EVALUATION OF THE EFFECTIVENESS OF AN ENERGY EFFICIENT DEMONSTRATION BUILDING

Stefan Tylak

Honours Bachelor of Science
(Specialist - Environmental Science)
(Major - Earth Science)

Postgraduate Diploma
(Energy and the Environment)

School of Engineering Science
Murdoch University
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DECLARATION

I hereby declare that, except where due acknowledgement is made in the text; this dissertation consists of my own work and has not been submitted for assessment at any other tertiary education institution.

..........................................................

Stefan Tylak
ABSTRACT

Demonstration projects play a vital role in the development and acceptance of new and improved technology because of the reluctance of society to engage in perceived risky investments in unfamiliar and often unproven technology. To this regard, energy efficient demonstration buildings should be able to prove their long-term performance and viability in order to stimulate more widespread acceptance of energy efficient building practices by effectively informing society of the potential benefits that are on offer.

This research project evaluated the effectiveness of Piney Lakes Environmental Education Centre as an energy efficient demonstration building three to four years after its commissioning in 2001.

A multidisciplinary evaluation of the thermal performance of the Centre, its residual energy demands, visitor numbers, objectives, operation and maintenance regime as well as its Building Management System was conducted.

The Centre frequently overheated during the summer time. Substandard night ventilation operation and a lack of surrounding vegetation were largely responsible for the regular overheating of the building. Incorrect user operation was also an influencing factor over the thermal performance of the building. Given these facts, there are opportunities for improvement in the thermal performance of the Centre.

Piney Lakes Environmental Education Centre provides a unique sustainable technology education and demonstration facility that can offer an increased level of awareness and education in the community about important environmental issues, including energy efficiency.
Piney Lakes Environmental Education Centre requires active, knowledgeable participation by the users, as well as regular maintenance to optimise the building’s performance, thus ensuring its integrity.

Demonstrating the performance, feasibility, practicality and desirability of energy efficient buildings to the general public, industry, utilities and governments, combined with information dissemination, promotion and marketing should advance the widespread adoption of energy efficient buildings.
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# ABBREVIATIONS AND ACRONYMS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>ACS</td>
<td>Adaptive Comfort Standard</td>
</tr>
<tr>
<td>BCA</td>
<td>Building Code of Australia</td>
</tr>
<tr>
<td>BMS</td>
<td>Building Management System</td>
</tr>
<tr>
<td>BOM</td>
<td>Bureau of Meteorology (Australia)</td>
</tr>
<tr>
<td>CD</td>
<td>Compact Disc</td>
</tr>
<tr>
<td>EES</td>
<td>Energy Efficient Strategies</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating, Ventilation and Air-Conditioning</td>
</tr>
<tr>
<td>ICLEI</td>
<td>International Council for Local Environmental Initiatives</td>
</tr>
<tr>
<td>IPMVP</td>
<td>International Performance Measurement and Verification Protocol</td>
</tr>
<tr>
<td>LCD</td>
<td>Liquid Crystal Display</td>
</tr>
<tr>
<td>LED</td>
<td>Light Emitting Diode</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
</tr>
<tr>
<td>MB</td>
<td>Megabytes</td>
</tr>
<tr>
<td>MUERI</td>
<td>Murdoch University Energy Research Institute</td>
</tr>
<tr>
<td>MWh</td>
<td>Megawatt-hour</td>
</tr>
<tr>
<td>NV</td>
<td>Night Ventilation</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Co-Operation and Development</td>
</tr>
<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>PLEEC</td>
<td>Piney Lakes Environmental Education Centre</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>RAIA</td>
<td>Royal Australian Institute of Architects</td>
</tr>
<tr>
<td>RAM</td>
<td>Random Access Memory</td>
</tr>
<tr>
<td>SAPS</td>
<td>Stand-Alone Power Supply</td>
</tr>
<tr>
<td>SEAV</td>
<td>Sustainable Energy Authority Victoria</td>
</tr>
<tr>
<td>SEDO</td>
<td>Sustainable Energy Development Office</td>
</tr>
<tr>
<td>USB</td>
<td>Universal Serial Bus</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile Organic Compounds</td>
</tr>
<tr>
<td>W</td>
<td>Watt</td>
</tr>
<tr>
<td>WA</td>
<td>Western Australia</td>
</tr>
</tbody>
</table>
1 Introduction

The building sector accounts for approximately 25-40% of final energy consumption in Organisation for Economic Co-Operation and Development (OECD) countries, with space heating accounting for the largest portion of energy consumption in both residential and commercial buildings (OECD 2003).

Considering the vast amount of energy used in the building sector, particularly for climate control, an ideal opportunity exists for significant reductions in energy consumption through the widespread adoption of energy efficient building practices.

Successful commissioning and operation of energy efficient demonstration buildings should facilitate public awareness and acceptance of energy efficient buildings. Energy efficient demonstration buildings should also provide useful data and valuable lessons that can contribute to research efforts in order to gain a better understanding of their performance and effectiveness.

1.1 Research Objectives

The following chapters comprise an evaluation of the effectiveness of Piney Lakes Environmental Education Centre (PLEEC) as an energy efficient demonstration building using both quantitative and qualitative methods.
Although energy savings and the protection of the environment are worthy causes in their own rights, human needs must also be met to ensure sustainability (Roulet 2001).

A thermal performance evaluation of the building under varying climatic conditions was conducted and viewed in the context of human comfort.

An inquiry into the residual energy demands of PLEEC was undertaken in order to evaluate that particular aspect of energy efficiency, as it should be an integral part of an energy efficient demonstration building.

The number of visitors to the Centre was investigated to assist in evaluating the degree of public awareness and acceptance of PLEEC.

Three qualitative parameters were considered in this evaluation:

- The first qualitative aspect of this study considered to what degree PLEEC had met its objectives;
- The second assessed how effectively the building was operated and maintained and
- Thirdly, an evaluation of the Building Management System (BMS) was conducted to determine its overall effectiveness in terms of building operation and functionality.

This dissertation presents an independent evaluation of the effectiveness of PLEEC. Recommendations for possible improvements
and solutions to the problems that have been identified and discussed are provided in the concluding remarks.
2 Background and Literature Review

2.1 Overview of Energy Efficient Buildings

Solar conscious design has existed for thousands of years. Solar architecture flourished in ancient Greek cities, as archaeological excavations show that entire cities were planned to allow their citizens equal access to the winter sun and individual homes were orientated to face south (Willrath & Cole 1992). Xenophon wrote in 400 BC of how to design the openings and placement of a given structure to allow for the natural heating and cooling of the building (Flasolar.com 2002). More recently, the Renewable Energy Institute (quoted in Balcomb 1992) stated in 1986 that passive solar design is an accepted and proven concept.

It is expected that government policies will play an important role in reducing the building sector’s environmental impacts. Unfortunately, few studies have been undertaken in this area. The OECD came to realise this and initiated the four-year OECD Sustainable Buildings Project in May 1998 with the “objective of providing guidance for the design of government policies to address the environmental impacts of the building sector” (OECD, 2003). The reduction of CO₂ emissions from the building sector was one of the three priorities of the project.

In Australia, interest in energy efficient buildings has been on the rise, as nationwide Energy Efficiency regulations in the Building Code of
Australia (BCA) could be seen as the first step towards greenhouse gas emission reduction in the residential building sector (Peterkin 2004). In Victoria, all new homes built since July 2004 must feature a greater range of energy efficiency and water saving features by achieving a 5 star energy rating (SEAV 2004). Of course, there are also barriers to the implementation of energy efficient buildings such as natural resistance to change as well as lack of knowledge and understanding.

2.2 What are Energy Efficient Buildings?

There are many basic principles that typically work together in an energy efficient building and should therefore be considered holistically during the design process:

- Site and climate;
- Orientation;
- Window positioning;
- Eave length/shading devices;
- Ventilation;
- Use of thermal mass;
- Insulation and
- Zoning of indoor spaces.

In 1985, Ternoey et al. (quoted in Balcomb 1992) stressed that the key to achieving good overall energy performance in buildings lies in the integration of daylighting, passive solar heating, and natural cooling in the overall design.
More recently, the OECD (2003) has stated that there are four basic principles in the design of an energy efficient building:

- Proper orientation and location on the site to maximise passive solar potential;
- Optimised building envelope design to minimise energy demand for operation;
- Maximise the use of renewable energy technologies and sources and
- To install energy efficient equipment for residual energy demands.

It is clear that many energy efficient buildings embrace passive solar principles. However, it is expected that the energy efficient buildings of today should also make use of available renewable energy, as well as install energy efficient appliances to minimise energy consumption.

### 2.3 Benefits of Energy Efficient Buildings

This Section is by no means an exhaustive literature review, but rather an overview of the benefits and savings that energy efficient buildings can offer.

A case study reported by Wilhide (2002) on an energy efficient demonstration home (Integer House in Garston, UK) reports that the
home consumes only half the energy of a comparable building, while using mostly standard or prefabricated elements during its construction.

Analysis of twelve monitored energy efficient institutional and commercial buildings by Gordon et al. (1986) (quoted in Balcomb 1992) supports this finding with overall energy savings compared to base-case buildings of the same size and function in the same location of about 47%.

Research into materials and advanced energy supply systems for high-performance housing is strongly related to the topic of passive solar energy utilisation (Santamouris 2003). It is therefore likely that energy efficient buildings in the future will achieve further energy reductions with more sophisticated materials and energy supply systems. This, however, must not be misinterpreted to mean that there are significant additional costs involved in designing and constructing energy efficient buildings.

In the early 1990’s, Nicklas and Bailey (2002) conducted a study on the energy performance and cost of daylit schools in North Carolina, USA. In this study, it was found that the net additional cost of the daylighting/energy investment for the Durant Road Middle School (completed in 1995) was less than 1% of the total construction budget and (when compared to typical new middle schools in the area) would be returned to the school system in less than a year. All of the new
daylit schools in the study had payback periods of less than three years, with energy cost savings of between 22% and 64% over typical schools, leading to enormous long-term benefits within the school system. This study concluded that, even excluding all of the productivity and health benefits, daylighting makes sense from a financial investment standpoint.

A landmark study by the Heschong Mahone Group (1999) found that daylighting in the Capistrano school district of California increased the rate of learning by 20-26%. Although this increase in productivity cannot readily be assigned a dollar value, the stimulation of learning by future generations is undeniably beneficial.
3 Piney Lakes Environmental Education Centre (PLEEC)

3.1 Overview of PLEEC

PLEEC was the result of a collaborative effort between the City of Melville, environmental groups, State and Federal Governments, industry and the Western Australian (WA) Lotteries Commission. The Rotary Club of Melville also provided funding as well as assistance with management and community overviews, while the Murdoch University Energy Research Institute (MUERI) graciously provided support by designing the power systems at no charge. With the planning and construction phases beginning in June 1999, the Centre was built in 2000 at a total cost of approximately $1.3 million and officially opened on November 24th, 2001. Photos of PLEEC are shown in Appendix A.

