FINAL TECHNICAL REPORT

CONTRACT No.: ENK6-CT-2000-00346

PROJECT No.: NNE5-2000-00511

ACRONYM: EVAPCOOL

TITLE: Passive Downdraught Cooling Systems Using Porous Ceramic Evaporators**.**

PROJECT CO-ORDINATOR: WSP ENVIRONMENTAL LTD

PARTNERS: UNIVERSITY OF NOTTINGHAM, UK

AXIMA LAB., SWITZERLAND

REPORTING PERIOD: FROM 1 March 2001 TO 30 August 2003

PROJECT START DATE: 1 March 2001 **DURATION:** 30 months

Date of Issue of this report: 30/10/2003

Project funded by the European Community under the Fifth Framework Programme (1998-2002)

CONTENTS

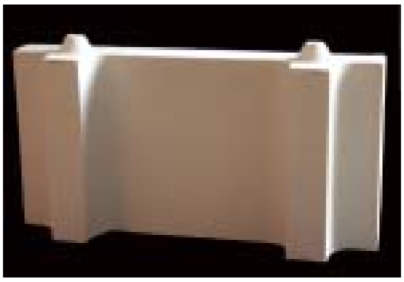
PART 1 - PUBLISHABLE REPORT

1.1 Executive Publishable Summary

The Evapcool project was initiated to design, develop and test new porous ceramic products for improved evaporator performance as part of an innovative cooling system and for integration within buildings. The main parameters affecting the rate of evaporation are ambient conditions (dry - wet bulb air temperature) and the rate of air movement over the evaporating surface, as well as water pressure and porosity of the evaporator. Theoretical models of both the direct and indirect evaporative cooling systems were found to have reasonable agreement with the climate chamber at Nottingham University. The casting technique was used in this project for the manufacture of the prototype evaporators, which were designed to be stacked, hung or cantilevered, according to the different options for building integration. The components developed in the project are the subject of a patent application, and commercial partners are being sought to make these components available in the market.

A design proposal for the integration of theses components within an office building in Teheran, Iran, was tested using dynamic thermal analysis (Trnsys) and CFD. Results indicated that for this location, the Evapcool system will meet 85% of the cooling load of the offices. Predicted annual energy savings for cooling were 32-42kWh/m2. The analysis for this project also revealed the degradation in performance with height of the array. From this data a simplified design tool has been developed to enable designers to size the system. A series of seminars and workshops devoted to downdraught cooling are planned to disseminate this research project.

1. Physical Model of Office Integration

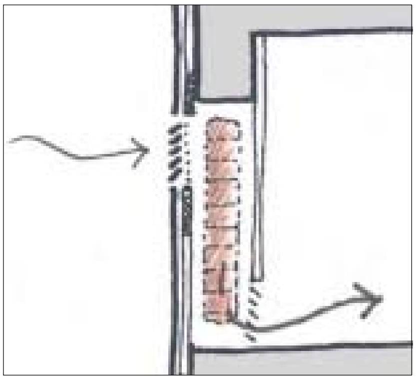


2. Stacked Evaporator Prototype

3. Hung Prototype

1.2 Publishable Synthesis Report

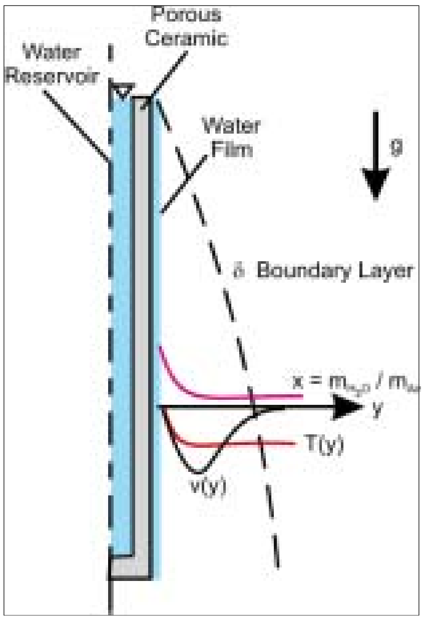
The Evapcool research project is concerned with the application of direct and indirect evaporative cooling in non domestic buildings. Evapcool was preceded by the Joule research project into Passive Downdraught Evaporative Cooling (PDEC - Contract No. JOR3-CT95-0078, 1996-1999). PDEC has been found to be technically and economically viable for non-domestic buildings. A number of buildings (including the recent Malta Stock Exchange [1]) have successfully applied the system. However, most PDEC applications use misting nozzles under high pressure to generate a high rate of evaporation and this has a number of disadvantages which tend to preclude its use for small non-domestic projects or residential buildings.



4. Principle of operation of the direct system

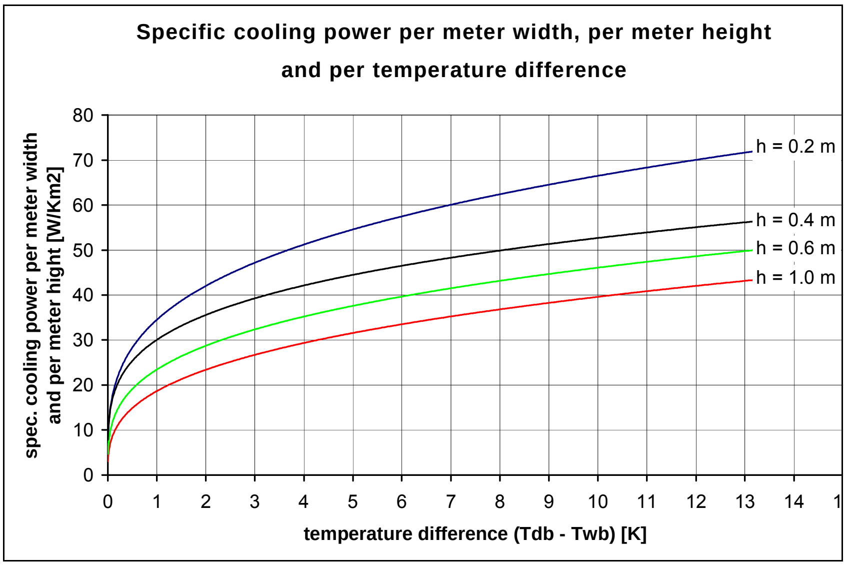
In reviewing traditional evaporative cooling techniques using porous ceramics, opportunities for improving the performance of this very simple technique became apparent and formed the basis of a patent application related to both direct and indirect evaporative cooling systems (UK Patent Application No. 0325891.0). It also became apparent that little analysis had been undertaken of the process of evaporative cooling through porous ceramic. The Evapcool Project was thus initiated in order to develop theoretical models of this process and to design, develop and test new products for improved evaporator performance and for their integration within buildings.

Theoretical Models – The rate of evaporation (and thus cooling) of a porous ceramic evaporator (PCE) depends on the ambient conditions (dry and wet bulb air temperature) and the rate of air movement over the surface, as well as the water pressure and the porosity of the PCE. The use of both CFD and dynamic thermal modelling contributed to the theoretical analysis and the creation of a simplified steady state calculation tool to enable designers to calculate the performance of different direct system configurations. A model was also developed of the indirect system but cooling performance for the indirect system was found to be 0.2-0.5 of the performance of the direct system and therefore the indirect system was not developed beyond the laboratory scale prototype.

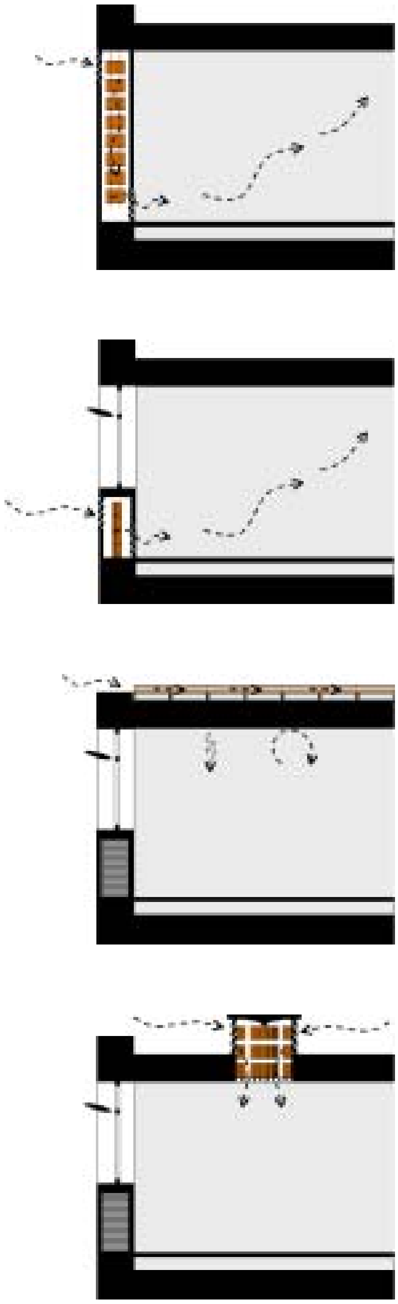


5. Assumptions of Theoretical Models

Prototype Design and Testing – Most ceramic building products (e.g. cladding panels) are produced by extrusion. By contrast, many domestic ceramic products (e.g. pots, jars, etc.) are produced by casting. The casting technique allows the creation of a container for water, but there are limitations imposed by this production technique on the size and shape of the container. Both the opportunities and limitations of the casting technique were explored in the process of designing a number of different ceramic components for the new direct and indirect evaporative cooling systems. Laboratory testing revealed that better performance would generally be achieved by the direct system, and so full scale prototype assemblies of two of the different components designs were tested in a climate chamber at University of Nottingham. Both systems showed similar values of specific cooling when compared at similar air volume flow rates. The experimental work allowed the performance to be characterised in terms of cooling as a function of the difference between saturated vapour pressure (e_s) and vapour pressure of the supply air (e).

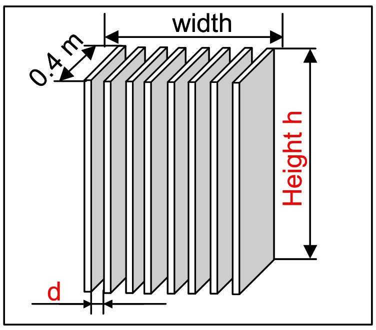


6. Specific cooling power per meter width, per meter height and per temperature difference.



7. Integration Options

System Design and Performance Analysis – Generic design solutions for the integration of the direct systems into wall and roof assemblies were developed to explore and illustrate the practical implications of application. These were illustrated through a series of generic drawings and model studies. The integration of these prototype systems into a small office building project in Teheran, Iran has also been proposed, and the overall system (i.e. building) performance has been assessed. Results from the analysis revealed that, for this case study in this location, the Evapcool

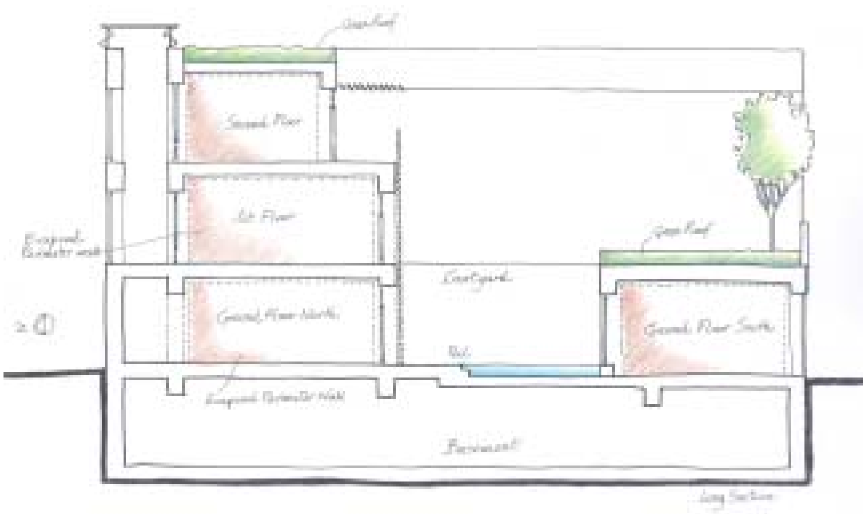


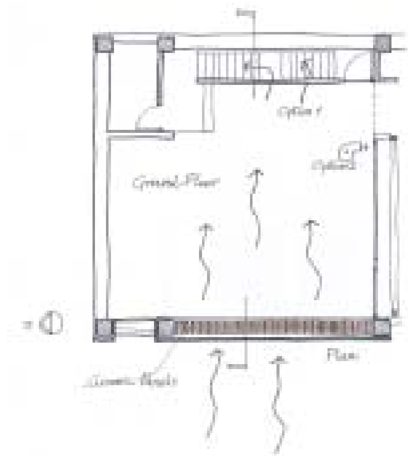
8. Direct System

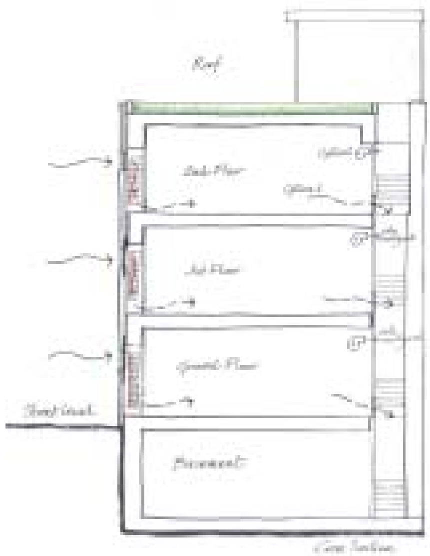
system will meet 85% of the cooling load of the office (i.e. a threshold temperature of 26degC will only be exceeded for 15% of the time). The predicted annual energy savings for cooling is 32-42 kWh/m2 (electricity based on a set point of 26degC), where the annual water consumption of the system was estimated at approximately 5liters per person per day.

