REINVENTING TRADITIONAL SYSTEM FOR SUSTAINABLE BUILT ENVIRONMENT: AN OVERVIEW OF PASSIVE DOWNDRAUGHT EVAPORTAIVE COOLING (PDEC) TECHNIQUE FOR ENERGY CONSERVATION

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ABSTRACT

There has been a drastic increase in the use of air conditioning system for cooling the buildings all around the world. Interest in reducing emission of greenhouse gases, caused by fossil fuels to power the cooling requirements of the buildings has stimulated the enthusiasm towards adoption of passive cooling techniques for buildings. Passive systems use non-mechanical methods to maintain a comfortable indoor temperature and are a key factor in mitigating the negative impact of buildings on the environment. Of the different methods to reduce the cooling load, passive cooling of houses and buildings is the most suitable and sustainable method. Passive downdraught evaporative cooling (PDEC) is a passive cooling technique which involves spraying of controlled volumes of microscopic water droplets into hot, dry ambient air, thereby causing it to cool and descend into a required capture zone within a building. This paper is a review paper in which a study of Passive Downdraught Evaporative Cooling (PDEC) as a passive cooling technique for providing thermal comfort and its significance in energy conservation in buildings has been done. The interrelationship between sustainability and cooling needs of buildings has also been discussed. Further two applications of PDEC in contemporary architecture (Torrent Research Centre, Ahmedabad, India and New office building at Catania, Italy) have also been analyzed. Finally a critical analysis of using PDEC system in the buildings has also been done.

Key Words**:** Passive, downdraught, evaporative, cooling, energy conservation.

1. INTRODUCTION

The last two decade have witnessed a grave energy crisis in developing countries especially during summer season, primarily due to cooling load requirements of building. There has been a lot of reliance on energy-consuming technology in cooling and ventilation system to achieve thermal comfort in buildings. The mechanical means of providing thermal comfort are not only unsuitable because of their initial and recurring costs but also because of non-availability of artificial sources of energy on a regular basis. Increasing consumption of energy has led to environmental pollution resulting in global warming and ozone layer depletion. Hence, the need to reduce the emission of greenhouse gases caused by fossil fuels used to power the cooling requirement of the buildings, has stimulated the interest towards adoption of passive cooling techniques for buildings.

In vernacular architecture, there are examples of passive cooling systems, particularly those using evaporative cooling particularly in countries around the Persian Gulf. However in modern times due to the availability of electrical power to run active cooling systems, focus on use of these techniques had been forgotten. Passive Downdraught Evaporative Cooling (PDEC) techniques offer significant potential for reducing the energy demands for cooling of non-domestic buildings in hot dry climatic regions. Passive downdraught evaporative cooling (PDEC) is a passive cooling technique which involves spraying of controlled volumes of microscopic water droplets into hot, dry ambient air, thereby causing it to cool and descend into a required capture zone within a building. From here the cool air enters the adjacent occupied spaces through carefully sized and controlled openings. With PDEC cooling process, the air temperature may be reduced by 70-80% of the wet-bulb temperature depression, providing the potential for very significant cooling in hot dry climatic regions.

2. COOLING NEEDS OF BUILDINGS AND SUSTAINABILITY IN ARCHITECTURE

Enhanced living standards in the developed world using climatically non-responsive architectural standards have made air conditioning quite popular. This has increased energy consumption in the building sector. There are more than 240 million air conditioning units installed worldwide

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according to the International Institute of Refrigeration (IIR). IIR's study shows that the refrigeration and air conditioning sectors consume about 15% of all electricity consumed worldwide (IIR, 2002). In Europe it is estimated that air conditioning increases the total energy consumption of commercial buildings on average to about 40 kWh/m^2/year (Burton, 2001).

It is evident that the total energy consumption of buildings for cooling purposes varies as a function of the quality of design and climatic conditions. In hot climates, commercial buildings with appropriate heat and solar protection and careful management of internal loads may reduce their cooling load down to 5 kWh/m^2/year, while buildings of low quality environmental design may present loads up to 450 kWh/m^2/year (Santamouris and Daskalaki, 1998). Hence, the quality of built environment has a large impact on environmental sustainability.

