C DBT < 46 C	If RH is low, a direct system increases comfort. If RH is high, an indirect system should be used	Pond or tower design can be integrated in the building or the landscape

Integration of PCS with Architecture

Sustainable architecture in developing countries should be respectful of local culture integrating new technologies when necessary, while remaining affordable. The building should minimize heat gains and use light efficiently applying simple principles such as shading, light colors, window design and insulation while harnessing natural energies with PCS such as an evaporative cooling system, radiant cooling or selective ventilation. PCS are easy to understand and build by architects and laymen and can integrate seamlessly with architecture.

Conclusion

Energy costs for cooling in warm developing countries due to bad architectural design hamper economic growth because they are a burden to commercial and industrial development. Passive cooling systems are economical to build and operate and could be integrated in different types of buildings to reduce energy costs and improve thermal comfort and life quality in developing countries, while saving non renewable energy and reducing pollution. Designing a sustainable green building involves all aspects of design and many issues, which are out of the scope of this paper, but if energy is saved and comfort is improved a big first step has been taken.

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