324: Post Occupancy Evaluation of non-domestic buildings using downdraught cooling: Case studies in the US

Rosa Schiano-Phan [1]*, Brian Ford [1]

School of the Built Environment,
University of Nottingham, Nottingham, UK[1]*
rosa.schiano-phan@nottingham.ac.uk

Abstract

This paper presents a summary of the results of a field survey investigating occupants' perception of four US buildings employing various forms of Passive Downdraught Evaporative Cooling (misting devices and cellulose mats). The buildings were surveyed as part of a European supported dissemination project which seeks to promote the use of Passive Downdraught and Hybrid Cooling (PHDC) amongst building professionals in Europe, China and India as a realistic alternative to conventional air-conditioning. The results of the surveys are presented and discussed drawing comparisons between the different cases. Of the four buildings surveyed two were perceived generally as unsuccessful in terms of their internal environment and two were perceived successful. The paper suggests that occupants have a better perception of the building when they have a degree of control over its operation and are aware of the design intention and the control strategy. It also emerged that other factors such as local culture and context have an impact over the occupants' response to passively cooled building.

Keywords: passive downdraught evaporative cooling, post occupancy evaluation

1. Introduction

In August 2003 over 50 million people in eastern and central US and Canada experienced a two day loss of electrical power, with an economic cost estimated to run into billions of dollars. This was directly related to a demand for air-conditioning which exceeded generating capacity [1]. With the market for room air-conditioning steadily increasing across the world and with the established evidence of global warming, this scenario can become ever more frequent in many hot climate countries. Also, the rising cost of crude oil doubling in the last two years has reopened the debate on the energy crisis and creates more incentives for energy savings and efficiency. Additionally, the environmental impact of air-conditioning such as the Global Warming Potential of HFC refrigerants is still high [2] and this calls for a fast and effective shift towards passive and refrigerant free forms of cooling.

In recent years, both research and applications of Passive and Hybrid Downdraught Cooling have been carried out worldwide [3] and we are now at a stage where a few pioneering buildings effectively showcase the use of such systems, as an alternative to mechanical cooling. To move to a situation where the number of applications grows rapidly, from a few pioneering buildings, to many thousands, will require widespread acceptance of this approach among clients and professionals, as well as increased awareness by the general public. As part of an EC funded project, a series of dissemination activities will be carried out to promote the developed technologies in Europe, China and India [4]. The project's activities include the creation of a design sourcebook, a simplified performance assessment tool, a website (where a full version of the sourcebook and case studies will be available) and a series of symposia and workshops.

2. Post Occupancy Evaluation

2.1 Objectives

Passive and Hybrid Downdraught Cooling (PHDC) has been shown to be technically viable and to perform in a range of different climatic zones around the world [5]. However, only in a few studies has the thermal performance of some of the pioneering buildings which incorporate PHDC been linked to occupant perceptions of internal conditions, maintenance requirements and actual energy requirements [6]. One of the EC project's objectives is to review these studies and the available performance and user perception data where possible and to undertake Post Occupancy Evaluation on those PHDC buildings not yet surveyed. As part of this project 10 case study buildings have been surveyed, four of which are presented in this paper. The ultimate goal of the investigation was to assess the occupants' perception of the buildings which employ passive and hybrid downdraught cooling and learn lessons about the design and management of these buildings.

2.2 Methodology

The Post Occupancy Evaluation (POE) surveys were undertaken in October 2007 in four buildings located in the South West of the United States (California, Arizona, and Utah). Each survey was undertaken during the course of one day using a two-page workplace questionnaire developed by the Building Use Studies, UK [7]. The survey included questions on: thermal comfort (summer and winter), air quality, lighting, noise, design, need, perceived health and productivity and image to visitors. In analyzing the data, however, particular emphasis has been placed on the summer performance and aspects such as perceived thermal comfort, air quality and control. During the surveys, the building manager was interviewed and the passive cooling system surveyed in order to gather information on issues of performance and maintenance.