Architectural sustainability is linked to the Brundtland definition, through an emphasis on limits to the carrying capacity of the planet and it point to the UK's Building Services Research and Information Association (BSRIA) definition of sustainable construction as 'the creation and management of healthy buildings based upon resource efficient and ecological principle' (Edwards and Hyett, 2001). In principle, sustainable buildings relate to the notion of climate-responsive design, which places emphasis upon natural energy sources with the aim of achieving building comfort through an interaction with the dynamic conditions of the building environment (Hyde, 2000). Sustainable architecture is an approach to design where building technology is integrated with the concept design and has the potential to reduce the need for high-tech systems and reduce the energy consumption of buildings. There are many different methods to reduce the cooling load, but Passive downdraught evaporative cooling (PDEC) adapted in buildings is one of the most sustainable methods. Since air conditioning is recognized as a significant factor in global warming and climate change, passives downdraught evaporative cooling proves to be both technically and economically viable alternative, especially in hot-dry or composite climate and where the cooling requirement is around 6-7 months in a year.

3. TRADITIONAL COOLING SYSTEM WITHOUT AIR CONDITIONING

Passive Downdraft Evaporative Cooling is an old technique was applied in Islamic architecture. Evaporative cooling was extensively used in the vernacular architecture in Pakistan, Iran, Turkey and Egypt (see Figure 1). The tradition of 'cooling without air conditioning', has its origins in ancient Egypt; it subsequently spread eastwards through the Middle East and Iran to north India with the Mughal empire, and westwards across North Africa to southern Spain. In the Middle East there is an established tradition of using various techniques to encourage evaporative cooling both within and between buildings. Wind catchers called 'malqafs' captured wind and directed it over porous water pots, causing evaporation and bringing a drop in temperature as a result of latent heat of vaporization (Ford, 2001). This system maintained a balance between two important parameters of passive cooling – thermal performance and ventilation effectiveness. In this tradition, wind-catchers guide the outside air over water-filled porous pots. This induces evaporation and brings about a significant drop in temperature before the air enters the interior of the building.

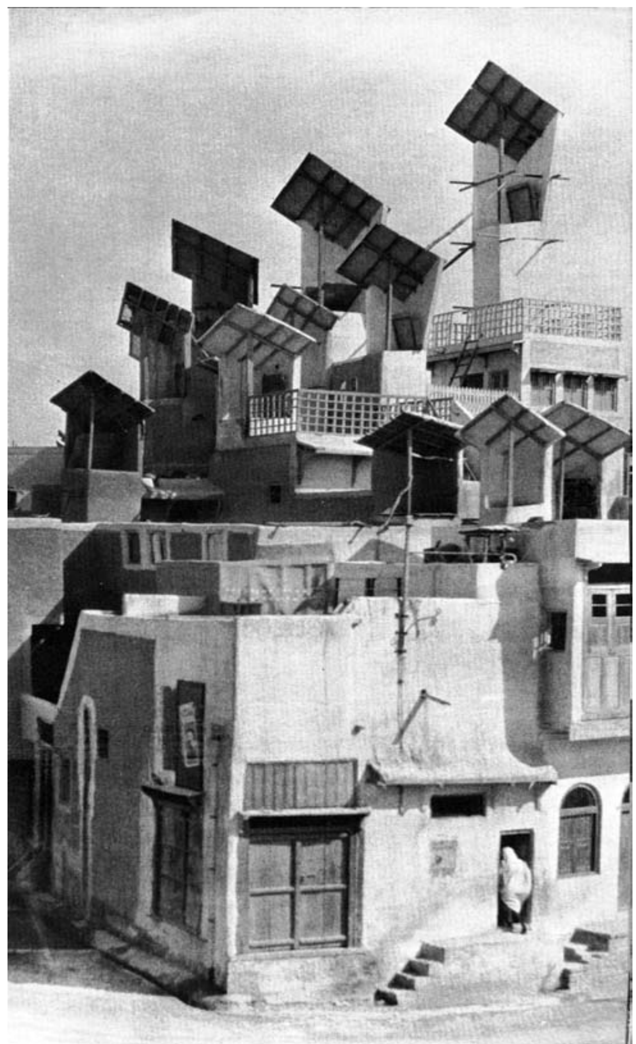

Figure-1: Wind catchers in traditional architecture of Sindh, Pakistan.

