Passive Evaporative Cooling: the PDEC project

Alfio Galatà, Salvo Sciuto
Conphoebus s.c.r.l. - Zona Industriale, Passo Martino 95030 Catania, Italy Fax. +39 95 291246

ABSTRACT

The growing use of conventional HVAC systems in offices and commercial buildings in Southern Europe is having a major impact on electricity demand. 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. Air can be delivered by capturing the wind within a tower, and cooling may be achieved by spraying microscopic droplets into the airstream. 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. While the potential of this technique has been already demonstrated, the cooling capability and indoor comfort have yet to be assessed, to promote a wider application to non-domestic buildings. To investigate the PDEC system, a three-years research is performing by a multi-disciplinary European Consortium, in the frame of the European Commission JOULE II programme. This paper will illustrate the PDEC Experimental Test Facility, and the experimental measurement campaign to inquire on the cooling capability and indoor comfort.

1. Approach

Significant efforts have been made in literature to reveal [1] the cooling loads of offices and commercial buildings, while research activities [2] have demonstrated passive cooling techniques offer a considerable potential for reducing fossil or fuel energy demand. Wind towers and chimneys have been largely adopted in buildings to catch the wind at higher elevations for natural ventilation, indoor air quality and free cooling for centuries [3]. The wind catcher apertures are oriented in the directions where wind is prevailing; part of the air entering the tower spread out in the living spaces, due to pressure coefficients difference. The portion of entering air is partially used to cool the building structure. With heavy structures the energy storage plays an important role in providing thermal comfort during the following hours.

Catching the wind and direct it into an evaporative tower, a cooling effect can be achieved by spraying microscopic water droplets into the airstream. This technique, already adopted [4] as prototype for cooling outdoor spaces, at the Seville EXPO '92, realizes a passive system and don't require any energy to operate.

The principles of passive downdraught evaporative cooling system (PDEC) have been studied through mathematical models in order to calculate the outdoor conditions (dry and wet bulb temperatures, relative humidities, air flow patterns, system effectiveness) for different input conditions (geometry, outdoor weather conditions). Theoretical studies and simulation results have been used to correctly dimension the PDEC equipment and to provide guidelines for architects, engineers, designers and consultants of cooling systems.

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2. The PDEC project.

To investigate the PDEC system and explore the application inside non-domestic (new or refurbished) buildings, a three-years research is performing by a multi-disciplinary European Consortium, in the frame of the European Commission JOULE II programme.

The project is co-ordinated by the *De Montfort University* (UK) and *Conphoebus* (I) is partner together with *University of Malaga* (ES), *Microlide* (F), *Mario Cucinella Architects* (F) and *Short&Ford Associated* (UK).

The partnership activities cover three main areas: Architectural Design Studies (ADS), Building Performance Assessment (BPA), Experimental and Monitoring (E&M) to finalise the following project objectives:

- establish a technical and financial feasibility of PDEC systems;
- monitor and optimise the performance of PDEC systems;
- stimulate interest and illustrate the application of PDEC products in energy efficient refurbishment and new buildings;
- quantify and compare the overall energy demands of PDEC and non-PDEC buildings;
- explore the applicability of detailed simulation models and the accuracy of their predictions for PDEC buildings;
- assess the indoor thermal comfort in PDEC buildings;
- produce a PDEC Design Guide for architects and engineers.

To realize all these objectives, ADS will produce a design of an Experimental Test Facility and two case studies of PDEC system integration in building refurbishment; BPA will be involved primarily in thermal and airflow simulations, cooling and electrical loads evaluations, thermal assessment comfort in the living space; E&M will carry out several experiments on a full-scale Experimental Test Facility, in view of the characterisation and the model validation of the PDEC technique.

3. The PDEC Experimental Test Facility.

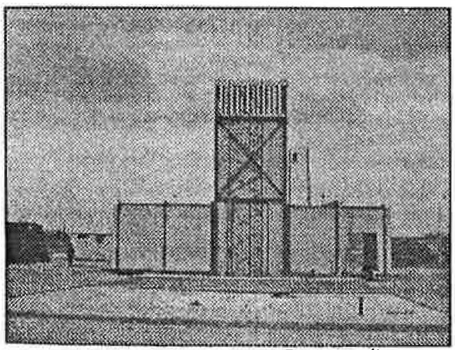

Figure 1 - Experimental Test Facility

The PDEC Experimental Test Facility has been erected on the Conphoebus test site, located in Catania (37.5° latitude, 15° longitude) and consists of a tower (4.1m x 4.4m x 10.7m) and two rooms (6m x 3.6m x 4m), connected to the tower on the south-north sides.