3. Case Studies

3.1 Climatic Context

The four case study buildings here presented are located in three main climatic regions. Buildings 2 and 3 (see section 3.3) both benefit from the Mediterranean climate of the greater San Francisco Bay area, characterised by mild wet winters and dry sunny summers (mean max Temperatures of 28˚C and afternoon RH of 35%). Building 1 is located in the more extreme climate of south Arizona, characterised by mild winters and very hot and dry summers (mean max Temperatures of 41˚C in August and afternoon RH of 20%). The climate of South Utah is in summer equally hot and dry (with mean max Temperatures of 32˚C and RH of 20%) but the microclimate of the Zion National Park (Building 4) is influenced by the canyon system, which provides greater annual rainfall and smaller diurnal swings [8, 9].

3.2 Systems typologies

As the name implies, PHDC generates a downdraught which circulates cool air within the space or through the building. Depending on the climate, and geometric opportunities open to the designers, different techniques could be used, including: Passive Downdraught Evaporative Cooling (PDEC) using either misting devices, wetted cellulose mats, 'shower' type fittings or porous surfaces; and mechanically induced Downdraught Cooling using cooling coils or dehumidifiers to generate a downdraught. The latter two techniques can be used when the ambient relative humidity of the air is too high to exploit direct evaporative cooling.

i) Misting devices

Misting devices (or 'micronisers' [10]) encourage evaporation by injecting a mist of tiny droplets into the air stream, resulting in very rapid cooling. Until recently, the smallest droplets have been achieved by using highly engineered brass nozzles taking water at high pressure (25-50bar). This approach was successfully integrated in the Torrent Research Centre Building in Ahmedabad [6], and subsequently in the Federal Courthouse in Phoenix [11]. This approach is highly effective in terms of the cooling achieved, but relies on high quality filtered water and even then frequent blocking of nozzles, dripping and 'overblowing' can occur, requiring regular maintenance and replacement of nozzles. More recently, atomising nozzles, which create tiny droplets by combining water under atmospheric pressure with a stream of compressed air, have been developed [12]. This arrangement retains the benefits of small droplet size, while reducing the risk of dripping and blocking of nozzles, thus reducing the maintenance as well as the capital costs.

ii) Cellulose mats

Fibrous mats have been used as a medium to support evaporative cooling for many centuries. In India, 'khus' mats (made from the roots of the honeysuckle plant) have been hung in open windows and doorways and sprinkled with water to promote evaporation and cooling of air as it passes through the building. More recently cellulose mats [13] have been used as a low cost porous material with a large surface area to induce evaporative cooling within so called 'Cool Towers' in a number of buildings in the US. The thermal performance of a 'cool tower' integrated into a building was first characterised by Cunningham & Thompson through their evaluation of the test building at University of Arizona [14].

3.3 Buildings typologies

The four case studies are all public buildings and all employ Passive Downdraught Evaporative Cooling (PDEC), however, the first two use water misting devices and the second two wetted cellulose mats. They are:

a) Building 1 - Federal Courthouse, Phoenix, AZ;
b) Building 2 - Research Centre, Stanford University, CA;
c) Building 3 - High School, Petaluma, CA;
d) Building 4 - Visitor Centre, Zion National Park, Utah.

a) Building 1 – Federal Courthouse, Phoenix, AZ

The 46,500m^2 six storey courthouse, by Architect Richard Meier, occupies two urban blocks in the west margin of downtown Phoenix. The building is oriented north south and the main entrance is located on the east side, preceded by a paved plaza. It consists of two volumes: a 6 storey office and courtroom block and a larger 6 storey atrium space. Despite the large glazed area, this is an inward looking building concentrating most of the offices and courtrooms on the south block. These open into the vast 107x46mt north atrium through the side balconies (Fig. 1), where the 120 water mister system is installed [15-17].

Fig 1. Building 1 - Sandra Day O'Connor Federal Courthouse, Phoenix, AZ

b) Building 2 – Research Centre, Stanford, CA
The two-storey building, designed by San Franciscan architect EHDD, is on a fairly open site with low rise surrounding buildings which do not obstruct the sky view and sunlight. With the east facing main entrance and its north-south orientation, this 1000m^2 building is arranged in such a way to maximise northerly daylight in the ground floor open lab area and first floor open plan office, where a 'night sky radiant cooling' system is installed. The front elevation (Fig. 2) is characterised by the 10m tower, which delivers Passive Downdraught Evaporative Cooling into the entrance lobby employing five water misting devices [18].

