A Post Occupancy Evaluation (POE) of Lark Quarry Trackways Building and Shelter, Winton, Queensland

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Abstract: The aim of the paper is to report the outcomes of a POE study of Lark Quarry Trackways Building and Shelter, Winton, Queensland. The project is of interest due to its design process, remote location and desert climate. The research approach uses a number of post occupancy methods, including a green design benchmarking tool and stakeholder feedback, combined with an environmental monitoring program over a period of one year. The outcomes of the research are recommendations for improving the climate responsiveness of the building, in particular to address overheating, and arguments for the adoption of new POE methods for evaluating buildings in remote areas.

Conference theme: Building Case Studies
Keywords: Thermal, Post-occupancy Evaluations

INTRODUCTION

The Lark Quarry study arose out of research work on improving the Post Occupancy Evaluation (POE) methodology to make it more relevant to architectural practices. This has involved prior research that argued that, to be relevant for current needs, POE’s have to be grounded more fully in sustainability issues and better nested within the design process; and also that a diagnostic framework should be created, incorporating aspects of both monitoring and investigative processes over time. This POE approach must also be scaled to match resources to the funding base of clients and the design team (Hyde & Davidson 2006; Hyde, Watson, Cheshire & Thomson, 2007).

The Lark Quarry project offered an ideal test case study. It has a relatively simple brief; it is located in a remote area in a highly fragile desert ecology that challenges the demands for sustainability (see Figure. 1). The client and design team are committed to establishing the framework of a longitudinal investigation to study the museum’s technical performance over time, initially for a twelve-month period. In addition a number of factors make this building a suitable test-bed for the purpose, due to its remote location, desert climate and lack of access to services.

First, the remote location means that the transportation and servicing of materials and systems is problematic, since the supply lines are long. Second, the building is located in a highly aggressive desert climate, with high temperatures in the summer, a large diurnal swing and significant humidity fluctuations; and it is cold in winter. Finally, the availability of services to the site is limited. Neither grid-based electric power nor reticulated water is available, which creates a need for a high level of building self-sufficiency.

These factors had implications for the POE methodology. The tyranny of distance not only has an influence on design and construction (a fourteen hour road trip or a two hour flight) but also has an impact on the POE methodology, in particular gaining access to the site and the building users, and retrieving as well as installing monitoring equipment. Many POE studies have a broad focus, which means they are costly and do not necessarily address the key issues. A scaled methodology was required to address the key research questions while being more cost effective and definitive in its approach. Consequently, four research questions are addressed in this paper:

1) How efficient was the POE methodology?
2) To what extent does the building achieve its design intentions?
3) How effective are the passive building strategies?
4) What suggestions can be made for improving the building’s performance?

The paper is divided into four parts: the first describes the research methods used and improvements to the POE methodology, the second describes the design intent and evaluation, the third examines the use of passive systems, and finally the fourth suggests ways of improving the building’s performance.

1 POE RESEARCH APPROACH

1.1 Research methods

Preiser (1995) has identified three ‘levels’ or types of POE – indicative, investigative, and diagnostic – and explains that these levels are related to the effort a practitioner must expend in undertaking a particular evaluation. Indicative POEs are quick, walk-through evaluations, involving structured interviews with key personnel as well as inspections in which both positive and negative aspects of building performance are documented photographically. Investigative POEs are more in-depth and use interviews and survey questionnaires, as well as photographic and physical measurements. Diagnostic POEs are focused, longitudinal and cross-sectional evaluation studies of such performance aspects as … safety, orientation … lighting, privacy, overcrowding, etc. (Preiser 1995: 22.)
Building on Preiser’s (1995) work, Bycroft and McGregor (2002: 5) explain the differences in each type of POE. They show that the indicative POE has a broad scope, which gives immediate feedback to the evaluator, whereas the investigative POE “involves a more detailed analysis,” and builds on the indicative approach by focusing on the technical aspects of the building’s performance. The post occupancy evaluation of the Lark Quarry Trackways combines elements of these types into a diagnostic framework, as it incorporates aspects of both the indicative and investigative processes outlined above. This framework sets up a longitudinal research methodology for monitoring the museum’s technical performance over a six-month period, as well as investigating the cultural and community impacts of the building. The work reported here examines the results of the monitoring work, of which there are three main components. First, walk-through evaluations, involving interviews with key personnel as well as inspections in which both positive and negative aspects of building performance are documented; second, thermal monitoring using temperature and humidity sensors and data loggers over a twelve-month period and third, a satisfaction questionnaire administered to the building users, mostly visitors to the museum.

