

AN INTEGRATED APPROACH TO ENERGY ANALYSIS IN BUILDING DESIGN – THE RELOCATABLE CLASSROOM PROJECT

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ABSTRACT

In 2005, the Department of Education and Early Childhood Development (DEECD) in the Victorian State of Australia introduced a new design for relocatable classroom buildings known as the 'N1' design. This was further refined in the 'N2' design incorporating additional Environmentally Sustainable Design (ESD) features. This paper presents further improvements made to the 'N2' relocatable classroom particularly with respect to operational and embodied energy through the use of building energy and lifecycle modelling during the early stages of the design process. This paper highlights how building modelling and life cycle thinking approaches may assist building design and construction.

INTRODUCTION

The Department of Education and Early Childhood Development (DEECD) is responsible for one of the largest asset portfolios in Australia. As of 2010, there were approximately 1157 primary schools and 250 secondary colleges servicing Victoria's student population. In these schools there are around 28,500 buildings including over 6,000 relocatable classroom buildings.

Generally, schools have relocatable classrooms for various reasons including:

- supplementing accommodation when student numbers increase in an existing school,
- providing temporary accommodation if works are being undertaken in the permanent buildings or if permanent buildings are demolished and are being rebuilt,
- providing temporary accommodation if a classroom is damaged, for example by flood or fire,
- being part of a new school to allow for future fluctuation in student numbers.

In 2005, DEECD introduced a new design of relocatable classroom buildings known as the 'N1' design. This was further refined in 2008 in the 'N2' design incorporating additional Environmentally Sustainable Design (ESD) features such as:

- double glazing
- wall and sub-floor insulation

- integrated building control system operating natural ventilation and restricting air-conditioning and heating operation to temperature set points (also operating night purging of hot air)
- motion sensors to turn off lighting, heating and air-conditioning when the room is not in use
- ceiling fans
- *SmartBreeze* solar powered unit on the roof of the building that extracts hot air from the space between the steel roof and the foil insulation. Hot air is extracted during summer to reduce heat build-up in the roof space. During winter, this unit takes the warm air from under the steel roof to supplement the relocatable classroom heating.

DEECD recently announced its first program under the Victorian Government Greener Government Buildings (GGB) initiative, the aim of which is to reduce the environmental impact and operational costs of schools by improving the energy and water efficiency of existing school buildings. In addition, one of DEECD's objectives is to design, develop, install, monitor and showcase an exemplar relocatable school classroom.

The aim of this Exemplar Relocatable Building Project was to develop a concept design for a relocatable classroom that addresses the Department's objectives mentioned above and subsequently, translate the concept into a design specification to build it as a showcase for a new generation of relocatable classrooms. This paper focuses on the development of the concept designs only.

The existing 'N2' design (Figure 1) made significant improvements on the existing Deep Fascia (DF) relocatable buildings in N1. To maximise energy savings potential from whole of life perspective for the existing 'N2' design, this research project has focused upon three areas:

- eliminating standby power (48% of energy is used outside school hours)
- improving thermal performance (responsible for 24% of the N2's power consumption)
- improving day lighting (responsible for 20% of the N2's power consumption)

