Abstract. The buildings sector accounts for 24% of Australia’s indirect Greenhouse Gas (GHG) emissions. Due to the life expectancy of existing building stock the greatest reduction in emissions before 2030 could be achieved through retrofits. Research in the past has shown that energy consumption in commercial buildings is complex and diverse due to the wide range of building fabrics and mechanical systems employed. Typically, the most effective energy saving strategies in commercial buildings have been in improving the heating, ventilation and air-conditioning (HVAC) design and efficiency, including improving the efficiency of chillers and heat pumps, and design strategies such as efficient mechanical ventilation systems, night purges, thermal mass and daylighting. This paper investigates and evaluates the energy performance of four commercial case study buildings with heritage values with various retrofit options in different climatic conditions in Australia. The paper explored the use of thermal and airflow modeling in assisting to understand the impacts of various retrofit options unto the energy efficiency of the case study buildings. The findings suggest different retrofit options that should be considered for achieving optimum energy efficiency impacts for existing buildings in Australia.

1. Introduction
The building sector in Australia accounts for 19% of total national energy consumption and around 23% of greenhouse gas emissions [1]. In 2008-09, Australia’s electricity consumption was 260,965 Gigawatt hours (GWh). Commercial and residential buildings constituted about 13% of this overall consumption [2]. The Centre for International Economics has noted that energy end use for commercial the sector has nearly tripled since the 1970s globally. Office buildings contributed to approximately 27% of the total commercial sectors greenhouse gas emissions during a similar period [3].

There are a number of researchers investigating the need for more comprehensive information on existing non-domestic building typology, distribution and energy use in order to gain better understanding of the existing building stock’s energy use for future policy formulation [4]. Research has shown that energy consumption in commercial buildings is complex and diverse due to the wide range of building fabrics and mechanical systems employed.

The Australian Government has adopted a proactive approach in conserving heritage buildings to maintain a sense of community identity. From a socio-economic standpoint, heritage conservation has the potential to nurture the cultural character of a community, provide opportunities for education and
interpretation, and even increase the economic value of property. Smith [5] explains that heritage conservation extends beyond conservation efforts to only protect the heritage property. Smith suggests that conservation must eventually increase community enjoyment of the heritage property without further deterioration in its current condition.

Rehabilitation of existing buildings provides many environmental and community benefits including maintenance of historical and architectural integrity, revitalising urban areas and avoiding negative environmental impacts and unnecessary consumption of materials and energy [6]. According to Bulleen [7], “reuse can create valuable community resources from unproductive property, substantially reduce land acquisition and construction costs, revitalize existing neighbourhoods, and help control sprawl.” The adaptation and rehabilitation of existing buildings has the potential to extend the useful life of the existing building stock and help reduce overall environmental impact by lowering raw material consumption and attendant pollution associated with the construction of new buildings.

This paper investigates and evaluates the energy performance of four case study buildings with various retrofit options in different climatic conditions in Australia.

2. Research methods
Four case study buildings are selected from buildings constructed between the 1870s and the 1960s, and they include a small cross section of building archetypes commonly found in most states and territories of Australia. In identifying suitable case studies, efforts were made to select buildings that were intact without extensive alterations, but unaltered examples are not common, and most of the selected buildings have gone through some form of alteration and/or extension. A summary of case study building characteristics is presented in Table 1.

### Table 1 Case study building characteristics

| Building Characteristics | Gross Floor Area | Net Lettable Area | Functional efficiency* | Building Characteristics |
|--------------------------|------------------|-------------------|------------------------|--------------------------|
| AMP, Townsville          | 1930s            | 1,289 m²          | 915 m²                 | 71%                      |
| Treasury, Melbourne      | 1960s            | 11,127 m²         | 9,382 m²               | 84%                      |
| Old Attorney General, Adelaide | 1900's    | 1,195 m²          | 894 m²                 | 75%                      |
| Lands Department, Sydney | 1870s            | 13,998 m²         | 7,470 m²               | 53%                      |

* Functional efficiency refers to the ratio of net floor area to gross floor area.

Sixteen intervention strategies were applied to each of the four case study buildings considered that aimed to improve operational energy efficiency. Interventions included changes to the building fabric, occupant behaviour, hot water supply and the heating, ventilation and air-conditioning (HVAC) system are applied. Tables 2 and 3 show the building interventions considered in the research.