The analysis also revealed the degradation in performance with height of the array. Greatest efficiency can be achieved if the height of the array can be limited to 0.2m. However, in practice, a greater height may be required in order to meet the cooling need. This data has been used in the definition of a performance nomogram to give designers the information required for preliminary sizing of a system.


9. ‘Hanging’ Prototype installed in Nottingham


12. Proposed integration at the Green Office Building in Teheran


10. Green Office, Teheran, Ground Floor Plan


11 Green Office, Teheran, Cross Section

Further developments and plans for exploitations - The project has developed a number of components which are ‘close to market’. These components are the subject of a further patent application (UK Patent Application No. 0325891.0) and commercial partners are being sought in various parts of Europe and in Iran. The development by UK ceramic manufacturers of new material for use in the moulds required for casting, may lead to substantial reductions in production costs. Evapcool system costs will have to be lower than the costs of ‘comfort cooling’ in Europe (desert coolers in Iran) if it is to be taken up very widely. This is possible, but will require wider knowledge of the opportunities and benefits of the system to encourage take up and application on a wider scale.

A working demonstration project is vital. The project in Teheran is due for completion in 2004 and further support for this project will be sought from the EC under the COOPENER programme. The University of Nottingham and WSP Environmental are also actively seeking the opportunity to demonstrate Evapcool in South of Spain and Greece.

A short publication summarising the experience, opportunities and implications of Evapcool, PDEC and Hybrid Downdraught Cooling would act as an important catalyst to promote further uptake. The interest in Iran shown for the project is also indicative of opportunities in other developing countries with similar climate regions. The Evapcool Partners would like to hear from companies, institutions and individuals interested in the further development of these low energy cooling techniques. A series of seminars and workshops entirely devoted to Downdraught Cooling is planned.

PART 2 - DETAIL FINAL REPORT

2.1 Objectives and strategic aspects

The environmental risks associated with climate change and the devastating effect of pollutant emissions in the atmosphere are the principal reasons behind the European Union's commitment to reducing the greenhouse gases to 8% of the 1990 levels (Kyoto Agreement) by 2012. Energy consumption by buildings, particularly in the non-domestic sector, represents 41% of the total energy consumption in Europe [2] and therefore greenhouse gases reduction in this sector by a replicable technology would have significant impact.

In recent years the European Commission has issued legislation which promotes the use of renewable energy together with a more efficient use of energy in buildings. The directive 2002/91/EC, published at the beginning of this year, sets out guidelines for regulation of energy performance in buildings across the member states and highlights the importance of thermal performance and energy efficiency in the building sector.

Across the European countries a large proportion of energy is consumed for cooling. The air-conditioning market is rapidly increasing in Europe and in 1997 it constituted 6% of the world's air-conditioning market. In the tertiary sector approximately 27% of buildings have air-conditioning and this number is constantly increasing [3].

The proposed Passive Evaporative Cooling (Evapcool) systems can potentially contribute to energy savings since their application relies on natural cooling processes based on water evaporation and solar power. The results of the project provide an understanding of the performance potential and the implications of building integration. This technique could make a significant contribution to reducing energy consumption in new and existing buildings in many European countries and throughout the hot dry regions of the world.

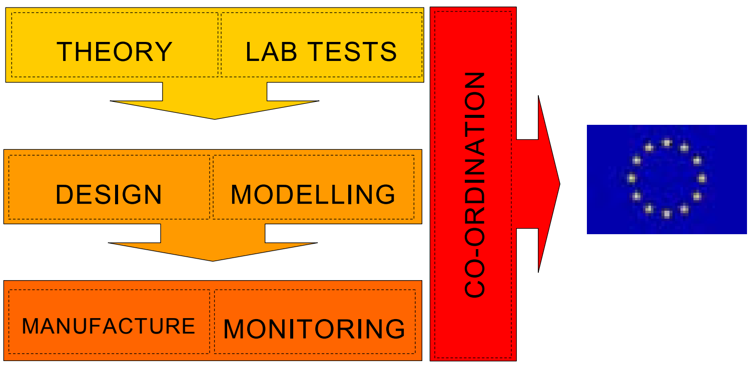
2.2 Scientific and technical description of the results

2.1.1 Background

This project was preceded by the JOULE Research Project into Passive Downdraught Evaporative Cooling (PDEC 1996-1999 Contract No. JOR3-CT95-0078) which concluded that in architectural and engineering terms a mixed mode approach (PDEC + back-up mechanical system) is technically and economically viable, and is competitive against conventional air-conditioning for office buildings in southern Europe [4].

The PDEC research was based on a specification using misting nozzles under high pressures (20-50bar) to generate a high rate of evaporation and to minimise moisture carry-over. This system provides improved performance and other advantages over directly wetted cellulose pads, but it still has a number of disadvantages: high quality water required, risk of nozzles blocking up, risk of dripping (carry-over), risk of microbiological contamination (Legionella), and other maintenance issues. A recent market assessment [5] has compared the cost of PDEC with comfort cooling (approximately 150-200 €/m2).

While PDEC is viable (and has been applied in a number of projects including the Malta Stock Exchange [1]), it is clearly desirable to develop a cooling system which avoids these problems. Alternative systems using porous media can overcome many of these disadvantages and would also extend the geographical and climatic range of applications. In order to promote wider confidence in this approach to cooling in Europe, further work is required to develop and improve products and systems specifically designed for this market, and this was the subject of this research.



1. Diagram showing Structure of Work

The project was divided into 6 work packages (WP1-6). Each work package had a Partner leader who was responsible for managing the tasks and delivering the results. The Partner leaders per each work package are listed below.

WP1 – Theoretical Models – *Axima Lab., CH*
Review of the theoretical basis for evaporative cooling through porous ceramic materials and the development of dynamic modelling tools to enable performance assessment of the technique applied to non-domestic buildings in both Northern and Southern Europe.

WP2 – Laboratory Scale Measurements – *Nottingham University, UK*
Design and construction of a laboratory scale prototype for two porous ceramic components/systems including quantitative performance testing for each system under controlled conditions of temperature, relative humidity and buoyancy air flow.

WP3 – Integrated System Design - *WSP Environmental Ltd., UK*
Investigate the architectural and engineering design implications in terms of detailed design, performance and cost, of the proposed passive downdraught cooling systems and their integration into the context of a 'real' building. Investigate the manufacturing options and limitations on the design of the prototype.

WP4 – System Performance Analysis – *Axima Lab., CH*
Evaluate the performance of a case study office building with a passive downdraught cooling system incorporating either direct or indirect ceramic evaporators and compare performance and cost with that of the same building with chilled water cooling coils.

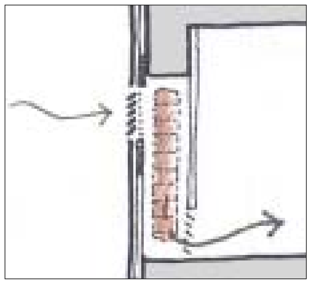
WP5 – Prototype Design & Manufacture – *WSP Environmental Ltd., UK*
Design and manufacture a full scale prototype of the proposed passive downdraught cooling systems.

WP6 – Prototype Installation & Testing – *Nottingham University, UK*
Install and test the full scale prototype systems in an existing climate chamber in Nottingham.

WP7 – Co-ordination – *WSP Environmental Ltd., UK*
Coordination, reporting and dissemination of findings.

2.1.2 Direct Evaporative Cooling

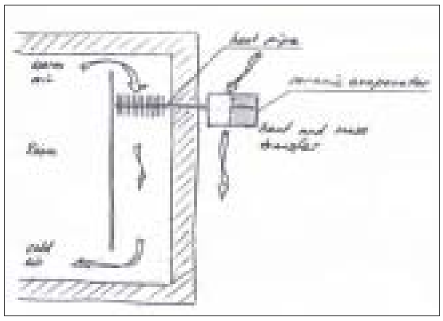
The passive direct evaporative cooling system is based on the use of porous ceramic water containers located within a duct or intermediate space between inside and outside of the building. These unglazed ceramic evaporators intercept the hot and dry air stream from the outside and deliver cooled and humidified air into the interior space (Fig. 2). The rate of evaporation depends on ambient conditions - dry and wet bulb air temperature, air flow rate and also, significantly, the water pressure and porosity of the ceramic evaporator. This implies that that the potential for evaporative cooling in a particular location can be derived from analysis of the local weather data.



2. Principle of operation of the direct system

2.1.3 Indirect Evaporative Cooling

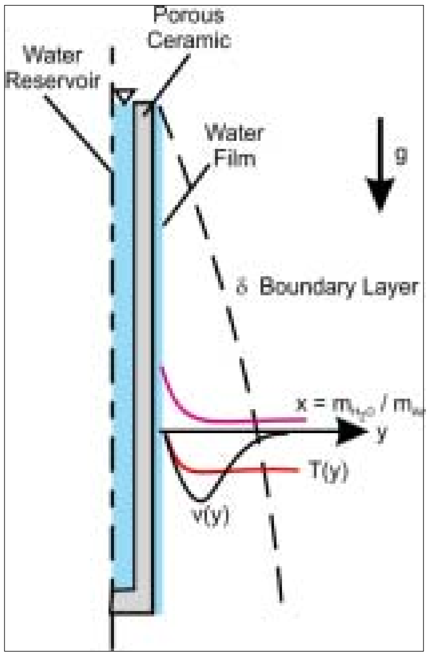
The indirect cooling system (Fig. 3) transfers the 'coolth' provided by the ceramic evaporator to an adjacent but separate zone. This is accomplished by heat pipes with cooling fins which transfer heat from the area needing to be cooled to the ceramic evaporator side.



3. Principle of operation of the indirect system

2.1.4 Development of Theoretical Models

The review of the thermodynamic principles regulating the process of evaporative cooling and the development of the theoretical model (heat and mass transfer) constituted the first task of the research. The main assumptions (fig. 4) for the model were: Adiabatic process of evaporation along a uniformly wetted surface (no moving water film); undisturbed air flow outside the boundary layer with constant temperature and humidity along the height of the plate. Thus the surface temperature is equal to the wet bulb temperature and the total heat flux "$\dot{Q}$" can be calculated according to the formula below (1).



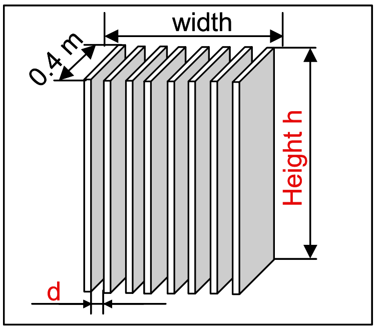
4. Main Assumptions

(1) $$\dot{Q} = h \cdot (Tdb - Twb) \cdot A \quad [W]$$

Where:
h = specific heat transfer coefficient [W/m2K],
Tdb = Dry bulb temperature [K],
Twb = Wet bulb temperature [K],
A = Surface area [m2].

Different models were explored in order to calculate the heat transfer coefficient under downdraught conditions, resulting from the negative buoyancy from phase change (evaporation). It was found that the calculation for a channel flow regime is the most representative of the laboratory scale monitoring results. A FORTRAN program and an Excel spreadsheet were developed to calculate the system's specific heat flux.

Based on the calculation model a methodology for the dimensioning of the direct evaporative cooling system was established. The methodology can be applied for a system similar to figure 5, where the height of the elements is variable but the other dimensions are fixed to 400 mm and 35 mm. The system parameters are the height of the system, the space "d" between the elements and the width of the system.

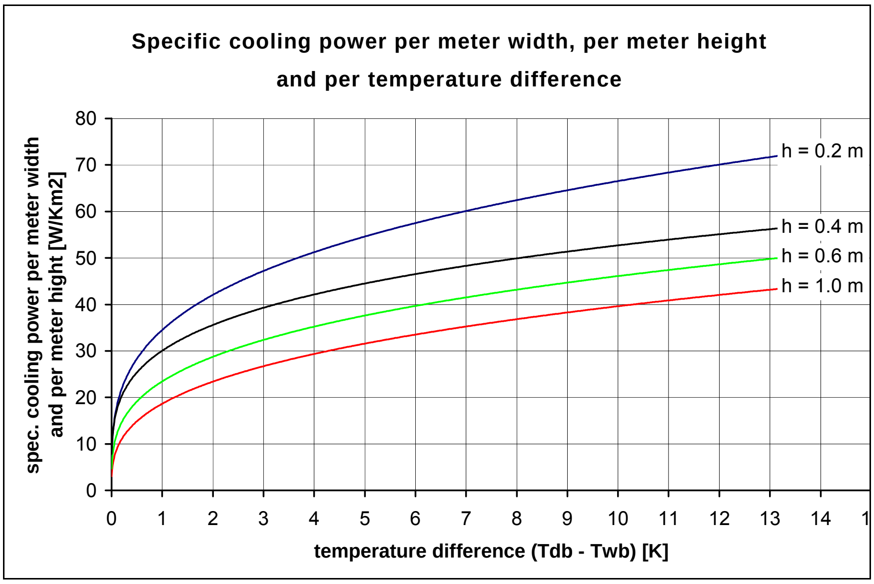


5. Direct System

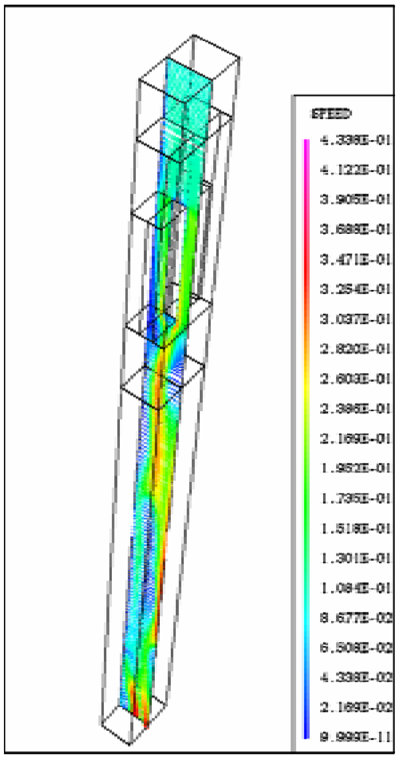
The specific cooling capacity decreases with increasing height (fig 6). For a target cooling capacity and a possible width, the height of the system should therefore be chosen to be as small as possible, consisting with meeting the cooling load. Furthermore, for each height there is an optimal space dimension which is only slightly depending on the temperature difference. The optimal space "d" can be determined by equation (3).