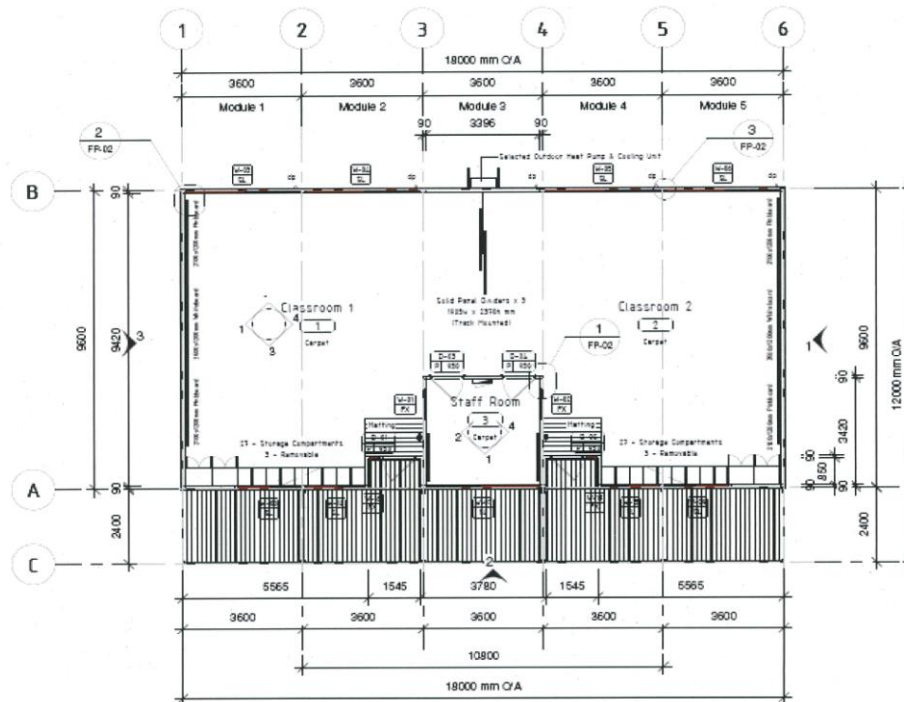


Figure 1 'N2' Floor Plan

APPROACH

The team used several methods to guide the redesign of the original 'N2' relocatable classroom using a sequential stepped process consisting of:

- A. Participatory Workshop,
- B. Site Visits and
- C. Building Energy and Lifecycle Modelling of the concept design.

A. Participatory Workshop

A participatory workshop was held with key stakeholders to assist in developing the 'problem definition' for the exemplar relocatable building project. The aim of this process was to focus on realistic design option/s using experience and expertise of various stakeholders, including various sections of DEECD, the architect, builder and project managers.

B. Site Visits

Site visits were undertaken to view the construction of the relocatable in the prefabricated factory as well as assess its performance in in-situ conditions at a school. This enabled better understanding of the construction process, and identified potential areas for improvement based on the observation of the construction process and a finished classroom in use.

C. Building Energy and Life cycle Modelling

The starting position for the integrated approach for the research consisted of the existing energy use and

life cycle modelling of a previous study commissioned by DEECD focusing on operational energy. This Relocatable Energy Audit Report (Bertram, 2010) noted that total energy consumption of cooling, heating, fans, lighting and electronic equipment for the 'N2' relocatable classroom amounted to around half of the annual electricity usage. Therefore, the operational energy modelling for the relocatable classroom was targeted at improving the energy usage of the classroom.

First principle method was used to calculate the operational heating and cooling energy loads and the impacts of lighting, ventilation modes and equipment used for the 'N2' relocatable classroom and subsequent improvement to the design of the classroom. This provided the information for the fabric of the relocatable only. The internal heat gains generated by the occupants, equipment and lighting were modelled based on the ASHRAE Handbook Fundamentals (ASHRAE, 2009). NatHERS simulation engine was used to determine the annual energy loads for the combination of building fabric and the internal loads. An added advantage of using NatHERS is that this meets requirements of the National Construction Code in Australia.

A life cycle simulation model was constructed for the relocatable building which included embodied, construction and operational energy (for heating, cooling and lighting) for the life cycle stages of the relocatable building (Figure 2). End of life for the relocatable was not considered primarily because the relocatables are largely reused, albeit in a different

function, i.e. accommodation. The primary energy and carbon emission flows associated with the embodied stage were modelled using the life cycle software *SimaPro* (Product Ecology Consultants, 2011), informed by the use of the bill of materials for the building.