Fig 2. Building 2 - Global Ecology Research Centre, Stanford, CA

c) Building 3 – High School, Petaluma, CA
The school complex, by local architects Quattrocchi-Kwok, is located on an open site, north east of the town centre. It comprises of twelve cluster buildings arranged around two main courtyards intersected by pathways and linked by covered walkways. The clusters include eight classrooms, one administrative building and three buildings employing PDEC by using cellulose mats system integrated at the top of four Cool Towers. These are: the library, the multi-use building and the gymnasium. They are located on the west, south and east corners of the complex respectively and overall account for a total gross floor area of approximately 2,435m^2 [19].

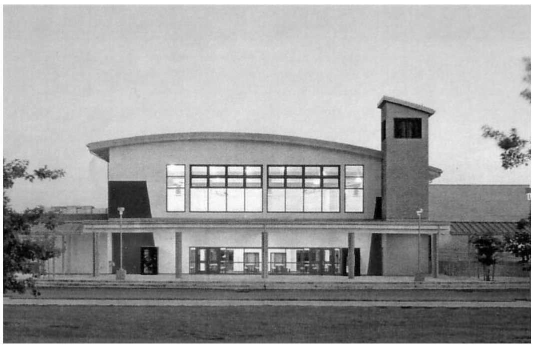

Fig 3. Building 3 - Kenilworth Junior High School, Petaluma, CA

d) Building 4 – Visitor Centre, Zion National Park, Utah
The Visitor Centre complex, designed by the architects of the U.S. National Park Services, comprises of an outdoor exhibition area and three buildings: the main visitor centre building (818m^2), the restrooms (256m^2) and the fee station (15.8m^2). The main building houses a book shop, the main reception desk and offices at the back. A total of two Cool Towers provide Passive Downdraught Evaporative Cooling using cellulose mats [20, 21].

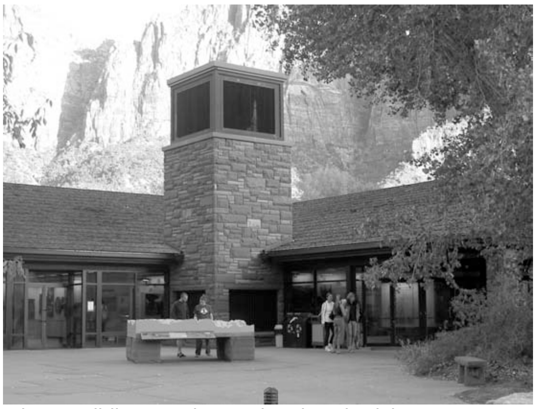

Fig 4. Building 4 - Zion National Park Visitor Centre, UT

4. Results of Post Occupancy Evaluation

4.1 Building 1 – Federal Courthouse, Phoenix
The occupants' satisfaction survey involved 19 subjects located in the atrium and the surrounding perimeter offices on the ground floor, where the impact of the PDEC system could potentially be greater. The summary of results (Fig. 5) shows that the majority of the subjects did not have a very good perception of the building, with aspects such a thermal comfort, air quality and controls being the most unsatisfactory. Noise and comfort gravitated towards more satisfactory conditions whereas 'Image to visitors' and 'Needs' were neutral. The large majority thought that the temperature in summer was too hot (88%) and a third of the sample perceived it varying during the day. Around 75% of the occupants also said to have little or no control on heating, cooling and ventilation confirming the comments made during the informal interview.

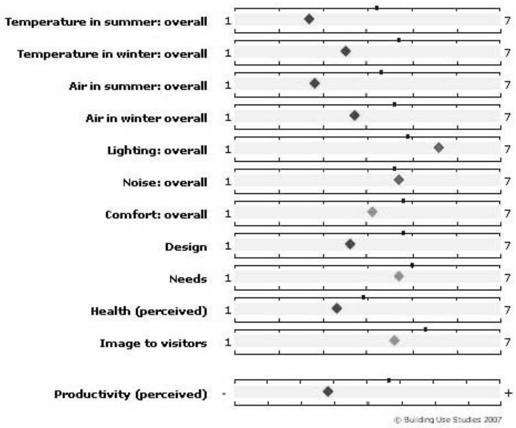

Fig 5. Occupants' satisfaction in Building 1 (Scale 1 to 7: unsatisfactory to satisfactory)