1.2 Research plan

The research plan involved several components: first, there was an initial discussion with representatives of the design team to ascertain the design intent for the project and to collect drawings and specification information. There was an initial two-day site visit in June 2006, when the instrumentation was installed, with a follow-up visit in early December 2006 when further spot measures and installation of equipment took place, followed by a final visit in June 2007, for discussions with Winton Council and to obtain user feedback and administer the questionnaire.

The initial field trip to Lark Quarry to install the measuring equipment gave researchers an opportunity to discuss the operational and environmental performance of the building with museum staff and members of Winton Shire Council. This was followed by fieldwork and site visits to set up the monitoring program. Initial spot measures were taken to assist with calibrating the electronic sensors and to obtain some initial data to assist with the diagnostic work. The POE study was extended to include the summer period, so a six-month period of measurement was used, between July, the coolest time of the year, and February, the hottest. Portable and non-intrusive data loggers were set up to measure diurnal temperature and humidity changes at 30-minute intervals over that period. Lux meters were used to gauge the effectiveness of the building’s skylights. Airflow within the building was measured with anemometers. Data on electricity and water usage could not be collected, due to a lack of available meters.

1.3 Improvement to POE methodology

Improvements to the POE methodology centred on minimising some of the limitations inherent in this type of study. One limitation was the availability of the built-in monitoring sensors and meters, which meant that it was difficult to gather data on the energy, water and waste consumption during ongoing monitoring. It was also difficult to gauge the operation of the photovoltaic system.

A further difficulty was accessing user information; the staff at Winton Council and rangers at Lark Quarry cooperated in assisting with the process, but time for training needs to be factored into the methodology to facilitate this. Finally, although the use of individual data loggers was a reliable way of collecting data, retrieving the equipment was problematic; two were lost in the final measurement period.

2 DESIGN INTENT AND EVALUATION

2.1. Design objectives and site constraints

The Lark Quarry Trackways Building is in a remote desert area, 120 kilometres southwest of Winton in Central Queensland, and accommodates a set of dinosaur footprints that are unique to the area and have been acknowledged to be of significant archaeological value. The Lark Quarry Conservation Park protects these excavated dinosaur footprints, which are 93 million years old and are the world’s best-known record of a dinosaur stampede. The isolation and fragility of this natural resource requires special consideration with regard to access, conservation and presentation.
A working group was established, with representatives from Tourism Queensland, the Queensland Parks and Wildlife Service, the Department of the Premier and Cabinet, the Queensland Heritage Trails Network and a number of consulting organizations, to produce a concept design and pre-feasibility study in order to advance the development funding for this project. The major issues considered by the working group were: preservation of the Trackways surface; ongoing funding of site facilities; additional requirements brought about by increased site visitation; and defining the interpretation focus for the facility.

Further issues were: promotion of the Trackways facility; accommodation at the facility; and the incorporation of ecologically sustainable design and technology, appropriate for the environment and for the experience. The Queensland Museum advised that the dinosaur tracks could potentially extend further into the hill on which they are situated, and that other, as yet undiscovered, palaeontologic resources might be found on any or all of the surrounding ridges. This site constraint resulted in the decision to locate the primary visitor facility, together with any camping accommodation, well away from the Trackways conservation building. The buildings are joined by an elevated walkway that brings visitors into the display area. From there a further walkway and viewing platform is used to enter and circulate around the Trackways building, so as to avoid damage to the rock floor.

Four main design requirements for the project were identified:

1) Conservation of the dinosaur tracks;
2) Provision of accommodation and access for visitors;
3) Interpretation to visitors of the meanings of the tracks and the surrounding landscape, focusing on the existing landscape and the history, theories, and information behind the dinosaur Trackways.
4) Showcasing of ‘best practice’ ESD (Ecologically Sustainable Development) principles.