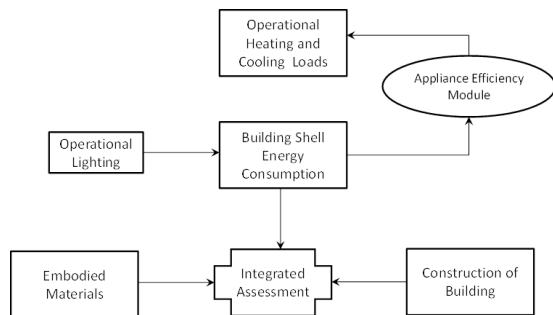


Figure 2 Structural framework of the life cycle model

Based on previous literature for Australian buildings, it was found that generally, building construction (including embodied materials) constituted 5% of the total energy use of the building, including operation (Pullen 2000 and Pullen et al 2006). The operational energy for heating and cooling was then integrated with the life cycle model (Delsante, 2005). The simulated operational energy for heating and cooling were then used in conjunction with the electrical appliance parameters and grid efficiency characteristics to estimate the primary energy and CO₂ emissions associated with delivering the lifetime building heating and cooling loads. A building lifetime of 25 years was used in this analysis.

The co-efficient of performance (COP, which characterises appliance efficiency) for an inverted air conditioning system differs for heating and cooling. Based on federal government reports the COP factors used for heating and cooling were 1.0 and 1.8 respectively (Department of Climate Change and Energy Efficiency, 2008). The grid efficiency (30.3%) and carbon intensity (1.3 kg CO₂/kWh) of electricity generation in Victoria were used for the analysis to estimate the total fuel cycle (combustion and pre-combustion) impacts (Australian Life Cycle Inventory, 2010).

In a subsequent analysis, the energy and carbon flows associated with the actual onsite operational energy consumption of the 'N2' relocatable building was also considered. This particular operational energy consumption included heating and cooling, in addition to energy consumed for standby, electronic equipment and lighting in the premises. The primary energy and carbon emissions associated with the operational energy consumption were integrated with the results from the embodied and construction stages to develop the life cycle model.

DISCUSSIONS

The major area of concern for energy use within the relocatable is standby power, with approximately half of the power being consumed outside of school hours (Figure 3). Addressing this one issue effectively halved the buildings' operational energy in the modelling undertaken. Space heating energy alone contributed to a quarter of the total energy use. In addition to the life cycle modelling, other strategies were identified to reduce standby energy use in procurement. A combination of behavioural change strategies and technical solutions were also considered. Procuring the most energy efficient appliances that provide critical infrastructure for the relocatable has the potential to reduce standby load. Selecting energy efficient CCTV and outdoor lighting can also lead to energy savings. The standby power reduction and procurement strategies and the behavioural change strategies were not reported in this paper.

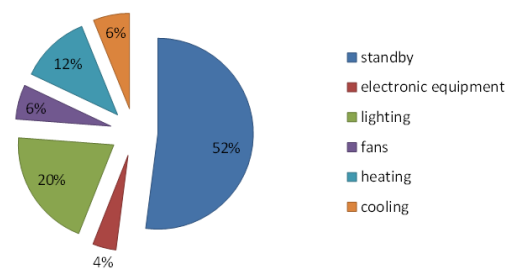


Figure 3 Breakdown of the annual electricity usage by 'N2' building, categorised by end use (Annual electricity consumption: 5999 kWh/year)

Three design concepts were proposed to significantly reduce the operational and embodied energy of the existing 'N2' design through building energy and life cycle modelling. The existing 'N2' design is the base case where the intervention strategies proposed for the three conceptual designs were the improvement made to the base case. The proposed design concepts are described below:

A. Conceptual Design 1 - Incremental improvement on existing 'N2'

The greatest challenge for the relocatable is that in reality, they may face a number of different cardinal orientations and will have to be optimised to perform in different climatic conditions within the one state. Conceptual Design 1 uses simple external window shading as a means to improve the energy performance of the relocatable. Other strategies considered are:

- Sealing gaps around doors and windows, and improve thermal breaking between modules and across steel frame
- Attention to detail in insulation installation, for e.g., simple aluminium shading for external windows

- Improving construction details to reduce thermal breaks
- Adding greater control to fluorescent lighting rows (so that lighting levels can focus where additional light may be required, as opposed to lighting entire space). Reduction in lighting by up to a third can occur by providing a switch for the central row of fluorescent lights, such that daylight on the perimeter of the classroom is utilised.

