# Construction and Energy Cost Saving using Building Simulation Procurement Guidelines for Sustainable Design and Construction of commercial building Projects in Australia

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## Abstract

Building simulation is a fundamental element of sustainable building design and construction. Decisions made early of the design stage have a huge impact on construction and energy saving on commercial building projects. Among various tools, techniques and guidelines for simulation and for sustainable design, the National Construction Code (NCC) approved and Australian Institute of Refrigeration, Air-conditioning and Heating (AIRAH) recommended Section J verification method (JV3) was adopted in the study to investigate the energy and cost savings of two commercial building projects in Australia. The two research questions have been highlighted. These include (a) What would be the best approach of construction cost savings using building simulation procurement guidelines and how it can be achieved? (b) What would be the range of construction cost saving compared to initial investment for simulation procurement of commercial building projects in Australia? The study highlighted that an alternative simulation approach rather than manual calculation is cost effective and 10 times of initial simulation procurement cost can be saved in construction depending upon the application of building elements (e.g. insulation, glazing, colour, orientation etc).

**Keywords**: Building simulation, Sustainable design, Construction, Commercial buildings, Project.

## Introduction

Buildings worldwide account for a surprisingly high 40% of global energy consumption (Energy Efficiency in Buildings, 2009). To reduce the energy consumption, Energy performance assessment of building at the design stage is critical. Building fabric, insulation and glazing are integral parts for energy efficient and sustainable building design and construction. Change of building fabric, particularly, building colour, insulation and glazing have significant effect on buildings' energy performance. Rahman et al. (2010) examined different energy conservation measures as retrofit options and highlighted that implementing low energy double glazing instead of single glazing can save up to 7% of energy of a university building in sub-tropical climate of Australia. Zhenjun et al. (2012) highlighted that using energy simulation is a cost effective and energy efficient approach in design, refurbishment and extension for the proposed building. However, building owners, operators, builders and contractors always seek for optimised cost options to obtain both the targeted energy and construction cost of the building. So the decisions at the early stage of the commercial building projects are critically important. Building projects follow the Pareto Principle or 80:20 rule. where 80% of the decisions affecting the project outcome and are

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made the first 20% of the projects life (Drogemuller et al., 2004; Kohler & Moffatt, 2003). To take early decisions, the sustainable indicators including energy and construction cost can be assessed at the initial phase of the design (Braganca, L. et al., 2014). Building simulation is a key component for sustainable building design. Australian Institute of Refrigeration, Air-conditioning and Heating (AIRAH) published an energy simulation procurement guideline and highlighted that facade design, HVAC optimisation, National Built Environment and Rating system (NABERS), Green Star and JV3 are the best simulation approaches for different target options to optimise the energy consumption of commercial building projects (Building Simulation Procurement, 2014). Among all the approaches, the JV3 method was selected in this study to optimise the cost options and to obtain a code compliance with National Construction Code. Compared to other simulation approaches, JV3 identifies the cost issue during the early design stage, preparation for tender documentation and finally, final design stage of the commercial building projects. Linking of early design decisions from architects and consultants have impact on cost of the building. This study highlighted that significant construction cost saving can be achieved using the integrated simulation approach made of data analysis and simulation, JV3, AIRAH benchmark and agreement between parties. This is an alternative simulation approach for energy efficient building design of commercial building projects. As per JV3 of NCC, as long as the proposed building annual energy consumption is less than DTS-compliant (Deemed-to-satisfy compliant) Reference building, a solution can be achieved. The Energy-efficient and cheapest building fabric and glazing options were identified and highlighted in this study using this integrated approach. Then the construction cost saving is compared between the NCC compliant proposed building and DTS compliant Reference Building. Finally the cost of simulation procurement is compared with cost of building fabric and savings are demonstrated.

## Methodology

First of all, several simulation approaches, regulations and codes for commercial constructions were studied. These include Simulation procurement guidelines of AIRAH, National Construction Code (NCC), Green Star and NABERS. The five energy simulation approaches were selected for their suitability at the early design stage and National Construction Code compliance of the commercial building projects (Table 1). The Table presented below demonstrated the advantages and disadvantages of each simulation approaches. From Table 1, it was identified that the JV3 simulation approach is applicable to any types of commercial building project for National Construction Code compliance and future energy savings.

The next part of the methodology was how to achieve the optimised construction cost of the commercial building projects in Australia. An integrated simulation approach made of JV3 (Section J, NCC 2014) and data analysis, AIRAH benchmark requirement (AIRAH, 2007), and agreement between parties, was developed. This is presented in Figure 1 to find out the optimised elements of building fabric including insulation and glazing and to optimise the cost of construction. The validation of this integrated simulation approach was examined on two commercial buildings in two different climate zones (Climate zone 2 and Climate zone 7) in Australia.