More recently, this tradition has been taken up by Hasan Fathy and others, and developed for cooling schools and other buildings. Often, the air flow rate is enhanced by catching and redirecting the prevailing wind. Fathy comments on design strategies to exploit these effects not only within buildings but in external spaces as well (Fathy, 1984). In north India, the Mughal palaces and gardens exploited evaporative cooling to delight the eye and other senses as well as providing thermal relief. Thin water chutes (salsabil) and other evaporative cooling techniques were features of Mughal architecture from the thirteenth to the seventeenth centuries. The intense dry heat and dust of the summer in north India calls for the creation of an internal refuge or haven from the extremes of the external world. The diurnal swing in temperature is dampened by the mass of stone and earth, and the air is further cooled by the evaporation of water in the ventilation air flow path. This is exemplified perfectly in the beautifully atmospheric Rai Pravina Mahal in Orcha ((Ford and Hewitt, 1996).

4. PASSIVE DOWNDRAUGHT EVAPORATIVE COOLING (PDEC)

Maintaining a comfortable environment within a building in a hot climate relies on reducing the rate of heat gains into the building and encouraging the removal of excess heat from the building. Passive-cooling techniques concentrate mainly on reducing unwanted heat gains into the building. In the twentieth century, evaporative cooling was applied in buildings throughout the world in conjunction with a mechanically driven air supply (known widely as desert coolers). Recently, attention has returned to the potential of exploiting the benefits of direct evaporative cooling while avoiding mechanical assistance by using buoyancy or wind forces to drive the air flow. In the late 1980s, a number of successful experiments were undertaken which tested the evaporation of water within a downdraught tower, hence the term Passive Downdraught Evaporative Cooling (Ford, 2001).

The device consists of single or multiple towers equipped with a water vapour supply placed on the top. This innovation consists of replacing the wetted pads with rows of atomisers (nozzles, which produce an artificial fog by injecting water at high-pressure trough minute orifices). During the constant injection of water, droplets descend through the tower and conditions close to saturation are produced along its length. Cool air descends the tower and exits at its base where it is delivered to the adjacent spaces (see Figure 2). The concept is based on the relatively large amount of energy required to convert water from its liquid to gaseous form within a local thermal imbalance with subsequence differences in air density. This leads to the movement of air from a zone of high pressure, where air is hot and less dense (top of the tower) to a zone of lower pressure, where air is colder and denser (bottom of the tower). The situation of the micronisers in a tower gives rise to a natural downdraught effect.

5. CONTEMPORARY APPLICATION OF PDEC

Contemporary passive downdraft evaporative cooling systems consist of a downdraft tower with wet cellulose pads at the top of the tower. Water is distributed on the top of the pads, collected at the bottom into a sump and recirculated by a pump. Certain designs exclude the re-circulation pump and use the pressure in the supply water line to periodically surge water over the pads, eliminating the requirement for any electrical energy input. In some designs, water is sprayed using micronisers or nozzles in place of pads, in others, water is made to drip. Thus, the towers are equipped with evaporative cooling devices at the top to provide cool air