B. Conceptual Design 2 - High day lit classroom

As the building envelope becomes more energy efficient, the embodied energy in material selection becomes more important when considered from a whole of life impact of the building. Alternative material and construction processes are considered. This concept also focuses on improving the day lighting capacity of the relocatable classroom.

This second concept aims to:

- Upgrade roof insulation to 100mm *Kingspan* roofing (which requires an estimated 50% less purlins)
- Utilise *Lite Steel Beams* for the frame of the structure, reducing the weight of the frame by an estimated 40%
- Reduce low area windows and introduce high glazed windows.
- Introduce top lighting, 4 Skydomes glass skylights with high R-values (making them bushfire compliant)
- Introduce reflective light shades

C. Conceptual Design 3 - Roof monitors and insulated panels

The third concept incorporates an architectural solution to increase daylighting, and alters the materials used in the building envelope to further increase thermal performance, utilising *Kingspan* insulated wall systems. There is no change to the existing envelope, however, material use and cavity dimensions have a limit on the potential insulation values that the relocatable is able to achieve and to construct an “air tight” building. The third concept includes:

- Recommendations from Concept Design 2 for a *Lite Steel Beam* structure; reduced low area windows and introduced high glazed windows and reductions in standby energy.
- Utilising *Kingspan* roofing and wall system
- Constructing roof monitors in modules 2 and 4 to increase daylighting.

Life cycle modelling consisting of operational and embodied energy performance simulation were used to analyse each of the three Conceptual Designs mentioned above to determine the energy consumption and environmental impacts in the form

of CO₂ emissions of each of the concepts proposed. Results are explained below.

RESULTS

In view of the scope of the paper, only two climatic locations in Victoria, namely Melbourne and Mildura, are reported for the three conceptual designs. Only South and West orientations were studied which represent the optimum and worst-case scenario for the orientation of the relocatable classroom. Using the intervention of increased floor insulation for all three Conceptual Designs showed that this intervention does not improve the operational energy of the relocatable classroom. In some cases, it increased energy usage marginally compared to the base case (for South-facing building in Mildura). In view of this finding, intervention using floor insulation was not recommended. In addition to embodied energy, building construction and operational energy (heating, cooling and lighting), standby power also significantly contributed to the building life cycle energy consumption. The influence of reducing standby power was only evaluated for the base case.

The results and findings of the impact of different interventions modelled for the three conceptual designs are discussed below:

A. Conceptual Design 1

In this particular intervention, the relocatable was assessed using the first principle method and LCA software. The impact of modelling embodied and building construction energy and emissions, and the consequent variation in operational heating and cooling requirements were analysed. Introducing aluminium window shading in the modelling made no significant improvements in the heating and cooling operational requirements of the building. This strategy will not be very effective when implemented exclusively. When the modelled reduction in standby power and lighting were considered, there was a third reduction in life cycle CO₂ emissions in this conceptual design when compared to the base case for South-orientation.

B. Conceptual Design 2

In this intervention, a new roof construction was introduced and the amount of steel in the columns and sub-structure was reduced significantly from the base case. The existing window area was also reduced by a third from the base case and additional windows of smaller sizes were added to higher levels in the relocatable building. In addition, four skylights were incorporated in the building modelling. When modelled, these interventions increased the primary energy and CO₂ emissions associated with the embodied and building construction stages marginally, but the overall impact was not significant. The building was modelled in South-facing and West-facing orientations in Mildura and Melbourne. When compared to the base case, the

