APPLICATION OF PASSIVE DOWNDRAUGHT EVAPORATIVE COOLING (PDEC) TO NON-DOMESTIC BUILDINGS


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ABSTRACT

The applicability of Passive Downdraught Evaporative Cooling (PDEC) for reducing energy consumption in hot dry climates is reviewed. A new EC Joule project explaining the application of PDEC in non-domestic buildings is described. The building performance assessment methodology which employs dynamic thermal simulation programs for thermal analysis, and computational fluid dynamics (CFD) codes for airflow modelling is discussed. The role which wind tunnel tests and field measurements have in producing improved models is noted. Preliminary results from CFD benchmark trials are presented.

KEYWORDS

Passive downdraught evaporative cooling; thermal simulation; computational fluid dynamics; EC Joule project; energy consumption.

THE POTENTIAL OF PDEC TECHNOLOGY

Within the EU Member States there is evidence to show that primary energy consumption continues to grow and this growth may be partly attributed to the increase in the use of air-conditioning systems in buildings.

A survey of over 1000 public and commercial buildings in Greece (Santamouris, 1992) has shown that the typical annual energy consumption for non-air-conditioned buildings is 140kWh/m², while that for air-conditioned buildings is in the range 226-250kWh/m². Such statistics illustrate a trend which is likely to be representative for other Southern European countries and their neighbours. Since electricity is the predominant energy source for air-conditioning systems, there is great potential for energy savings and reduction in CO₂ emissions, through the application of ambient cooling techniques. One such technique is Passive Downdraught Evaporative Cooling (PDEC).

The idea of delivering cool air to a building, by capturing the wind within a tower, is not new (Bahadori 1985). It has also been shown that air flow rates can be enhanced and supply air temperatures reduced if water is encouraged to evaporate in the airstream. Cooling may be
achieved by passing the air over damp pads (Hicks et al. 1991), passing it through falling water droplets (Gillet et al. 1991) or by spraying microscopic droplets into the airstream. This project focuses on the latter technique as illustrated in the PDEC tower described by Cunningham & Thompson (1986), but employs micronisers to deliver the droplets. With direct evaporative cooling, the air temperature may be reduced by 70-80% of the wet-bulb temperature depression, thus providing the potential for very significant cooling in hot dry climatic regions. For example, dry-bulb temperature reductions of over 12°C have been recorded in Seville (Gillet et al. 1991). The PDEC technique has been applied to experimental buildings in Arizona, USA, and to the ‘Avenue of Europe’ cool towers at the Seville Expo’92 (Alvarez et al. 1992). A concise summary of previous work is contained in a recent paper by Ford and Hewitt (1996).

**PDEC IN NON-DOMESTIC BUILDINGS**

A recently announced EC JOULE contract brings together experts in the renewable energy in buildings field. The project will assess the applicability of PDEC technology within Europe with the potential of exporting the technology to other hot dry climates. It is intended to consolidate European expertise in architectural design, engineering design and manufacture, and computer simulation, whilst contributing to European competitiveness in the field of renewable energies in buildings.

The main project deliverable will be a PDEC Design Guide to explain:
1. the construction, operation and control of PDEC systems;
2. the environmental (energy and comfort) benefits which they offer in Southern Europe and surrounding regions;
3. their cost and building engineering implications; and
4. the design of micronisers and their control.

While the project is multi-disciplinary in nature, each partner has clearly defined areas of responsibility and the research can be divided into four areas: architectural design studies (SFA, MCA); building performance assessment (ESII, IESD); experimentation and monitoring (CON, MIC); and co-ordination (IESD).

The architectural design studies will include one real building refurbishment (the former Pavilion of the Americas at Expo’92) and two new buildings. Interim architectural designs will be assessed on a multi-criterion basis involving building performance simulations, cost and structural integrity calculations, and appraisals by quasi-clients. The final designs will then be produced and their energy use and thermal comfort conditions for various European locations evaluated.

Building performance assessments are thus a key part of the project. This paper describes the assessment methodology and in particular the roles played by dynamic thermal simulation programs (DSPs) and computational fluid dynamics (CFD). The relationship to physical modelling and experimentation is noted.

**BUILDING PERFORMANCE ASSESSMENT**

In simple terms, a PDEC building (Fig. 1) can be divided into three distinct zones: 1. the wind catcher, which may include straighteners for the air once it has entered the tower; 2. the evaporative cooling zone, in which the micronisers are located and the incoming air is cooled; and 3. the surrounding spaces into which the cooled air is delivered.
In such a building, air velocity and humidity will play a more important role in controlling comfort than in conventional buildings where air and surface temperatures alone are often taken as the crucial parameters. DSPs can provide an estimate of the average airflow rates, temperatures and humidities and the way these vary with time. They are, however, unable to predict local air velocities, temperatures and humidities.

