Application of Passive Cooling Methods

Khairul Enam

Abstract

The paper discusses the various possibilities of passive cooling methods and their application potentials in the warm-humid region of Bangladesh. The paper attempts to recognise the natural balance of global system as a generating force, opens a new dimension in Architecture and landscape design, the dimension that has been long ignored. The concept of passive system is a new beginning of an old forgotten idea. The study attempts to compile some of the results of works on passive cooling and outlines an approach towards site planning and design.

The study is concerned with the following passive cooling systems:

a. Radiative cooling
b. Convective cooling
c. Evaporative cooling

The study also attempts to suggest some outline on the application of passive systems in the context of Bangladesh.

INTRODUCTION

The overall impact and heat exchange of urban sink with built forms are being evaluated by modelling approaches. There are basically two categories of urban climate modelling. The first one deals with microclimate variations occurring below roof level or street level, known as urban canopy-layer (UCL). The second one is the urban boundary-layer (UBL) models that simulate the climatic variations occurring above roof level of the heat sink. UBL models are extensively used (Taesler, 1986) and are divided into classes, i.e. convective, radiative and dynamic models, depending on their purposes. The UBL models express the urban boundary conditions in simulating average values of urban roughness and surface temperature.

A more detailed study of an area could be accessed by Urban 3 models which fall into the first category of modelling. The Urban 3 interprets a city by a series of rectangular blocks intermixed with streets, parking lots and parks. The specific sizes of the built volumes and built areas along with its material characteristics, distribution and climatic data are the basic input of the model.

The model gives an idealistic overview of the urban situation and the results are considered to depict the general conditions. The model operates well in a street canyon arrangement, but in a complex where canyon type building arrangements are not followed, the results of the model may deviate from the reality.

The thermal comfort criteria out-doors is quite different to that of indoors. There has been substantial work done on the comfort issues in out-door spaces at EXPO'92, Seville. The studiess how that thermal balance out-door results in :

ESW=M(I-U) + (R+C) + H - Cres - Eres - Edif
Where M(I-U) is the net metabolic heat production
H= Direct, diffuse and reflected solar radiation absorbed by the subject.
R=Represents the long wave radiation exchange with the surrounding surface.
C=Air convection
Cres - the sensible heat
Eres - the latent heat due to the respiration
Edif - the skin diffusion heat

ESW- The regulation sweating term, the only means of attaining thermal balance and giving a measure of the adaptive effect of the body, and consequently the level of comfort.

Where
HD = direct solar gain
Hd = diffuse solar gain from sky
Hr = reflected solar gain from vertical and horizontal surfaces
ARC = long wave radiation exchange to sky
ARS = long wave radiation exchange to surfaces
Cv = convection with the air
E = evaporation or sweating[1]

It is observed that the body can balance the heat only by sweating and to some extent reradiating to sky, with much discomfort. The study further indicated that radiative heat gain (direct + diffuse + reflected), can be controlled to some extent, and long-wave heat exchange and air convection can be attempted to achieve a cooling effect.

The techniques applied for the control of out-door spaces at the EXPO'92 followed the main conditioning actions, i.e. blocking solar radiation by a large tent and patio, reduction of surface temperature by employing water ponds (15 hectares) and cascades running over 400m at a height of 6 inches.

Air temperature is reduced by installing 12 cool towers equipped with wind catchers and micronizers.

The micronizers (water sprays) are used extensively in the foliage of trees and pergolas which produced cool air flow in the pedestrian areas of the EXPO'92 complex. There are about 12 different systems with 7000 micronizers installed in the complex to attain the air cooling conditions.

Early examples of passive cooling systems can be observed in Moghul gardens (1526-1757).[2] The gardens were cooled by intelligent use of thermal resistant materials, plants and water.

Khairul Enam, B. Arch., M. Arch., Professor. Specialized in housing. Involved in research on 'Passive Design strategies in Urban Micro-level Outdoor Environment' and preparation of National Building Code. Areas of interest are design of commercial buildings, landscape design and urban climate.

References

1. Guerra, J. Alvarez S., E. Rodriguez A., Velazquez R., Comfort issues in the outdoor spaces at EXPO '92'. Published in PLEA '91', Proceedings of the Ninth International PLEA Conference, Seville, Spain, 1991.
2. Bowen, A. B. Cooling Achievements in the Gardens of Moghul India. Paper Published in the proceedings of the International Passive and Hybrid Cooling Conference, 1981.

Three types of gardens were built by the Moghuls, the palace gardens, tomb gardens and pleasure gardens. Gardens were conceived as the extension of indoor living spaces. Plants were used both for decorative and shading purposes. The extensive use of water for evaporative cooling was the most striking feature of the garden. The cooling qualities of water had been exploited by a large water body, fountain surface flowing, and spray. The layout of gardens was planned to allow breezes to flow over the water bodies and fountains to cool the garden pavilions. The combined effect of all the elements provided cool relief from the arid heat of the Indian climate.