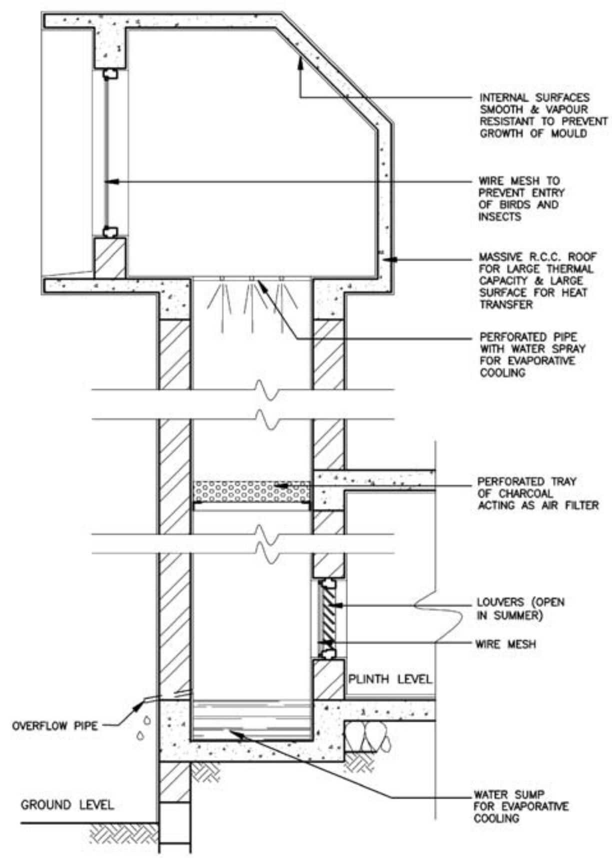

Figure-2: Cross Sectional details of Passive Downdraught Evaporative Cooling.

by gravity flow. These towers are often described as reverse chimneys. While the column of warm air rises in a chimney, in this case the column of cool air falls. The air flow rate depends on the efficiency of the evaporative cooling device, tower height and cross section, as well as the resistance to air flow in the cooling device, tower and structure (if any) into which it discharges (Thompson, Chalfoun and Yoklic, 1994).

Two examples are presented below from India and Italy:

5.1 Torrent research centre, Ahmedabad

The first large-scale application of PDEC was in the Torrent Research Centre, a pharmaceutical research laboratory in Ahmedabad (see Figure 3). Designed by Abhikram Architects and completed in 1998, this project demonstrated that this approach to cooling could be applied to a large, complex laboratory building ((Ford, et al. 1998). The total built up area of the complex is approximately 20,000 Sq. Mts. 72% of the central building has achieved human comfort conditions using Passive Downdraft Evaporative Cooling (PDEC). It has been able to establish extremely low levels of energy consumption, as well as considerably decreased carbon dioxide emissions per square meter of area. Around 200 metric tons of air-conditioning load is saved. The performance has been consistent over the past eleven years of its use. It has realized healthy financial returns on the investment in the way of building costs. The entire cost of the building will be recovered from the electrical savings alone, in 13 years of operation (Abhikram 2009).

Measurements of air temperature and relative humidity in different parts of the building in April 1998, revealed that very significant cooling and high air change rates were achieved. Peak temperatures of 27°C in the ground floor laboratory and 29°C at first floor, were achieved when the external maximum reached 38°C. Over the same period, air change rates of 9 per hour on the ground floor and 6 per hour at first floor were recorded. The staff reported that, during the summer (February-June) the laboratories are comfortable without fans and are not stuffy or smelly, as most chemistry labs are, even when air conditioned. During the monsoon (July-September), the evaporative cooling system is not operated, of course, so ceiling fans are used to enhance comfort for these two to three months. In the first year since its occupation, the Torrent Research Centre was reported to have used approximately 64% less electrical energy than the equivalent conventionally air-conditioned building (Ford, 2001).

5.2 Office Building in Catania, Italy

A high performance example of PDEC is the design proposed by Mario Cucinella Architects for the new office in Catania, Italy (see Figure 4). The design consists of a 27m wide by 70m long, 4 storey office building punctured by nine 3m diameter glazed cylindrical PDEC towers. These towers protrude above the roof of the building by about 6m. The microniser spray and baffles to avoid wind effects were located in this tower head region. Air entered each of the 3 floors and the ground floor through high level openings in each PDEC tower leaving the building via the highly glazed double-skin facade. The main idea was to create a number of PDEC towers that passed through the building vertically. Each tower cooled the air in the adjacent area when needed (see Figure 5). The towers were also used for night ventilation and to bring daylight into a deep plan space (Elizabeth and Ford, 1999).

