BDP ENVIRONMENT DESIGN GUIDE

Post-Occupancy Evaluation of Passive Downdraft Evaporative Cooling and Air Conditioned Buildings at the Torrent Research Centre, Ahmedabad, India

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Post occupancy evaluations of buildings are noted for their ability to provide vital feedback regarding a building's performance in use. In addition to obtaining physical measurements of thermal performance and energy consumption, it is crucial to obtain feedback on user experience and satisfaction with the building environment to gain a true picture of the effectiveness of low energy buildings. This paper will report findings of a study aimed at investigating building performance and occupant experience of the Torrent Research Centre in Ahmedabad, India. The Centre comprises six laboratory and office blocks, four of which incorporate a passive downdraft evaporative cooling system (PDEC). Air conditioning is restricted to the two equipment intensive laboratories. While a number of earlier publications have reported on the configuration of the environmental control systems and the thermal performance of this building, this paper will provide insights into the occupants' experience and feedback on the building and will detail the comparative performance of the PDEC and air conditioned (AC) blocks. Occupant perception of overall comfort (summer, winter and monsoon), temperature, air movement and quality, lighting, noise, productivity, health, design, image and workplace needs was evaluated using the Building Use Studies workplace survey.

The co-location of PDEC and AC blocks offers a unique opportunity to compare performance while overcoming issues arising from contextual differences such as conditions of work, attitudes and expectations of employees likely to occur between respondents in different countries. The findings reveal occupant satisfaction in both the PDEC and AC blocks to be well above Building Use Studies' international benchmarks. In addition to their lower energy consumption, the overwhelmingly positive user satisfaction responses of the PDEC blocks validate the integration of alternative climate control systems such as evaporative cooling in contemporary buildings in India.

Keywords: *post occupancy evaluation; occupant satisfaction; passive downdraft evaporative cooling*

1.0 Introduction

In keeping with a rich tradition of climate responsive vernacular architecture in India, a number of passive solar and energy efficient non-residential buildings have been developed over the last two decades in India (see Majumdar 2001a). These are designed and developed in response to growing concerns for minimising energy dependence in a context where increased urbanisation fuels power demand, over 30% of electricity energy is consumed in commercial and domestic buildings, and air conditioning accounts for 50% of energy use in modern commercial buildings (TERI, 2005). The Torrent Research Centre Building in Ahmedabad has been widely reported as a unique example for climate responsive design which integrates a passive downdraft evaporative cooling (PDEC) system. A detailed description of the design process, building configuration, environmental control system and thermal performance can be found in an earlier study completed by Baird (2001). The building was revisited at the end of 2004 by the authors with the aim of investigating building performance and occupant experience.

2.0 Post Occupancy Evaluation Methodology

Post occupancy evaluations of buildings are noted for their ability to provide vital feedback regarding a building's performance in use. In addition to obtaining physical measurements of thermal performance and energy consumption, it is now widely recognised that feedback on user experience and satisfaction with the building environment is necessary to gain a true picture of the effectiveness of low energy buildings (BRI, 2001).

The present study comprised of a site visit of the building while in use, interviews of key stakeholders (architect, consultant, and client) and the administration of an occupant survey. In addition, information regarding energy consumption was sourced from the building owner-occupier based on in-house metering and energy bills, and information as to temperature monitoring was sourced from previous studies.

The occupant survey used was the Building Use Studies Survey (BUS) Workplace Questionnaire. The BUS questionnaire is a post occupancy evaluation instrument developed by Building Use Studies, UK. The BUS survey method was originally developed for the Office Environment Survey (Wilson and Hedge, 1987), and then adapted for the PROBE (Post-occupancy Review Of Buildings and their Environment) project (1997-2002) in the United Kingdom published through the *Building Services Journal*. The database comprises over 260 buildings worldwide. The two page paper-based 'standard' questionnaire was selected for its capacity to provide feedback on a range of 63 variables covering aspects of overall comfort, temperature, air movement and quality, lighting, noise, productivity, health, design, image and workplace needs. While the standard questionnaire includes questions relating to comfort, temperature and air in summer and winter, they were mirrored to cover the monsoon season when many parts of the Indian subcontinent experience hot humid conditions.

It should be noted that the results are not derived, for example, from estimations for thermal comfort that may be obtained by applying calculation methods such as PMV (Predicted Mean Vote after Fanger, 1970) or adaptation models (after Auliciems, 1983) to monitored temperature data. Rather the survey data and open ended comments provide a rich description of users' experience and assessment of temperature, air, noise, lighting and comfort overall.

Based on extensive research, the developers of BUS (Leaman and Bordass, 2005) have noted that perceived productivity as used in the BUS survey is considered the best available indicator (as opposed to number of sick days, or number of key strokes that can be achieved within a set time frame) that is common to all respondents in a building, and enables comparison across buildings.

The survey instrument has proven to be a robust instrument for measuring users' experience in office environments worldwide. It has been used by the authors in the United Kingdom, Ireland, the USA, Canada, Australia, New Zealand, Germany, Japan, Singapore, India and Malaysia. Other non-western locations where BUS has been used include Saudi Arabia, Tanzania and China[1].