The third part of the methodology was to analyse the cost of the proposed building using the integrated model approach and compare it with the DTS compliant Reference Building.

Finally, the cost comparison was conducted between the simulation procurement and cost of constructions.

Table 1: Comparison of Simulation approaches for commercial building projects

| Simulation Approach | State wise Regulatory Requirement / Protocol in Australia | Advantages | Disadvantages |
|---|---|---|---|
| Façade Design | No | Concept to design | Only concept design no optimisation in building elements |
| HVAC optimisation | No | Schematic design to construction of HVAC systems | Only HVAC system optimisation no building fabric optimisation |
| NABERS | Yes under a commitment agreement | Office building in operation stage | Apply only to more than 2000 $m^2$ floor area |
| Green Star | Regulatory: No<br>Protocol: Yes | Concept through to contract documentation | Simulation packages are not available for all types of commercial buildings. |
| JV3 of National Construction Code | Yes | Design, Construction and final documentation of any type of commercial buildings fabric. Predicted the future energy consumption and construction cost savings | HVAC systems may affect the real energy consumption of buildings |

## Modelling and Simulation of two case studied buildings

First, all architectural design data including floor plan, elevations, sections, site plan, wall and roof constructions, glazing and finishes schedules were collected. Second, DesignBuilder version 3.4 software with EnergyPlus version 8.1 simulation engine (ABCB newsflash, 2006), was used in this study. Using all the information and architectural drawing, two model buildings were developed in DesignBuilder. The floor plans and 3D views of the model buildings are shown in Figure 2 and Figure 3. Deemed to satisfy (DTS) Lighting and HVAC schedules for JV3 (Office schedules: 2500 hr/yr) as per NCC were used in the simulation to satisfy the section J performance requirement (JP1). After the modelling, the construction details and glazing were inserted in DesignBuilder.