(3) $$d = 9.375 \cdot h + 15.625$$

Where h = height of the system [m]; d = space between the elements [mm]

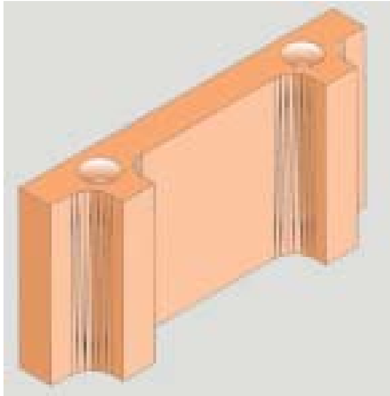


6. Specific cooling power per meter width, per meter height and per temperature difference. The diagram can be used to calculate the cooling power.

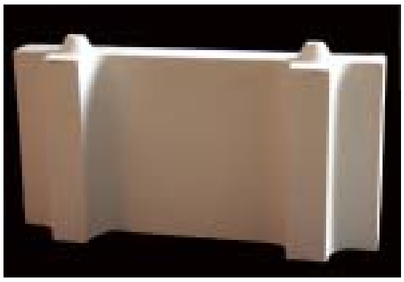


7. 3D CFD simulation of experimental duct

Additional CFD analysis was undertaken in order to simulate the direct system test duct (Fig. 7). The results from the simulation and the laboratory experiment conducted at Nottingham University can be compared on the basis of the specific heat flux q [W/m^2]: q_{cfd} = 80 W/m^2 and q_{exp} = 138 W/m^2. Uneven distribution of air temperatures in the laboratory measurements and neglecting the effect of thermal radiation (20W/m2) in the calculation may explain the discrepancy of the results.

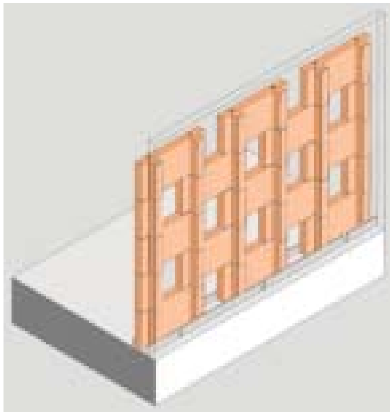

8. 3D of Stacked Evaporator

The indirect system was modelled for the ceramic and heat pipe parts respectively. It was concluded that a relatively larger surface of evaporators compared to the surface of heat-pipe is required. The relationship between cooling action "Q" (W) and dry/wet bulb temperature depression is linear and the system performance is mainly dependent on the evaporative end. The theoretical cooling potential of the indirect system was found to be between 5-50W/m^2 of evaporator, for buoyancy driven airflow. Fan driven air flow over the heat pipe fins can significantly improve performance.


9. Stacked Evaporator Prototype

2.1.5 Prototype Design and Manufacture

Different types of component have been developed, targeting different types of office building integration. Their shape and assembly technique are related to the opportunity for integration within building elements. Their geometry is mainly influenced by maximisation of the evaporative surface versus volume of water, and limitations of the manufacturing process. Other components of the Evapcool system include the water supply and distribution systems the supporting structure, vents and access panels.


10. 3D of Stacked prototype assembly

Three prototype options correspond to three different structural and assembling principles and are proposed for different types of building integration. The design of the 'stacked' evaporators (figs. 8-11) made full use of the potential of cast porous ceramic as their shape would be very difficult to realise with another industrial manufacturing technique. The evaporators were designed to create a self-supporting system where no other components were required other than a drip tray for collection of possible seepage and the water supply pipes.

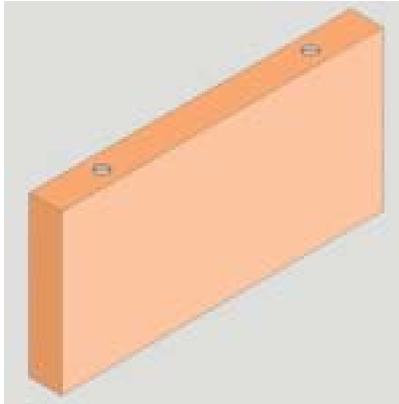

11. Staked Prototypes

The 'hung' option (figs. 12-15) was developed to fit with the typical dimensions for reinforced concrete columns within an office building. One undeveloped idea was to combine the structural support with the water distribution function provided by GRP tubes. A simpler option was given by placing the evaporators on either stainless steel rods or aluminium sections integrated into the wall duct.

The ‘cantilevered’ option (figs. 16) envisaged cladding type applications. The design of the prototypes was limited by the mechanical properties of the ceramic and the manufacturing process of casting. It is clearly desirable to minimise the costs associated with the supporting and water distribution components.

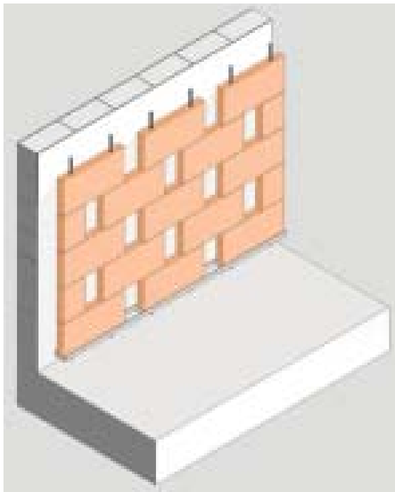
The limiting factors of the design and manufacturing of the prototypes were a) mechanical properties of the ceramic; b) manufacturing process; and c) cost. The ceramic casting technique was regarded as the most suitable for the manufacture of the porous ceramic reservoir because it enable the manufacture of highly porous ceramic and of relatively complex closed shapes, which other ceramic manufacturing techniques such as drawing or pressing could not achieve. However, the casting technique does not allow the manufacture of very large items.

The cost of the ceramic evaporators increases with the complexity of its geometry. This is due to a more complex and expensive mould and also a longer production cycle. However, recent research undertaken in the ceramic manufacturing industry has resulted in a chemical alternative to the use of chalk moulds. This could potentially lower the cost of expensive chalk moulds as well as reduce the production time. The target cost of the Evapcool System has been estimated as 150-200 €/m2, which corresponds to the cost of comfort cooling in Europe (year 2002).

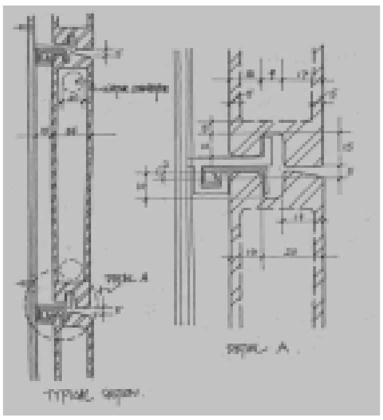


12. 3D Hung Evaporator

13. Hung Prototype



14. Hung prototype assembly option 1



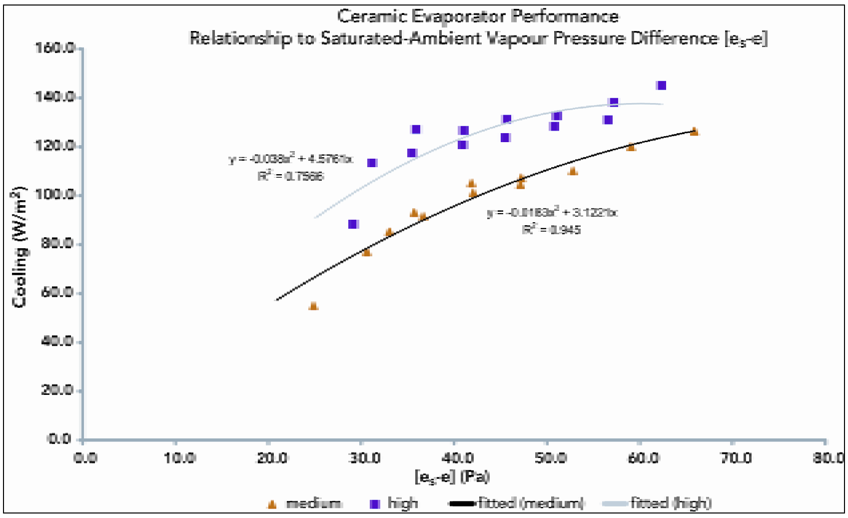
16. Cladding System

15. Prototypes supported on rods

2.1.6 Laboratory Scale Measurements

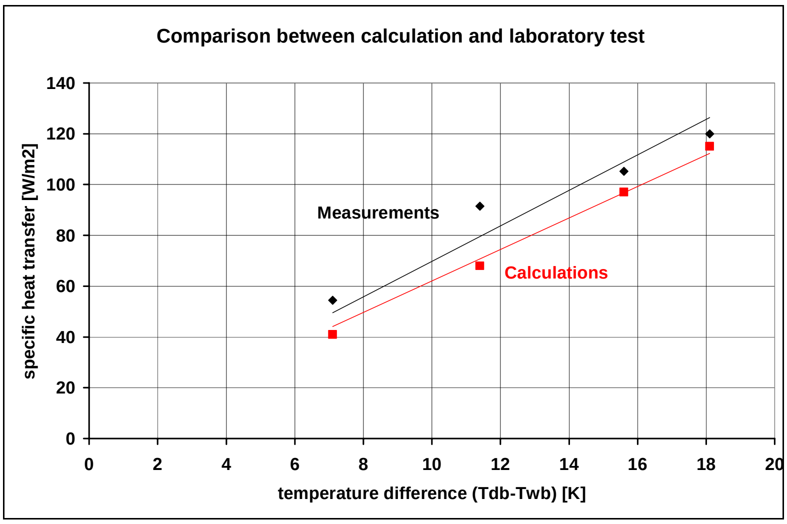
17. Ceramic Evaporator with Heat Pipe

Ceramic evaporators were tested in both direct and indirect cooling configurations (fig. 17). A chilled water cooling coil was also tested for comparative purposes. The performance of direct cooling ceramic evaporator prototypes was characterised in terms of a parameter that expresses the force driving the evaporation of water from a wetted surface (saturated-ambient vapour pressure difference [e_s-e]).



18. Measured Cooling for Direct System

Significant cooling was measured for the direct cooling ceramic evaporator systems tested in single and twin row configuration, as well as low and high supply water pressure. For medium and high porosity evaporators, cooling achieved varied from a minimum of 55 W/m^2 to a max of 224 W/m^2 for each respectively (fig. 18). The indirect system performance ranged from minimum cooling of 9.6 W/m^2 to maximum 48.9 W/m^2. The chart below compares the theoretical models with the lab scale results (fig. 19).



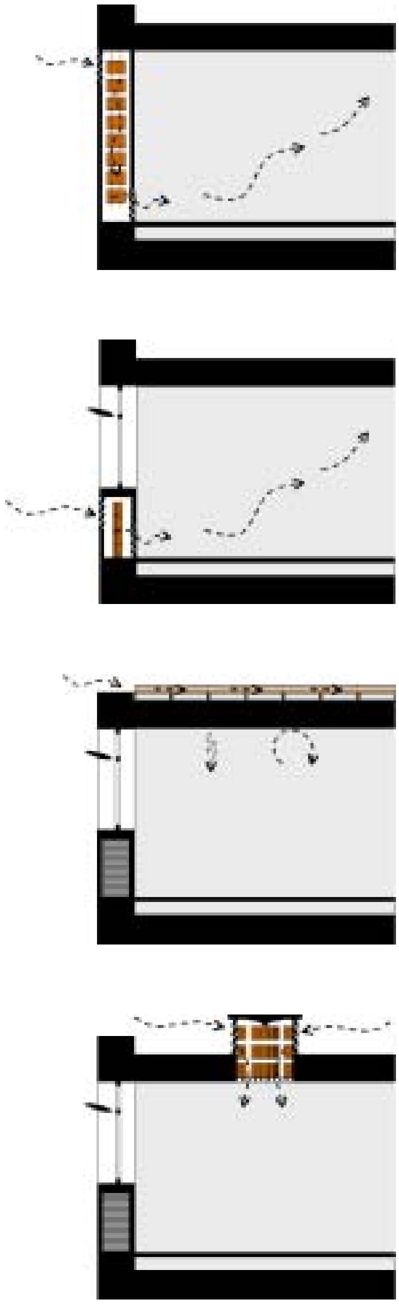
19. Heat transfer per surface area in function of the temperature difference for measurements of the laboratory test and calculations.