Analysis of survey responses for each variable yields a mean value which may be simply assessed in relation to the selected scale, or compared with the mean value from the BUS dataset benchmark together with its upper and lower 95% confidence intervals (which are based on the previous 50 buildings analysed). The results for the BUS Survey are presented in Section 3. Unless stated otherwise, responses to the variables are sought on a 7-point scale. In the discussions of survey response means and their standard deviations (SD), reference is made to three types of scale:

- A-type scale where better values are found towards the 'right hand' of scale, 1=worst, 7=best
- B-type scale where better values are found towards centre of scale, 4=best
- C-type scale where better values are found towards the 'left hand' of scale, 1=best, 7=worst.

The survey was administered to occupants of the Torrent Research Centre in December 2004. The questionnaires were personally distributed to all occupants (by one of the authors) over the course of a day. Where occupants were absent from their workstations, questionnaires were placed on the desks with requisite information letters. The majority of the completed questionnaires were personally collected on the same day, with the author returning over the next couple of days to collect remaining questionnaires.

A total of 292 surveys were distributed and 164 responses returned, 64 from the air conditioned (AC) blocks, 100 from the PDEC blocks. There were limited differences in terms of the demographics in the AC and PDEC buildings. Respondents in both groups were predominantly male (AC=92% and PDEC=89%) and majority were under the age of 30 (80% in AC and 70% in PDEC). Most of the respondents had worked in the building longer than one year (54% and 53% in AC and PDEC respectively), and roughly a quarter to a third of respondents reported that they were seated next to a window (AC 23%, PDEC 30%). The offices were predominantly open plan with the exception of senior management. 47% in PDEC shared their office with more than eight others, and another 24% shared their office with five to eight others. Similarly in the AC buildings 43% shared their office with more than eight others, and another 30% shared their office with five to eight others.

3.0 Building Design Process and Outcome

The TRC complex is comprised of a range of pharmaceutical research facilities and related support services, housed in a group of a dozen or so buildings. This study was focussed on the main group of five three-storey laboratory buildings and one administrative block radiating from a circular-plan core building (see Figure 2). Started in 1994, construction was completed by 2000, the laboratories having been occupied progressively since the latter part of 1996.

Principal architects for the project were the husband and wife team of Nimish Patel and Parul Zaveri practicing under the name of Abhikram since 1979. From the outset, they resolved that all of their buildings would be able to work during daylight hours using the minimum of electrical energy. In time, this objective evolved into one of the practice's six statements of basic design philosophy, viz, '*Conservation of resources is the primary guideline for all the projects*' (Abhikram 1998). Environmental design consulting services for the typical laboratory block on this project were provided by the London-based firm of Short + Ford Associates who had carried out pioneering work on natural ventilation systems in Europe. The design served as a prototype for the remaining laboratory buildings and administrative buildings that were developed and detailed by Abhikram with assistance from Solar Agni International, Pondicherry. The design of the more conventional air conditioning systems, for those parts of the building which required them, was undertaken by engineering consultant Mr M Dastur of New Delhi, while the design and construction of the water spray used in conjunction with the PDEC system was carried out in-house by Torrent's Assistant General Manager (Engineering) Mr S B Namjoshi, and his team.