2.2 Design requirements and strategies

The design requirements are addressed through the provision of three buildings and their linking walkways. The Trackways building conserves the footprints: visitors enter by a walkway which is suspended above the footprints to provide protection and security. Additional visitor requirements are accommodated by an entrance shelter and Interpretation display area. As visitors arrive at the site they are accommodated in the entrance area, which is a shelter with minimal enclosure. It is set on a three-metre grid, and contains seating and information. The building has heavyweight walls and floor, and a lightweight roof. From here visitors move across the elevated walkway and into the display area. This is connected to the Trackways area on one side and has a lightweight floor and roof. The building has fixed glazing on three sides, with horizontal shading to the east. Another walkway allows visitors to travel outside from the display area to the further viewing area on the top of the butte to the north of the building.

Weather protection and security for the footprints

The first requirement involved protecting the Trackways footprints from the effects of weather and from other sources of damage, such as animals. A key influence on the position, geometry and form of the Trackways building is the nature of the dinosaur tracks. The excavation is approximately 22m by 22m, and is roughly triangular. The resulting building is a large ‘shed’, consisting of a steel superstructure (on a six-metre grid) that spans the tracks and supports the enclosure (see Figure 2). The form has additional bays added to the roof structure, which extend the building into the hill to keep ground water away from the footprints.

Minimising exposure of the footprints to excessive range of temperature and humidity

The second major requirement is minimising the temperature and humidity range, which it is thought might cause stress to the footprints and possible fracturing and cracking (the footprints were formerly covered by rock and were unearthed accidentally by Opal mining) (Winton Council 2007). These requirements are addressed through the use of a highly defensive building envelope to minimise heat flux. Two strategies are used – insulation and thermal mass. The lightweight cladding system of 100mm thick sandwich panels (see Figure 1) gives a thermal resistance (R-value) of 1.5, while the roof provides an R-value of 2.5. The internal walls are made of rammed earth, 300 to 450mm thick and, in conjunction with the rock floor of the Trackways, provide thermal storage for the building. One wall to the north has since collapsed and the rammed earth has been removed.
Figure 3: Centre. Water conservation strategies are used and the technology is integrated under the building. (Source: Lin Martin.) Left. Display area to provides an opportunity for visitors to gain an understanding of the environmental qualities of the building. Right. Plan of the Trackways building, the dinosaur tracks are in the large space, with the display area forming the entrance. A walkway enables viewing of the footprints (Source: Gall Medek).

Providing visual and thermal comfort for the visitors and staff

A third requirement for this building is that it should accommodate visitors who are interested in viewing the footprints. To this end, strategies for creating visual and thermal comfort have been selected. Visual comfort strategies involve maximising daylight, which is brought into the Trackways building by ten angular selective 1.2m square skylights. During the design phase, modelling of daylighting in the Trackways building showed that these would provide adequate daylight for differing sky conditions, all year long (Wilraith, op cit: 3). Light is admitted through the roof and a diffusing panel is placed at ceiling level to reduce glare (Figure 3). Providing thermal comfort for visitors and staff was a major determinant in the design of the project. Similar strategies to those that provide protection to the footprints, using a highly thermal defensive envelope, are used to control comfort within the building. Visitors are expected mainly in the cooler seasons.

<table>
<thead>
<tr>
<th>Table 1a Mahoney Table (source DA-SketchPAD).</th>
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<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<td>14.2</td>
<td>14.2</td>
<td>15.2</td>
<td>15.0</td>
<td>15.6</td>
<td>15.8</td>
<td>16.8</td>
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<td>2</td>
<td>2</td>
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<td>*3= 0</td>
<td>*4= 0</td>
<td>*5=0</td>
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<td>30.0</td>
<td>30.0</td>
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<tr>
<td>Day low limit</td>
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<td>25.0</td>
<td>25.0</td>
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<td>34.7</td>
<td>31.6</td>
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<td>+</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>+</td>
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<td>24.0</td>
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<tr>
<td>Night low limit</td>
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<td>17.0</td>
<td>17.0</td>
<td>17.0</td>
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<td>17.0</td>
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<tr>
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<td>11.1</td>
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<td>0</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<tr>
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<td>0</td>
<td>6</td>
<td>-</td>
<td>= 6</td>
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</table>