Other examples of deriving passive cooling from the landscape are briefly discussed in the following passage.

A large tree could be used for cooling for both horizontal and vertical surfaces. The precise placement of a tree south and west of a residence can optimize the energy saving during the warmest afternoon periods of summer.[3]

Table 1 indicates the experimental results conducted by John H. Parker, 1981, on effects of shading by plants on vertical surfaces.

Table 1
Average reduction in surface temperature for east and west facing light-coloured walls with various types of landscape plants providing shade or cover. Data was recorded on warm summer days in Miami, Florida.

Landscape Elements	Average temp. reduction (ATR) during day with no direct sunlight °F	ATR during day with direct sunlight °F
Large tree		
Moderate-size	6.4	24.5
Shrub		
Tree/hedge	7.6	24.3
Combination	10	28
Moderately thin vine	8	13.8
Moderately thick vine	7.5	16

The temperature reduction capabilities of a tree by evapotranspiration is recorded by Bowen, 1980. A single tree of medium size is found to reduce the shaded area temperature by 2 to 3°C

Duckworth and Sanbury 1954, found that the temperature of Golden Gate Park was 8°C cooler than the nearby areas.

3. Parker, J. 'A comparative analysis of the role of various landscape elements in passive cooling in warm humid environment'. The paper was published in the proceedings of the International Passive and Hybrid Cooling Conference, p. 368.

A full size tree as Moffat's experiment result evaporates 1460 kg of water per sunny day, which is equivalent to 870MJ cooling capacity.

According to Moffat's observations, the latent heat transfer from wet grass can result in 6 to 8°C cooler surface than an exposed soil surface. One acre of grass area can transfer more than 50 GJ/day.

All these studies indicate that plantation and grass areas can play a vital role in reducing the air temperature of an environment. The challenge is to show that these potentials for passive cooling could be employed rationally in the out-door environment.

Evaporative Cooling

Evaporative cooling has a significant contribution in the hot dry regions. In hot humid regions during hot summer days when RH values are comparatively low, evaporative cooling may be employed for passive cooling.

The mode of evaporative cooling :

A. Water spraying :

The results of different observations and experiments are summarized here.

The exposed exterior pavements and surfaces are heated by solar radiation and the hot ambient air can be cooled effectively and inexpensively by spraying them with water. As water evaporates it draws most of the required latent heat from the surface thus lowering its temperature. The surfaces can be sprayed intermittently, since it is only necessary to keep the surfaces moist. — Yellott. 1961

B. The skytherm system, proposed by Harold Hay, 1965

The system was thermopond on roof in thermal contact with structural roof and covering the ponds by movable insulation. Hay proved that, under suitable climatic conditions, comfortable conditions can be maintained indoors by covering the ponds with insulating panels during the day in the summer and during the night in the winter.

C. The energy roof :

The cooling capability of the 'Energy roof' invented by A. L. Pittinger and W.R. White was investigated during a four-year programme carried out in 1977 and 1978, at the College of Architecture, Arizona State University.

The system uses a roof pond supported like Harold Hay's Skytherm by a metal ceiling. The insulation floats on the water in the pond under a thin, transparent plastic film. For winter heating the water from the pond is pumped up during daylight hours to a distributing tube, which allows it to flow in a thin layer above the insulation. In summer the same pump is operated at night for radiative cooling. In addition a water spray causes evaporative cooling to take place at the upper-surface of the plastic film, further removing heat from the water flowing under the film.

D. The cool pool :

The cool pool is proposed and tested by Karen Crowther at Davis, California (1979). The pool is supported by a concrete roof and is shaded by louvers from the direct rays of the sun, so that it "sees" only the northern sky. The pool water, in addition to radiative losses, cool water then circulates through the warm interior spaces and rises back to the pool again.

In out-door spaces water bodies with open systems, intermittent sprays and fountains can minimise the solar heat. The methods have already been in use for centuries in the Middle East, India and Bangladesh. However, integrating the method with trees, sheds and grass areas can further improve the thermal conditions of our environment.

Radiative Cooling

The main source of radiative cooling is the clear sky. All material objects emit heat in the form of infrared radiation. The intensity of this radiation is dependent on the temperature and emissivity of the object.

The Materials like concrete, glass, paints and water have high emissivities in the infrared part of the specturm. A highly reflective or transitive material has an emissivity near zero. The hemispherical emissivity of the radiator can have values between zero and one.