Figure-3: Passive Downdraught Evaporative Cooling in Torrent Research Centre, Ahmedabad.

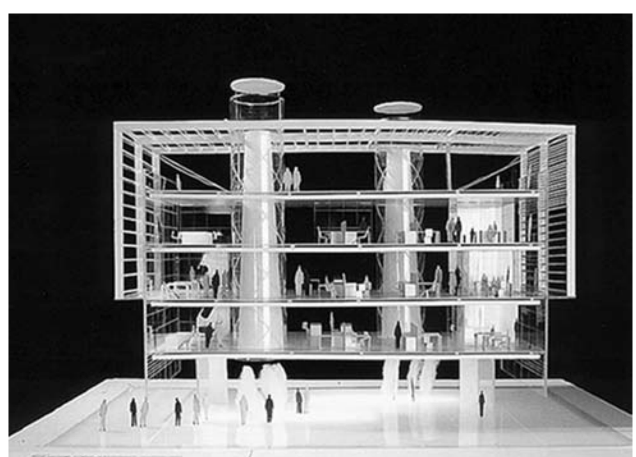

Figure-4: The new office Building in Catania, Italy by Mario Cucinella Architects.

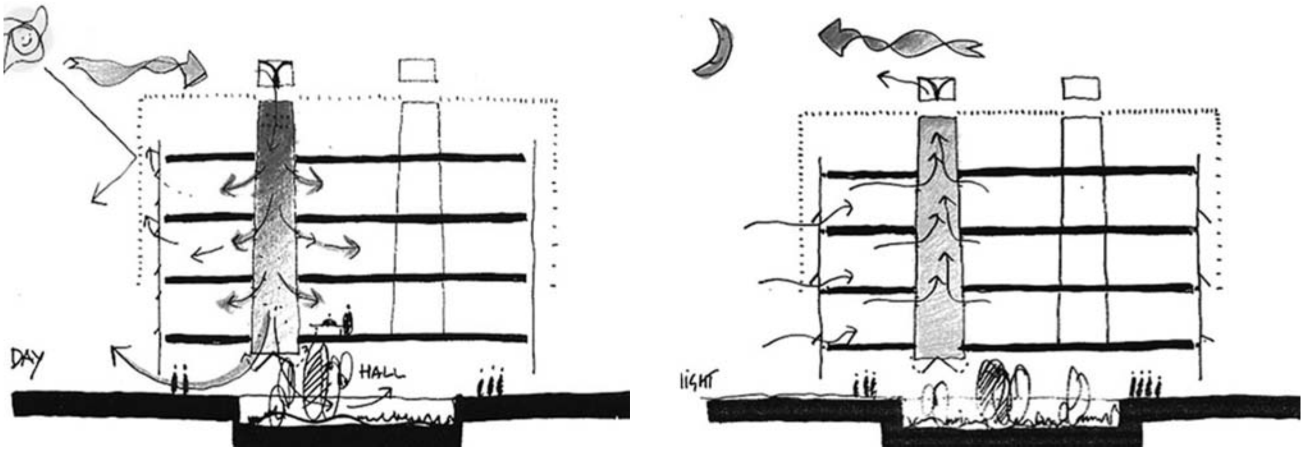

Figure-5: Day and night functioning of PDEC in office building in Catania.

Architect Mario Cucinella, a partner in a multidisciplinary research group funded by European Commission's Joule program, explored how to apply this passive cooling technique to commercial buildings in southern Europe's hot and dry regions (Cucinella et al, 1998). Thermal analysis of the Catania office building was undertaken by ESII using PASSPORT-Plus in which a PDEC tower model had been incorporated and the CFD program FLUENT. The thermal simulation analyses indicated that:

- The tower height should be 6m above the building roof;
- Under this system, peak cooling loads could be reduced by a third, from 82 W/square meter to 58 W/square meter, compared with the original single atrium design.
- With an external air temperature of 29°C and an internal heat load of 30.7 W/m2 thermally acceptable conditions could be obtained on the office floors using PDEC;
- PDEC alone could not maintain comfort throughout the year and so had to be supported by a mechanical cooling system;
- For a building which is wholly air-conditioned the annual cooling energy demand would be 28.5 kWh/m2 of floor area. Using PDEC supported by mechanical cooling, the predicted cooling energy demand was 20.9 kWh/m^2, an energy saving of 27%. The water demand for PDEC cooling was equivalent to 10 litres per person per day.