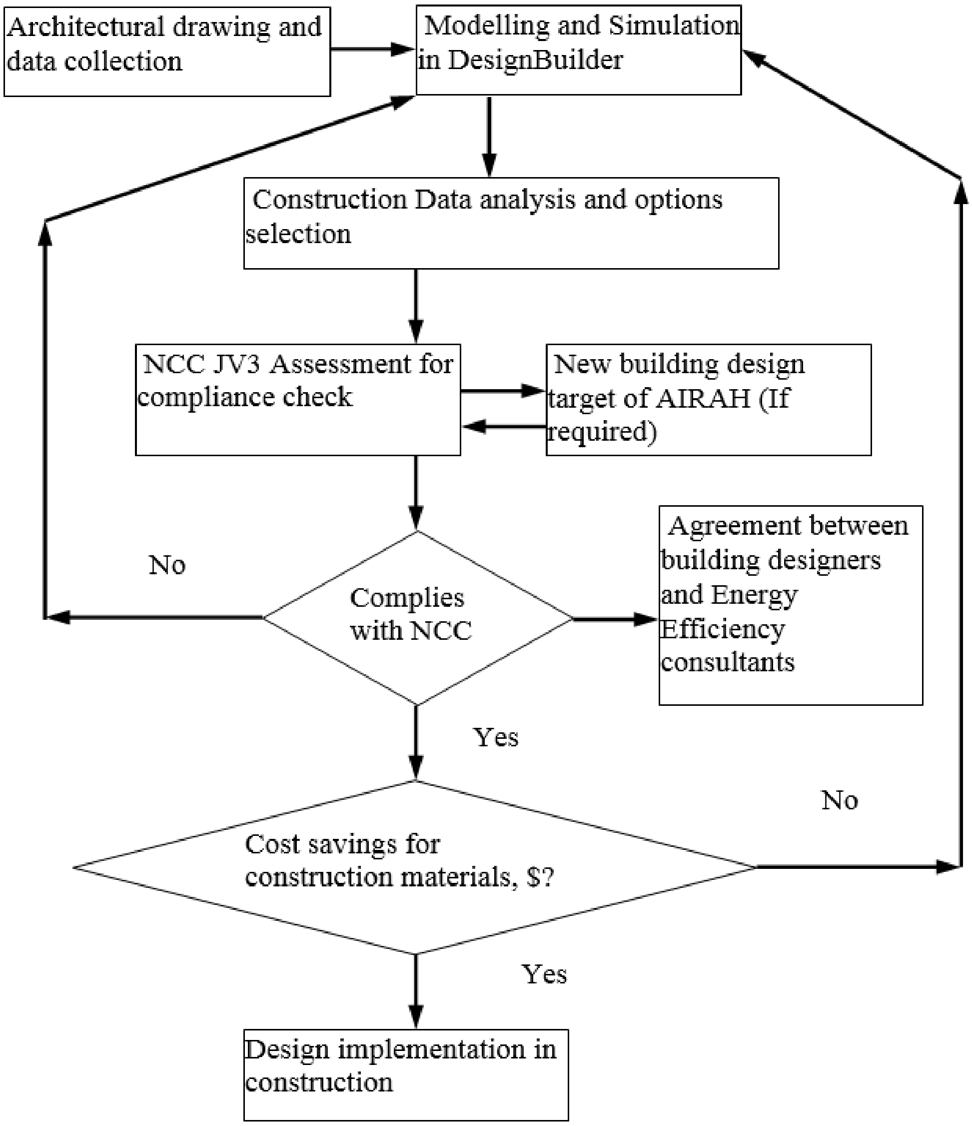


Figure 1. An integrated approach for optimised building elements and cost saving

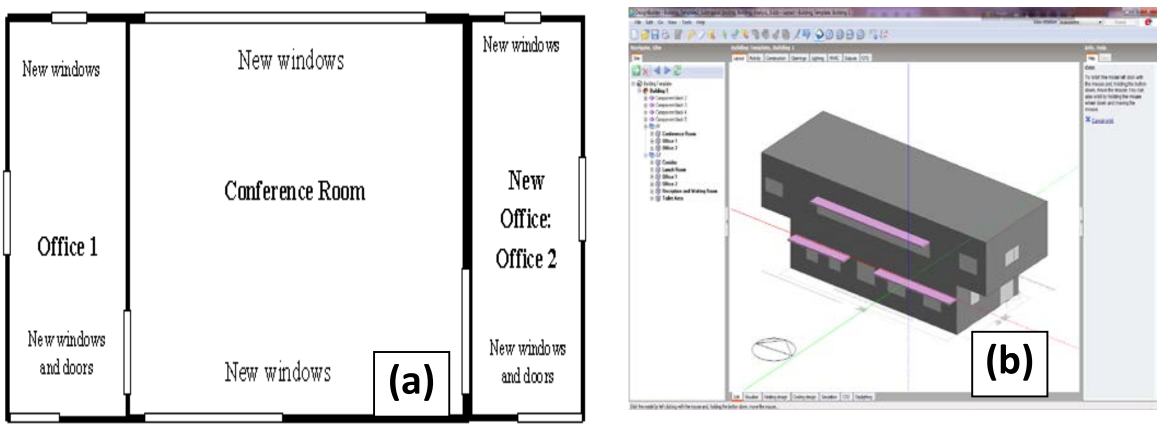


Figure 2. Typical Floor plan (a) and 3D model of the two storey Office building (b)

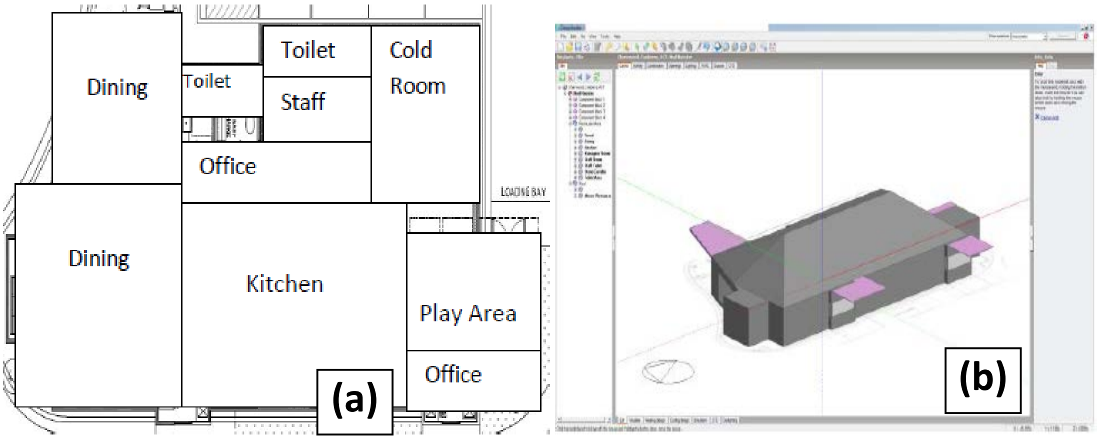


Figure 3. Floor plan (a) and 3D model of the single storey Restaurant building (b)