Each of the case study building owners were surveyed to provide key information regarding building operation, geometry, materials and energy use. The annual energy (both gas and electricity) demand of all four case study buildings before and after interventions was modelled using the building simulation software tool IESVE for Engineers. This software assesses the building as a complete system, i.e. the location and orientation, the characteristics of the built form, the type and efficiencies of the heating, cooling and hot water systems, the fuel types used, as well as the energy demand and heat gains from lighting and office equipment. The results from these simulations were used to estimate energy use for each building considered, under each intervention scenario. The operational energy consumption loads
considered are heating, ventilation and air conditioning (HVAC), lighting, lifts, office equipment and hot water. Operational energy use (natural gas and electricity) for each case study building in the base condition was estimated using the National Australian Built Environment Rating System (NABERS). For the operational energy usage, the case study buildings are remodelled in eight capital cities in Australia to compare the energy impacts under various climatic conditions.

| Table 2 Building interventions considered |
| --- |
| **Type** | **No.** | **Interventions** | **Description** |
| Building Envelope | 1 | Sealing | Window s sealed to reduce air infiltration from 0.35 ACH to 0.25 ACH. |
| | 2 | Roof insulation | Roof insulation added when not installed and increased if present. |
| | 3 | Windows: low-e film | Low emissivity film added to existing glass panes. |
| | 4 | Windows: Soft plastic film | Insulating soft plastic film added to existing glass panes. |
| | 5 | Windows: Secondary glass pane | A secondary glass is installed on the inside of the existing window recess. |
| | 6 | Windows: Timber frame low-e double glazing | New timber windows are installed that incorporate low emissivity double glazing. |
| HVAC | 7 | Chiller upgrade | The efficiency of the chiller system is assumed to be increased from a Nominal EER (Energy Efficiency Ratio) of 3.13 to between 4.38 and 5.50. |
| | 8 | Cooling setpoint 25 deg C | The setpoint at which cooling systems activate is increased from 23 to 25 deg C. |
| | 9 | Cooling setpoint 26 deg C | The setpoint at which cooling systems activate is increased from 23 to 26 deg C. |
| | 10 | Boiler upgrade | The efficiency of the boiler systems in the building were increased from 80% to 89%. |
| | 11 | Night purge | Night purging describes the strategy to use the cool night air to cool the building. |
| Lighting | 12 | Lighting upgrade | Increase the efficiency of building light fittings from T8 equivalent to T5 equivalent efficiency. |
| | 13 | Switch off equipment after hours | Office equipment is switched off outside working hours. |
| | 14 | Open windows and increase cooling setpoint to 26 deg C | Windows are opened during working hours if temperatures are between 23 and 26 deg C. |
| Hot water | 15 | Gas-boosted solar hot water | Gas boosted solar hot water is installed to replace existing systems. |
| Combination | 16 | Top combination* | A combination of the four best interventions for each building is applied. See Table below. |

* The interventions considered under the Top Combination are shown in Table 3.

| Table 3 Top combination interventions considered |
| --- |
| **No.** | **Intervention** | **AMP, Townsville** | **Treasury, Melbourne** | **Old Attorney General’s, Adelaide** | **Lands Department, Sydney** |
| 7 | Chiller upgrade | X | X | X | X |
| 9 | Cooling setpoint 26 deg C | | X | X |
| 12 | Lighting upgrade | X | X | X | X |
| 13 | Switch off equipment after hours | X | X | X | X |
| 14 | Open windows and increase cooling setpoint to 26 deg C | X | | |

3. Research results and discussions
3.1. Base building
Table 4 shows the base building energy consumptions (both gas and electricity) for the four case study buildings and the results for the 16 interventions applied to the buildings.

Cooling represents the highest impact for AMP building in Townsville and contributed the lowest impact for the Old Attorney General building in Adelaide. This difference is likely to be driven by the
climate in both locations. Townsville has a greater number of days where cooling is required, and humidity levels are typically higher requiring cooling systems to expend more energy in removing latent heat. Adelaide, in contrast, has fewer cooling days and lower humidity levels, reducing cooling energy needs. Differences may also be driven by the nature of the building’s design, construction and building materials used.

The highest heating consumption is the Old Attorney General building in Adelaide. It is likely that the high contribution for this building is in part due to a climate driven need for heating and in part due to relatively lower cooling loads required for this building.