2.1.7 Integrated System Design

The integration of direct system prototypes into the building fabric was investigated in relation to a generic office building and to a specific case study project. The study showed that these components can be integrated within walls or roofs in a variety of ways to deliver cooling to perimeter areas of both existing and new buildings (fig. 20).

20. Physical Model of Office Integration

A range of different generic system/component types were developed, for integration within wall and roof assemblies. These proposals were produced to explore the implications of the integration of these new components within what may be considered to be a typical concrete frame commercial building (fig. 21). They could potentially form the basis of a cost analysis, and also help to highlight related issues of control and maintenance. The generic types developed included: Perimeter Column, Perimeter Wall, Wind-catcher, Light-vent Pipe, Double façade, Roof tiles.

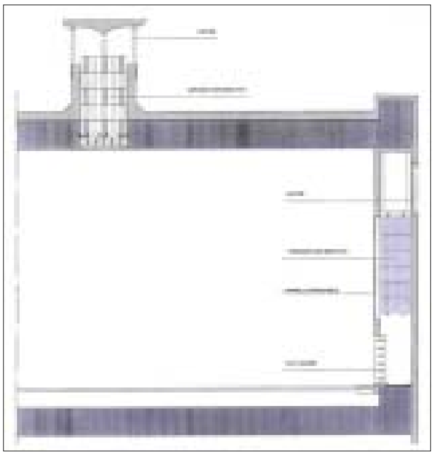


21. Integration Options

The Integration of EVAPCOOL panels as a ***Perimeter Column*** (Figs. 22, 23) incorporates an external supply air grille at high level and internal grille at low level, with 35mm ceramic panels hung in rows adjacent to a structural concrete column (typically 450 – 500mm). This arrangement has the advantage of achieving a large surface area relative to the area of external wall required. The model illustrates that such an arrangement could be achieved either side of a column, and still allow a considerable area of glazing. Removable panels on the interior allow access for maintenance.

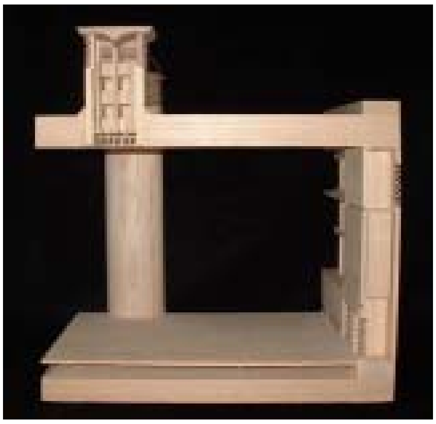
An arrangement in which interlocking panels are simply stacked to form a perforated ***Wall*** below the cill of the window was also developed. (Figs. 24, 25). The external supply grille is below the cill, and the internal grille is at floor level. This arrangement could be used for the full height of the room where there is no window. It is simple to construct, but has the disadvantage of a small surface area of panels relative to the external wall area required.

A '***Wind catcher***' type of roof mounted ventilator can be fitted with stacking or plain panels to provide a source of evaporative cooling for top floor rooms (Fig. 26). In order to provide the large area of evaporator required, a continuous 'ridge' type ventilator would deliver more cooling. In the configuration shown, interlocking panels provide a large surface area relative to the volume enclosed, and importantly do not reduce the floor area of the floor served. This type of component also has the advantage of potentially serving areas, which are remote from the perimeter (i.e. deeper plan spaces). Motorised dampers provide control at ceiling level. Maintenance can be provided from the roof, so does not cause disruption to the occupied floor.



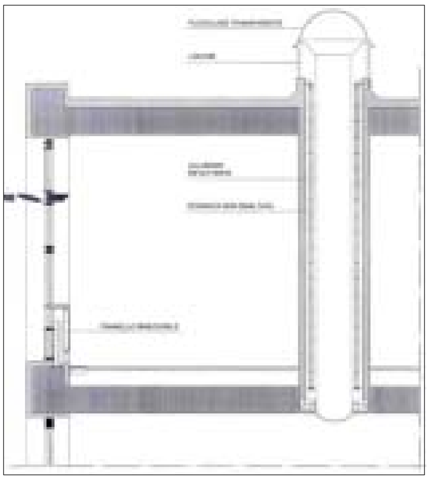
22. Perimeter Column and Windcatcher

The incorporation of EVAPCOOL ceramic panels within the ventilated cavity which can be created outside a ***Light-pipe*** enables the system to bypass the top floor and deliver cooling to lower floors (Fig. 27). Such a component could usefully be located 6 – 10 meters from the perimeter, to deliver both light and cooled air to the deeper part of the plan. This system is also probably most suited to refurbishment projects rather than new build. The cylindrical duct surround minimises both the physical and visual intrusion on the top floor. The duct cover would include removable access panels for maintenance, and motorised dampers would provide control at ceiling level of the floor served.



23. Physical model showing integration

Double façade construction can have definite acoustic and thermal benefits, but can also give rise to increased overheating risk, and consequent cooling load. Recent buildings have resolved the overheating risk by making the whole façade openable using automated glazed louvers. This solution is extremely expensive, and also reduces the acoustic effectiveness of the 'buffer zone'. EVAPCOOL panels incorporated as cladding within the cavity of the double façade (Figs. 28-29) would induce direct evaporative cooling of the air within the cavity, preventing overheating. This innovation would enable the external façade to be sealed, reducing the cost (associated with opening facades), improving noise reduction, and reducing the cooling load in adjacent offices.

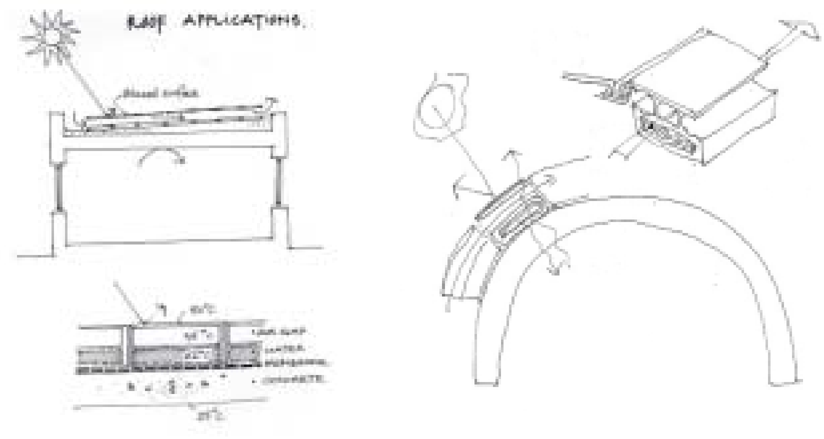


24. Window cill and Light-vent-pipe

The integration of EVAPCOOL panels in ***Roof*** (Fig. 30) construction could provide significant *indirect* cooling to spaces below. This could be applied in developing countries like India, where 'high performance' insulated roofs are rare and top floors frequently overheat. Mallick [5] has described the use of ceramic pots within built up roofs in Bangladesh to reduce solar heat gain. The integration of EVAPCOOL panels would not just reduce solar

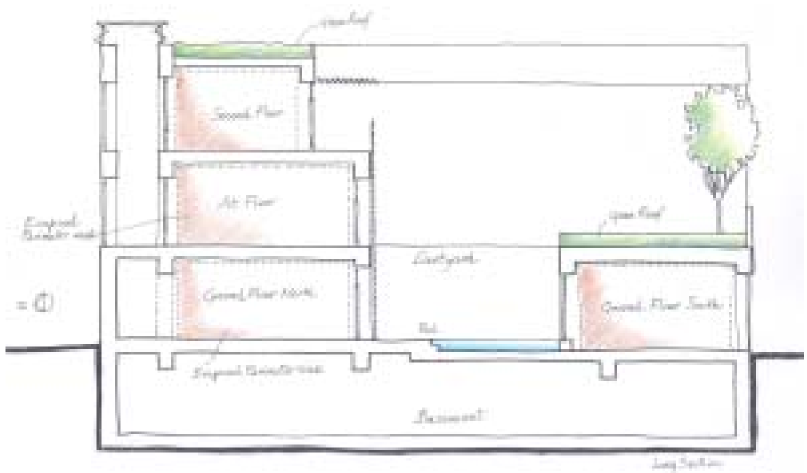
25. Physical model showing integration

heat gain through the roof, but through evaporative cooling, also further reduce the surface temperature of the ceiling.



30. Roof Application of the Evapcool system

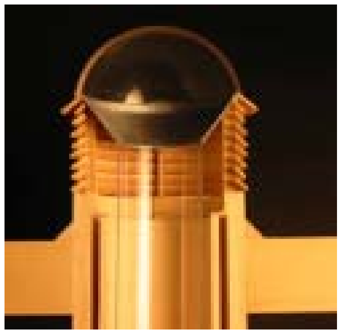
Evapcool Systems have been included in the design for a small office building in Teheran, Iran (Fig. 30). With very hot and dry summers Teheran has the ideal climate for the application of evaporative cooling and mechanically driven desert coolers are widely used.



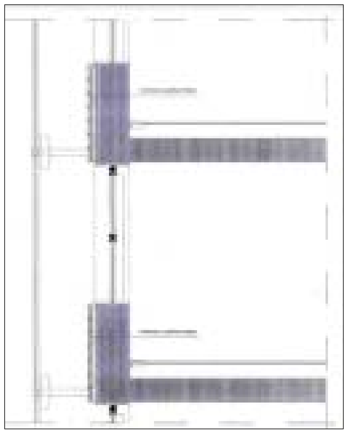
31. Proposed integration at the Green Office Building in Teheran

EVAPCOOL ceramic panels will be integrated within the perimeter wall of the offices located on the ground and top floors (fig. 32-33). A 'windcatcher' type of installation was also proposed on the South side of the building as part of an environmental design strategy for the North and South offices. This project is planned for construction in 2004. It has been estimated that the EVAPCOOL system will meet 85% of the cooling load of the offices.

26. Windcather



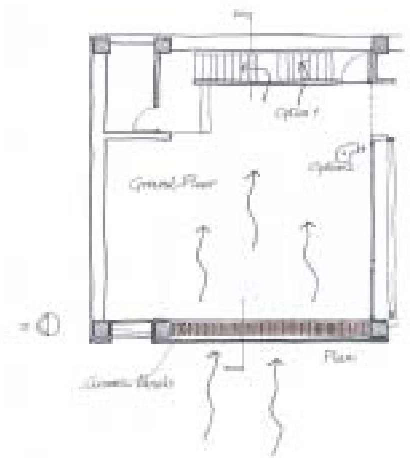
27. Light-vent Pipe



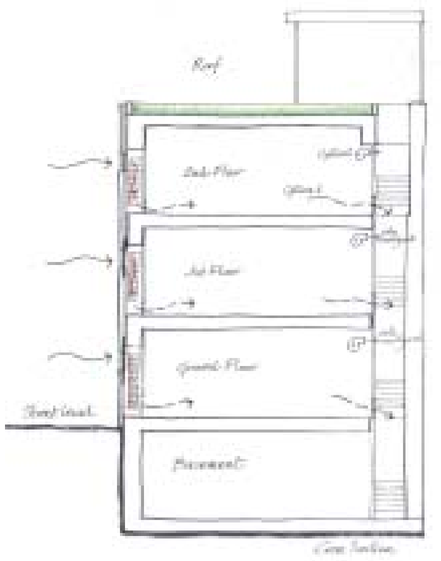
28. Double facade

29. Lyon Convention Centre by R. Piano

2.1.8 System Performance Analysis

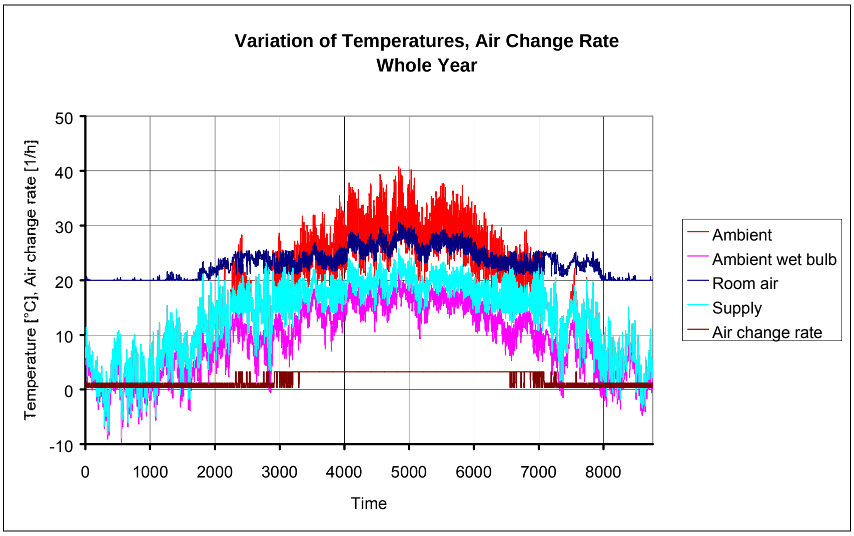


32. Ground Floor Plan



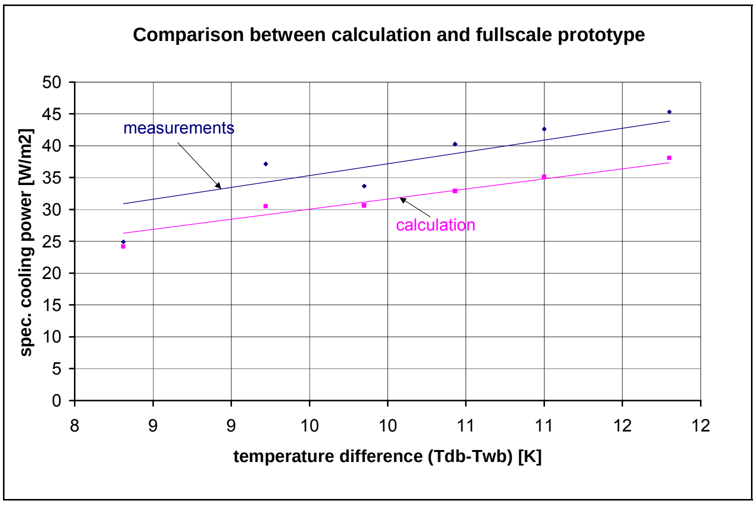
33. Cross Section

The results of the dynamic simulation (fig. 34) for the Teheran Office buildingshowed that for 85% of the time indoor temperature is below 26degC. Increasing the height of the elements from 0.8 m to 1.2 m did not reduce the number of hours above 26degC significantly. It was found that by reducing the temperatures, the humidity is also increased. The predicted annual energy saving for cooling was 32 - 42 kWh/m^2 (electricity based on T set point of 26degC) where the annual water consumption of the system was estimated as 12.3m^3/annum (approximately 5 litres per person/day).