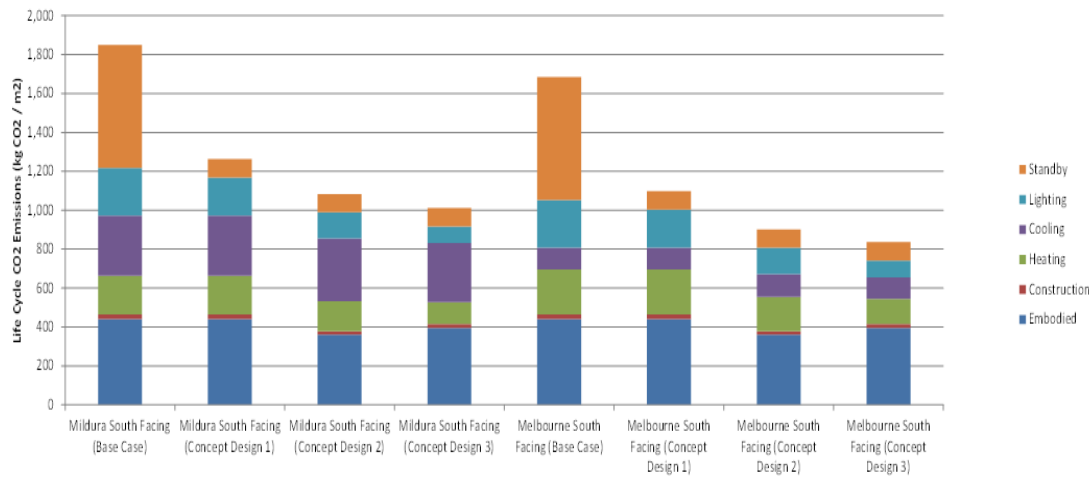


Figure 4 Summary of the modelled life cycle CO₂ emissions for the base case, Concept Designs 1, 2 and 3 scenarios for Melbourne and Mildura (South-orientation)

South-facing building in Mildura required a reduced heating requirement (17 MJ/m².Year), but an increased cooling requirement (64 MJ/m².Year). The West-facing orientation of the same building required significantly higher cooling loads (91 MJ/m².Year).

When modelled in the Melbourne climate, the results were similar to Mildura conditions. The South-facing building in Melbourne had a reduced heating (19 MJ/m².Year) but an increased cooling requirement (23 MJ/m².Year). The West-facing orientation case in Melbourne consumed much higher cooling loads (33 MJ/m².Year) when compared to the South-facing case. Hence, there is a trade-off effect: the energy gains from reduced heating are offset to a certain extent by increased cooling. Since the heating appliance considered is less efficient than the cooling appliance, the margin of net gains is reduced even further in the operational stages. However, there was an over-all reduction in both life cycle primary energy and life cycle CO₂ emissions. This conceptual design was very effective as it reduced the energy and CO₂ emissions associated with the embodied and building construction processes. When compared to the base case, the life cycle CO₂ emissions reduced for the Mildura and Melbourne South-facing cases respectively. But, when the influence of reducing standby power and lighting was considered, the total impact of the reductions was significant (Table 3, in both South-facing cases in Mildura and Melbourne) in life cycle CO₂ emissions was achieved in this conceptual design.

C. Conceptual Design 3

In this intervention, the roof construction and the substructure were the same as in Conceptual Design 2. However, the materials and construction on the external walls were changed to using Kingspan wall systems. In addition, the area of skylight was increased by five times to maximise daylighting. The interventions were modelled in Mildura and Melbourne for both South-facing and West-facing

orientations. In Mildura, it was found that both the heating (13 MJ/m².Year) and cooling (60 MJ/m².Year) requirements of the building reduced when compared to the base case. The same trend applied to Melbourne as well: the heating (14 MJ/m².Year) and the cooling (22.1 MJ/m².Year) requirements reduced when compared to the base case. This conceptual design was very effective in reducing the modelled over-all life cycle primary energy consumption and life cycle CO₂ emissions. When compared to the base case, the life cycle CO₂ emissions reduced by almost a quarter for both the Mildura and Melbourne South-facing cases. When the influence of reducing standby power and lighting were considered, a total reduction of almost half (in Mildura and Melbourne, Table 3) life cycle CO₂ emissions was achieved in this conceptual design.