<table>
<thead>
<tr>
<th>Table 1b Strategies developed from the Mahoney Table in 1a (source DA-SketchPAD)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Standard strategies, recommendations for a building form and fabric in this climate</th>
<th>Lark Quarry strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layout : compact courtyard plan</td>
<td>Separate pavilion buildings</td>
</tr>
<tr>
<td>Spacing: compact estate layout</td>
<td>Compact layout not provided</td>
</tr>
<tr>
<td>Air movement : no cross-ventilation is required</td>
<td>No cross-ventilation, little ventilation</td>
</tr>
<tr>
<td>Opening sizes: very small: 10-20% of wall surface</td>
<td>Small windows but large windows in the Display area</td>
</tr>
<tr>
<td>Opening position: Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Opening protection: full permanent shading</td>
<td>Shading provided</td>
</tr>
<tr>
<td>Walls and floors : heavy, over 8 hours time-lag</td>
<td>Light weight, some mass internal walls, mass floor.</td>
</tr>
<tr>
<td>Roof construction: heavy, over 8 hours time-lag</td>
<td>Light weight</td>
</tr>
<tr>
<td>External features: outdoor sleeping area is advisable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

Addressing ESD principles.

The building is also designed according to ESD principles. These requirements were developed in the pre-design phase during the briefing process. ESD principles minimise impacts on our local and global environments, while benefiting the local community. This involves using local materials and labour where possible, choosing materials that have low embodied energy and are reusable or recyclable (embodied energy is the energy used to create or manufacture materials).
Collecting water from roofs and processing waste water on site is a priority, involving installing closed system composting toilets which use little water, with the end product disposed of off-site or used as fertiliser. Little grid power is available on site, so power is supplied by a grid-connected solar system. Passive systems, such as the use of natural daylight and passive heating and cooling were integrated in the project. Finally it was ensured that there would be minimal impact during construction and that the site would be re-vegetated with local native plants (Winton Council 2007).

With regard to the ESD objectives, the building was benchmarked under the Green Globe Design and Construct Standard (Law & Hyde 2002, Hyde et al 2007). The building has meet these requirements and valuable lessons were learned. Design strategies suggest the building should achieve high levels of efficiency in the areas of water, energy and waste (Hyde 2007). Yet, as seen in the first section, a limitation of the POE was that it was difficult to get data on these factors.

2.3 Design feedback and evaluation

In summary, does the building design match its design intent? Many of the issues concerning the design intent were addressed in the Green Globe Assessment. This was a design phase assessment and used data from the design process. For example part of the Green Globe Design and Construct Assessment focused on the use of passive design strategies. Mahoney Tables are used in the assessment of buildings in composite climates (ones that have both hot and cold periods) like Queensland. This creates conflicting requirements, hence a weighting system is used to assess the relative importance of these requirements. ‘The system accommodates the duration and severity of the various climatic factors and classifies precisely the nocturnal and diurnal thermal stress in centigrade scale of temperature. The comfortable hot and cold periods are clearly outlined’ ( DA Sketch Pad.) From the Tables idealised design strategies can be generated, as seen in Table 1, and these can be compared to those in the project.

From Table 1 it can be seen that most of the strategies used in the project are consistent with the idealised Mahoney recommendations. Planning of desert buildings favours a more compact courtyard plan, preferably around a water feature to promote evaporative cooling. In this case the planning involved using separate pavilion buildings. The main deviation regarding construction is with the walls, where heavyweight construction with an eight-hour time lag is recommended. In the case of this project, the Trackways building, lightweight insulated walls are used with thermal mass located inside this skin, and a heavyweight floor. This form of construction is favoured as it insulates the thermal mass from the exterior, in theory improving the flywheel effect, which uses the thermal mass as a heat sink. For this the thermal mass must be purged at night to extract heat that is absorbed during the day.

The Display area shows the highest inconsistency, with mainly lightweight walls and floor (only one wall uses heavy weight construction), with large tinted windows and some horizontal shading.

3 MONITORING RESULTS

The monitoring examined the effectiveness of the passive systems, firstly to moderate the external temperature range and secondly to provide thermal comfort for the staff and visitors.