A *wind catcher* (light metallic structure supporting two bent elements, symmetric respect to the north-south axis) is mounted on the top of the tower to catch the wind. This component has two apertures (1.7m x 3.7m) on the east-west sides, according to the meteorological prevailing wind direction of the site (figure 2). In order to better regulate the wind speed coming into the tower, two *moveable louvers* are mounted in the wind catcher apertures.

Just below the wind catcher, a *straightener* is installed to convey the air flow patterns towards the microniser spring system.

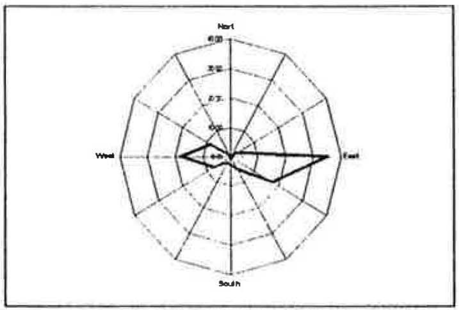

Figure 2 - Prevailing wind direction at the Conphoebus test-site.

The wind catcher and the straightener designs have been achieved through scaled down wind tunnel experiments.

The *microniser spring system* consists of five independent circuits composed of variable number of nozzles, each one with a water flow rate of 6 litres/hours. This arrangement gives the possibility of injecting water from any number of nozzles from 1 to 31.

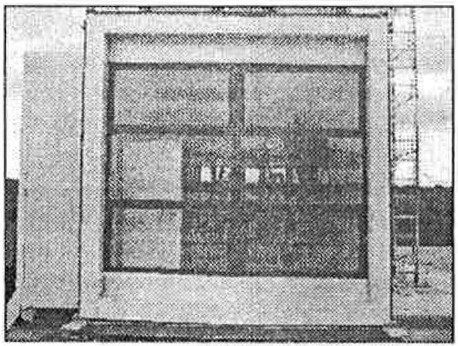

Figure 3 - External windows

External windows (figure 3) are installed in the glazed facade of the rooms, and are composed of four openings, two at the upper part of the frame and two at the lower part of it. These openings are operate through a swinging pane which is opened to outside up to a certain maximum angle around an upper horizontal axis.

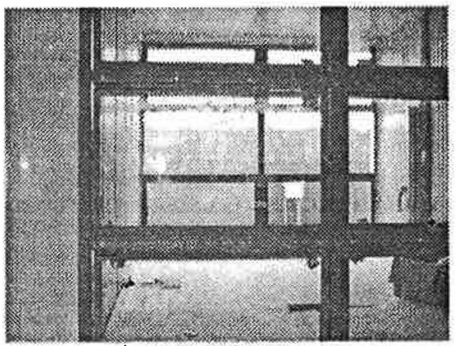

Figure 4 - Internal windows

Internal windows (figure 4) allow the air to flow between the tower and rooms. The window is composed of twelve openings (three horizontal x four vertical) and has much more possibilities of mounting and openings. They can be opened to inside (room) or to outside (tower) through a swinging pane around its upper or its lower axis (four operating possibilities for each opening), with an adjustable aperture angle.

In the room south *suspended ceiling* and *floating floor* with two *ventilation grills* are also installed.

4. Experimental activities.

The experimental campaign of measurement on the PDEC system will be carried out during the next summer to perform full scale measurement on the tower/micronisers and on the complete PDEC experimental building. The overall set of experiments are intended to cover the different requirements for model validation, components design and characterisation, control strategies, comfort assessment etc.

The comprehensive knowledge of the physical phenomena which constitute the rules of the PDEC functionality will allow to understand:

- the relationships between wind speed and wind direction with the mass flow of the air outside the wind catcher;
- the temperature and humidities profiles and air patterns across different section of the tower;
- the thermal comfort inside the rooms (temperature and humidities profiles and air patterns at different levels);
- the cooling capability of the microniser rings as function of the size of droplets, of the contemporary operating nozzles and of their position into the tower;
- the control strategies to optimise the cooling and ventilation performances of the system.