PLEEC is a valuable resource that reaffirms the City of Melville’s commitment to living within the earth’s carrying capacity and encourages students, the community and professional groups to draw inspiration from environmentally sustainable technologies, climate sensible building design, resource conservation and biological waste treatment systems, all of which demonstrate aspects of sustainable urban living (Melville City Council no date).
3.2 Objectives of PLEEC

The objectives of the PLEEC project were to:

- Establish a unique Environmental Education Centre that offered the community access to education and demonstration facilities covering the environment, renewable energy technologies, energy efficient building designs, solar lighting and environmentally friendly technologies for waste treatment and water treatment;
- Increase community awareness in the area of energy efficient solar passive building design, renewable energy technology systems, the more efficient use of energy and the sustainable use of resources and
- Provide a base and resource centre for local environmental groups to visit and meet in, thus expanding the Council support for local environmental management.

According to the Mayor of Melville Katie Mair (no date), PLEEC aims to encourage people to build more energy efficient homes and buildings that are more in tune with the environment as well as nature. The Centre is a working educational facility that gives people an opportunity to learn about sustainable issues first hand.

Resources Available

PLEEC offers a wide range of resources including:

- Organised building tours;
• Self-guided tours of the Centre and Piney Lakes Reserve;
• School excursion activity sheets;
• Ongoing community workshops/programmes to promote sustainable living;
• Information on the PLEEC website and
• Brochures on various topics relating to sustainability.

With assistance from the Melville Rotary Club, the City of Melville originally planned to set up an Environmental Trust Fund whose purpose would be to research, educate and also provide publicity on sustainability issues. Although Council approved this proposal, it did not come to fruition because a board of trustees and funding were not established.

3.3 PLEEC Literature Review

There were no formal, published documents on PLEEC at the time of writing. There were however, many unpublished documents as well as a case study that focused on PLEEC.

A case study on PLEEC was conducted by Bourne (no date) - a third year Environmental Science student at Murdoch University. Background information on the Centre is given, as well as its sustainability features and the benefits it offers to the wider community. Bourne (no date) states that PLEEC is not only an example of how new,
more sustainable technologies can be used in everyday life, but also that the Centre has the potential to become a major tourist attraction.

A normal building of the same size as PLEEC would use approximately 12 Megawatt-hours (MWh) of energy per year, whereas PLEEC uses only about 4 MWh per year (Melville City Council no date). Considering that PLEEC generates its own electricity using renewable energy, it is estimated that it can effectively save 12 MWh per year of conventional power generation, translating into about 12 tonnes of CO$_2$.

The construction of PLEEC prompted a study in 2002 that carried out a theoretical analysis of the energy efficiency of passively solar designed and naturally lit schools across WA (Baverstock 2002). Although detailed results from this study are confidential, it concluded that designing schools to utilise natural light with passive solar architecture is economically viable and that they could function without air-conditioning if they are in temperate climates of WA below 20ºS latitude.

### 3.4 Description of Location and Site

PLEEC is located on the 68 hectare bushland Piney Lakes Reserve, approximately 10 km South South West of the centre of Perth, Western Australia. Piney Lakes Reserve is at the northern gateway to Beeliar Regional Park, a 3500 hectare wetland that stretches 20 km south from the City of Melville. Piney Lakes Reserve is located in the suburb of
Winthrop and is indicated by a red star in Figure 3.1 (Mapquest 2005).

The geographical co-ordinates of Piney Lakes Reserve are:

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
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<tbody>
<tr>
<td>Latitude</td>
<td>32º 03’ S</td>
</tr>
<tr>
<td>Longitude</td>
<td>115º 50’ E</td>
</tr>
</tbody>
</table>

Figure 3.1: Piney Lakes Reserve Locality Map (MapQuest.com, Inc 2005; AND Products B.V. 2005)

Piney Lakes Reserve is south of Leach Highway and West of Murdoch Drive and includes recreation and landscape amenities. PLEEC is in the heart of a large conservation area within Piney Lakes Reserve that is being restored to its natural state of Banksia woodland. A satellite image of Piney Lakes Reserve as seen by Google Earth (2005) is shown in Figure 3.2.
3.5 Description of Climate

Perth has a Mediterranean type climate with mild, wet winters and hot, dry summers. Although the average monthly temperatures in Perth are generally in the range of human comfort for most of the year, large diurnal temperature fluctuations outside the comfort range are common. As a result, winter heating and summer cooling are usually required to maintain temperatures within the range of human comfort inside buildings. On an annual basis, Perth has 391 heating degree-days (based on 15°C) and 308 cooling degree-days (based on 24°C) (EES 1998a, quoted in EES 1998b).
Average monthly temperatures for Perth were calculated from Bureau of Meteorology (BOM) data and are shown in Table 3.1. These temperatures are the mean of four values: the mean daily maximum and minimum monthly temperatures for Perth Airport (BOM 2004) and Perth Metro (BOM 2005). Values from both the Metro and Airport sites were averaged to increase the overall accuracy because while the Metro site is spatially closer to PLEEC, the Airport site has been collecting data for 48.4 years longer than the Metro site.

Table 3.1: Average Temperatures for Perth (°C) (BOM 2004, 2005)

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
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<th>Nov</th>
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<tr>
<td>24.2</td>
<td>24.6</td>
<td>22.8</td>
<td>19.6</td>
<td>16.3</td>
<td>14.0</td>
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<td>16.7</td>
<td>19.7</td>
<td>22.3</td>
<td>18.4</td>
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3.6 Building Description

There are many environmentally sustainable features incorporated into the design and operation of PLEEC that are beyond the scope of this study and will therefore not be covered in this report. Specifically, these features include a stand-alone power supply (SAPS) consisting of wind and photovoltaic (PV) power, as well as a self-contained water supply and biological wastewater treatment system. The construction of PLEEC used recycled materials such as fly ash, recycled road surfacing materials and old power poles from the Melville area.
Floor Plan

There are three main rooms in the central area of the Centre; the Rotary Room, Lotteries Function Room and the Administration Room. The main upper storey also contains the foyer, a kitchen and toilets. Figure 3.3 illustrates the upper storey floor plan of PLEEC; blue stars indicate locations of the four instrumentation sensors. Photos of PLEEC are shown in Appendix A.

![Figure 3.3: Upper Storey Floor Plan of PLEEC (blue stars indicate the BMS instrumentation sensor locations)](image)

The lower storey of PLEEC is shown in Figure 3.4. Although not as large as the upper storey, the lower storey contains a laboratory, the energy room (housing the battery bank and inverter), the water treatment room and a maintenance room.
Free-Running Condition

The operation of buildings is responsible for a significant share of energy consumption in many countries - up to 50% of the primary energy consumed by buildings in the European Union (EU) is for the provision of indoor climate control (Santamouris 2003). In Australia, Heating, Ventilation and Air Conditioning (HVAC) accounts for around 43% of the energy consumed in commercial buildings (Langston 1997, quoted in OECD 2003).

The design of PLEEC takes a different approach in that it does not rely on active climate control, but rather operates in a free-running condition without a thermostat. In order to maintain the indoor temperature within the range of human comfort, the Centre incorporates a hybrid design.
that uses state of the art technology in both passive and semi-active forms, thus greatly reducing the need for conventional heating and cooling.

**Climate Sensible Design Principles**

Climate sensible design considers many climatic variables as well as the local topography, as these factors are unique to each specific location and are used to help to make the building more comfortable naturally.

Climate sensible designs often incorporate passive solar systems in which heat collection and storage functions are integrated into the building in such a way that little or no additional energy is needed to operate the system (Szokolay and Sale 1979).

There are many climate sensible and passive solar features that work to keep PLEEC naturally cool in summer and warm in winter:

- The long-axis of the building is predominantly orientated in an East-West direction, enabling the passive solar features to be optimised;
- The Eastern part of the building is angled at 30 degrees East of North to take advantage of the early morning winter sun for start-up heating;
- Solar pergolas designed at a specific angle are used on the North and North East sides to permit winter sun to enter for heating and lighting but exclude unwanted summer sun;
• Windows are strategically positioned to capture the cooling South West summer breezes;

• Low emissivity windows are used on the Southern windows to reduce heat loss in winter and heat gain in summer;

• Addition of clerestory windows on the North side provide extra solar gain and more even ambience of natural light;

• Massive rammed limestone walls store solar radiation received during winter days and release it as heat during the colder nights and also buffer the temperature extremes by storing the warmth in winter and the coolness in summer;

• Advanced roof design constructed out of polystyrene panels without metal purlins so as to dramatically reduce thermal bridging, giving the roof a very high insulation value of R3.0 or above;

• Suspended, concrete slab-on-ground for additional thermal mass;

• Earth sheltering to the North wall and basement benefits from the insulating properties of the surrounding soil, which is relatively warm in winter and cool in summer and

• Insulated verandas to the South West and parts of the East.

**Semi-Active Systems**

Semi-active systems employ techniques that complement the climate sensible and passive solar principles and are designed to maintain thermal comfort inside the building with a minimum amount of energy. The semi-active systems at PLEEC are predominantly automatic, being controlled by the BMS described in the following Subsection.
The semi-active systems utilised at PLEEC include:

- An automatic night ventilation (NV) system that cools the thermal mass of the building on relatively cool summer nights with mechanical fans and dampers, by expelling hot air out of vents near the ceiling and drawing cooler air in from vents near the floor;

- Two automatic solar air heaters (one collector over the Administration Room and the other over the Rotary Room) that provide supplementary heating via ductwork (photos in Appendix A);

- Automatic, independent photoelectric control of lights to integrate natural and artificial lighting systems;

- Manually operated ceiling fans to circulate the air for increased thermal comfort in the summer or to move warm air downward in winter;

- Energy efficient lighting, with low energy fluorescent tubes and reflecting light boxes and diffusers as well as motion sensors for lights in the kitchen, bathrooms and storerooms and

- A BMS, which is described in the following Subsection.

Building Management System

PLEEC features a computerised BMS installed by Siemens Building Technologies. The system provides energy management control for the building through monitoring of the NV system, solar air heaters and the renewable energy system and then managing these systems with the use of fans, motorised dampers, actuators and sensors.
Figure 3.5 is an image of the interactive BMS workstation screen display for one of the solar air heaters.

*Figure 3.5: BMS Screen: Solar Air Heater Information (Siemens 2001)*

The BMS was originally intended to display data from the energy requirements of the building in real time on a dedicated website, enabling global exposure to the performance of PLEEC. However, this was never implemented.
3.7 Centre Management

Initially, the City of Melville was forced to come up with additional funds because demands for the use of the facility as a venue exceeded expectations; this resulted in a need for more staff.

In terms of staffing, there has typically been one full time Co-ordinator, one part time Volunteer Resource Centre Co-ordinator and several volunteers for front desk attendance and enquiries.