34. Results of Dynamic thermal Model

By comparing the modelling results with the results from the full scale measurements it was found that the model predicted a smaller cooling power than the test results (Fig. 35). On average the difference was of about 16%. Considering the difficulty of measuring the outlet temperature in the full-scale test overall there was good agreement between the two sets of results.



35. Comparison between calculations and full-scale testing

2.1.9 Full Scale Prototype Monitoring

The full-scale direct prototype systems were installed and performance tested in the climate chamber of University of Nottingham. The tested systems were: the ***Perimeter Column*** (fig. 36) (hanging/suspended column) and the ***Perimeter Wall*** (fig. 37).

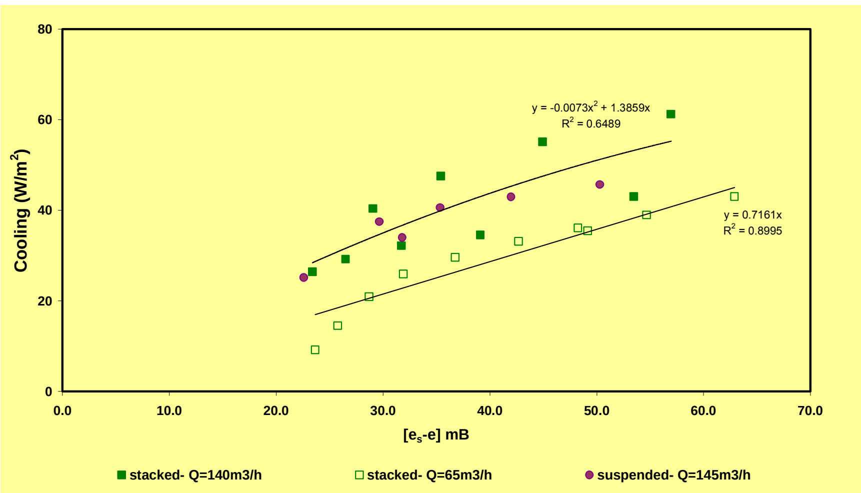

36. ‘Hanging’ Prototype installed in Nottingham

The stacking option was assembled from two types of evaporator. Coned holes and extensions on the top and bottom respectively, allow them to locate, while also channelling the water. These were stacked to form a wall. The second system, designated was assembled using 400mm×200mm×35mm ceramic units which were placed on a frame 70mm apart.

During the experimental work the two systems were tested at two different air volume flows and a variety of DB Temperatures and RH combinations. Tabular and graphical presentation of the results (Fig. 38) show the cooling performance of the suspended row system reaching a mean maximum cooling of 45.7W/m2 at 44.3degC and 45.5%, and air volume flow rate of 145m3/hr. The stacked wall system recorded mean maximum cooling of 61.2W/m2 at 43.5 oC and 35.8%, inlet conditions, and air volume flow rate of 140m3/h. At an airflow rate of 65m3/h, mean maximum cooling is 43.0W/m2 at 44.1 oC and 32.6 %, inlet conditions.


37. ‘Stacking’ Prototype installed in Nottingham

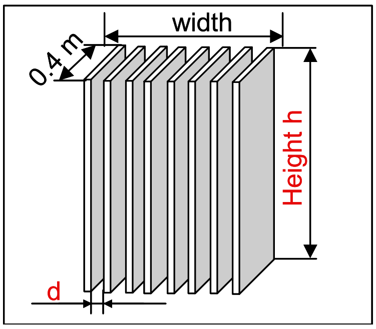
Both systems show similar values of specific cooling, when compared at similar air volume flow rate. This indicates a potentially similar performance at other operating conditions.



38. Specific cooling power of monitored prototype systems

2.1.10 Simplified Design Tool

A simplified design tool was developed for estimating performance and for the preliminary sizing of systems. This methodology is outlined below (Table 1). The method is subdivided in different steps, from preliminary analysis to commissioning and refers to case study project in Teheran.



40. Direct System

Following the Theoretical and Performance Analysis a Performance Chart (fig. 39) was created for the dimensioning of the Evapcool system. These notes explain how to use the chart and calculate the total cooling output of the system.

In the Evapcool system (fig. 40) the system parameters are the height of the array, the space “d” between the elements and the width of the system. The height is variable and a multiple of 0.2 m where the other evaporators’ dimensions are fixed to 400 mm and 35 mm. The optimum spacing between the columns of evaporators is given by the formula below (6).

(6) $$d = 9.375*h + 15.625;$$

Where d is the spacing between the evaporators and h is the height of the system. The width is also variable and depends on the availability of space and the type of integration.

The chart below shows the specific cooling power of the Evapcool system per meter width and meter height as a function of the dry and wet bulb temperature difference. It is shown that the specific cooling capacity decreases with increasing height. Therefore for a target cooling capacity and a given width, the height of the system should be chosen to be as small as possible.

In using the chart the steps are the following:

1. Climate Analysis

A climate analysis will assess the suitability of the local climate for the application of passive evaporative cooling. The criterion is WBT below 24degC for 100hrs in summer and a high wet – dry bulb air temperature difference.

2. Design Strategy

Develop a design strategy for the integration of the Evapcool system at building level.

TABLE 1 - EVAPCOOL SIMPLIFIED DESIGN TOOL

1. A climate analysis will assess the suitability of the local climate for the application of passive evaporative cooling. The criterion is WBT below 24degC for 100hrs in summer and high ∆wb/dbT.

2. Develop a design strategy for the integration of the Evapcool system at building level.

3. Identify the design weather conditions, i.e. the typical wb/db depression for your location in summer and enter this value on the x axis of the Evapcool design chart.

4. Choose the system type you wish to integrate in your building. The systems differ by height (0.2 to 1.2m). Each system is represented by a curve on the Evapcool chart.

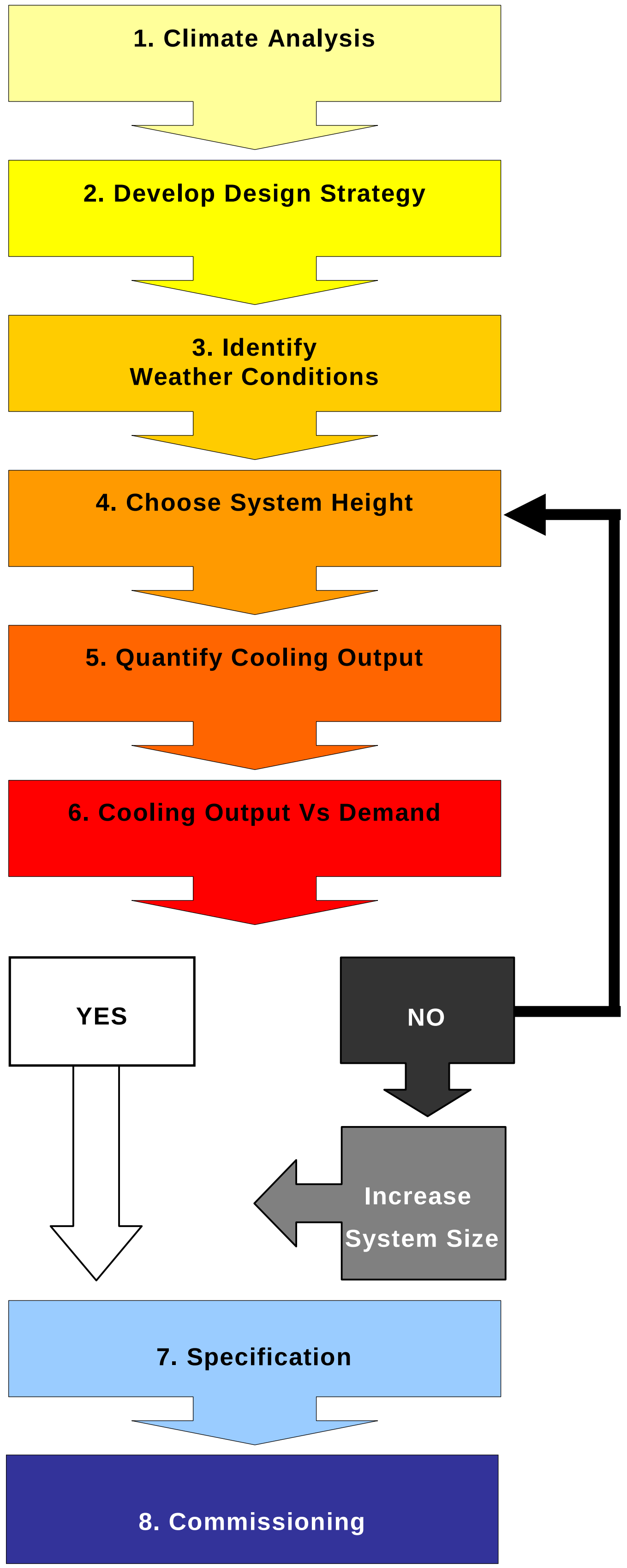
5. On the Evapcool chart you can identify the cooling output that each 1m wide system can produce under the prescribed weather conditions.

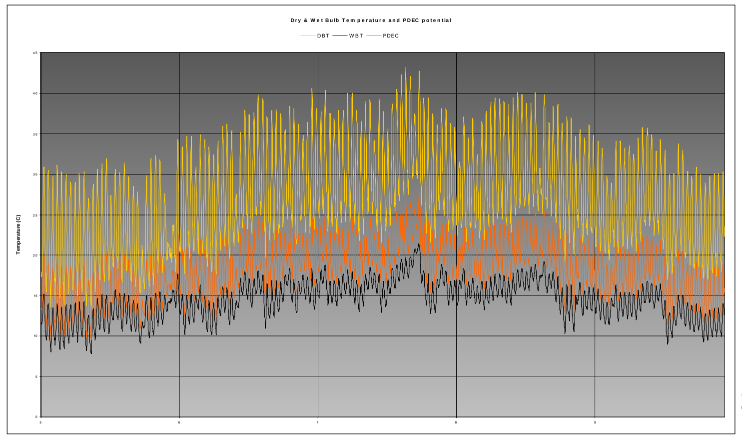
6. Calculate the building's cooling demand and compare it to the cooling output of the Evapcool system chosen.

* If the cooling output meets the requirements go to stage 7. If it doesn't you can either choose a different system height or increase the width of the current system.

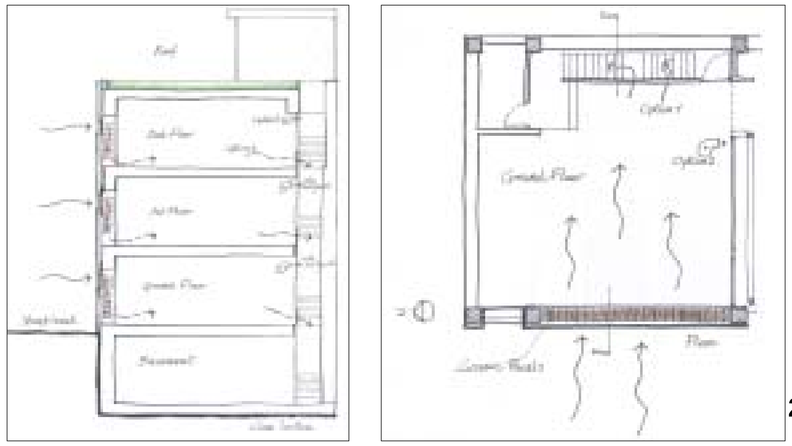
7. Specify the system components using specification tables, detail drawings and system schematics for the distribution of water.