1 Source: 2006 Communication from Adrian Leaman, Building Use Studies.

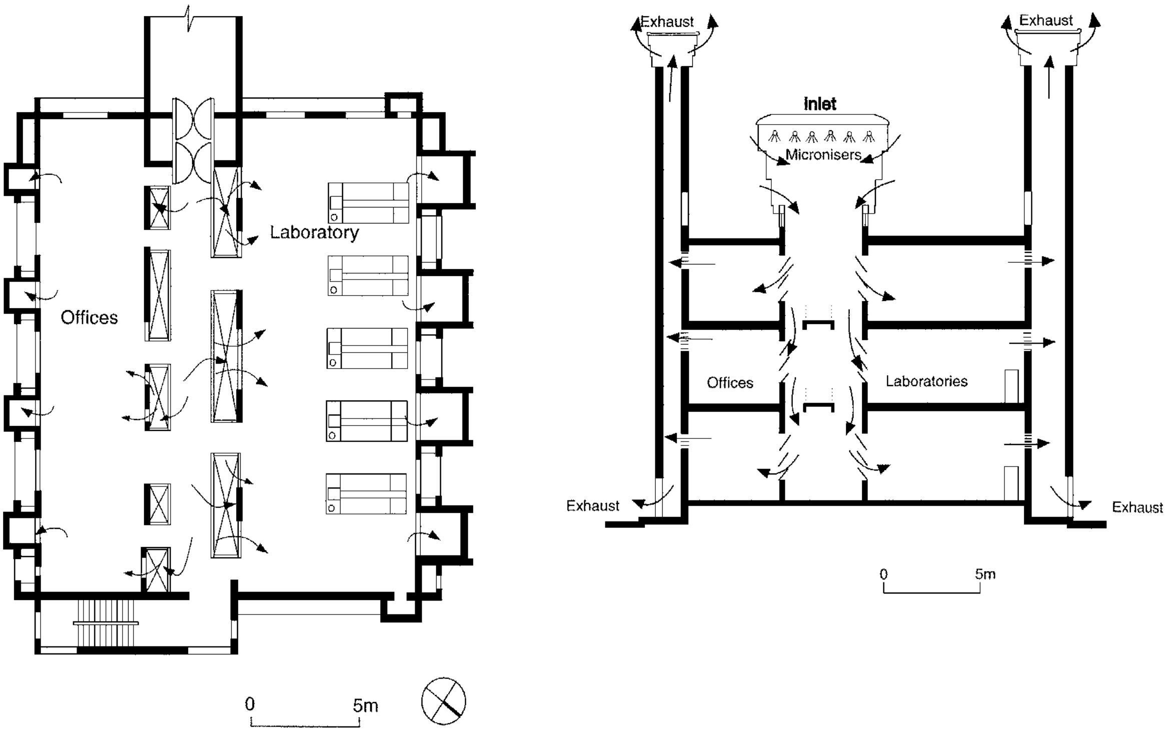


Figure 1. Plan and Section of a PDEC Building

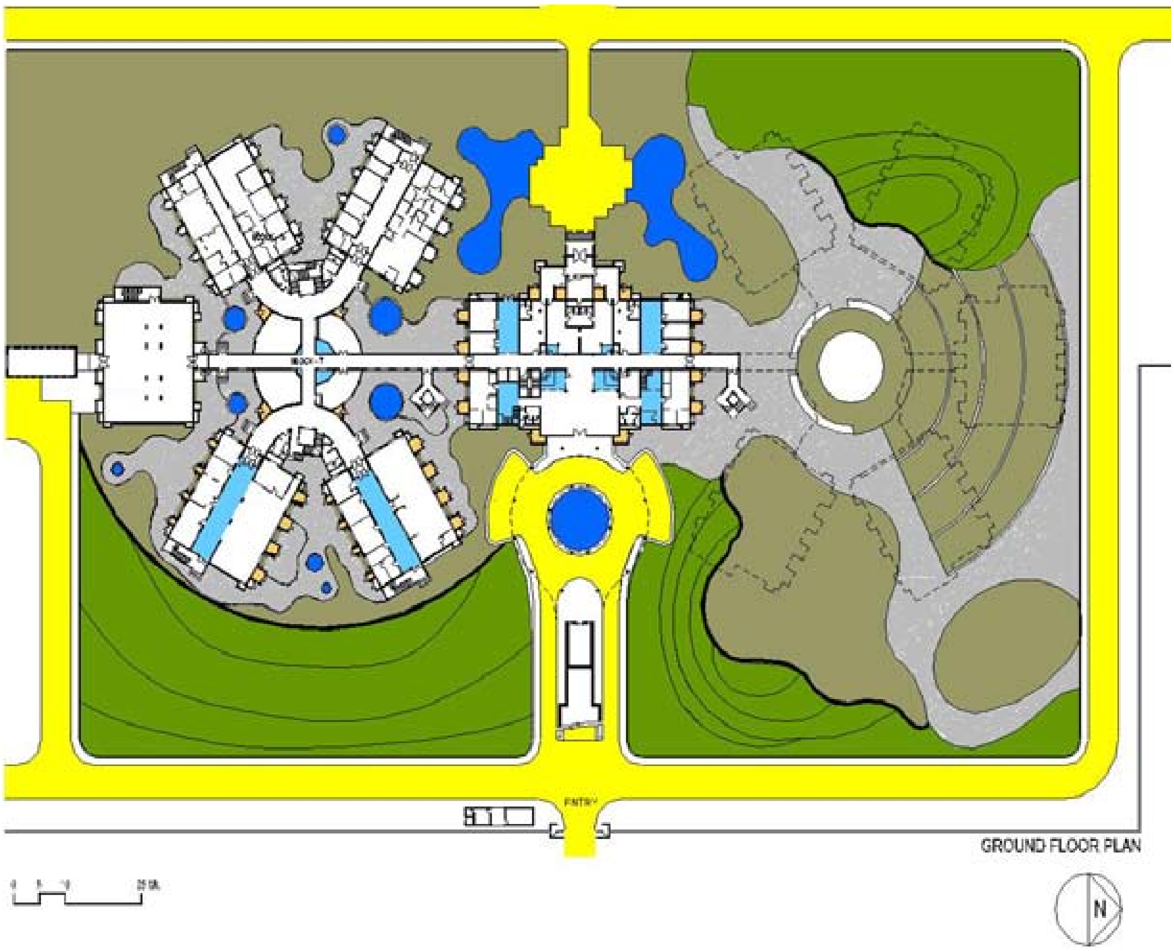


Figure 2. Torrent Research Centre – Layout Plan

Figure 3. Torrent Research Centre – (drawings and photo courtesy: Abhikram)