During the course of this study, the full time Sustainable Development Educator for PLEEC had a change of employment and departed the Centre on February 2\textsuperscript{nd}, 2005. This position was not permanently filled by a full time Sustainability Education Officer until March 16\textsuperscript{th}, 2005. This changeover of staff resulted in a six-week gap during which there was no full time employee responsible for the operation of the Centre.

3.8 Main Activities at PLEEC

PLEEC serves many purposes, both publicly and privately. The Centre provides access to a working example of a sustainable facility for educational purposes to students of all ages, community groups and the general public. PLEEC is also used as a venue for corporate seminars/workshops, as well as on a regular basis for community consultation and environmental forums. Overall, there has been an
overwhelming interest from visitors and people wishing to use the Centre.

3.9 PLEEC Awards and Recognition

In 2000, PLEEC won the Electrical Innovation Award from the Electrical Contractors Association.

The second achievement for PLEEC was a Commendation by the Royal Australian Institute of Architects (RAIA) in 2001.

The Buildings Category of the National Banksia Environmental Award was also presented to PLEEC in 2002.

In 2003, the City of Melville won category 11 ‘Eco-building’ in the WA (Western Australian) Environment Awards for PLEEC.

On behalf of PLEEC, the City of Melville was a Finalist for the Prime Minister’s Award for Environmentalist of the Year in 2004.

The Natural Edge Project (2003) states that “the Piney Lakes Environmental Education Centre is arguably the best practical demonstration of a sustainably designed facility in Australia”.
4 Methodology

4.1 Introduction

As mentioned in Chapter One, this study used both qualitative and quantitative methods to provide a multidisciplinary evaluation of the effectiveness of PLEEC. The following sections provide details on the different methodologies used throughout this study in order to evaluate the degree of thermal comfort within the building, its effectiveness as an energy efficient demonstration building as well as other factors influencing energy efficiency.

4.2 Thermal Performance Evaluation

There has been mounting evidence that the climate, particularly outdoor climate, has an influence on human comfort temperature. Auliciems (1983) and Humphreys (1981) (quoted in Emmanuel 2005), having analysed over fifty thermal comfort studies utilising over 250,000 subjects, found strong correlation between the reported comfort temperatures and the outdoor temperatures under which they were obtained. Therefore, to evaluate the level of human thermal comfort within PLEEC, it was crucial to perform an analysis that considered both the indoor and outdoor air temperatures.
4.2.1 Data Collection and Validation

Instrumentation

The collection of thermal data was achieved by direct measurement using the BMS described in Section 3.6. The BMS featured a Siemens Desigo Insight integrated control system, with connection to the control system achieved via an Ethernet TCP/IP connection with four Smart II field controllers located throughout the building. The location of the four Smart II sensors is shown in Figure 3.3. The BMS consisted of the following elements:

- BMS management workstation;
- BMS supervisor controller (NCREL/A) (shown in Figure 4.1);
- AS1000 small point controllers for the two solar air heaters and
- Four – Smart II field controllers, for acquiring data as well as providing dedicated control of input and output devices and miscellaneous exhaust fans.

Figure 4.1: Original BMS Supervisory Controller (NCREL/A)
Solar Time

All times logged by the BMS were found to be 12 minutes (0.20 hours) ahead of local standard time (Western Standard Time), which uses 120°E as the standard time meridian.

According to Muneer (2004), the apparent solar time (AST) may be determined using the following equation (all terms are to be expressed in hours):

\[ \text{AST} = \text{standard time (LCT)} + \text{EOT} \pm \left( \frac{\text{LSM} - \text{LONG}}{15} \right) \]

Where:

EOT is the equation of time and may be obtained as expressed by Woolf (1968, quoted in Muneer 2004);

\[ \text{EOT} = 0.1236\sin x - 0.0043\cos x + 0.1538\sin 2x + 0.0608\cos 2x \]

\[ x = \frac{360 \left( \text{DN} - 1 \right)}{365.242}, \text{DN} = 1 \text{ for 1 January in any given year, LSM is the longitude of the standard time meridian (120°E) and LONG is the longitude of the given locality (116°E).} \]

0.2 hours must be subtracted from the standard time (LCT) for PLEEC because the clock on the BMS workstation was 12 minutes fast.

The algebraic sign preceding the longitudinal correction terms contained in the square brackets should be inserted as negative for longitudes that lie West of LSM (as in the case for PLEEC) and vice
versa. The LSM and LONG themselves have no sign associated with them.

Therefore, for PLEEC:

\[
AST = \text{standard time (LCT)} - 0.2 + EOT - [(120 - 116)/15]; \\
AST = \text{LCT} - 0.2 - 0.27 + EOT;
\]

Apparent solar time = local standard time - 0.47 hours + EOT.

**Difficulties Encountered**

There were several difficulties encountered during this study with data collection from the BMS. The main problem experienced was delayed and incomplete data collection. This resulted from a lack of BMS management and maintenance, including upgrading of both the computer hardware and software.

Initially, the author was unfamiliar with the BMS operation, as was the then Sustainable Development Educator at PLEEC. Upon discovery of this fact, Siemens Building Technologies was contacted for assistance in data collection and retrieval. It took several site visits by Siemens Building Technologies throughout the spring of 2004 to obtain rudimentary data from the BMS.

There were technical difficulties associated with data acquisition and storage. The system exhibited a lack of stability and flexibility. Specifically, the BMS would simply ‘drop-out’ or go offline periodically...
without warning. This resulted in loss of data because of the lack of automatic data storage (this is described in more detail in a following paragraph). At the time of writing, this problem remained unanswered.

Humidity measurements were often incomplete regardless of whether or not the BMS was online (this is described in more detail in the following Subsection).

There was a lack of flexibility in the data logging, with an inability to control how frequently parameters were recorded. It was found that some parameters were logged 20 times per minute. This excessive collection of temperature and humidity measurements was unnecessary due to the thermal inertia of the building. Measurements every 10-15 minutes would have been ideal.

Automatic data storage was not possible at any time during the data collection period as a result of shortcomings in the software used by the BMS. To safeguard the collection of as much data as possible, manual data saving by either the full time Co-ordinator at PLEEC or the author was mandatory on a regular basis. The data was saved in IBM compatible spreadsheets to the hard drive of the BMS workstation computer. The workstation computer would not allow data to be saved to a writable compact disc (CD) or a universal serial bus (USB) drive, while the limited data storage capacity of floppy disks was insufficient.
As a result, data files were transferred from the workstation computer to another Personal Computer (PC) via e-mail attachment.

Although Siemens Building Technologies suggested that upgrading the BMS computer (i.e. re-partitioning the main C drive) and the Desigo Insight software would solve virtually all of the problems experienced, it was not within the budget of the City of Melville.

These difficulties resulted in an application for an extension in the length of study to gather a more substantial data set. An extension of the dissertation until November 4th, 2005 was granted to permit the collection of further data. The collection of complete winter data was not possible however, due to the disconnection of the BMS for upgrading purposes combined with the subsequent delayed installation of the new BMS and dissertation time constraints.

**Data Acquisition and Monitoring Period**

Parameters measured by the BMS for the purposes of this study included ambient temperature (°C) and relative humidity (%) from the four Smart II sensors. Values were logged in ‘trend viewer’ and then imported into a spreadsheet with time and date stamps. Each parameter logged by the four field controllers was assigned its own code by the BMS, for a total of eight codes as follows:

- Rsuz_0001 - Rotary Room temperature;
- Rsuai_0002 - Rotary Room relative humidity;
An initial aim of the research project was to obtain data from more than one season to evaluate the thermal performance of the building under different climatic conditions. As a result of the difficulties previously mentioned, data acquisition did not commence until November 26th, 2004 and was ceased on June 2nd, 2005.

The regular data saving did not entirely avoid data loss, as the instability of the BMS and subsequent system crashes occasionally led to loss of data that had not yet been saved. All of these temporal gaps in the data were well known because of the manual nature of the data collection. The period that experienced the largest data gap was for virtually all of January and February, 2005, when the BMS crashed and could not be tended to due to lack of available personnel.

The humidity measurements frequently posed problems, with the unexplainable disappearance of data from the beginning of the data set. At the time of writing, this problem remained unanswered. Fortunately, this did not cause significant difficulty because the temperature data

- Rsuz_0005 - Lottery Functions Room temperature;
- Rsuai_0006 - Lottery Functions Room relative humidity;
- Rsuz_0026 - Administration Room temperature;
- Rsuai_0027 - Administration Room relative humidity;
- Rsuz_0030 - Outdoor temperature and
- Rsuai_0031 - Outdoor humidity.
was much more important for the thermal performance evaluation in this study and was only affected once by this problem throughout the entire study period. To complete this data set, temperature readings taken by the Murdoch University On-line Weather Station (1998) from December 10th to the 16th, 2004 were used. This was acceptable because of the close proximity of Murdoch (approximately 2km) to PLEEC.

**Instrument Calibration**

The Smart II field controllers (BMS sensors) were calibrated using a digital thermometer, maxima-minima thermometers and a psychrometer. These devices were held adjacent to all four Smart II field controllers on the walls to minimise picoclimatic differences (i.e. caused by air films). Sufficient time was also provided to ensure that stable readings were taken once the devices were in equilibrium with their surroundings.

The digital thermometer was a microprocessor controlled ‘Delta OHM – HD 9215’, integrated with a Pt100 sensor. The instrument was last calibrated on April 4th, 2005, with re-calibration due on April 4th, 2006. The HD 9215 digital thermometer proved to be very consistent with the BMS measurements, with the largest deviation being only 0.3ºC and the average deviation being 0.15ºC.

Four ‘Hinco Instruments’ maxima-minima thermometers were also used to confirm the accuracy of the Smart II field controllers. Compared to
one another, the largest deviation between any two was found to be not greater than 1.0°C, while the average deviation was 0.6°C. When these thermometers were compared against the BMS measurements, the largest deviation was found to be 1.0°C, while the average deviation was 0.5°C.

A ‘Hisamatsu Assman – model MR-70’ motor-driven psychrometer was used to calibrate the BMS sensors for both relative humidity and temperature measurements. Operation details of this psychrometer are found in Appendix B. Readings of both the wet and dry bulb temperatures were taken to determine the relative humidity using a psychrometric chart. Dry bulb temperatures were also compared to the temperature measurements from the BMS to further guarantee its accuracy. Most of the relative humidity measurements from the psychrometer were very close to those taken by the Smart II field controllers, with the largest deviation on the order of about 5% and the average deviation about 2%. The largest deviation of the dry bulb temperature readings from the BMS measurements was found to be 0.7°C and the average deviation 0.5°C.

The temperature readings taken by the Smart II field controllers may be considered to be accurate to within ±0.4°C if the mean of the average deviations is taken. However, the average deviation of the temperature readings from what may be considered the most accurate device, the HD 9215 digital thermometer, was only 0.15°C. As a result, the
accuracy of the BMS sensors is likely to be higher than $\pm 0.4^\circ$C. These relatively small deviations demonstrate that the temperatures recorded by the BMS had a high level of accuracy for the purposes of this study.