CFD programs can, in principle, overcome these limitations. They can cope with wind and buoyancy-driven flows, radiant exchanges between surfaces, convective exchange between the air and (thermally massive) surfaces, and the two phases associated with water droplet evaporation. Thus they can consider all the thermophysical phenomena which are important in PDEC buildings, and so, in theory, produce realistic estimates of local air speeds, humidities and temperatures.

Although DSPs and CFD codes can model the building (zone 3 in Fig. 1) reasonably well, difficulties arise because the rate of airflow from the wind catcher (zone 1) depends on wind speed, wind direction and tower design and the air supply temperature depends on the performance of the evaporative cooling zone (zone 2). Both of these in turn depend on the air flow paths through the building and the way they are controlled. These features present significant modelling difficulties but modelling methods are being developed to overcome them.

**Thermal Analysis**

To model a PDEC building, DSPs should be able to predict buoyancy and wind induced air flows through the PDEC system itself, the air flows through the building to which the system is connected, and the cooling effect of the evaporating water droplets in the supply air stream. None of the existing DSPs can handle all these aspects in their off-the-shelf form and only a small number are capable of solving an air flow network problem in tandem with the more conventional building and plant network. ESP-r (ESRU 1995) and the recently developed, but not yet published, PASSPORT+ code falls into this category. Other software (e.g. Matthews et al. 1994), and algorithms for existing software such as TRNSYS or DOE2, have been developed to simulate evaporative cooling units.

The likely performance of PDEC towers in a factory building in India have been evaluated in the IESD. A simplified approach was used in conjunction with ESP-r to assess different design strategies. The evaporative cooling system was assumed to be capable of reducing the ambient air temperature by 70-80% of the wet-bulb temperature depression. The resulting air temperatures were pre-calculated on an hour-by-hour basis. In the model, the critical spaces within the building were then ventilated with air from this reservoir of cool air at various air change rates, and design advice was given on the basis of extensive parametric studies.

In this project it is anticipated that wind tunnel tests will be undertaken to produce simplified algorithms which can predict the relationship between wind speed and direction and the air flow rate from the wind catchers. These algorithms will be validated by the full-scale tests to be undertaken in Catania. A module which describes the enhancement to this flow from the evaporative zone and the reduction in the air temperature will be generated. The starting point for this module is the simplified one-dimensional zonal model of Alvarez et al. (1991). This was used to model the PDEC towers in the ‘Avenue of Europe’ at EXPO’92. The coupling between such a model and the rest of the DSP will be a particularly difficult task.
Airflow Modelling

CFD is still a young and developing technology and so, not surprisingly, a literature search produced no references to CFD being applied directly to PDEC systems. The only airflow analysis carried out on PDEC systems was the simplified one dimensional zonal model of Alvarez et al. (1991). This project will therefore serve to evaluate the suitability of CFD for modelling such systems. The CFD codes being used for the project are CFX-F3D (CFDS 1995) used by the IESD, FLUENT (User Manual 1995) used by ESII, and a new code being developed by ESB.

It is anticipated that the use of CFD for modelling zone 3 will prove relatively simple. The difficulty lies in how to model the evaporative zone since this involves a change of phase, as the incoming dry air absorbs the moisture produced by the micronisers. Alternatives have been explored through a series of benchmarks.

In one PDEC benchmark a simplified representation of the evaporative zone was used in which solid heat sinks represent cooling by evaporation; one result is shown in Fig. 2. Although it is simple, this method of modelling introduces errors because the solids induce friction which reduces air flow.

In a second benchmark, direct evaporative cooling has been modelled using the axi-symmetric flow space shown in Fig. 3. The CFD codes will be used in different ways to model this benchmark. ESII will use a particle transport model to predict the transport and evaporation of individual particles, whilst the IESD will adopt a multiphase approach in which interphase drag, heat transfer, and change of thermodynamic phase are modelled. This work is currently in its very early stages, however, Fig. 4 shows a preliminary result using the multiphase model in CFX-F3D.
Fig. 3 Description of the second PDEC benchmark. The ambient air temperature is 40°C, D - dropsize, v - injection velocity, T - water temperature.

The results from the simplified model of Alvarez et al. (1991) will provide a useful point of comparison for the three CFD codes as will measurements on the full-size experimental building.

The equations used to model particle transport are transient in nature, so a time-step needs to be specified in the solution process. Different time-steps are required for different particle sizes. Unfortunately, FLUENT is unable to deal with this situation. Consequently, ESII are developing a new CFD code to deal with particles of different radii. Preliminary comparisons between CFX-F3D predictions and those from the new code are encouraging.

CONCLUSIONS

(i) A new Pan-European project has begun which will produce guidance for architects, engineers and building energy analysts concerned with the design of buildings which incorporate passive downdraught evaporative cooling.

(ii) A literature review has revealed little previous work to evaluate the performance of PDEC in buildings.

(iii) A methodology for developing tools by which PDEC systems can be modelled has been outlined and the role of DSP, CFD and physical testing explained.

(iv) A new CFD code which can simulate water droplets of different radii is being developed. Preliminary comparisons between this code and a conventional program are encouraging.

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REFERENCES