The Board of Torrent Pharmaceuticals Limited had decided to make a major investment in research and needed a new facility in order to expand this aspect of their operation. They also proved willing to embrace the Abhikram design philosophy. From the environmental point of view, the intent was to maximise the use of natural light and ventilation, use locally available natural materials, and control the ingress of dust. All of which was a fairly tall order in a climate with three distinct seasons – hot and dry from March to June with temperatures reaching well over 40ºC, warm and humid from July to September during the monsoon, and cool and dry from October to February. With the appointment of Abhikram as architects for the Centre, designing of the first laboratory block commenced in early 1992. A central corridor concept, with working spaces on either side, was developed and the PDEC method of cooling adopted for the final design in February 1994. In this scheme the air was supplied via the central corridor and exhausted at the perimeter as indicated on Figure 1.

While many aspects of environmental design were taken into account, Dr C Dutt, Torrent's Director of Research, was quite prepared to take a 'wait and see' position on some issues – for example, on the questions of the potential for rain penetration via the ventilation towers, or for lack of air movement in some locations. He was also open to the concept of designing for a threshold temperature (28-28.5ºC) which could be exceeded for a certain number of hours, rather than some absolute value. In this connection, the designers were unstinting in their admiration for him as a critical, but immensely supportive client (Chauhan, 1998).

Each laboratory building has a similar 22m by 17m plan, with a 4-m wide corridor flanked by 5-m deep office spaces and 8-m deep laboratory spaces (see Figures 1 and 2). Two of the five laboratory buildings are air conditioned, the other three equipped with the PDEC system. The larger main administrative building (see Figure 2) is located to the north of the laboratories, and a utilities building to the south, with a two level corridor spine linking. The entire complex covers 22,600m² of floor space, of which around 3,200m² is air conditioned. The central plant for this research facility includes two oil fired steam boilers with a capacity of 4 tonnes/hr each, two 175cfm air compressors, two 725KVA diesel generator sets, and some 350 tonnes of refrigeration capacity.

Overall control of solar heat gains is achieved by judicious design of the glazing. The fixed windows are shaded externally by horizontal overhangs, and in the vertical plane by the air exhaust towers which project from the facade. The buildings are thermally massive – the reinforced concrete construction framed structure has plastered cavity brick infill walls and hollow concrete blocks filling the roof coffers plastered inside. Vermiculite is used as an insulating material on both roof and walls. External surfaces are white – the walls painted, the roof using a china mosaic finish.

The critical climatic time of the year is the hot dry season when mid-afternoon outside temperatures regularly reach 40ºC or more. These are the conditions under which the PDEC system is designed to operate. It does so by piping water through nozzles at a pressure of 50 Pa to produce a fine mist (dubbed the 'microniser' system by Brian Ford) at the top of the three large air intake towers located above the central corridors of each laboratory building. Evaporation of the fine mist serves to cool the air which then descends slowly through the central corridor space via the openings on each side of the walkway (see Figure 1). At each level, sets of hopper windows designed to catch the descending flow, can be used to divert some of this cooled air into the adjacent space. Having passed through the space, the air may then exit via high level glass louvred openings which connect directly to the perimeter exhaust air towers. Night time ventilation is also an option during this season. During the warm humid monsoon season when the use of the microniser would be inappropriate, the ceiling fans (introduced to ameliorate the muggy conditions experienced during the first monsoon season) can be brought into operation to provide additional air movement in the offices and laboratories. In the cooler season the operating strategy is designed to control the ventilation, particularly at night, to minimise heat losses – this is done simply by the users adjusting the hopper widows and louvred openings in their individual spaces to suit their requirements.

Each of the building blocks surveyed was originally designed for an occupancy of 25 scientists. With the expansion of activities, increase in staff and overlapping shifts in recent years, some of the buildings currently house as many as 70-80 people working at the same time.

4.0 Post Occupancy Evaluation Outcomes

Figure 4 and Figure 5 represent the summary performance of the building for critical variables. As evident both the PDEC blocks and the AC blocks returned mean scores that were significantly better or higher than both benchmark and scale mid-point for all of the categories. The consistently positive responses with respect to international benchmarks and scale mid-point is certainly worthy of note. With the Torrent building being only the second building to be surveyed using the BUS methodology in India, it could be argued that regional benchmarks will be necessary before more context specific comparisons can be made. Nevertheless the co-location of PDEC and AC blocks at Torrent offers a unique opportunity to compare performance while overcoming any potential issues arising from contextual differences such as demographics, conditions of work, attitudes and expectations of employees likely to occur between respondents in different countries. It should be noted that the analysis presented here focuses on the comparison of the overall performance of the PDEC and AC buildings. Further sub analyses of various parts of the buildings (for example by building blocks, floors, departments) are considered outside the scope of the present study. Standard deviations of responses are noted in the paper and it is also worth noting that comments received were fairly consistent across the buildings. Detailed results and their implications are discussed below.