Data Validation

All acquired data was validated using range tests with lower and upper limits for the parameters.

Temporal gaps in the data were well known because of the manual nature of the data collection and duly noted in the preceding ‘Data Acquisition and Monitoring Period’ Subsection.

The outdoor temperature data was examined for values that were not between 0ºC and 43ºC, since these are approximately the minimum and maximum temperatures experienced in Perth. No values recorded for the outdoor temperature were found to lie outside this range, with a recorded minimum temperature of 9ºC and a maximum of 41.8ºC.

The indoor temperature data was also examined for spurious values, although using a smaller range than that for the outdoor because of the significant thermal mass. A range of 12ºC to 35ºC was chosen for the indoor temperatures to account for the thermal inertia of the building. No values recorded for the indoor temperature were outside this range, with a recorded minimum of 18.2ºC in the Rotary Room and a maximum of 32.9ºC in the Administration Room.
A humidity range of 10% to 100% was set for the outdoor data, where the minimum recorded humidity was 24% and the maximum recorded was 100%. When the humidity was found to be 24%, the corresponding temperature reading for the same time period was 37.6°C. This low humidity reading was therefore justified, as the saturation vapour pressure of the atmosphere rises with increasing temperature, thereby allowing it to hold more water vapour, which translates into a lower relative humidity.

A humidity range of 30% to 80% was used for the validation of indoor humidity values, since the smaller range of temperatures experienced indoors would logically lead to a smaller range of humidity levels. The minimum humidity recorded indoors was 32% in the Administration Room, while the maximum humidity recorded indoors was 79% in the Rotary Room. Although these values are somewhat extreme relative to the chosen range, these are justified because the reading of 32% occurred at a time when the temperature in the corresponding room was 29.9°C or greater and the reading of 79% occurred at a time when the temperature in the corresponding room was 25.1°C or lower. These high and low humidity readings with correspondingly low and high temperatures respectively are justified because they conform to the inverse relationship between temperature and relative humidity.

Since humidity only contributes to an uncomfortable feeling at the upper limits of the temperature range, this data suggested that it was not likely
to be a major influencing factor in the occurrence of uncomfortable conditions. The results did not appear to have any abnormal situations suggesting that the temperature readings were inaccurate or human thermal comfort was adversely affected.

### 4.2.2 Semi-Active Systems

**Solar Air Heaters**

An initial aim of the research was to collect data from the solar air heaters to evaluate their efficiency as well as effectiveness in maintaining comfort temperatures within the building during winter. This would have included collector temperatures, air velocities and times of operation. This however, was not possible due to difficulties with the BMS previously mentioned.

During the initial BMS set-up, it was determined that the solar air heaters would only operate during the months from April to September, when the indoor temperature was below 20°C and the panel temperature of the collectors was 5°C above the room temperature. The temperature in the Lotteries Function Room and the Administration Room was averaged by the BMS for the purposes of solar air heater control.

The lack of logged solar air heater operation data resulted in the inability to integrate their function into the thermal performance
evaluation and accurately determine their effectiveness because their operation was controlled by parameters that were not recorded.

**Night Ventilation**

An initial intention was to log data regarding the times of operation of the NV system in order to evaluate its effectiveness in purging heat within the Centre during summer nights to maintain thermal comfort conditions. This objective proved to be unattainable due to the inflexibility of the BMS operation, especially since it could not be ascertained whether or not the NV system was operating due to the restricted range of conditions under which it would automatically operate.

For the purposes of NV, the two exhaust fans would only operate when the indoor temperature was above 20ºC and the outdoor temperature was below 20ºC during the months of October to March. Additionally, they would only operate after midnight and run for a maximum of four hours. The temperature in the Lotteries Function Room and the Administration Room was averaged by the BMS for the purposes of NV control. Eventually, a visit to the Centre at 00:28 on March 30, 2005 by the author confirmed that the NV system was operating when the specified conditions were met.

The lack of accurate NV operation data did not pose any significant problems with the thermal performance evaluation because its
operation was strictly controlled by parameters that have been obtained and also because the NV was evidently functioning in relation to both the indoor and outdoor thermal conditions when viewed manually.

4.2.3 Thermal Comfort Temperature Range

It was ascertained through personal communication with the chief architect responsible for the design of PLEEC (Baverstock 2005) that for the purposes of ensuring human thermal comfort, the design aimed to maintain the interior of the Centre between 18ºC and 28ºC.

As stated at the beginning of Section 4.2, there is a strong correlation between the average outdoor temperature and indoor comfort temperature. An “Adaptive Comfort Standard” (ACS) that has been derived from temperature preferences in naturally conditioned spaces as a function of the average mean outdoor temperature has been presented by de Dear and Brager (2001, 2002, quoted in Emmanuel 2005):

Lower 80 percent acceptable limit:  \( T_c = 14.3 + 0.31T_o \)
Lower 90 percent acceptable limit:  \( T_c = 15.3 + 0.31T_o \)
Optimum comfort temperature:  \( T_c = 17.8 + 0.31T_o \)
Upper 90 percent acceptable limit:  \( T_c = 20.3 + 0.31T_o \)
Upper 80 percent acceptable limit:  \( T_c = 21.3 + 0.31T_o \)
Where \( T_c \) is the comfort temperature and \( T_o \) is the average mean monthly outdoor air temperature (for mean outdoor temperatures between 5\(^\circ\)C and 33\(^\circ\)C).

Using the temperature data for Perth shown in Table 3.1, the coldest mean monthly temperature is 13.1\(^\circ\)C in July while the warmest is 24.6\(^\circ\)C in February. Assuming that the Centre is able to maintain its design temperature of 18\(^\circ\)C to 28\(^\circ\)C, it would be expected that approximately 80% of people are likely to find it comfortable in winter and approximately 90% of people are likely to find it comfortable in summer.

### 4.2.4 Thermal Comfort Evaluation

Both internal and external temperature data were plotted to provide a visual representation of how well the Centre remained within the human thermal comfort range. The data was chosen from different times of the year to illustrate how the building responds under varying climatic conditions and corresponding changes in outdoor ambient air temperature. This also demonstrates the effect of the thermal mass, as a time lag between changes in the indoor and outdoor temperature is evident. These graphs form the basis of the thermal performance evaluation that ultimately determines how effective the Centre is at maintaining interior temperatures within the range of human thermal comfort. The results are viewed in the context of the time frame during which the Centre is occupied.
4.3 Residual Energy Demands

Electrical Appliances

As pointed out in Section 2.2, the OECD (2003) states that one of the four basic principles in the design of energy efficient buildings is to install energy efficient equipment for residual energy demands.

The author evaluated the efficiency of the higher power consuming appliances according to their energy ratings when tested in accordance with the relative Standards (AS/NZS 4474.2:2001 for the refrigerator/freezer and AS/NZS 2007.2:2003 for the dishwasher).

Other residual energy demands, including non-electrical appliances, were also evaluated in terms of energy efficiency.

Semi-Active Systems

The suitability of the solar air heaters and NV system installation into an energy efficient building as a means of maintaining thermal comfort conditions was assessed and suitable comments made.

4.4 Visitor Numbers

The number of visitors to the Centre is of particular interest due to the demonstration nature of the Centre. A graphical representation illustrates visitor numbers and a quantitative analysis was carried out on
visitor numbers to PLEEC. This assisted in evaluating the degree of
class awareness and acceptance.

4.5 Qualitative Building Evaluation

4.5.1 PLEEC Objectives

The degree to which PLEEC has met its objectives was considered in
order to evaluate its effectiveness in achieving its initial aims and
comments were made where appropriate.

4.5.2 Community Awareness Survey

A survey of the general public was originally planned to establish the
extent of community awareness with regard to the PLEEC and its
effectiveness as an energy efficient demonstration building. A proposal
was submitted to Murdoch University’s Research Ethics Committee and
it was subsequently rejected for several reasons. A meeting with the
Chair of the Human Research Ethics Committee to resolve the
Committee’s concerns failed to satisfy both parties. As a result, this
survey was abandoned. Unfortunately, no viable alternatives were
available that could offer similar insight into the degree of general
community awareness with regard to PLEEC and its energy efficient
demonstration building.
4.5.3 Building Operation and Maintenance

The overall operation of the building and ongoing maintenance was investigated to determine how effectively issues have been addressed and how they continue to be addressed. This assists in evaluating the effectiveness of the Centre because a properly functioning demonstration building is likely to be more successful. Solutions to identified problems and recommendations on possible improvements were made where appropriate.

4.5.4 Building Management System

The BMS was evaluated from a holistic perspective, focusing on its effectiveness in controlling the building and maintaining it within the thermal comfort zone. Both hardware and software issues as well as user-friendliness were scrutinised. An analysis of the progress to date with the BMS upgrade was conducted, while possible solutions to identified problems were provided.
5 Presentation of Results

5.1 Thermal Performance of PLEEC

Introduction

As explained in Section 4.2, data acquisition did not commence until November 26th, 2004 and ceased on June 2nd, 2005. There was also a substantial data gap in January and February, 2005. The following values assume that a full 24 hours of data were collected for each day; this was not always the case. There is therefore a small overestimate of the percentage of data collected.

Data from a total of approximately 111 days out of a possible 189 days (November 26th, 2004 to June 2nd, 2005) was collected (59%) during the study. However, if the data gap of 49 days in January and February are excluded, 79% of data was collected out of a possible 140 days. The original aim of the study however, was to obtain data for four months between September and December, 2004. If this were the only period available for data collection, data recovery would have only been 19%.

Difficulties with plotting the data were experienced because of the immense file sizes that resulted from the excessive, inflexible data acquisition described in Section 4.2. A computer with a minimum of 512 Megabytes (MB) of Random Access Memory (RAM) was required to process the larger data files, as 256 MB of RAM was insufficient.
Figures 5.1 to 5.4 represent the thermal performance of PLEEC under different climatic conditions at four different times of the year: late spring; early summer; early autumn and late autumn. Figures in Appendix C represent additional autumn data, while the remaining data and graphs may be found in Appendix D (an attached CD).

As stated in Subsection 4.2.4, there was a focus on the building temperatures during the hours when the Centre would be occupied. This was generally taken to be 08:00 to 22:00, as it is not uncommon for rooms to be occupied by customers renting a room after hours.

Late Spring Performance

Figure 5.1: PLEEC Temperatures – November 26 to 30, 2004
From November 26\textsuperscript{th} to the 30\textsuperscript{th}, 2004, all rooms were well within the range of human comfort, with the exception of the Administration Room which briefly reached 28\textdegree{}C during the late afternoon on the 27\textsuperscript{th} and 28\textsuperscript{th} of November.

The Administration Room was consistently hotter than the other rooms, while the Rotary Room was consistently cooler than the other rooms.