6. PERFORMANCE ANALYSIS OF PDEC SYSTEM

The PDEC system depends on two basic factors that determine its effectiveness: (1) amount of cooling of the ambient air achieved, and (2) the rate at which this conditioned ambient air replaces the stale air within the building. The former can be easily achieved by increased air-water contact zone. This factor usually dictates the height of the tower and in turn, influences the massing of the building design. The second factor, however, requires a complex interplay of different variables to achieve an effective performance. These variables dictate the configuration of the tower termination, the positioning of multiple towers within the building, circulation pattern within the building, and even the configuration of openings between adjacent spaces served by these towers. The temperature of the incoming ambient air drops while crossing the pads. Therefore, the height of the tower and the area of the wetted pads are not expected to have any appreciable effect on the temperature of the air in the tower in a given combination of ambient dry and wet bulb temperatures. However, these two system design factors affect the airflow rate, and hence the total cooling effect generated by the system (Givoni, 1994).

Through evaporative cooling, the ambient air can potentially be cooled down to the dew point temperature simply by saturating it with moisture. This type of cooling is thus particularly efficient in relatively dry climates. But in humid climates it is also possible to generate cooled air flow through evaporative cooling (Yajima and Givoni, 1997). PDEC systems have been used with various types of cooling devices such as spray assemblies (pressure and ultrasonic nozzles), aspen fibre pads and corrugated cellulose pads. The performance analysis would thus vary depending on the evaporating cooling facilities provided in the tower. Aspen pads cause a high pressure drop relative to sprays and corrugated media, but they are low in cost. Spray devices may require efficient mist eliminators for removing fine droplets from the air because mist impedes air flow ((Thompson, Chalfoun and Yoklic, 1994). PDEC can avoid the need for ductwork, fans and suspended ceilings, thereby reducing the overall height of buildings. In less severe climates, or in less demanding buildings, PDEC might avoid the need for air-conditioning entirely. PDEC provides 100% fresh, cool air with no re-circulation – as is often the case in air-conditioned buildings. PDEC ought, therefore, to provide an environment with high air quality.

In a research project funded by the European Commission, Mario Cucinella Architects and partners, an assessment of the potential application ofÊPassive Downdraught Evaporative Cooling in Southern Europe was done. The table 1 below summarises the stock areas and potential energy savings of four European countries and shows that energy savings could be around 1.5% to 2.5% of the national annual electricity consumption.

6.1 Limitations of PDEC

The hardness of the water is a significant factor, therefore water quality has to be good otherwise nozzles will block. High pressures (>40 Bar) are required to minimize water droplet size and maximize evaporation, which implies more expensive pumps and plumbing. The risk of microbiological contamination of the water supply to the misting nozzles must also be minimized. This can be addressed by a combination of design measures (including the use of UV filters in the supply line to the micronizers), regular maintenance, and testing, but it would clearly be better if this was not an issue. In many parts of the world the potential disadvantages of using micronizers (risks of microbiological contamination, blockage of micronizers, high-pressure stainless-steel plumbing fittings are a powerful disincentive. 'Low-Tech' solutions may be more appropriate in locations where water quality is poor, or where high-pressure plumbing is unfamiliar. The practical integration of such systems within the building envelope is fundamental to the feasibility of this approach. If simpler techniques currently under investigation do prove technically and financially viable, the market potential could be significant.