Key to BUS Summary Charts

These are summaries of some of the variables used in Building Use Studies building occupant assessments.

The mean value from the survey is assessed against upper and lower limits from the benchmarks for both the benchmark value itself and the scale midpoint.

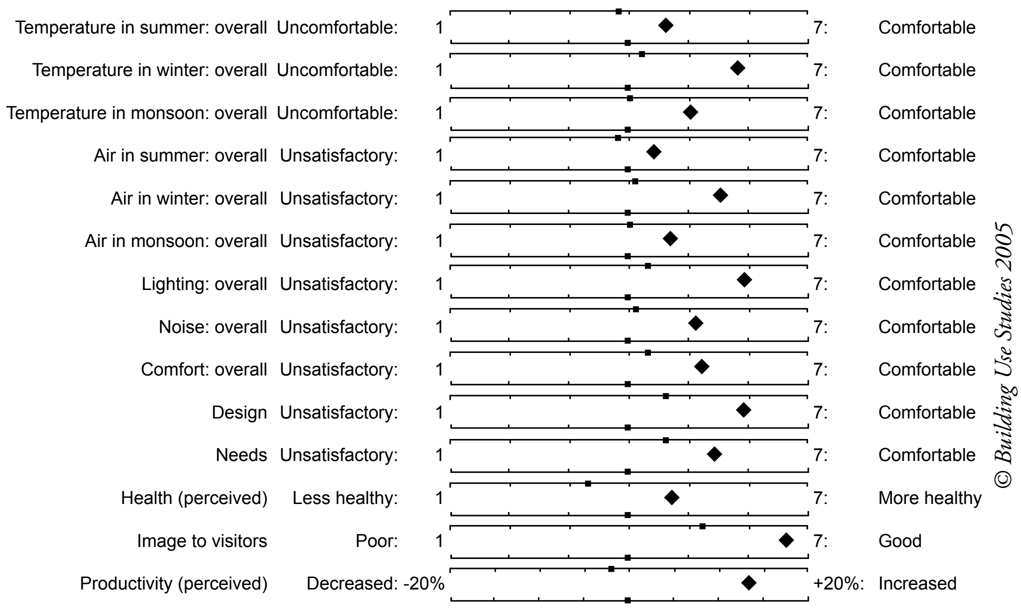
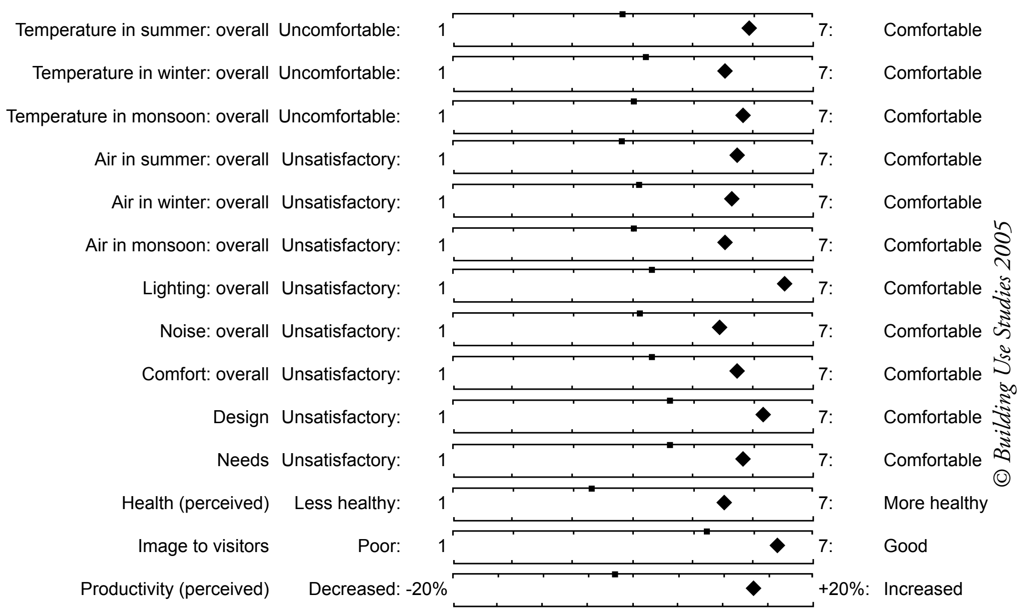


Figure 4. Building Use Studies Summary Chart for PDEC Buildings at Torrent Research Centre
100 respondents – December 2004.



Perceived productivity for AC buildings was rated at +20.88%

Figure 5. Building Use Summary Chart for AC Buildings at Torrent Research Centre
64 respondents – December 2004.