The maximum indoor temperature occurs several hours after the maximum outdoor temperature.

\textbf{Early Summer Performance}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure52.png}
\caption{PLEEC Temperatures – December 10 to 20, 2004}
\end{figure}
Although the maximum outdoor temperature on December 11th, 2004 was only about 23ºC, the maximum Administration Room temperature on the same day was about 29ºC.

Figure 5.2 illustrates that every room was uncomfortably hot in the late afternoon on December 14th, 2004. The worst level of thermal comfort was recorded in the Administration Room, with uncomfortably hot temperatures for a substantial amount of time every day from December 10th to December 20th, 2004. The Administration Room was consistently hotter than 28ºC for virtually three full days. The Administration Room was once again consistently hotter than the other rooms, while the Rotary Room was consistently cooler than the other rooms (although not significantly cooler than the Lottery Functions Room).

The time lag of about six to seven hours between the maximum outdoor and indoor temperatures during this period was considerable.
Early Autumn Performance

Figure 5.3: PLEEC Temperatures – March 20 to 28, 2005

An important feature of Figure 5.3 is that all rooms within the Centre experienced overheating from March 22\textsuperscript{nd} to 24\textsuperscript{th}, 2005. The Administration and Lottery Functions Rooms were overheated for virtually the first five days of this period, while the Rotary Room overheated on the 22\textsuperscript{nd}, 23\textsuperscript{rd} and 24\textsuperscript{th} of March, 2005. The maximum-recorded outdoor temperature of 41.8ºC occurred on March 23\textsuperscript{rd}.

A noteworthy feature on this graph is that the maximum Administration Room temperature on March 25\textsuperscript{th} was higher than 31ºC even though the maximum outdoor temperature on the same day was only just over 28ºC for a short period of time.
The time lag between the maximum outdoor and indoor temperatures was typically about four hours, while the Administration Room once again experienced higher temperatures than the other two rooms.

The temperature decline indoors during the early morning hours of March 24th to the 27th (see Figure 5.3) was minor considering the outdoor temperature was up to 6ºC lower than the indoor temperature. Under these conditions, the NV system did not operate because the outdoor temperature was greater than 20ºC.

Late Autumn Performance

![Figure 5.4: PLEEC Temperatures – May 24 to 30, 2005](image)
The minimum outdoor temperatures from May 24th to the 30th were less than 18ºC every night, with no outdoor daytime maximum greater than 28ºC.

The indoor temperatures were all within the range of human thermal comfort throughout the entire period. Both the Lottery Functions and Rotary Rooms experienced an unusual increase in temperature on the evening of May 25th.

With the exception of May 25th, the time lag for these dates was typically two hours or less, with some dates exhibiting very little time lag between the maximum outdoor and indoor temperatures.

**Minimum and Maximum Recorded Temperatures for All Data**

A summary of both the indoor and outdoor minimum and maximum temperatures recorded is presented in Table 5.1. The lack of cold temperatures is due to the absence of winter data.

<table>
<thead>
<tr>
<th></th>
<th>Rotary Room Temperature</th>
<th>Lottery Functions Room Temperature</th>
<th>Administration Room Temperature</th>
<th>Outdoor Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minimum</strong></td>
<td>18.2</td>
<td>19.7</td>
<td>18.3</td>
<td>9.0</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>30.5</td>
<td>30.8</td>
<td>32.9</td>
<td>41.8</td>
</tr>
</tbody>
</table>

*Table 5.1: Extreme Temperatures Recorded over Study Period (ºC)*
5.2 Residual Energy Demands

Electrical Appliances

There are various electrical appliances at PLEEC. The only devices that were evaluated in this report however, are those that were either tested by the joint industry/government energy-rating program, use a high amount of power, or could offer energy savings through a change in user operation or replacement by a more efficient device. At PLEEC, these included: a dishwasher, a refrigerator/freezer, a refrigerator, lighting, a microwave oven, several urns, four computer monitors, two heaters and the semi-active thermal control systems.

Kitchen Goods

The only devices in PLEEC for which there was a mandatory energy rating under the joint government and industry energy-rating program were the dishwasher, the refrigerator/freezer and the refrigerator. Both the dishwasher and refrigerator/freezer in the kitchen achieved a score of 1.5 out of a possible 6 stars. The additional refrigerator in the laboratory was of an age that predates the energy-rating program and Minimum Energy Performance Requirements for refrigerators that have been mandatory in Australia since October 1st, 1999. Therefore, it may be concluded that this appliance was at least two years old when the Centre was commissioned in November 2001.
Lighting

All of the lighting in the Centre was relatively low energy consuming fluorescent tube style, most of which were controlled by photoelectric sensors as described in Section 3.6 that were operational throughout this study. The lighting was also fitted with reflecting light boxes and diffusers to increase their overall efficiency.

Microwave Oven

The microwave oven had a 1000-Watt (W) rating. It is important to note that this rating is the power output of the device, whereas the power input was actually a maximum of 1450W.

Urns

PLEEC also had several electric urns that were used for hot beverage preparation. They were of varying sizes: 20L (2400W), 8L (1800W) and 1.7L (2200W).

Computer Monitors

There were a total of four computer monitors at the Centre, all of which were of the conventional type (cathode ray tube) up until June 2005. All of the monitors were manually turned off after hours to avoid standby (parasitic) power consumption, as were all of the computers other than the BMS computer.

1 The BMS workstation computer monitor was the only one that was replaced with a Liquid Crystal Display (LCD) monitor during the study.
Heaters

Two electric heaters were occasionally used at PLEEC. There was a resistive fan heater that was rated for a maximum of 2000W, although its operation was limited to the 1000W setting (by a note written on the fan in marker). The other heater was a 1000W resistive bar heater. The fan heater was only used to heat rooms prior to the arrival of visitors, not during the time when visitors were actually present. The bar heater was typically used by staff as a more direct source of personal heat.

Semi-Active Systems

The solar air heaters and the NV system described in Section 3.6 were both electrically operated.

Gas Usage

The only devices at PLEEC that used gas from the Liquefied Petroleum Gas (LPG) storage tanks were the stove/oven in the kitchen and the boosting system on the solar thermal hot water system.

5.3 Visitor Numbers

The PLEEC visitors represented in these results are only those that have been physically recorded, including customers. Therefore, the values presented are the minimum number of visitors to the Centre; the true total number of visitors was most certainly higher. A high
proportion of the total visitors recorded are those that attended booked events at the venue as opposed to walk-in visitors.

![Figure 5.5: Visitor Numbers – September 2001 to September 2005](image)

Over the 49 months of available data, a total of over 43,500 visitors were recorded, equating to an average of about 890 visitors per month.

There were three very noticeable peaks where the monthly number of visitors exceeded 2,500. These correspond to April 2002 (2751), March 2003 (2746) and November 2004 (2561) and are described in Chapter Six. The cumulative number of visitors has gradually risen over the four years since the Centre opened.
5.4 Qualitative Building Performance

5.4.1 Fulfilment of Objectives

PLEEC provides community access to an education and demonstration facility that covers a wide range of environmentally sustainable features. More extensive education programs will be launched in 2006; after the venue marketing that is currently being undertaken is completed.

Determining the degree of community awareness in energy efficient buildings was not possible in this study for reasons presented in Subsection 4.5.2.

Local environmental groups, non-profit organisations, community and church groups, staff from both local and state government as well as private organisations, companies and individuals use the Centre.

As part of the design philosophy, the PLEEC aimed to demonstrate how schools could function without air conditioning and thus be designed in the future, and also to reinforce the benefits of climate sensible design. In this respect, PLEEC has fallen short by regularly experiencing uncomfortably hot conditions during this study for reasons discussed in Chapter Six.
5.4.2 Building Operation and Maintenance

Operator training

Upon commencing the position, the Sustainable Development Educator only received very basic instructions over the course of about 15 minutes with regards to proper building operation (Hammond, P. 2004, pers. comm., 8 Sep.). This was certainly an insufficient amount of time dedicated to training the building manager on how to operate this unconventional building in its optimal state.

In March 2005, the new Sustainability Education Officer received training for a total of three days (one day with each of the previous three employees - only one of which was employed full time). He also reviewed the building manuals and the Education Officer’s Guide, as well as contacted various companies whose systems were installed at PLEEC to gain a better understanding of building operation (Marrison, M. 2005, pers. comm., 12 Oct.). However, some of the information provided to him was either wrong or only partially accurate, while other information was incomplete or missing. This was mainly caused by a lack of continuity in staffing and decentralised building reference information. Not one staff member had a complete understanding of the intricacies of the complete building operation.

There has generally been a lack of information regarding proper operation of the building provided to unsupervised users of the Centre that are present after hours. This is of particular importance
considering that their actions may affect the function and performance of the building. This has been realised by the Sustainability Education Officer who, at the time or writing, was providing face-to-face training to after hours hirers regarding building operation and also supplying them with ‘after hours user notes’ that cover building operation, troubleshooting and avenues for assistance (Marrison, M. 2005, pers. comm., 12 Oct.).

Building Maintenance

Maintenance issues were of particular concern during the transition of full time employees at the beginning of 2005 due to understaffing and lack of management. Many concerns were dealt with after the appointment of the full time Sustainability Education Officer in March.

Williams Electrical provided maintenance and technical support to a limited extent for PLEEC and staff. Siemens Building Technologies has rarely been hired\(^2\) to address issues related to the operation of the BMS. Several other companies are consulted to provide assistance with building support and maintenance.

Future Grid-Connection

Grid connection of PLEEC in the future is possible because of power limitations and power disruptions in the past. Additionally, the cost of a

\(^2\) Although Siemens Building Technologies was a Centre sponsor, they are not required to provide ongoing maintenance at no charge (see Section 5.4.3).
connection to the power grid would not be significantly higher than the cost of replacing the battery bank. Grid connection would provide unrestricted access to reliable electricity, relieving concerns over the limited power production and peak power use and hence the successful operation of the Centre. This would ensure that venue hire and customer satisfaction would not be affected by the SAPS limitations.

5.4.3 Building Management System

It was anticipated that the use of the BMS would become more sophisticated as the building users became more familiar with its operation and potential (Davis no date). In reality however, the opposite generally occurred, with users being unable to achieve the expected benefits from the BMS.

As mentioned in Section 4.2, there were both hardware and software issues with the BMS, resulting in sporadic problems with building functionality. An example of a more serious issue was a periodic loss of communication between the inverter, BMS and the generator. This resulted in a lack of response by the generator to start on the BMS’s demand, leading to power failures as well as excessive diesel consumption by the generator. Manual manipulation and close monitoring of systems was required in an attempt to ensure building integrity (Marrison 2005a). Although the reason for the loss of communication was still unknown at the time of writing, it had not occurred since the partial installation of new BMS infrastructure. Other
issues that arose from the power failures included disruptions to BMS controls such as ceiling fans, security lighting and the alarm system.