8. At commissioning stage installation and maintenance manuals will be prepared for the client.

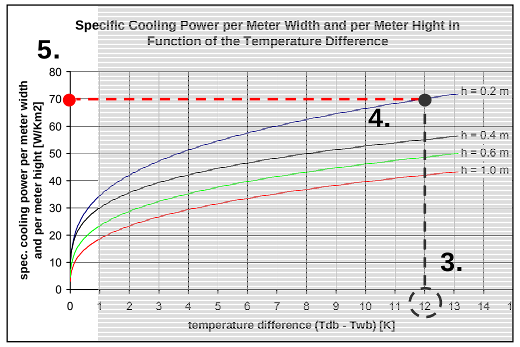


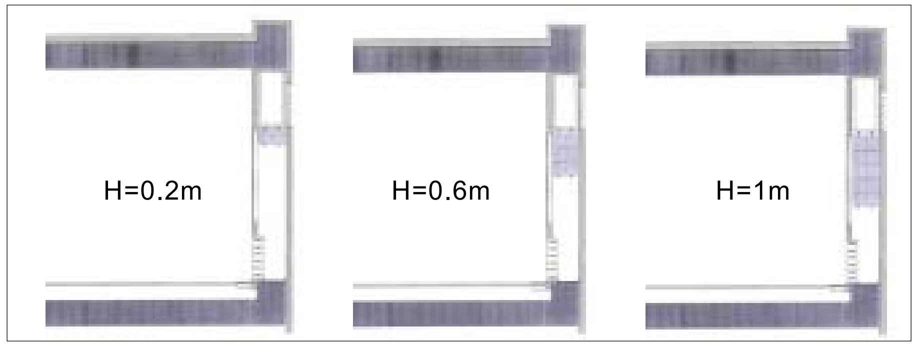


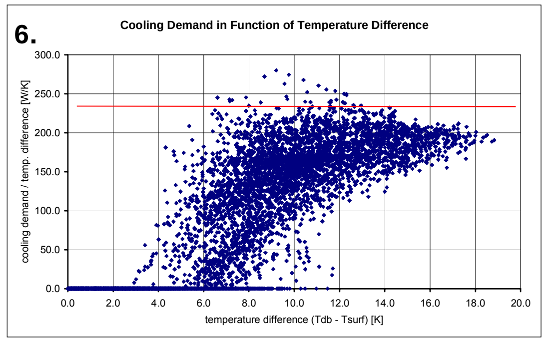
1.



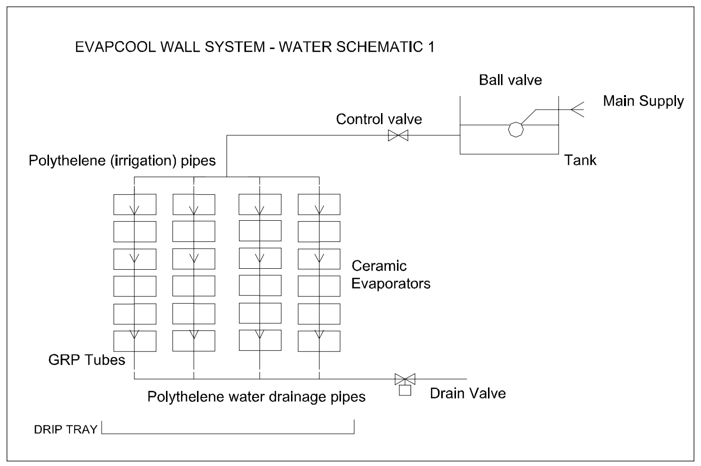
2.

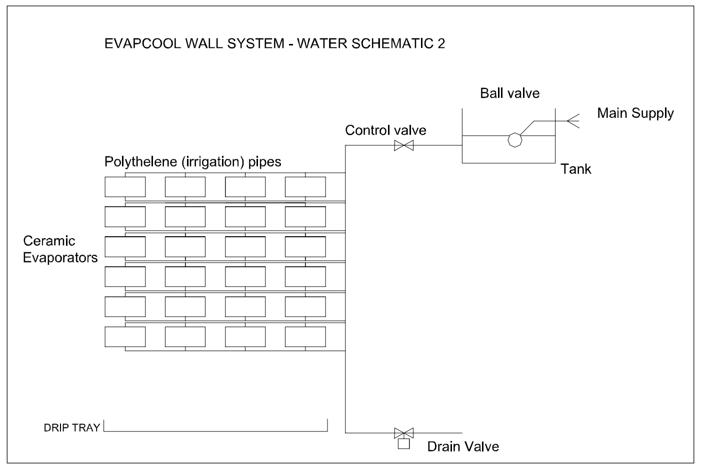






8.

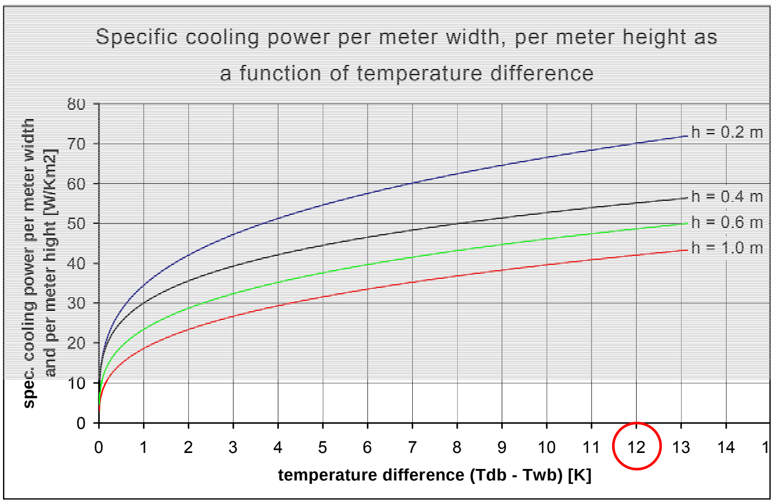




7.

3. Identify Weather Conditions

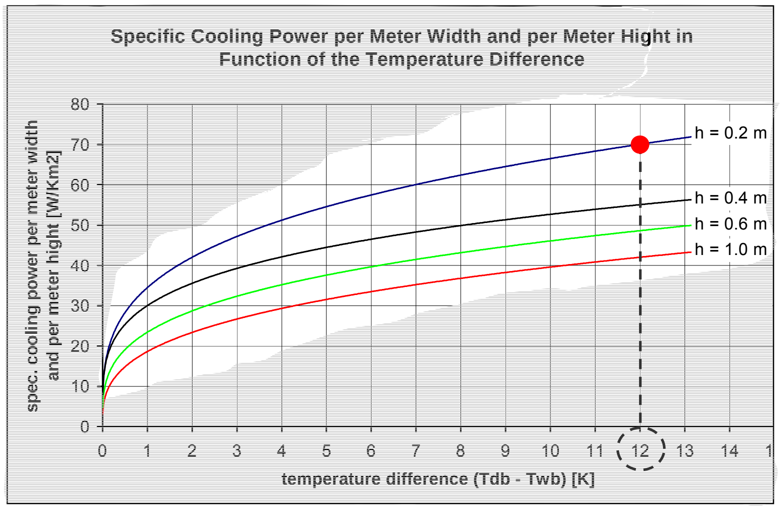
In order to derive the specific cooling power the first step is to enter the wet – dry bulb temperature difference we are designing for.



39. Performance Chart for calculation of the system total cooling power

4. Choose System Height

For the given temperature difference it is possible to choose a different system height.



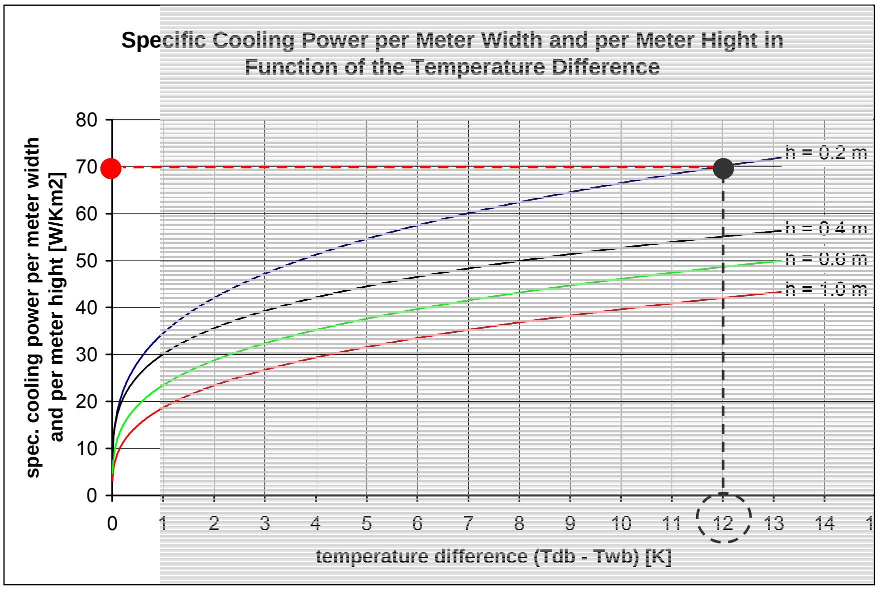
5. Quantify Specific Cooling Power

The total cooling output Qt [W] is calculated as follows:

(7) $$Qt = Qs \times \Delta T \times h;$$

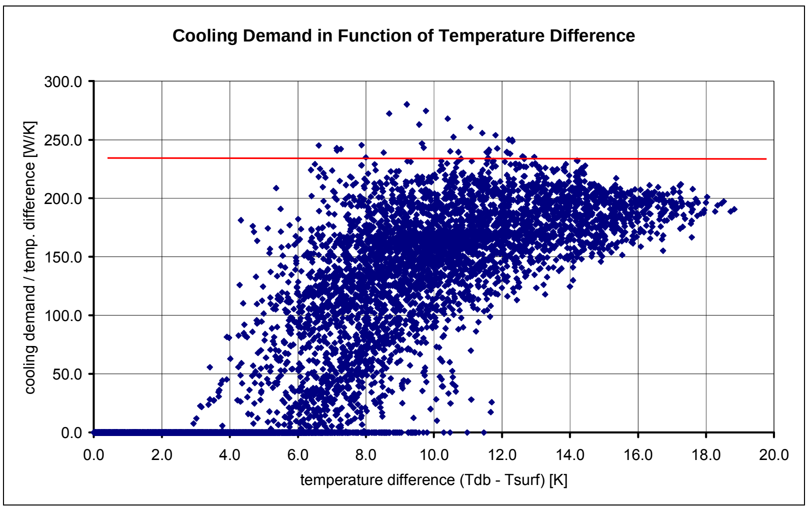
Where Qs is the specific cooling power [W/m2.K] (derived from the chart); ΔT is the dry-wet bulb temperature difference and h is the system height.

With a temperature difference of 12 K, a system of 1 m width and 0.2 m height has a total cooling power of 70x12x0.2=168W. A system of 0.6 m height at the same conditions would have a total cooling power of 49x12x0.6=353W. This shows that by doubling the width of the system with 0.2 m height we achieve almost the same cooling capacity as a 1 meter wide system with 0.6 m height.



6. Cooling Output Vs Cooling Demand

The basic requirement for the application of the dimensioning method illustrated above is the knowledge of the cooling demand and the related temperature difference for a certain case. In the Teheran project the Evapcool wall system was 6.5m wide. With a temperature difference of 12K and a height of 0.8 this gives a cooling power per Kelvin of 45x6.5x0.8=234W/K. This can be compared to the hourly cooling demand of the office expressed as cooling demand over temperature difference [W/K] as shown in the graph below (fig. 41). In the Teheran project this allowed the dimensioning of the system prior to the full dynamic thermal simulation performed using Transys modelling software.



41. Cooling Demand as a function of wet/dry bulb temperature difference

7. Specification

Specify the system components using specification tables, detail drawings and system schematics for the distribution of water.

8. Commissioning

At commissioning stage installation and maintenance manuals will be prepared for the client.

2.1.11 Conclusions

During the 30 months research project on 'Passive Downdraught Evaporative Cooling Using Porous Ceramic in non-domestic Buildings' the following objectives were achieved:

Theoretical models of downdraught cooling resulting from evaporation through porous ceramic panels in both direct and indirect systems were developed. The design and development of new products for improved performance of passive downdraught cooling systems were undertaken. Specifically, two innovative direct evaporative systems incorporating porous ceramic evaporators were designed, manufactured and tested.

A comparison between the performance of the direct and indirect evaporative cooling systems with conventional chilled water cooling coils under buoyancy driven airflow was made. The architectural and engineering implications of integrating these new passive downdraught cooling systems and components in a case study building were investigated.

A brief summary of results for each work package is enclosed.

WP1 – Theoretical Models – *Axima Lab., CH*

The theory of evaporative cooling through porous ceramic materials and its adaptation onto dynamic modelling tools was investigated. A methodology for the preliminary assessment of the system performance and a steady stated simulation tool were developed. The analysis established, in accordance with the experimental results, that in buoyancy driven conditions and for highly porous ceramic the direct system can achieve a specific cooling power of 100W/m2 of ceramic surface area.

WP2 – Laboratory Scale Measurements – *Nottingham University, UK*
Laboratory scale evaporators were designed and manufactured for the direct and indirect systems. These were tested in controlled conditions within the climate chamber at Nottingham University. The measurements showed a specific cooling power of 100-200W/m2 of ceramic surface area of the direct system but very low air velocities. This compared with measured cooling results of the indirect system of 10-50W/m2. Air velocities were too low to measure implying that buoyancy forces alone are not sufficient to drive a significant air flow in the configuration tested.