The upper and lower limits are based on 95% confidence level. This creates the criteria for the green, amber or red results for the test as follows: **Green diamonds represent mean values significantly better or higher than both benchmark and scale midpoint (a good score)**. Amber diamonds are mean values no different from benchmark and scale midpoint (a typical score). Red diamonds are mean values significantly worse or lower than benchmark and scale midpoint (a poor score). **Benchmarks are represented by the small blue rectangle on the top scale of each variable.** They are drawn from British, Australian and International datasets, depending on context. There are no benchmarks available for monsoon season as yet. All of the summary variables above are rated on a (A type) 7-point scale where 7 is best and 1 is worst. © Building Use Studies 2005

4.1 Temperature, Air Quality and Overall Comfort

As noted the PDEC buildings were developed with an approach towards designing for a threshold temperature around 28 ºC which could be exceeded for a certain number of hours. Previously monitored temperatures in 1997 and 1998 had indicated that internal maximum temperatures could be maintained 12-14 degrees below the external peak and that internal temperatures were around 5 ºC lower than average external temperatures (Baird, 2001). Ford (1999) reports temperatures of 27 ºC to the ground floor and 29 ºC to the first floor with outdoor temperatures at 38 ºC and Majumdar (2001b) reports temperatures of 29-30 ºC being achieved when outside temperatures reach 43-44 ºC. Majumdar also reported temperature fluctuations did not exceed a 4 ºC range over any 24 hour period, when temperature fluctuations outdoor were as much as 14-17 ºC. One of the early issues noted was a tendency for air to by-pass the top floor (Ford et al, 1998).

As seen in Figure 4, overall ratings of summer and winter temperatures are significantly higher than the midpoint and benchmarks for the PDEC buildings (summer Mean=4.61, SD=2.1; winter Mean=5.84, SD=1.2; A type scale). This is also the case for overall Air conditions (summer Mean=4.44, SD=1.9; winter Mean=5.54, SD=1.3) and Comfort overall (Mean=5.16, SD=1.6). The overall results for Temperature Air and Comfort for PDEC in this survey corroborates earlier reports that *'comfort conditions have not been compromised'* (Majumdar, 2001 b). Figure 5 shows similarly positive results for the AC buildings.

Figure 6 shows occupants consistently rated temperatures on the colder side of neutral (mid point of a scale of too hot – too cold) in the AC buildings. The mean scores for AC buildings were 4.35 in summer (SD=1.0), 5.29 (SD=1.0) in winter and 4.66 (SD=0.8) in monsoon on a B type scale of 1 to 7 where 1=too hot and 7=too cold. This is not surprising given that the controlled AC labs are maintained at temperatures around 22-24 ºC in comparison to a more adaptable range of generally 5 ºC less than the outside mean temperatures in the PDEC buildings. On the same scale the means scores for the PDEC buildings are close to neutral in monsoon and on the colder and warmer sides of neutral in winter and summer respectively.

The overall satisfaction for Comfort, Air Quality and Temperature seen in the PDEC buildings, particularly in context of acceptable temperature ranges that are much higher than those deemed acceptable in air conditioned and western contexts is worthy of further study. This latter aspect has resonance with the field studies such as those of Nicol et al (1999, cited in Nicol and Humphreys, 2002) amongst office workers in Pakistan where office workers were found to be comfortable at temperatures between 20 and 30 ºC with no cooling apart from fans, and the assertion of Nicol and Humphreys following their extensive work in this field across a number of countries that *'optimal indoor environments in a building are a function of its form, its services [the researchers define this to include controls and building management] and the climate in which it is placed'*.

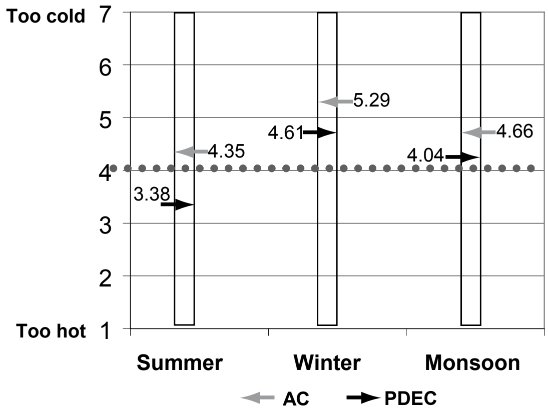


Figure 6. BUS Results Temperature (too hot/cold)

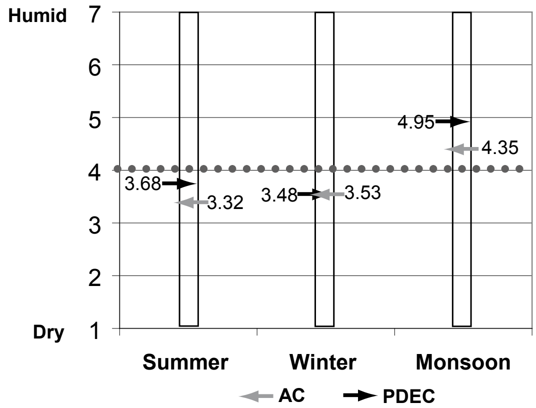


Figure 7. BUS Results Air (dry/humid)

The performance of the building in the monsoon season was of particular interest in the PDEC buildings. Following the first year of occupancy ceiling fans were installed as a consequence of the experience of 'muggy conditions' in the building as noted by the client (Dutt, cited in Majumdar 2001 b). Occupant responses for this season were generally positive. In addition to the scores above midpoint for overall satisfaction with temperature (Figure 4) and close to neutral rating of experienced temperatures (Figure 6), occupants experienced some concern about air humidity (Figure 7, Mean=4.95, SD=1.4 on a B type scale 1=dry and 7=humid) and moderate satisfaction with overall air conditions in monsoon (Mean=4.68, SD=1.5 on an A type scale 1=unsatisfactory, 7=satisfactory).