At the beginning of the study, the Sustainable Development Educator was informed by Siemens Building Technologies that the cost of an on-site visit to address BMS functionality issues would be approximately $1000. Likewise, when the BMS was experiencing problems in March 2005, Siemens Building Technologies was contacted and a price of over $3500 was quoted for a system upgrade. The upgrade did not occur at the time because the cost was over budget for the City of Melville.

Although a service call to address BMS issues was imminent in the middle of March, 2005, this was cancelled because upgrading of the BMS was approved at the beginning of April, 2005. When the upgrade was initiated and the BMS was disconnected at the beginning of June, 2005, MaxMon software was used on a different computer as a temporary means of providing building functionality. However, a number of problems were still not fully remedied during the BMS upgrade. These included: disruption to power supply and power failure, inefficient operation of building systems and reduced functionality of the venue (Marrison 2005b).

The contract for the new BMS was awarded to NRP Electrical Services, although it lacked a formal design brief in writing, nor were there any
guarantees with respect to the final date of completion or overall system performance. A phone call was received at PLEEC in the latter part of August 2005 from NRP inquiring about the BMS performance. This was about 10 weeks after the commencement of the installation. NRP had mistakenly thought that the system had been fully installed and operational. At the time of writing, the hardware upgrade appeared to be complete while the software installation remained unfinished. As a result of the lack of interface software, the new BMS had not yet been operational.
6 Interpretation of Results

6.1 Thermal Performance Evaluation

6.1.1 Building Performance

Late Spring Performance

It was no surprise that the building virtually remained within the thermal comfort conditions during the period shown in Figure 5.1; this was because the outdoor temperature also remained within the comfort range (during the occupancy time frame).

The Administration Room was consistently hotter than the other rooms, while the Rotary Room was consistently cooler than the other rooms. This is because the Administration Room has significantly more northerly glazing and lack of an earth berm, while the Rotary and Lottery Functions Rooms have much less northerly glazing and protection from the earth berm.

The time lag between maximum outdoor and indoor temperatures was due to the thermal inertia inherent within the building as a result of the massive structure.

Early Summer Performance

The Administration Room was uncomfortably hot on December 11\textsuperscript{th}, 2004 even though the maximum outdoor temperature was only about
23°C. Two main factors contributed to this: there was a significant amount of heat stored in the thermal mass of the building from hotter days that preceded this occurrence; and the NV would not have been active. In this case, the large thermal mass actually had an adverse effect and worked against achieving thermal comfort conditions.

The NV would not have been operating during the early morning of December 14\textsuperscript{th}, 2004 because the outdoor temperature did not fall below 20°C (see Section 4.2). This was the likely cause for the uncomfortable thermal conditions in every room during the late afternoon on the same day (see Figure 5.2). Additionally, the overnight temperature for the following two days was also warm, leading to insufficient operation of the NV system.

The substantial time lag between the maximum outdoor and indoor temperatures was due to the heat transfer through the building envelope that must occur before it reaches maximum temperature. Additionally, paved urban areas absorb up to 85% of the incident solar radiation, with this radiation eventually emitted as sensible heat (Emmanuel 2005). Although PLEEC is not set in an entirely paved, urban area, there are paved areas to the north side of the building that would emit sensible heat at the end of the day.

It is presumed that overheating of the Centre was common during January and February, when no data was available, as these months
are characterised as having the highest monthly average temperatures throughout the year (see Table 3.1) and the NV system would not have been operational for much of the time because the overnight temperatures are regularly higher than the set point on the BMS.

**Early Autumn Performance**

An important fact to consider for this period in Figure 5.3 is that the minimum outdoor temperature was not less than 20ºC for the entire period with the exception of between approximately 02:00 and 07:00 on March 23rd, 2005. As a result, substantial overheating occurred in all rooms for several days. This was also evident on March 25th, when the maximum outdoor temperature was just marginally over 28ºC for a brief period of time, yet the maximum Administration Room temperature was over 31ºC on the same day. This demonstrates how the thermal mass can have a negative effect on the thermal condition of the building because of the massive amount of heat stored in the building fabric.

The slow temperature decline during the early morning hours of March 24th to the 27th was indicative of the lack of NV because the outdoor temperature was up to 6ºC lower than the indoor. This relatively large temperature gradient should have led to greater indoor cooling.
Late Autumn Performance

Ideal conditions were seen during this period in Figure 5.4, with indoor temperatures staying within the range of human comfort at all times despite the fact that outdoor temperatures reached below 12ºC at one point. These comfortable indoor conditions resulted from the moderate outdoor daily temperatures combined with solar gain.

Upon investigation of the building activity, the unusual temperature rise in both the Lottery Functions and Rotary Rooms on May 25th was due to an information evening that had an attendance of about 60 people. The internal heat load of about 6000W is very evident; it actually caused a temperature rise of up to 2ºC in the Lottery Functions Room.

A possible explanation for the rapid thermal response of the building (short time lag) during this period could be that windows may have been open, as the indoor air temperature would mimic the outdoor temperature much more closely with a high rate of infiltration. Having open windows during this period is very plausible considering that the outdoor temperature was comfortable when the Centre was occupied.

6.1.2 Additional Comments

Generalisations

Overheating of Centre
The interior of the Centre frequently experienced uncomfortable temperatures during hot weather, and even overheated on days with
comfortable outdoor temperatures. The full benefit of the NV system was not realised because it did not operate on many nights given that the outdoor temperature was not below 20°C. This lack of hot air purging from the thermal mass overnight led to elevated temperatures within the building during the next day. Under this dysfunctional NV system operating regime, the large thermal mass actually had a detrimental effect on the thermal performance of the building. Significant cooling could have been achieved with outdoor temperatures above 20°C, as long as the temperature difference between the interior and exterior was appreciable, and the set points in the BMS were changed to permit operation of the NV system under these conditions.

_Time Lag_

The time lag between the maximum outdoor and indoor temperatures was greatest at times when the outdoor temperature rose rapidly. This was likely enhanced by having the doors and windows closed to reduce heat infiltration into the Centre. The time lag is caused by the thermal inertia inherent within the massive structure of the building.

The time lag was short at times of comfortable outdoor temperatures, when windows were likely opened for fresh air. This allowed indoor and outdoor temperatures to mimic one another due to rapid air exchange.
Occupant Behaviour

The operation of passive solar buildings requires active occupant participation to optimise their performance. However, behaviour control of indoor conditions has been considered to be a weakness in free-running buildings because the actions of building occupants are beyond the control of building designers and it is felt that there is a danger that controls will not be used optimally from an energy standpoint (Bruant et al., 1996, quoted in Santamouris 2003). Filippin et al. (2005) have reported that the benefits of an energy-saving building design can be easily lost due to human mis-management of the whole dwelling.

Nicol and Humphreys (2002: 564) (quoted in Emmanuel 2005) state that the fundamental assumption of the adaptive approach is expressed thus: “If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort”. This would include such actions as opening a door or window, drawing blinds or using a fan. It is probable that the thermal performance of the building during the study period was influenced by adaptive actions by the occupants.

Incorrect building operation may not always be evident; opening the blinds at night time in the winter or having them closed at night time during the summer are unfavourable practices. These actions would increase heat loss from the building in the winter and reduce heat loss from the building in the summer.
Landscape Design

The surrounding landscape affects the thermal performance of PLEEC, as the site characteristics and type of land cover influences the adjacent microclimate. For this reason, landscape design and development was part of the initial PLEEC design process.

Vegetation provides relief from solar radiation by shading, absorption of radiation and evaporation. A tree shading a window can reduce a room’s temperature by up to 12ºC (SEAV no date). Even an isolated tree can transpire up to 379 litres of water per day (Kramer and Kozlowski, 1960, quoted in Emmanuel 2005). This vapourisation can be equivalent to the cooling provided by five 5800W/m² air conditioners running 20 hours per day (Federer 1971, quoted in Emmanuel 2005).

In a study of a passive solar building in central Argentina, Filippín et al. (2005) speculated that the effect of high outdoor temperatures causing undesired heating of the building envelope would have been attenuated by well-established surrounding vegetation and plant coverage.

The original design brief integrated significantly more vegetation around PLEEC than there was during this study, particularly on the northeast side of the building (Baverstock, G. 2004, pers. comm., 21 Oct.). The lack of vegetation on the northeast side of the building contributes to the consistently higher temperatures recorded in the Administration Room.
6.2 Residual Energy Demands

Electrical Appliances

Kitchen Goods

The energy rating of the dishwasher, refrigerator/freezer and the additional refrigerator were extremely poor. Considering the two energy rated appliances only achieved 1.5 out of 6 stars, there is great potential for improvement in their efficiency. Furthermore, the energy consumption of the refrigerator in the laboratory was undoubtedly high, since it predates mandatory energy efficiency labelling.

These appliances with poor energy efficiencies are detrimental to the demonstration of this energy efficient building because the clearly visible stickers indicate their low standard.

Highly energy efficient appliances with a 6 out of 6 star rating should have been installed during the commissioning of the building. This is especially true in view of the fact that the relative cost of energy efficient appliances compared to the overall cost of the building construction is very small. Furthermore, PLEEC has a SAPS whereby a primary goal should be to use electricity in the most efficient way that is practically possible in order to permit the installation of the smallest feasible system in order to minimise system costs. Moreover, the repairs in August 2005 to the dishwasher that were in excess of $500 should have been put towards the purchase of a new, energy efficient dishwasher.
Lighting

The fluorescent lighting, reflecting light boxes and diffusers with photoelectric control are much more efficient than conventional lighting. An opportunity does exist however, to demonstrate even more energy efficient, state-of-the-art Light Emitting Diode (LED) lighting.

Microwave Oven

Energy ratings for microwave ovens are not compulsory. The microwave oven at PLEEC has a peak power consumption of 1450W; perhaps a model with a lower peak power consumption should have been chosen.

Urns

The fact that there are urns of three different sizes can assist in the promotion of energy efficiency. This may be accomplished by preventing an unnecessary, excessive amount of water from being boiled by limiting the size of the urn in relation to the amount of water needed.

An opportunity exists to eliminate the urn with the smallest volume (1.7L – 2200W) whose power consumption is actually higher than the 8L urn (1800W) and use the LPG-powered stove instead. In terms of primary energy consumption, boiling water with a gas-powered stove is more efficient than using electricity. In the case of PLEEC, the electricity is...
generated by renewable means and is therefore expensive. In a grid-connected system, there are significant losses inherent in the generation and transmission of electricity. Eliminating the small urn may not be very effective however, because most people are used to boiling water in a short period of time using a high power urn and they may therefore resort to using the 8L urn with more water to achieve this result if the 1.7L urn is unavailable.