4.2 Building 2 – Research Centre, Stanford

The 20 subjects interviewed for the survey were mainly located on the open plan first floor offices. The results (Fig. 6) show that occupants have a very good perception of the building, with aspects such a thermal comfort and air quality being overall the most satisfactory. Design and image to visitors were particularly satisfactory exceeding a mark of 6 on a scale 1 to 7. However, from detailed analysis of the results and occupants comments it is apparent that there is a slight overheating problem for a short period in summer (especially on the top floor) but this seems to be not a major reason for concern by the staff. Specifically, 71% thinks that the temperature overall is comfortable (47%) or neutral (24%). However, when prompted on whether it is too hot or too cold, 59% perceives it to be between slightly warm and too hot. Also, for the majority of the staff air is fresh, odourless and generally satisfactory. For 47% of the occupants it can be dry, which perhaps can be related to the 'night sky radiant cooling' [ref] being employed in most of the offices. The majority still think they have little or no control on heating and noise especially. However, 44% thinks to have good control on ventilation, with a result that is significantly higher than benchmark. For cooling control 34% thinks to have some control, which is no different from benchmark but lower than the scale midpoint.

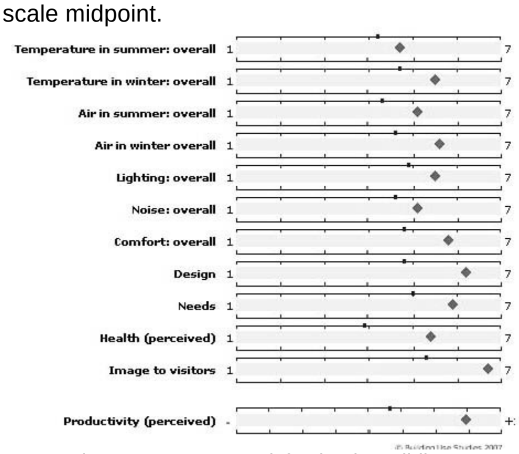

Fig 6. Occupants' satisfaction in Building 2 (Scale 1 to 7: unsatisfactory to satisfactory)

4.3 Building 3 – High School, Petaluma, CA

The survey involved the small group of teaching and library staff who usually occupy the studied buildings. The results (Fig. 7) show that occupants have a very negative perception of the building, with aspects such as air quality being the most unsatisfactory. Thermal comfort in summer was also unsatisfactory with a mark of 3 on a scale 1 to 7. In fact, the overall rating for summer temperatures is lower than both the midpoint and benchmark with 67% of the subjects dissatisfied and perceiving the conditions as too hot. This is actually the least negative score out of all the other parameters but it must be considered that the school is not occupied in the hottest summer months and that the summers in Petaluma are not too extreme. The air quality overall in summer was significantly lower than scale midpoint and benchmark, with a percentage of dissatisfied of 62%. The majority of the interviewed also thought that the air was stuffy and smelly implying that the air change rate is insufficient. Also, 100% of the occupants said to have little or no control on heating, cooling and noise.

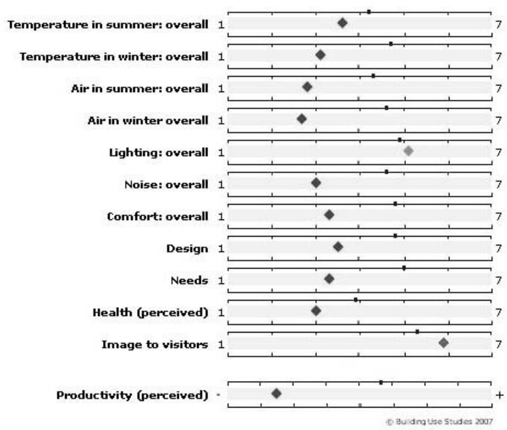

Fig 7. Occupants' satisfaction in Building 3 (Scale 1 to 7: unsatisfactory to satisfactory)