Open ended comments to comfort and ventilation arising from both PDEC and AC blocks were predominantly positive, Comments from the PDEC included '*Everything in this building is well equipped for work and comfort*' (PDEC), '*Satisfactory, well ventilated good infrastructure*' and '*Good ventilation*'. Nevertheless there are some experiences of discomfort in summer for the PDEC buildings: '*If summer can be taken care of this will be a wonderful place to work at*' (PDEC), as well as some concerns about odours during this period '*Stuffy in summer with lots of odour and poor ventilation*'. It is likely that the increase in internal heat gains and latent loads from increased occupancy (see Section 2) in the PDEC buildings results in more incidences of internal conditions sliding above acceptable levels, particularly when temperatures peak outdoor in summer. Monitoring of temperature conditions and ongoing changes to occupant needs, coupled with evaluations of user experience, would be necessary to study this in detail.

4.2 Lighting

Both types of building performed well in terms of overall lighting. Figure 4 and Figure 5 indicate there was general satisfaction with the lighting conditions overall (PDEC=5.86, SD=1.5; AC=6.46, SD=1.0 on an A-type scale - 1=unsatisfactory, 7=satisfactory). Both the PDEC and the AC buildings had similar configurations in terms of layout, window to wall ratios and access to daylight. Not all workstations received natural light and this was evident in some of the individual open ended comments: '*Natural light is insufficient*'; (PDEC); '*Lighting is very good at TRC. Whether it is natural or artificial is up to the [location] of work*' (PDEC); '*Lighting is good, natural light is less*' (AC).

Nevertheless the detail scores for natural light (B-type scale, 1=too little to 7=too much) were close to mid point – 3.82, (SD=1.7) for PDEC and 3.96 (SD=2.0) for AC. Artificial lighting on the other hand rated closer to the 'too much' end of the B-type scale, with PDEC=4.86 (SD=1.5) and AC=4.79 (SD=1.5). The building also rated well for minimum glare from the sun and sky. The overall satisfaction with natural lighting is particularly noteworthy given the low window to wall ratios of the facades that were employed in order to minimise fabric heat gains, coupled with the provision of diffused daylight to the central walkways and offices adjoining air inlet/outlet towers.

4.3 Noise

Open ended comments suggest that there were minor issues with noise from colleagues, inside and from other people, however as evident in Figure 4 and Figure 5, there was general satisfaction with the noise conditions overall – (PDEC=5.09, SD=1.6; AC=5.39, SD=1.5 on an A-type scale – 1=unsatisfactory, 7=satisfactory). The green-field setting of Torrent buildings on the outskirts of the city has meant there are no particular issues with noise from external sources even in the buildings with openable windows and PDEC systems installed.

4.4 Control

In the PDEC buildings, occupants are able to adjust hopper windows to inlet towers and louvres, operate ceiling fans and switch on lights. Responses show a perceived lack of control for cooling heating ventilation and noise (more or less about the mid point on an A-type scale 1=no control and 7=full control) and low rating of importance for control (under 20% rated control as important). However as evident in sections on Comfort and Productivity, this had little impact on overall comfort and perceived productivity. This would corroborate Leaman and Bordass' findings (2005) that the strength of the relationship between perceived control and productivity declines as the buildings perform better.

4.5 Design, Needs and Image to Visitors

As noted elsewhere (Baird, 2001) the building is distinguished for its overt expression of thermal environmental control systems. The nature of the design process which involved a close collaboration of the users and the design team has been discussed previously (see Baird). The recent site visit revealed that all current users were very aware of the design intent of the building and were appreciative of its unique ventilation and cooling systems and appearance.

Users across all the buildings blocks and functions were consistent in their high rating for Design and Image to visitors. In addition, they rated the building highly for its ability to satisfy their needs (5.44, SD=1.6 in PDEC and 5.79, SD=1.3 in AC, A-type scale) overall. Mean scores were also consistently better than benchmark and scale midpoint for aspects such as cleaning, availability of meeting rooms, space in the building, space at the desk, storage space and furniture.

4.6 Health and Productivity (Perceived)

Interestingly, the mean responses for both PDEC and AC suggest users at Torrent feel more healthy when they are in the building (4.74 in PDEC and 5.53 in AC, A-type scale – see Figures 4 and 5). In addition, the building returned perceived productivity rating of +20.88% for AC (SD=15.4) and +13.66% (SD=19.3) for PDEC on a 9-point scale of '-40% or less' to '+ 40% or more'. Positive responses to both health and productivity were corroborated by the majority of the open ended comments.