WP3 – Integrated System Design - *WSP Environmental Ltd., UK*
Generic types of building integration were developed to investigate the architectural and engineering design implications in terms of detailed design and performance of the proposed passive direct systems. Different types of wall and roof integrated systems were developed and described in detailed drawings (scale 1:10) and a physical model of an office room. Their integration and performance in the context of an office building project in Teheran was also investigated. A cooling strategy and an outline specification of the proposed system were developed.

WP4 – System Performance Analysis – *Axima Lab., CH*
The performance of the case study office building in Teheran was evaluated and compared with that of the same building with conventional air-conditioning. Dynamic thermal simulation assessed the annual performance of one representative office and CFD analysis investigated the system's performance under forced ventilation in peak conditions. Results showed that comfort can be achieved for 85% of the occupied time and that the specific cooling achieved with an airflow of 145m3/h is approximately 32W/m2.K. This is in partial agreement with the full-scale prototype measurements which report a specific cooling power 16% higher under the same conditions.

WP5 – Prototype Design & Manufacture – *WSP Environmental Ltd., UK*
Two full-scale ceramic prototypes of the direct system were designed and manufactured. Pre-production detailed drawings (scaled 1:10, 1:1) were prepared to enable the manufacture of the ceramic prototypes. These were delivered to the test facilities of Nottingham University for the full-scale monitoring. The

manufacturing options and their limitations on the design of the ceramic prototypes were thoroughly investigated. The design highlighted issues of cost and geometrical limitations of the manufacturing process, assembly of the prototypes components and their maintenance. This experience suggests that alternative methods of manufacture and assembly should be investigated.

WP6 – Prototype Installation & Testing – *Nottingham University, UK*

The two full-scale prototype systems were installed and tested in an existing climate chamber at Nottingham University. The test rig was designed (architectural drawings scale 1:20) and the chamber was modified to simulate a full-scale room and two full-scale perimeter wall and perimeter column systems. The test was performed under controlled conditions and forced ventilation. The results showed that for the high porosity ceramic prototypes a specific cooling power of approximately 40-45W/m2.K is achieved.

WP7 – Co-ordination – *WSP Environmental Ltd., UK*

The Co-ordination of the tasks and management of the Consortium was carried out throughout the duration of the project. This was done by assuring a constant dialogue and communication with and amongst the partners. Problems of delayed delivery of the full-scale ceramic prototypes and the eviction of one of the partners seriously undermined the timing of the project. However, the Consortium overcame these problems completing the tasks in the given timescale. The technical and financial reporting to the Commission was also carried out. The achieved results have been disseminated in conference papers and posters and articles to journals and magazines. Further dissemination and promotion is planned.

Cooling Rate

The research concluded that for the direct evaporative system a large area of porous ceramic panels is required to achieve significant cooling under buoyancy driven air flow. Buoyancy driven air velocities for the porous ceramic panels were negligible compared to tests for chilled water cooling coils. The direct evaporative system can provide a specific cooling rate of 40-45W/m2.degC (ceramic surface area per degC of wet/dry bulb differential) at an air flow rate of 145m3/h.

Energy Savings

Performance can be improved by the introduction of a low wattage fan. Significant energy savings (30-40kWh/m2 per annum) still can be achieved compared to the use of conventional air-conditioning but this makes the system very similar to a conventional desert cooler (the advantage being that it is building integrated).

Capital Costs

A cost appraisal of the system and its components has not been undertaken as yet. However, an outline specification of the system was undertaken for the case study building and this could constitute the basis of a cost analysis. It is envisaged that until economies of scale are achieved, the cost of the ceramic prototype will be potentially higher than the other system's components. A preliminary cost estimate from an Italian ceramic manufacturer suggested that for 1,000 evaporators the cost would approximate to 6,000 Euro (30 €/m2). The cost of comfort cooling in Europe is 150-200 €/m2 (year 2002).

Maintenance

Salt deposition on and into the ceramic evaporators can lead to risks of blockage of the water connections between the evaporators. Possible solutions include periodic washing with descaling solutions or the use of an ionised system. It is envisaged that for good practice such a maintenance regime should be applied every year.

Water Consumption

In the case study building the annual water consumption for the was estimated to be 12.5m3, which equates to 5.7l/person per day and represents only 11% of the daily office water consumption per person (50l). Also, comparing the system water consumption of 165mm/m2 to the annual precipitation of Teheran (270mm/m2), rain water could be a viable option for the system's water supply.

Further investigations are required on alternative and effective ways of integrating the direct evaporative system making full use of the building geometry and natural buoyancy driven air flow. Alternative types of integration such as wind towers and double facades should be explored in order to achieve a totally passive solution which will bring additional energy and cost savings.

Further Work

It is proposed:

- To develop proposals for the integration of porous ceramic cooling within Double Facades to be subject of a further R&D research project.
- A detailed cost appraisal of the developed systems and their components as part of a Market Assessment on the applicability

of the proposed direct evaporative system to residential buildings in South of Spain.

- The integration of the theoretical models within other current practice simulation tools and the development of nomograms for the preliminary sizing of the developed system by architects and designers.
- The dissemination of the developed techniques and related systems to a wider audience of designers, architects and professionals in the construction industry, through workshops, seminars and other events.
- The exploitation of the developed and patented ideas as described in the Technological Implementation Plan. This will include a search for potential investors/manufacturer to whom licence the commercialisation of the cooling systems and components.

2.3 Acknowledgements

The partners acknowledge the contribution of George Papagiannopulos, Mario Cucinella Architects, Elsa Ceramiche s.a.s. and Atelier One structural engineers and WSP Civils for their kind assistance during the project.

2.4 References

[1] Ford, B., Diaz, C. “Passive Downdraught Cooling: hybrid cooling in the Malta Stock Exchange”. Plea Conference, Chile, November 2003.

[2] Eicker, U. Solar technologies for buildings. Wiley Books, Chichester, UK, 2003

[3] Adnot, J. "Energy Efficiency of Room Air-Conditioners", EERAC, study for the Directorate General for Energy (DGXVII) of the Commission of the European Communities, May 1999

[4] The European Commission, ‘Passive Downdraught Evaporative Cooling in Non-Domestic Buildings’ (1996-‘99), general information can be found on the EC website: http://www.dbs.cordis.lu/cordis-cgi/

[5] Ford B., at al. “Market Assessment of opportunities for passive downdraught cooling in Southern Europe”. Plea Conference, Chile, November 2003.

[6] Mallick, F. H. Unpublished doctoral thesis, Architectural Association, London, 1994.

Additional publications and dissemination activities by the partners:

E Ibrahim, L Shao, S B Riffat, “Performance of porous ceramic for building cooling application", Energy & Buildings, 2003; Vol. 35 Issue 9: pp941-949.

E Ibrahim, L Shao, S B Riffat, “Experimental investigation of porous ceramic evaporators for building cooling application", CIBSE/ASHRAE International Conference – Building Sustainability Value and Profit, Edinburgh, Scotland, September 2003.

E Ibrahim, L Shao, S B Riffat, “Porous ceramic for building evaporative cooling", International Conference on Sustainable Development in Building & Environment, Chongqing, China, October 2003.

B. Ford, R. Schiano-Phan, “Evaporative Cooling Using Porous Ceramic Evaporators – Product Development and Generic Building Integration”, ‘The Plan – Architecture and Technologies in detail’, Centauro srl. Bologna, Italy, October 2003.

B. Ford, R. Schiano-Phan, “Evaporative Cooling Using Porous Ceramic Evaporators – Product Development and Generic Building Integration”, Plea Conference, Chile, November 2003.

PART 3 - MANAGEMENT REPORT

3.1 List of Deliverables

A list of Deliverables with related planned and actual completion dates is included below.

D1- Report on the theoretical basis for evaporative cooling through porous ceramic evaporators – Planned month 6; Completed month 6.

D2 – Report on theoretical basis for dynamic models which predicts performance of porous ceramic evaporators within: a) a downdraught tower and b) a whole building – Planned month 12; Completed month 16.

D3 – Report on proposed modelling methods to predict performance of Chilled water cooling coils under negative buoyancy driven air flow. – Planned month 12; completed month 17.

D4 - Report on the design and manufacture of two laboratory-scale components/systems, including design drawings (scale 1:10) – Planned month 10; completed month 6.

D5 - Prototype laboratory scale units of the proposed systems delivered to the test laboratory – Planned month 10; completed month 7.

D6 – Report on the performance characteristics of the two systems, with comparative data on conventional a/c. – Planned month 12; completed month 15.

D7 - Report on the architectural and engineering design implications of the proposed systems integrated within case study buildings – Planned month 16; completed month 27.

D8 - Technical report incorporating architectural and engineering detailed drawings for the two porous ceramic systems including a review of pertinent legislation covering design and specification – Planned month 18; completed month 27.

D9 - Report on the manufacturing options and limitations of the design of the prototype – Planned month 18; completed month 27.

D10 - Report describing the comparative analysis of the proposed passive downdraught cooling systems in the context of the case study building. – Planned month 18; completed month 30.

D11 – Technical report including design and working drawings (scale 1:50 / 1:10) describes the manufacturing solutions for the full scale prototype. – Planned month 18; completed month 27.

D12 – Two full scale porous ceramic prototype systems for direct and indirect evaporative cooling delivered to the test site. – Planned month 18; completed month 28.

D13 – Field data which can be used to calibrate the computer models. – Planned month26; completed month 30.

D14 – A report with comparative analysis of the performance of the full scale prototype systems. – Planned month 26; completed month 30.

3.2 Comparison of initially planned activities and work actually accomplished

A critical overview of the technical state of the research by work packages follows.

Work Package 1 – Development of Theoretical Models

Stated Objectives	Work Planned	Work Performed	Achieved Objectives	Reference / Deliverables
1.1 To review the theory behind the evaporative cooling process through porous ceramic materials and to develop the theoretical basis for two specific system ideas based on direct and indirect evaporative cooling	Review of previous work on evaporative cooling through porous ceramic.	√	√	D1
1.2 To develop a dynamic modelling methodology to predict temperature, relative humidity, air velocity and cooling capacity achieved through porous ceramic evaporators within a) a downdraught tower b) a building, arising from direct and indirect evaporative cooling.	Development of theoretical model describing the evaporative process in the direct and indirect system.	√	Detail modelling of direct evaporative cooling system using Computational Fluid Dynamics; steady state computer script able to predict the cooling performance of the direct system for given environmental conditions. The results of the script correlates well with lab scale measurements.	D1 D3 Minutes of Partners Meeting 02/10/02
	Development of dynamic modelling methods to predict performance of proposed evaporative systems within a tower and a building.	The analysis focused on the prediction of performance of the direct system components in a shaft and in an office using CFD. A simplified computer script has been developed to predict the cooling capacity (W/m^2 surface area) of the direct system.	The comparison was made between indirect system and chilled beams (D3).	D2 D3 Minutes of Partners Meeting 02/10/02

Work Package 2 – Laboratory Scale Measurements

Stated Objectives	Work Planned	Work Performed	Achieved Objectives	Reference / Deliverables
To design and build a laboratory scale prototype of two component/system ideas and to test each system under controlled conditions with measurements of temperatures, relative humidity and air velocities, and to compare these results with the performance of a conventional chilled water cooling coil under the same test conditions.	Design and manufacture of laboratory scale prototypes for the direct and indirect systems	A lab scale ceramic prototype was developed to be used both for the direct and indirect systems. The prototype was supplied in the preferred shape and size but in different porosity in order to assess influence on performance.	√	D4 D5
	Laboratory test of both direct and indirect system in vertical duct inside test cell to assess the cooling capacity as function of the environmental conditions and porosity.	As planned	The test on the direct system shows a cooling capacity of up to 200W/m2 for high porosity panels in a single row stack. Poor performance (15-50W/m2) has been recorded for the indirect system.	D6
	Comparative test with refrigerant based chilled water cooling coil.	As planned	√	Addendum 1 to D6
	Not originally planned.	Further investigations were required on: 1) Performance of evaporators in single row stack. 2) Effect of water pressure. 3) Assessment of Passive Down-draught. 4) Accelerated Salt deposition.	√	Addendum 2 to D6

Work Package 3 – Integrated systems design

Stated Objectives	Work Planned	Work Performed	Achieved Objectives	Reference / Deliverables
3.1To investigate the architectural and engineering design implications of the proposed passive downdraught cooling systems and their integration into case study office buildings in South of Europe.	Explore the design options for the direct and indirect systems in the context of a case study building in South of Europe. Architectural integration into a case study building looking at the geometry, volume and building's cooling demand.	A matrix of options, containing all the envisaged system types and applications, has been outlined. Due to the poor performance of the indirect system, the analysis will be focused on the direct system exclusively and a live office building project in Teheran will be used as a case study.	Investigation of the architectural and engineering implications of the proposed passive direct evaporative cooling system and its integration into a case study office building in Iran.	Minutes of partners Meeting 02/10/02 D7 D10
3.2 To develop detail design studies of the two porous ceramic systems and provide constructional and engineering solutions which are technically and economically viable.	Preliminary sizing of the component based on results of the theoretical modelling and lab measurements.	A preliminary sizing is being investigated and two main components (block and cladding panel) were designed.	The indirect system was not developed. The direct system was developed to the point of being 'edible to market'.	D8
3.3 To review pertinent legislation for the design, specification, installation, running and maintenance of the proposed systems.	Review of all relevant legislation.	No relevant legislation found.	-	-
3.4 To investigate the manufacturing options and limitations on the design of the prototype components.	Architectural and engineering detailing of the proposed systems.	Investigations were undertaken to design the water supply system and structural elements required according to the type of application and structural solutions.	√	D9