4.4 Building 4 – Visitor Centre, Utah

The Post Occupancy Evaluation survey involved the whole of the permanent staff, which for such a small building was only 6 people. The results (Fig. 8) show that occupants have a fairly positive perception of the building, with aspects such as image, design and needs being the most satisfactory. Thermal comfort in summer was neutral with a slightly higher mark than scale midpoint but no much different from benchmark. The same applied for air quality and lighting. Noise in such a multi-functional open space seems to be problematic with 83% perceiving the acoustic conditions as unsatisfactory. Specifically, 60% thinks that the temperature in summer is too hot and varies during the day. This confirms some of the outcomes of the earlier post occupancy monitoring showing overheating in the bookshop area [21]. However, the fact that the temperature seems unstable for some can be due to the fluctuations of occupancy, with waves of visitors instantaneously increasing the thermal loads. Also, the thermal mass is mainly placed on the floor and some of the walls only, which perhaps is not as effective as if applied on roofs and south walls also. For most of the staff air is still, fresh and dry. Overall half of the sample considers the conditions satisfactory and the other half unsatisfactory. However, measured airflows in each tower were approximately 7.55m^3/s during operation in the summer 2002 with a delivery temperature of 27˚C whilst outdoor temperature was 47˚C [21]. Again 83% of the occupants said to have little or no control on heating and cooling and noise but, during the informal interview, they were all aware of the building strategy showing an appreciation of the design.

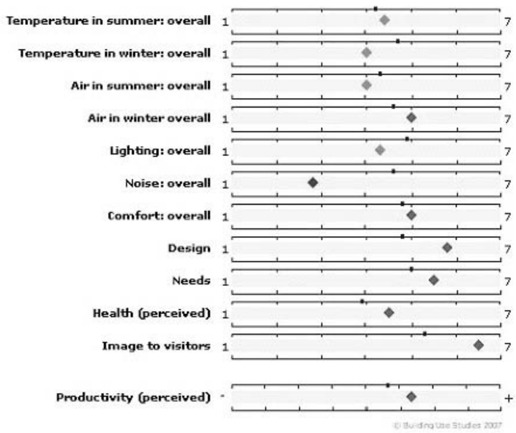

Fig 8. Occupants' satisfaction in Building 4 (Scale 1 to 7: unsatisfactory to satisfactory)

5. Conclusion

The results of this study show that in Buildings 1 and 2 the overall occupants' perception of the building was very poor. This is not necessarily related to the performance of the passive cooling system, which in the case of Building 1 is effectively functioning after an extensive period of troubleshooting and constant maintenance. However, the combination of a questionable design proposition such as the extensive use of glass in a desert climate as well as the use of PDEC as a mere buffering of the air-conditioned spaces, results in a very inefficient use of water. Moreover, the occupants' expectations of a fully air-conditioned atrium and the narrow band thermal adaptability given by a fully A/C lifestyle contribute to the negation of the designers' original intention to create a loosely controlled transitional space offering an indoor public plaza. In the case of Building 2, the problems originate in the design process and in the lack of participation of the end users. Also, the total lack of a maintenance regime and of an energy manager, who is dedicated to the troubleshooting of the cooling system, has resulted in most of the building's Cool Towers not working at all.

For Buildings 3 and 4 the occupants' survey shows very different and much more positive results. The very good occupants' perception of the first is mainly related to the overall building design and performance. Although the PDEC tower is only marginal to the building's cooling strategy, the radiant cooling system is effective in dealing with a large proportion of the cooling loads. The occupants, for the very nature of their work, are aware of environmental issues as well as of the building strategy and controls, and this certainly plays a role in the success of this example. Similarly, in Building 4 the sensitivity towards the environmental agenda was also favourable to the application of passive design and the operation of the Cool Towers. More importantly, however, a dedicated team of designers and maintenance engineers have provided extensive troubleshooting to the initial technical problems that were encountered.

In summary the study has revealed that while Passive Downdraught Evaporative Cooling systems, which incorporates misting devices or cellulose mats, are a practical option to avoid mechanical cooling, their success, both in terms of performance and occupants' perception, will depend on:

- Appropriateness of the overall building strategy
- Suitable system design
- Components' specification
- On site maintenance
- Robustness of control system
- Occupants' awareness of building strategy
- Occupants' degree of control over their working environment.