3.1 Climate interpretation

Climate data from the Mahoney Tables shown in Figure 1a gives details of the humidity and temperature conditions with reference to comfort levels of 25 degrees C and 60 per cent humidity. Whilst the humidity indicators are low, the day temperature stress is high, with mean maxima of over 30 degrees C for seven months of the year. Night stress on the other hand is minimal, with temperatures at the comfort level or below.
Figure 5: Psychrometric information for Longreach. The climate delivers significant under-heating in winter and over-heating in summer, the area being notorious for extreme variations in temperature. Low relative humidity dominates the yearly moisture cycle. Key. + Maximum internal temperature

3.2 Mitigating the diurnal range in temperature

The aim of the passive design strategies is to reduce the influence of outside temperature, in particular the high points and low points over the daily range of temperatures. To examine effects of the passive design, readings of the surface temperatures of the footprints are needed; hence a surface temperature sensor was placed on the footprints and isolated from the surrounding air. A control sensor was placed outside the building to monitor air temperature. Figure 4 shows the data from the data logger ST 5 located on the footprints. In July for some of the coolest days, external air temperature ranges were about 10 degrees C; 6 degrees C minimum at night and 18 degrees C maximum in the day. The surface temperatures of the footprints on these coolest days were minimum 16 degrees C and maximum 21 degrees C, range of 5 degrees C. On the hottest days, the temperature was 35 degrees C minimum and 38 degrees C maximum (external air temperatures 33 to 45 degrees C, range of 12 degrees C).

3.2 Thermal comfort for visitors and staff

Psychometric information

Thermal comfort can be achieved by a range of strategies, through passive solar heating in winter; for the other months, temperature levels are mostly higher than the comfort zone and thus require cooling. The Psychometric chart provides useful data to examine the extent to which these strategies are practicable. For passive cooling, three strategies can be used for extending the human comfort zone in the building (See Figure 5).

1) Air effect through ventilation. One of the best methods in this situation would be to use the stack effect, where cold air enters the lower areas of the building during the night and displaces the lighter, hotter air exiting from the upper levels. Air will need to be filtered to prevent dust from entering the building.

2) Thermal mass. This is key to stabilizing the temperature for user comfort in this building. In addition to thermal mass, insulation and limits to the glazing area are also important for comfort issues, as well as for preserving the dinosaur footprints. Night purging is needed for temperatures over 33 degrees C.

3) Evaporative cooling. The average relative humidity level ranges around 20 to 50 per cent during the year, hence this strategy can be used to 40 degrees C with indirect cooling, i.e. where the evaporative process is linked to an air-conditioning system.

Figure 6 Data logger AT 7 (595626) located on top of the eastern rammed-earth wall inside the building, measuring internal air temperature and relative humidity.
Figure 7: The visitor’s responses to thermal comfort and other related issues compared to overall satisfaction with the building. Rating 5 is highest satisfaction, 0 is lowest.

To measure thermal comfort for the purposes of this paper, the extreme conditions were examined, i.e. days of lowest and highest temperature, reasoning that these are likely to be the days of greatest discomfort. What constitutes thermal comfort for occupants in this building will vary widely; staff using the building will acclimatise to local conditions and so will have a very different perception of comfort to that of the visitors; many of the visitors are from overseas or are from different locations within Australia. Hence two indicators for comfort were used. The first measures comfort indicators by using temperature and humidity monitoring data and comparing these with the comfort parameters found in the psychometric chart (Figure 5). The second uses a questionnaire to get feedback from visitors.

Comfort indicator 1. Temperature and humidity measurement

Figure 6 shows the output from AT7 (595626), which gives a maximum internal temperature of approximately 38 degrees C, relative humidity 25 per cent. Comparing this data to the psychometric chart it is seen that on the hottest days the temperature will be well beyond the comfort zone. It is also beyond the conditions that can be moderated by thermal mass, even with night purging, which the building does not provide. A strategy that could moderate conditions is indirect evaporative cooling that would not affect the air humidity but reduce internal temperatures through the latent heat gain from evaporation. Problems may exist in generating the electrical energy to power this system. An adaptive approach may be better, where visiting times are coordinated with the coolest time of the day, i.e. a period from 6-10 am, periods in the afternoon being avoided.