Work Package 4 – System Performance Analysis

Stated Objectives	Work Planned	Work Performed	Achieved Objectives	Reference / Deliverables
To evaluate the performance of the case study buildings in Europe with a passive downdraught cooling system incorporating either direct or indirect ceramic evaporators and to compare this performance with that of the same buildings with chilled water cooling coils.	To test the architectural design proposal for the integration of the direct and indirect systems compared to the cooling coil option. Thermal performance and air flow analysis of the proposed systems for a typical year. Energy analysis to compare the performance of the three systems and explore issues of control using Dynamic Thermal Modelling and Computational Fluid Dynamics.	The analysis has focused on the direct system. Scenarios mapping seasonal and diurnal control strategies were investigated and tested. The performance analysis was undertaken within the case study building and a comparison was made between the porous ceramic direct evaporative system and the cooling coil system. The CFD and DTM were undertaken for different zones of the case study building.	Evaluation of the performance of the case study building in Teheran incorporating the direct systems.	D10

Work Package 5 – Full Scale Prototype design and manufacture

Stated Objectives	Work Planned	Work Performed	Achieved Objectives	Reference / Deliverables
To design and manufacture a full scale prototype of each of the proposed passive downdraught cooling systems: a) direct porous evaporator type, b) indirect porous evaporator type.	Design of full scale units arising from a consideration of architectural, engineering, manufacturing and performance issues of previous tasks. Manufacture of two full scale prototype for the direct and indirect systems delivered to the test site.	The design of the full-scale units for the direct evaporative system focused on two types of component: a) block, b) cladding panel. The manufacture concentrated on two variants of the direct evaporative system: Stacked and Hung. They were delivered to the test facilities in Nottingham for the full scale prototype testing.	Design and manufacture of the full scale prototype for the developed variants of the direct passive evaporative cooling system.	Minutes of partners meeting on 02/10/02 D8 D9 D11 D12

Work Package 6 – Testing and Installation

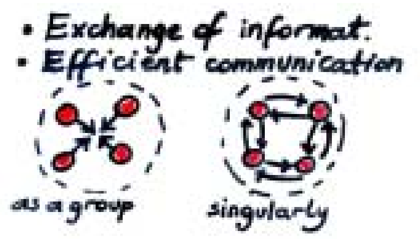
Stated Objectives	Work Planned	Work Performed	Achieved Objectives	Reference / Deliverables
To install and test the full scale prototypes of the proposed porous ceramic downdraught cooling system design and manufactured in WP5. The purpose is to investigate actual performance under buoyancy driven airflow and real weather conditions.	Five month monitoring campaign in test facilities in Nottingham. The test was performed as a combination of long-term and short-term experiments. Data on DBT, RH and air velocity were recorded and analysed to calibrate models.	The installation and testing was performed on two variants of the direct evaporative system as specified in WP5. The full-scale prototype testing of the two variants was performed under controlled conditions in the test facilities in Nottingham. UNOTT was involved in the set up of the installation and the monitoring in the climate chamber.	Installation and testing of two types of the direct evaporative cooling system in controlled conditions. The tests were performed in the climate chamber of the University of Nottingham.	Minutes of partners meeting on 02/10/02 D13 D14

Work Package 7 – Co-ordination

Stated Objectives	Work Planned	Work Performed	Achieved Objectives	Reference / Deliverables
7.1 To carry out the co-ordination and management of the research activity.	Assure a good level of communication between the partners. Arrange regular meetings. Be responsible for liasing with the Commission.	The tasks were carried out as planned. Delay was experienced in the delivery of the MTR (due in June 02). This was due to a series of resourcing problems during the summer. Also problems of communication with the ceramic manufacturer absorbed most of the co-ordination time, aggravated by their limited knowledge of the English language. The resourcing problem of P1 has been successfully overcome with the allocation of a full time person engaged exclusively on the research project for the last 12 months of the project.	√	Progress Report Mid Term Report Final Report Technical Implementation Plan
7.2 To carry out the reporting activity and the dissemination of the results of the research.	Report to the Commission on the developments of the research and the results of the completed work packages. Periodic issue of 6 and 12 months progress reports, Mid Term Assessment, Final Report and Technical Implementation Plan.		√ The dissemination work so far included the preparation of the PLEA conference paper to be presented in Chile in Nov 2003 and the publication of an article in the architectural magazine The Plan.	
7.3 To develop exploitation plans and registration of patents.	A technical Implementation plan will be developed.		√	

3.3 Management and Co-ordination aspects

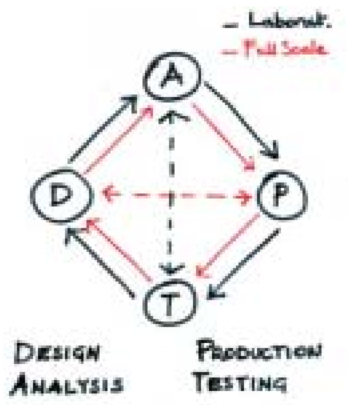
The co-ordination of a research project and the management of an international consortium is a particularly onerous task especially for first time co-ordinators. During this 30 months project there were several aspects of co-ordination that required good communication skills and familiarity with the contractual rules of the European Commission's Framework. At times, many issues related to the organisation of work and communication with the Commission constituted obstacles to the even progress of the research. This chapter reports on the main aspects of co-ordination throughout the project, highlighting the problems encountered and, where appropriate, making some suggestions for future reference.



42. Diagrams of communication strategy

Management of co-ordination task

Since the beginning of the project the co-ordinator (WSPE) put in place a structure for managing the project and co-ordinating the work of the partners. Since the kick-off meeting the co-ordinator tried to clarify for the partners the rules and structure of the project. This was done in the form of a brief presentation on the Goals, Resources and Process of development of the Research Project (Fig. 42, 43). Important aspects such as Contractual rules, Process of payment, Confidentiality, Intellectual Property, Internal Communication, Delivery of results and Reporting were discussed and an agreement on all those issues was sought from the start. However these aspects were dealt on an 'ad hoc' basis. Previous experience on the PDEC project had suggested the extreme difficulty of obtaining a Consortium Agreement.



43. Diagrams of Work Packages structure

Contractual Rules

The partners were invited since the beginning to read the *Annex II* of the Contract containing the contractual terms and conditions between the Consortium and the Commission. It must be said that for organisations which are for the first time in partnership with the Commission and are not familiar with the way it operates, the language and presentation of these rules (with their legal terminology) is not very reader friendly and at times lacks transparency.

Intellectual property

It was agreed that Intellectual Property arising from the research project is shared jointly by the partners. When the initial research proposal was made in 1999 a confidentiality agreement on the outcome of the research was signed by the partners. After the failure of the first application Brian Ford and Prof. Saffa Riffat applied for a joint patent on the ideas of direct and indirect evaporative cooling systems using porous ceramic evaporators. This constitute a so called background patent to any future patent on direct systems arising from the project. After numerous discussions and the eviction of Il Coccio Umidificatori from the Consortium, a patent application on the two direct evaporative systems developed was put forward by University of Nottingham and WSP Environmental. Axima was not interested in patenting the idea and therefore did not subscribed to the application. By patenting the developed products UNOTT and WSPE are hoping to be able to either licence (or sell) the rights of manufacture to a ceramic manufacturer for the commercialisation of this product as part of a novel passive cooling system. The application was made at the end of the project but it is still unknown if it will be successful or not. More details on the commercial exploitation of results are included in the Technical Implementation Plan.

Confidentiality and Dissemination

Confidentiality and the commercial nature of the project implied that any paper or publishable material had to be circulated in advance between the partners and the information released in them to be subject to the partners' approval. According to the EC guidelines on IPR the general rule was to disseminate the *whats* and *whys* of the research but not the *know-how*. Several papers have been published since the beginning of the research and all contributed to the dissemination of the results. A list of titles is included in the references of Part I.

Internal Communication

Assuring an effective and constant communication amongst the Partners and between the Consortium and the Commission is one of the most difficult and time consuming tasks for the co-ordinator. Regardless how good a structure is put in place for an efficient management of this task, there are barriers that are often underestimated. 'Language' barriers, both from the linguistic and professional point of view are very difficult to overcome and are the principal cause of faults in a project. Even where 'English' is the common language in our project, 'communication' problems were experienced, amongst the others, with Il Coccio Umidificatori. Il Coccio was the Italian partner carrying out one of the crucial tasks of the project: manufacture of laboratory and full-scale prototypes. Although members of the co-ordination team were Italian mother tongue, deeper misunderstandings occurred throughout the project. These were mainly related to the fact that Il Coccio was a very small organisation and their business language was not up to scratch with the international community. Communicating with them was a particularly time consuming task as all the correspondence had to be translated and they did not seem to make an effort to actively overcome this problem. Also, as unfortunately it is custom in many Italian businesses, they were quite flexible on deadlines and delivery dates which was very disruptive and completely unacceptable in an international context. This also demonstrated how unfamiliar they were with the problems of the construction industry where the commitment to quality and timing are essential. Although, on a technical level it cannot be denied that the contribution of Il Coccio was very valuable, overall the partnership with them was a clear burden for the Consortium and very hard work for the co-ordination. The co-ordinator takes a big risk in taking on partners with which they are not familiar. This risk should be recognised in the reconnection of the coordinating partner.

Throughout the duration of the project the obvious patterns of communication were assured by recurrent partners meetings and task specific meetings. Exchange of emails and constant correspondence was promoted, not only between partners and co-ordinators but also amongst the partners, for the accomplishment of the administrative and technical tasks. Partners meetings took place in Nottingham (UNOTT), Winterthur (AXIMA lab), Florence and London (WSPE) acting as a forum for communication and decision making at different stages of the project.

Timescale and Delivery

A timetable for the 30 months duration of the project was prepared and discussed with the partners at the beginning of the project. It was emphasised the importance of looking well in advance to deliverables dates and meeting dates, planning the successful routes to an on time delivery. Indicative deadlines and optimum periods for drafting and commenting on deliverables were suggested. Inevitably the rate of success of this forecast was very small as the actual delivery dates largely overrun the predicted deadlines. Nevertheless it was very important to have a timescale which gave the partners guidelines on the duration of the tasks and completion dates. The prepared timetable was continuously discussed and adjusted according to the work in progress in order to project as a realistic forecast as possible. Severe delays on completion of tasks and issue of deliverables were experienced occasionally and this was especially the case for the delivery of the full-scale prototypes.

The development of the theoretical models took longer than anticipated. Minor delays also occurred in the production of the laboratory prototypes due to unforeseen production difficulties at the manufacturing plant in Florence, Italy, and consequent slight delay in the experimental programme at UNOTT.

During the second year problems with one of the partners were experienced and this once again disrupted the continuation of the other tasks. Partner No. 4, Il Coccio Umidificatori srl. underwent a period of financial difficulties and was taken over by a company called Industrie Ceramiche Toscane spa. After numerous attempts to prompt ICT to fulfil their tasks and contractual obligation with the Commission, they communicated to us that they were not willing to be involved in the Evapcool Project. This inevitably led to the eviction of P4 from the Consortium.

Regrettably problems with the supply of the ceramic prototypes lead to continuous and severe delays in their delivery to Unott's test facilities. The prototypes were not shipped to University of Nottingham until the 21st of June 2003. Obviously this considerably delayed the other tasks, having a negative impact on the development of the research. Much effort was placed by UNOTT, who overcame this delay and managed to complete the required task by the end of the project. However if the tests had been done as planned more time would probably be allocated to the investigation of other aspects arising from the first set of measurements. Also, delays were experienced in the delivery of the work performed by Axima on the Performance Analysis of the case study.

Reporting

Reporting to the Commission is another crucial task of the co-ordinator. The level of information that the Commission requires is often very detailed and often no flexibility is given in the reporting format. Procedural changes can make the reporting task the co-ordinator a very time consuming affair, particularly when reports are sent back to the co-ordinator for minor amendments. Similarly, the amount of administrative forms to fill in before and during the project is sometimes excessive.

Lessons and suggestions

Retrospectively it is now quite clear that some of the major obstacles to the efficient development of the project were poor understanding of the rules, difficult communication with some of the Partners and at times excessive bureaucracy (especially at the contract preparation stage), and lack of flexibility from the Commission. Possible ways of overcoming these problems should be sought by the Commission with the help of project co-ordinators. From this Consortium experience it is proposed that the following measures are taken into consideration by the Commission:

- Training for first time co-ordinators
- Introductory seminars for first time partners
- More resources allocated for Co-ordination
- More transparency in the bureaucratic procedures
- Clearer and simpler rules accessible by anyone
- More and closer assistance from the Commission
- Partners Satisfaction Survey and Feedback questionnaire at the end of the project

Overall the project was a very interesting and challenging experience for the Consortium. From the technical point of view the partners feel to have accomplished the goals set at the beginning of the project and are reasonably pleased with the outcome of the research. The hypotheses outlined in the research proposal have all been verified and more knowledge has been acquired on passive direct evaporative cooling systems using porous ceramic as a mean to provide cooling in non domestic buildings. However, further investigation is required to assess if this is a commercially viable technique. From the management point of view the co-ordination team and the Consortium have overcome quite reasonably the obstacles presented along the project and made possible the successful completion of the research in the given timescale.

The contact person for the future follow-up of the project is:

Rosa Schiano-Phan
WSP Environmental Ltd.
Buchanan House
24-30 Holborn
London EC1N 2HS