Leaman and Bordass (2005) identify the following 'killer variables' that produce positive correlations with productivity: positive responses to comfort, responsiveness to need, clarity of design intent to users, robust ventilation and air conditioning systems, and attention to designing for workplace needs. With all of these factors present in the Torrent building, the positive results for perceived productivity reinforce the value of these influencing factors in shaping users' experience.

4.7 Energy

The total energy consumption for PDEC and AC combined (includes light, equipment and AC for 2 blocks) for the 6 blocks in 2005 was 647000 kWh[2]. This averages to 54 kWh/m².a (based on a floor area of 12000m² for the surveyed buildings). In the absence of benchmarkable data for buildings such as Torrent comprising labs and offices with extended hours of operation in hot dry climate in India, the building may be compared to available data and targets for office buildings. For example, the energy consumption at Torrent is extremely lower than the typical energy consumption in Indian commercial buildings which has been reported to be the range of 280-500kWh/m².a (Singh and Michealowa, 2004). Further, the Torrent energy consumption performance compares very favourably to the target for newly developed fully air conditioned office buildings under the recently introduced environmental rating scheme TERI-GRIHA. Current targets for best practice under that scheme are set not to exceed 140 kWh/m².a for day use office building in a 'composite' climate[3]. Not only is the Torrent building located in a 'hot dry' climate which is more demanding of energy for space conditioning than would be the case in a 'composite' climate, the building has equipment loads which are higher than typical offices and it is used over longer hours than typical office buildings. Clearly even against more stringent targets, the building has delivered low energy outcomes. These can be attributed to its attention to climate responsive design as outlined in Section 2.

5.0 Conclusions

While the Torrent Research Centre has previously been widely reported for its attention to passive solar design, the present study is noteworthy in being the first aimed at a detailed investigation of user experience in conjunction with building design and performance. In addition to the implications of the findings in relation to design approach, building design and management discussed above, the following conclusions are noteworthy.

The building demonstrates excellent environmental outcomes. The inclusion of a number of factors such as client commitment for environmental design, clear goals for environmental performance, an integrated multidisciplinary team approach to design that is mindful of user needs, and responsive building management during commissioning and operation as described in Section 2, and consequent outcomes for low energy and user satisfaction as seen in Section 3 corroborate arguments (Thomas and Hall, 2004) for such factors to remain integral to the design process to achieve positive outcomes.

Although the AC buildings produced somewhat better results than buildings incorporating the passive downdraft evaporative cooling systems in the BUS survey, it is important to note that the BUS results of the PDEC buildings were also consistently better than international benchmarks and scale mid-points. Further study is anticipated to establish regional benchmarks that would enable comparisons against other buildings in India; however the overwhelmingly positive user satisfaction responses of the PDEC blocks coupled with their lower energy consumption validate the integration of alternative climate control systems such as evaporative cooling in contemporary buildings in India.

The findings outlined in this paper show that this building, completed over 10 years ago, continues to satisfy expectations for a contemporary workplace of high quality that is simultaneously energy efficient. While the wider implications of the success of climate responsive buildings for the Indian subcontinent where there is currently a large scale development of 'glass boxes' that are both energy intensive and inappropriate for the climate are discussed in a paper by Thomas (2006), the building performance outcomes seen in Torrent certainly reinforce the value of a climate responsive approach to building design in any location. Even in those situations where air conditioning is inevitable, the climate responsive approach via attention to minimising facade heat gains and daylighting coupled with a user responsive approach to design, commissioning and ongoing management is a model worth emulating for future buildings in order to achieve buildings that are both energy efficient as well as capable of enhancing work place quality.

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2 Source: 2006 Communication from Dr C Dutt, based on in-house metering and electricity bills.

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Biography

Leena Thomas, BArch, MArch (Research), is a Senior Lecturer in Architecture at the University of Technology Sydney. Leena coordinates the Environmental Studies strand in the School of Architecture where she has introduced a strong emphasis on integrated environmental design. Her research and consulting activities expand her interest in sustainability in design. She has completed a number of funded projects and publications on designing and operating comfortable living environments, post occupancy evaluation and building environmental performance.

Dr George Baird is a Professor of Building Science at Victoria University of Wellington's School of Architecture in New Zealand. He specialises in building environmental science and engineering services, building performance generally, and the energy efficient design and operation of buildings. His major book publications include Energy Performance of Buildings (CRC Press, 1984), Building Evaluation Techniques (McGraw Hill, 1996), and Architectural Expression of Environmental Control Systems (Spon Press, 2001). He is now investigating the users' perceptions of sustainable commercial and institutional buildings around the world, of which the Torrent Research Centre is one of over thirty case studies. A recipient of a 1999 NZ Science and Technology Bronze Medal "for singular contribution to energy efficiency of New Zealand buildings and to building performance research….", and of the inaugural 2002 IPENZ Technical Award in the field of Energy Engineering, this year he was the recipient of a World Renewable Energy Network Pioneer Award.

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