All these activities ought to improve CFD/thermal algorithms and ADS, and will constitute a knowledge base for PDEC systems and confidence in this technology.

5. Measurement Sets.

Measurement sets will be finalised to:

- *Air intake zone* (wind catcher, louvers);
- *Cool air production zone* (micronisers)
- *Air distribution zone* (elements of coupling between the tower and rooms);
- *Occupied space zone* (air flow inside the rooms and air outlets the rooms).

All the measurement will regard the external meteorological conditions (solar radiation, wind speed and direction, dry and wet bulb temperatures, atmospheric pressure), the inlet, internal and outlet tower conditions (air velocities, dry and wet bulb temperatures, pressure difference), the environmental room conditions (air velocities, dry and wet bulb temperatures). Continuos monitoring of the physical magnitudes and control strategies will be performed with short/long terms experiments having the following objectives:

- to test the effectiveness of the evaporation and accurately define the size of the evaporative zone;
- to explore the cooling capability of the tower, independently of the rooms that will be served and the number of contemporary operating microniser need for the required cooling production - for fixed diameter of the nozzles - without fog (of water);
- to define the transient time between the starting injection of water and the cooling regime;
- to characterise the air pattern inside the tower, eliminating any risk of up-draughts (system going into reverse).

Moreover control strategies would be studied for ensuring a required volume flow of air, a required evaporative cooling effect, the fast response at variations of the wind velocity to the control mechanisms.

All possible configurations, by combining all the possibilities of the wind catcher apertures, internal and external openings, number of operating micronisers, will constitute the short/long terms measurement set of the PDEC Experimental Test Facility.

Since the purpose of the experiments deals with air flow phenomena, the variability of the experimental variables can be extremely high (specially with variable wind conditions). Therefore, few seconds should be the frequency of monitoring, while the stored values will be the average of the sampled values over the whole acquiring period.

The position of the sensors will be fixed for some of them (meteo sensors, control variables, etc.) and movable for the others, depending on the test performed. The position of the movable ones will be explicitly mentioned in each test.

Special attention will be focused for the accuracy and reliability of the measurement of air velocity inside the tower, due to the probable presence of droplets of water in the air. Visual techniques such as smoke trials, tell-tail (e.g. of papers) or tracer gas would help to visualise the level of turbulence as well as the speed and air movements.

6. CONCLUSIONS

The experimental campaign will provide as much information as possible about the performance of the PDEC systems and will allow to:

- learn about the behaviour of PDEC systems;
- validate the models developed to predict PDEC system's performance;
- derive useful design rules for the PDEC Design Guide;
- implement control strategies for a proper operation of PDEC systems.

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BIBLIOGRAPHY

1. M. Santamouris et al.
"*Energy Characteristics and Savings Potential in Office Buildings*".
Solar Energy, Vol. 52 No. 1, 1994
2. M. N. Bahadori
"*An Improved design of wind towers for natural ventilation and Passive Cooling*"
Solar Energy, Vol. 35 No. 2, 1985
3. B.H. Ford, M.G. Hewitt
"*Passive Downdraught evaporative Cooling in non-domestic Buildings - A Review of the current state of the art*".
4th European Conference: SolarEnergy in Architecture and UrbanPlanning. Berlin, March 1996
4. S. Alvarez, E. Rodriguez et al.
"*Avenue of Europe at EXPO '92: Application of Cool Towers*".
"*Full scale Experiments in EXPO '92: The Bioclimatic Rotunda*".
5. R. Belarbi, M. Sperandio, F. Allard
"*Design methodology for assessment of evaporative cooling potential*".
European Conference on Energy Performance and Indoor Climate in Buildings. Lyon, November 1994
6. N. Bowman, K. Lomas, M. Cook, H. Eppel, B. Ford, M. Hewitt, M. Cucinella, E. Francis, E. Rodriguez, R. Gonzalez, S. Alvarez, A. Galatà, P. Lanalde, R. Belarbi
"*Application of Passive Downdraught Evaporative Cooling (PDEC) to non-domestic buildings*".
World Renewable Energy Congress IV, Denver (USA), June 1996.