7. CONCLUSION

The use of air conditioning has increasingly penetrated the market during the last few years and greatly contributes in the rise in absolute energy consumption due to improving standards of life and increasing world population. Since air conditioning is recognized as a significant factor in global warming and climate change, passives downdraught evaporative cooling proves to be both technically and economically viable and is competitive with respect to conventional air-conditioning. Countries such as India can benefit more where most of the population resides in hot and dry or composite climate and where the cooling requirement is around seven months in a year. The technique of passive downdraught evaporative cooling has only recently been applied to buildings, but has enormous potential to displace the need for conventional air conditioning.

Table-1: Potential energy savings through PDEC (ALTENER, 2012).

Country	Commercial buildings area millions m2	National electricity consumption millions KWh	PDEC potential energy savings millions KWh	Energy saving as % of national electricity consumption	Reduction in CO2 emissions tonnes pa	Potential value of energy saving pa euro million
Greece	39	46,099	1,124	2.44%	766,596	85.4
Spain	116	201,159	3,341	1.66%	1,472,654	257.9
Italy	161	283,737	4,637	1.63%	2,809,643	490.4
Portugal	25	41,146	720	1.75%	391,414	59.0

With the ever growing global concern for the use of energy and resources, architects have a greater responsibility to design buildings that are environmentally sustainable. Therefore, in present day architecture, it is now essential for architects and building engineers to incorporate PDEC as a passive cooling technique in buildings as an inherent part of design and architectural expression and that they are included conceptually from the outset. Incorporation of PDEC would certainly reduce our dependency on artificial means for thermal comfort and minimize the environmental problems in buildings caused due to excessive consumption of energy and other natural resources and will evolve a built form, which will be more climate responsive, more sustainable and more environmental friendly.

REFERENCES

Abhikram Q. & A. (2009), Green by design, **Home Review**, Marvel Infomedia Pvt. Ltd., Mumbai.

ALTENER-Solar Passive heating and Cooling: Market Assessment of the Potential Application ofÊPassive Downdraught Evaporative Cooling in Southern Europe, (2012, January 14). Available http:// www.phdc.eu/index.php?id=10.

Burton, S. (2001) **Energy Efficient Office Refurbishment**. London, James and James Science Publishers.

Cucinella, M., Elizabeth, F., Ford, B. et al, (1998), **The Application of Passive Downdraught Evaporative Cooling (PDEC) to Non-domestic Buildings,** Final Publishable Report, De Montfort University, UK.

Edwards, B. and Hyett, P. (2001) **Rough Guide to sustainability**. London, RIBA Publications.

Elizabeth, F. and Ford B., (1999) **Recent Developments in Passive Downdraught Cooling - An Architectural Perspective**. London, James and James Science Publishers.

Fathy, H. (1986) **Natural Energy and Vernacular Architecture**. University of Chicago Press.

Ford, B. (2001) Passive downdraught evaporative cooling: principles and practice. **Architecture Quarterly**, Vol. 5, No. 3.

Ford, B. and Hewitt, M. (1996) Cooling without Air Conditioning - Lessons from India. **Architecture Quarterly**, Vol. 1, No. 4, pp. 60 - 69.

Ford, B., Patel, N., Zaveri, P. and Hewitt, M., (1998) Cooling without Air Conditioning: The Torrent Research Centre. **Proceedings of World Renewable Energy Congress V**, Florence, Pergamon.

Givoni, B. (1994) **Passive and low energy cooling of buildings**, New York, Van Nostrand Reinhold.

Hyde, R. (2000) **Climate Responsive Design: A Study of Buildings in Moderate and Hot Humid Climates**. London, E. & F. N. Spon.

International Institute of Refrigeration - IIR. (2002) **Report on Industry as a partner for sustainable development – refrigeration**. Paris, France.

Santamouris, M. and Daskalaki, E. (1998) **Case Studies - In Natural Ventilation**. London, James and James Science Publishers.

Thompson, T.L., Chalfoun N.V. and Yoklic M.R., (1994) Estimating the performance of natural draft evaporative coolers. **Energy Conversion and Management**.

Yajima, S. and Givoni, B., (1997). Experimental performance of the shower cooling tower in Japan, **Renewable Energy**, Volume 10, issue 2/3, pp. 179-183.