6. Acknowledgements

The authors would like to thank all the individuals met during the POE field survey who contributed to the undertaking of this by granting access to the buildings and providing valuable information. Namely: Mr Kevin Winschel, Building Services Technician, GSA, Phoenix Office; Dr Chris Field, Director of the Global Ecology Centre; Mr William Deeths, Deputy Principal, Kenilworth Junior High School; Mr Ron Terry and James Lutterman at Zion National Park Visitor Centre; Mr Paul Torcellini, NREL. We would also like to acknowledge the PHDC partners and their contribution to the project.

7. References

1. Biever, C. 20 November 2003. 'Preventable failures caused US power blackout'. In NewScientist.com news service [online]. Available from: http://www.newscientist.com/article.ns?id=dn4405 [Accessed June 2008]
2. Pearson, F., 2003. 'New, Natural and Alternative Refrigerants'. In: Building Sustainability, value and profit [online]. CIBSE-ASHRAE Conference, London, 24-27 September 2003. Available from: http://www.cibse.org/index.cfm?action=showpage&TopSecID=4&PageID=366 [Accessed 14 June 2004].

3. Brian Ford Associates et al., 1999. Passive Downdraught Evaporative Cooling in Non-Domestic Buildings (PDEC). Final Report, EC Project JOR-3CT950078.
4. Promotion and Dissemination of Passive and Hybrid Downdraught Cooling in Buildings (PHDC). FP6 Project no.: TREN/07/FP6EN/S07.70683/038418 PHDC. Website: www.phdc.eu.
5. Ford, B. et al., 2003. Final Report. Solar Passive Heating and Cooling. EC, ALTENER Calster 9 – Part I. (4.1030/c/00-009/2000).
6. Thomas, L., Baird, G. 2006. 'Post-occupancy evaluation of passive downdraught evaporative cooling and air-conditioned buildings at the Torrent Research Centre, Ahmendabad, India'. In
7. Building Use studies (BUS). Website: www.usablebuildings.co.uk
8. City-Data.com, 2008 [online]. Available from: http://www.city-data.com [accessed February 2008].
9. National Weather Service Forecast Office, 2008 [online]. Available from: http://www.wrh.noaa.gov/psr/ [Accessed May 2008].
10. Spraying Systems, Ltd. Website: www.spray-uk.com.
11. Carter, B., 2001. 'Meier's green shift'. Ecotech, March 2001, pp. 14-17.
12. Ingeniatrics. Website: www.ingeniatrics.com
13. Munters Corporation. Website: www.munters.us
14. Cunningham, W.A., Thompson, T. L., 1986. Passive Cooling with Natural Draft Cooling Towers in Combination with solar chimneys. Passive and Low Energy Housing, PLEA Conference, 1986. Hungary, The Hungarian Society of Science.
15. Meier, R. & Frampton, K. & Rykwert, J. & Holl, S., 2004. Richard Meier Architect. New York: Rizzoli International Publications, Inc.
16. Stephens, S. 'Play Misty for Me: At the center of Meier's Phoenix courthouse, a water-cooled atrium' [online]. Architectural Record, Project Portfolio: Sandra Day O'Connor United States Courthouse. Available from: http://archrecord.construction.com/projects/portfolio/archives/0103courthouse-1.asp [Accessed February 2008]
17. Arup, 2007. Projects: Phoenix Federal Courthouse [online]. Available from: http://www.arup.com/americas/project.cfm?pageid=249 [Accessed February 2008]
18. AIA/COTE Top Ten Green Projects, 2007. Carnegie Institution of Washington Global Ecology Center (Global Ecology Research Center) [online]. Available from: http://www.aiatopten.org/hpb/overview.cfm?ProjectID=809 [Accessed March 2008].
19. Schiano-Phan, R., Ford, B., 2008. 'PHDC Case Studies' [online]. Available from: www.phdc.eu [will be available from September 2008].
20. NPS 2003. *Zion National Park Map and Guide* [online]. Washington, D.C.: National Park Service. U.S. Department of Interior. Available from: www.nps.gov/zion/MapGuidesummer_2003.pdf [Accessed February 2008].
21. Torcellini, P. Long, N. Pless, S. Judkoff, R., 2005. *Evaluation of the Low-Energy Design and Energy Perfomance of the Zion National Park Visitors Centre* [online]. Golden, Colorado: National Renewable Energy Laboratory. Available from: http://www.osti.gov/bridge [Accessed March 2008].