Figure 4 summarises the modelled life cycle CO₂ emissions results for the base case, Conceptual Designs 1, 2 and 3 for Melbourne and Mildura (South-orientation). Overall, Conceptual Design 3 provides the optimum operational and life cycle energy saving for the relocatable building (South-facing). The relocatable building located in Mildura consumed higher operational energy as compared to the Melbourne location due to the more extreme weather experienced in those areas.

Tables 1 and 2 show the comparison of modelled operational heating and cooling loads and embodied energy between the original 'N2' relocatable building (base case) and the three Conceptual Designs proposed in this paper. Table 3 summarised the CO₂ emissions for embodied, construction, heating, cooling, lighting and standby energy analysed for the original 'N2' design as compared to the three Conceptual Designs in Mildura and Melbourne for South-orientation building. South-facing results are presented as it is the optimum orientation for the relocatable building with the best outcomes.

Table 1 Comparison of modelled operational heating and cooling loads and embodied energy for original and improved 'N2' designs in Mildura (South Orientation)

Design Concept	Interventions	Heating Load (MJ/m ²)	Cooling Load (MJ/m ²)	Embodied Energy (MJ/m ²)	In comparison to original 'N2' design
Original 'N2' Design – Base Case	-	22.1	61.6	6687.1	-
Concept Design 1	<ul style="list-style-type: none"> • Improve thermal breaking and construction details • Sealing of air gaps • Window shading • Improve lighting control 	22.6	59.2	6725.1	<ul style="list-style-type: none"> • Heating increased by 2.4% • Cooling decreased by 4% • Embodied energy increased by 0.6%
Concept Design 2	<ul style="list-style-type: none"> • Improve roofing construction • Reduce structural framing sizes and numbers • Reduce low level windows area • Introduce high level windows • Introduce skylights 	17.0	64.3	5822.1	<ul style="list-style-type: none"> • Heating decreased by 23.1% • Cooling increased by 4.3% • Embodied energy decreased by 12.9%
Concept Design 3	<ul style="list-style-type: none"> • Introduce all improvement in Concept Design 2 • Improve external walls construction • Introduce rooftop monitors 	12.5	60.2	6441.7	<ul style="list-style-type: none"> • Heating decreased by 43.4% • Cooling decreased by 2.3% • Embodied energy decreased by 3.7%

Table 2 Comparison of modelled operational heating and cooling loads and embodied energy for original and improved 'N2' designs in Melbourne (South Orientation)

Design Concept	Interventions	Heating Load (MJ/m ²)	Cooling Load (MJ/m ²)	Embodied Energy (MJ/m ²)	In comparison to original 'N2' design
Original 'N2' Design – Base Case	-	25.7	22.4	6687.1	-
Concept Design 1	<ul style="list-style-type: none"> • Improve thermal breaking and construction details • Sealing of air gaps • Window shading • Improve lighting control 	26.0	22.0	6725.1	<ul style="list-style-type: none"> • Heating increased by 1.5% • Cooling decreased by 1.8% • Embodied energy increased by 0.6%
Concept Design 2	<ul style="list-style-type: none"> • Improve roofing construction • Reduce structural framing sizes and numbers • Reduce low level windows area • Introduce high level windows • Introduce skylights 	19.4	23.4	5822.1	<ul style="list-style-type: none"> • Heating decreased by 24.2% • Cooling increased by 4.5% • Embodied energy decreased by 12.9%
Concept Design 3	<ul style="list-style-type: none"> • Introduce all improvement in Concept Design 2 • Improve external walls construction • Introduce rooftop monitors 	14.3	22.1	6441.7	<ul style="list-style-type: none"> • Heating decreased by 44.1% • Cooling decreased by 1.5% • Embodied energy decreased by 3.7%

Table 3 Comparison of modelled CO₂ emission breakdown results for the original 'N2' design and the three Conceptual Designs for Mildura and Melbourne (South Orientation)