For the interventions results shown, significant (27% to 42%) reductions in energy consumption are possible for each of the case study buildings considered. The greatest reductions are achieved when a combination of interventions is applied. The highest impact interventions tended to relate either directly or indirectly to building equipment, lighting and mechanical systems. The occupant related interventions, although potentially involving a perceived compromise, provided significant benefits, well worth the potential challenges (e.g. asking occupants to tolerate higher interior temperatures) associated with their implementation. It is noted that some interventions (e.g. sealing) are effective in reducing heating load but not for cooling energy consumption due to the nature of the building construction and the climatic condition. The high impact interventions found in this study are not typical to heritage buildings, which shows that the findings will have wider application for designers and specifiers seeking to reduce the environmental impacts of existing or heritage buildings alike.

### Table 4 Base building and 16 interventions energy consumptions estimated in NABERS

| Building | Not Lettable Area (m²) | BASE ASSESSMENT | ESTIMATED NABERS RESULT BASED ON APACHE SIM RESULTS |
|----------|------------------------|-----------------|-----------------------------------------------------|
|          | Natural Gas Use (MJ/m².year) | Energy Consumption |                                      |
| AMP, Townsville | 915 | Not connected to gas | |
| Treasury, Melbourne | 9,382 | 251 | 232 | 251 | 206 | 128 | 134 | 120 | 251 | 246 | 1,871 | 218 | 256 | 284 | 306 | 283 | 244 | 346 |
| Old Attorney General’s Buildings, Adelaide | 894 | 257 | 246 | 202 | 257 | 209 | 212 | 220 | 257 | 256 | 231 | 335 | 307 | 310 | 336 | 290 | 206 |
| Lands Department, Sydney | 7,470 | 51 | 25 | 51 | 50 | 47 | 47 | 47 | 51 | 51 | 46 | 51 | 56 | 51 | 62 | 63 |
| Electricity Use (kW/hr/².year) | | | |
| AMP, Townsville | 915 | 260 | 250 | 256 | 255 | 254 | 245 | 217 | 239 | 230 | 257 | 237 | 224 | 229 | 260 | 146 |
| Treasury, Melbourne | 9,382 | 333 | 336 | 332 | 318 | 349 | 346 | 325 | 306 | 317 | 296 | 333 | 333 | 294 | 275 | 329 | 333 | 205 |
| Old Attorney General’s Buildings, Adelaide | 894 | 126 | 126 | 125 | 126 | 125 | 124 | 117 | 119 | 117 | 126 | 110 | 117 | 103 | 118 | 124 | 78 |
| Lands Department, Sydney | 7,470 | 225 | 226 | 225 | 224 | 227 | 226 | 224 | 211 | 211 | 206 | 225 | 225 | 201 | 189 | 202 | 217 | 145 |

#### 3.2. Operational energy investigations for base building in eight capital cities

Figures 1-4 show the operational energy uses for each of the base building (without any interventions applied) remodelled in the eight capital cities in Australia. The AMP Building which was originally modelled in Townsville was remodelled in Brisbane also.

Heating and cooling (system natural gas and system electricity) contributed the most to the total operation energy usage (between 40-57% for AMP Building; 39-59% for Treasury Building; 35-53% for Old Attorney General Building; and 49-66% for Lands Department Building). Equipment and lighting contributed around a quarter each to the total annual operational energy usage for the four case study buildings assessed in various capital cities locations. The three traditional heavy construction (high thermal mass) buildings’ (AMP Building, Lands Department Building and Old Attorney General Building) thermal performances are in response to the local climatic conditions with heating being the predominant driver for colder climates and cooling the predominant driver in hotter locations (Figures 1, 3, & 4). Cooling load is the main operational energy usage (between 26-56%) in Treasury Building.
**Figure 1** Operational energy for AMP Building

**Figure 2** Operational energy for Treasury Building

**Figure 3** Operational energy for Old Attorney General Building
Figure 4 Operational energy for Lands Department Building (typical curtain wall construction) in all eight capital cities except in Hobart and Melbourne which equipment energy usage is slightly higher, between 1-6% (Figure 2). The high cooling load could be partly due to the highly glazed façade of the building and the high exposure of the building (as there is minimum overshadow from surrounding buildings). These findings are also true for the operational energy performances of the four case study buildings in their respective original locations. The Lands Department Building uses the most operational energy.

4. Conclusion
The study found that it is possible to significantly enhance the energy efficiency of the heritage buildings. Intervention strategies such as switching off equipment when not in use; upgrading the efficiency of lighting; upgrading the efficiency of the chiller and raising the cooling setpoint (and opening windows if needed) provide high impact in reducing the energy consumption. Operational heating and cooling (system natural gas and system electricity) contributed the most to the total operation energy usage for the base buildings as remodelled in eight capital cities in Australia.

5. Reference
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