**Computer Monitors**

It was determined that the LCD BMS monitor uses 72% less energy (168W) than the conventional (600W), remaining monitors. Although upgrading the BMS monitor to LCD was a step in the right direction, an opportunity exists to increase energy efficiency by replacing the remaining three monitors with LCD models as well. Turning off the monitors manually after hours is an excellent way to avoid standby (parasitic) power consumption. Moreover, ensuring that all computers are turned off after business hours, except for the BMS computer, which stays on for building functionality, helps to conserve electricity.

**Heaters**

Although the two heaters at PLEEC were only used intermittently during the winter, resistive electric heaters are extremely inefficient when viewed in the broader context for reasons previously mentioned relating to generating heat with electricity. Although a conscious effort was
made to refrain from using the heaters in the presence of visitors, this does not take away from the fact that their use is inappropriate in a climate sensible, energy efficient demonstration building.

**Semi-Active Systems**

Contrary to the resistive heaters, the solar air heaters and the NV system are much more efficient users of electricity because of their ability to transfer a significant amount of energy into or out of the building envelope.

**Gas Usage**

In terms of primary energy consumption, the use of LPG for the kitchen range and solar thermal hot water booster rather than electricity is more efficient for reasons previously explained.

**6.3 Visitor Numbers**

The low number of walk-in visitors (see Figure 5.5) reflects a lack of publicity and promotion of the venue as well as any structured educational information at the Centre (Marrison 2005c).

The three months that saw a much greater number of visitors than usual were April 2002, March 2003 and November 2004. Due to lack of information and resources, the reason behind the very high visitor
numbers in April 2002 and March 2003 cannot be ascertained. The Environment Festival ‘Envirofest’ (November 20-21) was responsible for the high number of visitors to PLEEC in November 2004, accounting for around 60% of total visitors in that month.

Overall, visitor numbers fluctuate on a regular basis and are heavily influenced by venue hire. Since many recorded visitors are simply attending the Centre for organised events, it cannot be assumed that the number of recorded visitors truly reflects the number of people who have actually gained information from the building itself.

6.4 Qualitative Building Evaluation

6.4.1 Evaluation of PLEEC Objectives

It is presumed that there is currently a generally low level of widespread community awareness about energy efficient buildings, with the exception perhaps of energy efficient appliances. The sustainable technology education and demonstration facility that PLEEC provides can be very beneficial in enhancing the level of awareness and education in the community about important environmental issues. It is human nature however, for society to have a resistance to change when it comes to accepting new technologies with an associated unfamiliarity. It is therefore highly desirable to ensure that a demonstration such as PLEEC is operated at optimum performance to promote acceptance through more realised benefits.
It is very difficult to determine the actual number of people who have been inspired by the Centre and implemented more energy efficient features and/or alternative construction methods into their own home as a result of visiting PLEEC.

In terms of providing a base and resource centre for local environmental groups, PLEEC has succeeded. There are many other groups of people mentioned in Section 5.4.1 that use the Centre.

The development of more extensive education programs will enhance community knowledge of sustainable issues, while the marketing of the Centre will increase visitor numbers.

The fact that PLEEC regularly experienced uncomfortably hot conditions over the summer of 2004/2005 appears to suggest that schools would not be able to function without air conditioning. However, it must be duly noted that the NV system was not operating under optimum conditions throughout this study and that the thermal condition of the building would have particularly suffered as a result. Furthermore, as acknowledged in Section 3.3, the study done by Baverstock (2002) concluded that schools in temperate climates of WA below 20ºS latitude could function without air-conditioning.
6.4.2 Building Operation and Maintenance

Operator Training

Considerable training and support relating to building operation and performance should be provided at the commencement of any new full time position being filled at PLEEC. Additionally, part time staff and volunteers should also receive training. Ongoing support as well as a centralised source of building information should be maintained to address any queries that arise with regards to Centre operation.

Face-to-face training of after hours users, as well as the provision of the ‘after hours users notes’ will undoubtedly improve the performance of the building.

Building Monitoring and Maintenance

According to the International Council for Local Environmental Initiatives (ICLEI) (2001), energy savings in buildings have a tendency to be lost over time as good energy management practices are overtaken by other priorities. Regular monitoring and reviewing of the results however, is a certain way of managing this dilemma and could be undertaken at PLEEC through proper operation of the BMS.

The BMS could act as an aid to provide more effective and efficient maintenance by monitoring run-times and conditions of components to produce computerised planning of maintenance schedules (The Royal
Institute of International Affairs 1992). This would permit better use of maintenance resources, while also supporting fault diagnosis.

Although modern electronic components are renowned for their very high reliability, faults can still occur. Given that electrical components govern and operate many of the systems at PLEEC, faults affecting the functionality of the systems may arise without warning or indication. Taking into account the fact that PLEEC is a demonstration building, it is imperative that it receives ongoing maintenance to detect any faults to ensure optimal functionality.

Ideally, ongoing support should be provided by the installers at little or no cost because of the demonstrative nature of the Centre. A simple arrangement that would encourage proficient building operation would be through a maintenance contract with the equipment supplier, with cost based on a fixed percentage of the initial capital cost.

**Future Grid-Connection**

Although connection to the power grid would offer a more reliable source of unlimited power and improve venue operation, it must be noted that the facility is unique because of its autonomous nature. As such, the Centre should be able to demonstrate its independence through a capability to operate in stand-alone mode if grid-connection does occur. Alternatively, with proper maintenance and management of the new BMS once it is installed, grid-connection should not be justified
because all essential loads were taken into consideration during the load analysis of the power supply design stage.

### 6.4.3 Building Management System

Energy management technology is of limited value in itself; it requires a close interaction with the people responsible for its operation and regular maintenance if optimum long-term performance is to be achieved (The Royal Institute of International Affairs 1992). The lack of proficient BMS operation at PLEEC was probably due to inadequate maintenance and management of the system, thus eventually leading to the unsatisfactory operation and performance of the building. A major obstacle to proper maintenance of the system was the costs incurred for service calls.

The submission of a formal design brief prior to the installation of the new BMS would have likely led to a more organised and proficient installation. A guaranteed installation and commissioning date, along with improved communication between NRP employees as well as ongoing technical support would have greatly improved the installation of the upgraded BMS, and hence the functionality of the Centre.

### 6.5 Significance of the Results

Throughout this study, many difficulties and inefficiencies relating to the overall operation of the building were experienced. This study has
determined that PLEEC requires active, knowledgeable participation by the users as well as regular maintenance to optimise the building performance and ensure its integrity.

The effectiveness of the NV system was not properly evaluated due to its decreased operability that resulted from the inflexible parameters in the BMS that control it. Altering the NV set points to allow for increased operation would reduce the overheating occurrences. For example, raising the maximum outdoor temperature at which the system will activate from 20°C to 24°C, or permitting the NV to operate as long as the outdoor temperature is 2°C lower than the internal temperature (from October to March) would accomplish this.

Although the Centre frequently overheated in the summer because of inadequate NV operation and possible incorrect occupant behaviour, it was evident that the thermal mass offered significant buffering capability against extreme temperature swings. The maximum-recorded outdoor temperature was 41.8°C, while the maximum-recorded indoor temperature was 32.9°C. Likewise, the minimum-recorded outdoor temperature was 9.0°C while the minimum-recorded indoor temperature was 18.2°C (see Table 5.1).

Conversely, there were occasions whereby the Centre was hotter in the summer than it should have been on relatively cool days because of the heat stored in the thermal mass that was accumulated during a
previously hot period. This demonstrates that if a building with significant thermal mass is not operated properly, unfavourable thermal conditions may transpire.

The Administration Room was consistently hotter throughout most of the study period than the other two rooms that were monitored. The higher levels of glazing in this room as well as the absence of earth berm protection and sufficient vegetation are all factors that contributed to this unequal heat distribution.

PLEEC does not meet the requirement of an energy efficient building with respect to residual energy demands. The exceptions to this are the semi-active NV system and solar air heaters, as well as the lighting.

The low number of walk-in visitors reflects a lack of publicity and promotion of the venue as well as any structured educational information at the Centre (Marrison 2005c).

PLEEC provides a sustainable technology education and demonstration facility that can offer an increased level of awareness and education in the community about important environmental issues, including energy efficiency. This type of facility is very beneficial for the adoption of energy efficient practices because of its ability to demonstrate the benefits that may be realised from these practices. This reduces the perceived risk by society to invest in new technologies.
The BMS was a major source of problems relating to building functionality, mainly as a result of insufficient maintenance and upgrading. Unfortunately, at the time of writing, the overdue upgrading of the BMS and its associated difficulties had not provided much support for improvement.

6.6 Limitations of the Study

Temporal Limitations

Many aspects of the study results are temporally limited in that they only focus on events during the study period: from the end of 2004 to the middle of 2005.

The results from the thermal performance evaluation of the Centre are not only limited to the study period, they also suffer from an incomplete data set within the period. There is no evaluation of the thermal performance of PLEEC in the winter season.

The evaluation of the operation and maintenance of the building, as well as the assessment of the BMS performance is also limited to the study period, as details of past activity were unavailable.
Thermal Performance Evaluation

Night Ventilation

The limited function of the NV system throughout the study prevented a proper evaluation of its effectiveness in maintaining thermal comfort conditions.

Solar Air Heaters

This study does not include a performance evaluation of the solar air heaters because of the lack of winter data and an inability to log parameters related to the operation of the solar air heaters, combined with the faulty air velocity sensor.

Ceiling Fans

Ceiling fan operation information was not possible to log from the BMS due the nature of their manual control. Ceiling-mounted fans can subjectively reduce the internal air temperature of a building by up to 3°C (Hyde 2000). Since the thermal performance evaluation has not taken into account ceiling fan operation, it is limited to the overall thermal performance of the building and not specific areas where people may obtain reprieve through the use of a ceiling fan.
Occupant Behaviour

The results of the thermal performance evaluation are limited because of the inability to incorporate specific details of occupant behaviour and their corresponding influence on thermal performance. This includes namely the opening and closing of doors and windows and the operation of blinds.

The number of visitors also plays a role in the thermal performance because of the heat load created by living bodies.

Visitor Numbers

The numbers of visitors presented were only those that have been physically recorded and do not accurately reflect the true number of visitors, which would most certainly be higher.

Public Awareness

It was not possible to determine how effective PLEEC has been at raising the level of public awareness for energy efficient buildings because of the rejection of the community awareness survey by the Human Research Ethics Committee (see Subsection 4.5.2).
7 Conclusion

7.1 Summary

This research project evaluated the effectiveness of PLEEC as an energy efficient demonstration building three to four years after its commissioning in 2001.

A multidisciplinary evaluation of the thermal performance of the Centre, its residual energy demands, visitor numbers, objectives, operation and maintenance regime as well as BMS was conducted.

Several difficulties described in Section 4.2 led to a lack of a complete data set throughout the study period. Regardless, enough data was collected to conclude that the Centre frequently overheated during the summer time. Substandard NV operation and a lack of surrounding vegetation were largely responsible for the regular overheating of the building. Incorrect user operation was also an influencing factor over the thermal performance of the building. Given these facts, there are opportunities for improvement in the thermal performance of the Centre.