The exposed surfaces will lose heat when ambient air temperature is lower than the surface temperature. Similarly, they will gain heat when air temperature is higher than the surface. The rate of these convective exchange between radiating surface and air is also dependent on wind speed. The cloud cover condition of atmosphere and ambient humidity greatly reduces the gradient heat loss of a surface.

The infrared heat transfer to sky occurs both in day and night. The effect are noticeable during the night when it is not masked by the abundant inflow of energy form the sun.

The infrared radiation emitted from substances at the earth's surface can be absorbed and reemitted many times by water droplets and atmospheric gases like carbon dioxide, water vapour and ozone before escaping into space.

All the exterior materials both in horizontal and vertical surfaces have high emissivites. Many of the severe conditions could be avoided if the surfaces were shaded to cut out the direct sun. Plants, patio, screens and buildings can play a significant role in providing the desired shading when landscaping and architecture jointly work towards the goal.

Convective Cooling or Ventilative Cooling

Historically, man has relied upon natural ventilation for comfort in buildings as well as out-door spaces during warm seasons. In tropical humid climates, the poor rural people are very primarily dependent on natural ventilation.

The out-door air movement in urban areas is influenced by built form and landscape. The structure/open space relationship are the basic determinants of wind movement in out-door spaces.

"Siting and site layout as well as landscaping represent two important groups of strategies to improve the micro climate around buildings. Saving existing shade trees and taking benefits from any local breeze are the primary recommendations for site planning."[4]

The wind effects in out-door spaces have been summarised by A. Fernandes, S. de Schiller and J. M. Evans in the study of Wind in Urban Spaces (PLEA'91). There are 12 studies regarding the behaviour pattern of wind movement in out-door spaces (p. 37), the wind movement effects in high-rise buildings, wise effect, venturi effect, etc. can be noted for effective use.

There are elaborate studies by Baruch Givoni showing the distribution of wind speeds in different urban configurations with different height-spacing ratio (Urban Design in Different Climates, 1989. p. 3-41 to 3-43). From the studies of: Acuk, 1975, it is observed that scattered high rise building devlopments in a predominantly low rise environment gives better relative wind velocity than an all low rise environment, in a canyon type layout.

The dynamics of air flow have been referred to as turbulent, laminar and separated flow in the studies of Arthur Bowen, "classification of air motion systems and patterns". The wind movement in or around the building is created by positive and negative forces. The experiment results show that with inclined and staggered building layouts better air flow results may be achieved in the leeward side. Trees and shrubs combined can direct the wind in the intended direction.

All these studies indicate that wind movement or ventilative cooling is a controllable feature and needs the attention of the designers at the conceptual level. The direction of wind, wind speed, layout of building, open spaces and planting all interact together to achieve an effective ventilation condition for outdoor comfort.

4 Fleury B., Antinucci M., D. Asiain J.L., and Yannas S., Horizontal Study on Passive Cooling, 1990. p. 4.

Application of passive cooling systems in Bangladesh context.

In Bangladesh nearly 80% of the total population who live in rural areas depend on passive systems for both out-door and indoor living comfort conditions. In rural areas people spend most of the day time in out-door spaces. The comfort of gentle breeze under the shade of trees are much more preferred than the closed indoor spaces. Extensive vegetation, water streams and ponds and very limited use of brick and concrete in structures and pavements, ensure an out-door environment that seldom crosses the comfort range in hot summer days.

Bangladesh enjoys warm-humid-monsoon climate and in the rainy season RH value of air varies between 80 to 88% with the air temperature between 28°C to 33°C. There is very low possibility for evaporative cooling in this season. The summer and winter season are comparatively dryer and the RH value range remains between 55% to 70%. Air temperature in summer rises upto 41°C and winter temperature remains between 7.22°C to 31.11°C.

The preliminary observations indicate that there are ample possibilities for the application of passive cooling systems in our urban areas that can substantially reduce the out-door temperature.

The following measures may be taken into account in the attempt for reducing out-door temperature.

a) To provide shade in the exposed pavements and streets by planting appropriate trees and shrubs.
b) Selection of materials with low reflectivity for pavements, streets and exterior building surfaces.
c) To adapt the passive planning considerations for streets and building orientation and layout, encouraging wind movement and shading.
d) use of water for evaporative cooling in hot summer and winter days.
e) Roof shading by patios or gardening.

The above measures, at least in part, are usually included in most of the ongoing or existing developments in urban design but the decision making regarding the outdoor environment primarily lacks climate consciousness objectively and are predominantly piecemeal in nature. The main input is required in the awareness and conceptual decision making level rather than on the financial aspect of the development projects.

An effective utilization of out-door developments in the passive approach of design needs elaborate studies in landscaping, material characteristics, planning tools and techniques as well as climatic factors.