	Embodied (kgCO ₂ /m ²)	Construction (kgCO ₂ /m ²)	Heating (kgCO ₂ /m ²)	Cooling (kgCO ₂ /m ²)	Lighting (kgCO ₂ /m ²)	Standby (kgCO ₂ /m ²)	% of CO ₂ reduction in comparison to original 'N2' design
Mildura							
Original 'N2' Design – Base Case	441	22	200	309	245	631	-
Concept Design 1	441	22	200	309	196	95	32%
Concept Design 2	360	18	154	322	135	95	41%
Concept Design 3	395	20	113	302	86	95	45%
Melbourne							
Original 'N2' Design – Base Case	441	22	232	112	245	631	-
Concept Design 1	441	22	232	112	196	95	35%
Concept Design 2	360	18	176	118	135	95	46%
Concept Design 3	395	20	129	111	86	95	50%

Conceptual Design 1 has the lowest levels of change for reducing energy use and is most economical but it does not provide significant overall benefit when compared to the original 'N2' design. The only contributing interventions for CO₂ reduction are improvement in lighting and standby energy usage.

Conceptual Design 2 significantly improved the modelled operational heating performance of the relocatable building, both in Mildura and Melbourne locations. The heating energy improvement also reduced the CO₂ emission by about a quarter for both locations.

Conceptual Design 3 provided the most significant modelled improvement in operational heating energy. The embodied energy increased marginally compared to the original 'N2' design, due to more energy intensive materials (e.g. steel used in roofing) being used in the design.

CONCLUSION

Three Conceptual Designs were proposed which can significantly reduce the power consumption of the existing 'N2' design.

The project team set out an ambitious 90% energy reduction target for the relocatable building and considered various requirements pertaining to the design of the relocatable building including construction cost, manufacturing, transportability and regulatory constraints. Effective strategies to reduce

the modelled standby power and the operational and embodied energy usage by improving the building envelope and introducing abundant natural lighting to

the internal environment of the relocatable building were proposed.

The strategies proposed for standby power control help to reduce operational energy use by at least half of the original requirement and Conceptual Design 3 could further reduce the lighting usage by about 65% and the operational heating and cooling requirement by about 46%.

The following can be concluded based on the base case model (original 'N2' building) and the modelling of the three intervention scenarios of Conceptual Designs 1 to 3:

- Conceptual Design 1 did not reduce the modelled life cycle energy consumption (including the operational heating and cooling loads) and life cycle CO₂ emissions by any significant margin.
- Conceptual Design 2 reduced the life cycle CO₂ emissions by 15% (Mildura) and 19% (Melbourne) when compared to the base case for south-facing orientation.
- Conceptual Design 3 reduced the life cycle CO₂ emissions by about 21% (Mildura) and 25% (Melbourne) when compared to the base case for south-facing orientation.
- Conceptual Design 3 provided the optimum overall energy saving for the relocatable building (South-facing) with about 15% reductions comparing both the South and West orientations.

- The West-facing building orientation cases released higher life cycle CO₂ emissions when compared to the South-facing orientations, due to the increased cooling requirements for the building in the case of the former.
- When the influence of reducing standby power was considered in conjunction with Conceptual Design 3, 50% of life cycle CO₂ emissions were reduced.
- One of the reasons for the lower level of reduction in life cycle CO₂ emissions from these interventions is the life time of the building (25 years). If one increases the life time of these buildings then with the same intervention strategies, CO₂ abatement can be realized for a longer period of time. Increasing building lifetime will therefore, lead to increased energy conservation and carbon reduction (when compared to the scenario in the base case, before intervention).

In recognition of the potential energy savings for the various strategies considered, it is recommended that the improvement proposed in Conceptual Design 3 be adopted for the new DEECD 'N2' relocatable building.

The use of building energy and life cycle modelling software in this project helped to test the various design options in improving the original 'N2' relocatable building's performance effectively in terms of time and cost. It also helped to provide confidence in applying the interventions investigated to the new relocatable building prototype to ensure expected outcomes regarding energy use and attendant emissions.

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