Table 2 Summer spot measurements

<table>
<thead>
<tr>
<th>EXTERNAL CONDITIONS</th>
<th>EXTERNAL RADIANT SURFACE TEMPERATURES °C</th>
<th>INTERNAL RADIANT TEMPERATURES °C (inside walls)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North</td>
<td>South</td>
</tr>
<tr>
<td>Time</td>
<td>AT (°C)</td>
<td>RH (%)</td>
</tr>
<tr>
<td>11:30</td>
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<td></td>
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<td>RH (%)</td>
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<tr>
<td>11:40</td>
<td>35</td>
<td>32</td>
</tr>
</tbody>
</table>

Comfort indicator 2. User satisfaction

Feedback from users seems to support some of the issues in the monitoring process. A questionnaire was used, based on the Dillon and Visher (1987) Building User Works Survey, which rates visitor’s satisfaction with aspects of the environment. It was administered to visitors during the summer of 2006.

A sample size of 23 was achieved. The results show that whilst the building was rated highly overall in terms of occupant satisfaction, overheating in the building was, and continues to be a problem. Most visitors found the building too hot and staff reported instances of heat stroke. A comfort meter was installed to assist staff with health and safety monitoring in the Trackways area, so as to alert users/visitors to the threat of heat stroke. More detailed analysis was carried out of the design strategies as compared to those suggested by the theoretical Mahoney Analysis (Table 1b), which provides recommendations for building design based on climate criteria. The building is not consistent with all the recommended strategies. In view of the largely lightweight construction, cross-ventilation is required, particularly in areas where visitors will spend the most time.
4. SUGGESTED IMPROVEMENTS

Furthermore, the summer performance has a small range; it is elevated towards the midday highest temperature suggesting the building is not passively cooling effectively. The aim should be to keep the building’s midday temperature in alignment with the night temperature. In this way, the seasonal range in surface temperature will also be reduced. Additional passive strategies are needed, i.e. more thermal mass and more ventilation, particularly at night; more insulation would address this problem. The need for more insulation is apparent in the spot measurements taken in summer. Comparison of radiant temperatures inside and outside the building shows high external surface temperatures on unshaded walls (see Table 1).

4.1 Hot spots compromising thermal comfort

Part of the research process was to determine hot spots in the building, i.e. areas where thermal comfort is compromised. Both the Trackways building and the entrance display facilities building are oriented along an east/west axis with orientation eight degrees west of north, with its longitudinal side facing North and South, thus minimizing exposure to West and East. The display area on the easterly side of the building had elevated radiant temperatures from the glass skin. Although shaded and tinted, the high ambient radiation in summer (37 degrees C was measured with an ambient air temperature of 34 degrees C, see Table 2) is absorbed by the glass and radiated into the building. Lack of operable windows elevates internal temperatures and reduces visitor comfort.

The detailed analysis carried out of the design strategies were compared to those suggested by the theoretical Mahoney Analysis (Table 1b), which makes recommendations for building design and suggests cross ventilation for overheating. The building is not consistent with all the recommended strategies. In view of the largely lightweight construction, cross-ventilation is required, particularly in areas where visitors will spend most time. Whilst it is recognised that the building brief limited visitors use of the building at hot times of the year, Winton Council is trying to use the building through out the year to promote tourism in the area. In view of this policy building improvements are needed.

5. CONCLUSIONS

Overall, the building is highly defensive and uses the building envelope to mitigate heat gains or losses to the exterior environment. As opposed to a defensive building, an interactive system is required, where the envelope works to accept favourable heat flux and reject unfavourable climate events. Not all of the available passive strategies are used; some of them are inconsistent with recommendations for this type of climate. And thirdly, in answering the question on what suggestions can be made for improving the building’s performance, our recommendations are that retrofitting the building is needed for five reasons:

1) There is a need to remove barriers to visitor access based on thermal discomfort. This will enhance economic returns and attract more visitors to Winton over the summer period.
2) The existing reduction of the seasonal and diurnal temperature ranges of the Trackways can be enhanced. Use of air effect to prevent overheating is needed to reduce the internal diurnal mean night temperatures. Passive solar heating is needed to warm the building relative to winter mean temperatures.
3) There are no mechanisms for controlling humidity; evaporative systems are needed to control moisture, low humidity prevails through the measurements period, hence water, collected on site, can be added to cool and regulate humidity within the building fabric.
4) A more interactive building envelope is needed, with a better synergy between the active and passive systems.
5) A more permanent monitoring system is needed, to help to regulate the building performance and to achieve the design objectives, without this is it difficult to obtain the information needed to regulate the internal conditions to the levels desired.

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