Several of the appliances and equipment used to meet the residual energy demands at PLEEC did not meet the requirements of an energy efficient building. Upgrading this equipment to maximise the energy efficiency of the residual energy demands is very plausible and highly recommended.
PLEEC provides a unique sustainable technology education and demonstration facility that can offer an increased level of awareness and education in the community about important environmental issues, including energy efficiency.

The BMS requires special attention because of the dependence of so many of the building’s systems on its reliable functionality. This warrants the establishment of a dedicated maintenance and management regime for the BMS, including the ability to alter the set points as needed.

This study has determined that PLEEC requires active, knowledgeable participation by the users as well as regular maintenance to optimise the building’s performance, thus ensuring its integrity.

Demonstrating the performance, feasibility, practicality and desirability of energy efficient buildings to the general public, industry, utilities and governments, combined with information dissemination, promotion and marketing should advance the widespread adoption of energy efficient buildings.
7.2 Recommendations

Improve NV System Operation

It is strongly recommended that the operational parameters of the NV system be changed because under the current regime there are too many summer nights when it will not operate.

Instead of the outdoor temperature having to be less than 20ºC, it should only have to be less than about 24ºC, with the indoor temperature above about 26ºC. This would permit summer time operation of the NV system at night so long as the outdoor temperature was reasonably cooler than the interior of the building. Alternatively, the NV system could be set to run in the summer under the circumstance that the indoor temperature is simply 2ºC higher than the outdoor temperature. It is recommended that the indoor temperature be at least 2ºC higher than the outdoor temperature not only because any less would provide minimal benefits with the same level of power consumption, but also to account for errors in the sensors over time.

It should be confirmed that the volumetric flow rate of the NV system complies with the design requirement of 15 air changes per hour, since this will influence the degree of heat exchange with the outdoors and effectiveness of the NV system.
Ensure Proper Building Operation

It is recommended that a simple, yet comprehensive and accurate building operator’s guide be produced to ensure proper building operation by users and also to provide a troubleshooting matrix. This will particularly work to assist users at times of minimal staff support.

The appointment of a regular maintenance contractor or engineer to PLEEC would greatly improve the functionality and performance of the building and its systems. In particular, the effectiveness of the solar air heaters has not been adequately addressed in this study.

Regular communication and cooperation between building operators, the City of Melville, installation and/or maintenance companies as well as research institutions would improve the success of PLEEC as an energy efficient demonstration building. This is particularly important in relation to PLEEC because of the relative unfamiliarity with its state-of-the-art design and operational techniques.

The suburban location of PLEEC allows for rapid solutions to problems at minimal cost relative to many other (particularly renewable energy) demonstration projects in remote areas.

Since the BMS acts as a control centre, its proper operation is vital to guarantee ideal building performance and hence deserves special attention. The BMS hardware and software must be kept up to date.
and maintained to guard against the type of difficulties encountered in this study and problems experienced by the Centre.

Regular up-keep of the BMS should be provided through the negotiation of a maintenance contract with NRP Electrical Services to provide service for a cost based on a fixed percentage of the initial capital cost. Ensuring proper operation of the BMS should also prevent the need for grid-connection through increased efficiency of power use.

The BMS could be used more effectively to assist with monitoring, fault diagnosis and maintenance of the building if it included closer links with its users and any regular maintenance program. Fault diagnosis by the BMS would improve the system performance by allowing more rapid problem solving, likely with less technical expertise.

Since PLEEC is an energy efficient demonstration building, optimal functionality and maximum visitor satisfaction is highly desirable because negative experiences tend to be remembered and would be unfavourable towards the acceptance of energy efficient buildings.

**Increase Efficiency of Residual Energy Demand**

The dishwasher, refrigerator and refrigerator/freezer should all be upgraded to appliances with maximum energy efficiency ratings.
The efficiency of the remaining computer monitors should be improved by replacing them with LCD monitors.

Although convenience would be sacrificed, eliminating the smallest urn and using the gas stove to boil small amounts of water would increase the overall primary energy efficiency. Likewise, gas or wood heaters should replace the electric heaters if this kind of supplementary heating were absolutely necessary.

**Landscaping**

Proper landscaping as per the original design should be undertaken to improve the thermal performance of the building. This would not only improve the overall thermal comfort of the Centre, but also create a better working environment for staff by reducing the degree to which the Administration Room overheats during the summer time.

**Maintain Building Technology Innovation**

According to Balcomb (1992), demonstration projects have proven to be an effective way to develop and disseminate knowledge on innovative passive system integration concepts and also that they should be tied to the latest advances. PLEEC should keep pace with advancing technology and evolve to meet future needs. As an example, PLEEC could demonstrate LED lighting, as this appears to be a very promising, energy efficient technology.
The objectives of PLEEC should also be amended to account for the overall steady uptake of technological advancements by society. This will ensure that the Centre maintains its role of demonstrating state-of-the-art technology and principles.

**Community Awareness**

In some respects, any publicity is good publicity. Increased awareness of energy efficient buildings can encourage their acceptance in the marketplace. Mechanisms to increase awareness include advertising through newsletters, newspapers, magazines, radio and television as well as on the Internet.

Incorporating PLEEC into the website (Government of WA 2004-2005) and brochures for ‘Sustainable Living in Western Australia’, through the Sustainability Policy Unit of the State Government would help to increase awareness.

Furthermore, a large promotional sign at the entrance to the PLEEC off Leach Highway (a major highway) that highlights its energy efficiency and renewable energy nature would help to increase awareness.

**Increased Education**

There is no doubt that the education of energy efficient practices and subsequent technology transfer to the broader community is a difficult
challenge. In this respect, PLEEC presents an opportunity to enhance the level of education through promotion of energy efficient practices. The energy efficient demonstration of the building should not be merely technical, but also institutional, legal, social, regulatory, and skills related. PLEEC should be used as a public resource and focus for: students, government, industry and media to promote learning on the subject of energy efficient buildings.

PLEEC could carry an environmental label that incorporates several performance parameters of the building as a means to provide visitors with information on the energy efficiency of the building as well as other positive attributes.

Information on the building’s performance should be displayed in real time on a dedicated website, enabling global exposure to the performance of PLEEC as well as information dissemination. Building information for visitors to the Centre should also be provided as part of the BMS upgrade. This could include displaying, in real time in a visible area, performance indicators such as indoor and outdoor temperatures.

Expansion of the PLEEC information on the Sustainable Energy Development Office (SEDO) website (Government of WA 2005) beyond just the renewable power generation aspect to include the additional energy efficient features it has to offer would inform people that the
principles of energy efficient buildings are not limited to relatively expensive renewable power generation.

There are visits by schools and other community groups as well as tours that partake in education programs at PLEEC. However, many visitors do not receive information relating to the energy efficiency of the building, often because the programme they are involved in does not cover those aspects. Increased inclusion of the energy efficiency features of the building into various education programmes would increase local community education. Participation in the education programmes should be increased through promotion and marketing.

It is a goal of the Sustainability Education Officer to set up interpretive signs around and within the building as well as increase the availability of information available in the building's foyer in order to help visitors gain a better understanding of energy efficient principles and to encourage acceptance. This is strongly encouraged and recommended to increase the level of community education.

**Research and Reporting**

There is an opportunity for an element of research under real-use conditions to be included in the objectives of PLEEC through a monitoring and reporting programme of the building’s overall performance. A remote access terminal would provide a means of simple data acquisition and fault diagnosis.
Demonstration projects are often government funded to prove the viability of a particular technology because of the reluctance of society to engage in a perceived risky investment in something they are unfamiliar with. In this respect, PLEEC should be able to prove its long-term performance and viability to stimulate more widespread acceptance of energy efficient building practices by effectively informing society of the potential benefits that are on offer.

There is currently a protocol that is internationally accepted as the standard for monitoring and evaluating energy savings, entitled *The International Performance Measurement and Verification Protocol* (IPMVP) (http://www.ipmvp.org/). This protocol is a set of framework documents that are used to: develop a measurement and verification strategy and plan for quantifying energy savings; and quantify emissions reductions and monitor indoor environmental quality. This would permit an accurate performance evaluation of the Centre.

In terms of conducting a more extensive thermal performance assessment, temperature, humidity and indoor air speed should be measured. Adherence to a Standard such as ASTM E1464-92 (2005) would provide credible thermal evaluation results that could be shared amongst a wide range of parties to further enhance the expertise in building design and operation. PLEEC could even provide a contribution into the development of new Standards.
Other attributes that should be measured to assess the building’s performance include user satisfaction, the visual environment (levels of illuminance and glare), noise levels, as well as indoor air quality measurements that take account of CO₂ concentrations and levels of other compounds such as Volatile Organic Compounds (VOC's).

Grid-connection should not proceed in an effort to preserve this unique off-grid demonstration as well as to conduct research in the stand-alone mode. This is particularly relevant because many SAPS are in remote areas where monitoring and research is difficult to conduct. In the case of grid-connection the facility should, at the very least, be able to switch to stand alone mode for demonstration and research purposes.

The close proximity of PLEEC to Murdoch University should encourage further research through its Energy Studies and Renewable Energy Engineering Programmes, thus contributing to learning development through dissemination of study results.

Demonstrating the performance, feasibility, practicality and desirability of energy efficient buildings to the general public, industry, utilities and governments, combined with information dissemination, promotion and marketing should advance the widespread adoption of energy efficient buildings.
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APPENDIX A

Photographs of PLEEC

Figure A-1: North view of PLEEC

Figure A-2: South view of PLEEC
Figure A-3: PLEEC - Administration Room

Figure A-4: PLEEC - Lottery Functions Room
Figure A-5: Rotary Room of PLEEC
APPENDIX B

Operation of the Hisamatsu Assman: MR-70 Motor-Driven Psychrometer

Assman’s Psychrometer is an instrument that has two thermometers placed in a frame with a ventilator on top. The two bulbs are installed in a double cylinder to prevent them from being affected by the direct rays of the sun.

Running the fan of the ventilator at the top causes air to be sucked through the double cylinder at a rate of more than 3.5 metres per second. Approximately three minutes after the start of the fan, read the dry and wet bulb temperatures and complete your calculation by using a psychrometric chart.

How to use it:
1. First screw out the cylinders in which the wet bulbs are installed with gauze around and pour water on the gauze with a syringe and then screw the cylinders back in.
2. Switch on the motor so that the fan starts revolving.
3. Set the psychrometer in the desired place.
4. After three minutes of the fan revolving, read the dry and wet bulb temperatures to find out the exact relative humidity value with a psychrometric chart.
APPENDIX C

Supplementary PLEEC Temperatures – Autumn 2005

Figure C-1: PLEEC Temperatures – March 3 to 11, 2005

Figure C-2: PLEEC Temperatures – April 11 to 18, 2005
APPENDIX D

See attached CD – additional data and graphs