Third, using the developed integrated approach (Figure 1), the energy simulation for Annual Energy Consumption (kWh/yr) of the two proposed buildings were conducted using different colour options of external walls and roof, without changing the insulation requirement of the external walls and roof. After that, walls and roof insulation were changed in building model and simulated. Then the results were analysed from the DesignBuilder simulation. When the requirement of wall and roof insulation was fixed, then the simulation was carried out using different glass products with different U value and Solar Heat Gain Coefficient (SHGC). Then, optimised options regarding the building fabric and glazing were selected for the proposed building based on the analysis results to make the building energy efficient. Finally these options were checked with JV3 compliance where the proposed building's energy consumptions were less than the Reference building. The results were acknowledged between parties and cost analysis was conducted using unit cost of construction (Rawlinsons, 2014). If the building with optimised construction options was non-compliant with JV3-check or cost savings were not achieved, the integrated approach (Figure 1) was followed until a compliant solution was achieved.

## Results

### Two storey Office building in a sub-tropical climate

For the two storey office building in sub-tropical climate (Climate zone 2), the optimised building elements are presented in Table 2. There were four combinations of the building elements. The annual energy consumption numbers were less than DTS compliant Reference building as shown in Figure 4. All of the combinations achieved NCC compliance, when the proposed integrated simulation approach was used. Then the cost of insulation, glazing and total cost was calculated. Out of four options, the option 3 was selected later on as it was a cost effective in terms of minimum insulation value and cost of glazing. This option was selected as an energy efficient solution, approved by the building designers, builders and authority. From Figure 5, it was demonstrated that there was no insulation cost required for external walls of ground floor, internal walls and floors of the building, when the integrated approach was used rather than using DTS calculation method. The insulation cost savings were achieved in all elements. It was observed that the difference between integrated approach and DTS calculation for the total cost of insulation and glazing were significant as illustrated in Figure 6. It was approximately \$12,130. Compared to simulation procurement (Approximately \$1100) it was 10 times higher. This means a simple investment in simulation during the early design stage can save at least 10 times higher cost of construction compared to initial investment. The consultation cost for DTS calculation was slightly lower than the integrated approach. However, there was no savings for the insulation and glazing using the DTS approach can be achieved, except the reduced consultation fees.

Table 2: Optimised building element options for the two storey office building

| **Insulation/Glazing Options** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| External walls | R2.5 | R2.5 | R1.5 | R1.5 |
| Roof+ceiling | R1.5 | R1.5 | R1.5 | R1.5 |
| Suspended floor | Nil | Nil | Nil | Nil |
| Colour (α) | 0.4 | 0.4 | 0.4 | 0.4 |
| Glass | Low e tint1 | Low e neutral | Film on clear | Low e tint 2 |
| U value, SHGC, VT | 3.6, 0.58, 0.42 | 3.6, 0.51,0.59 | 3.6, 0.51, 0.70 | 3.8, 0.41, 0.32 |

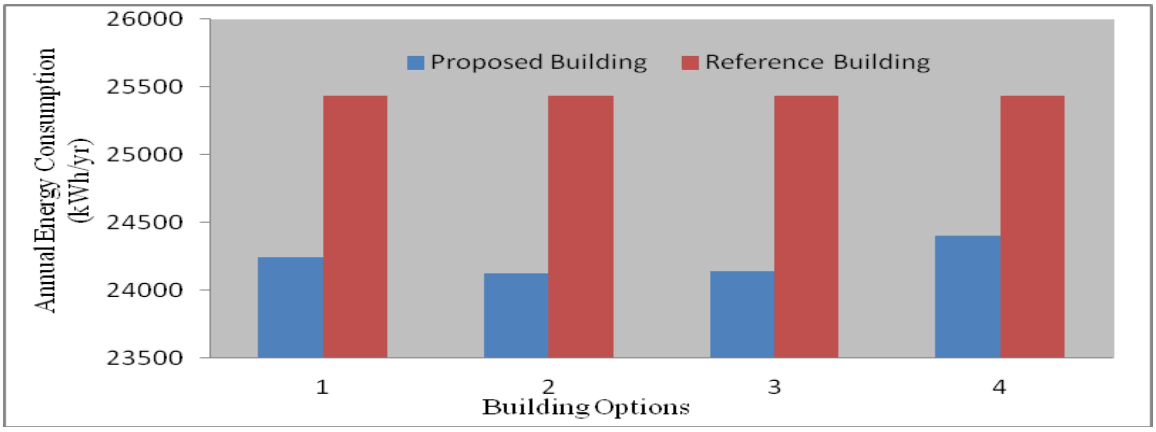


Figure 4. Four options and their compliance with Reference building of NCC

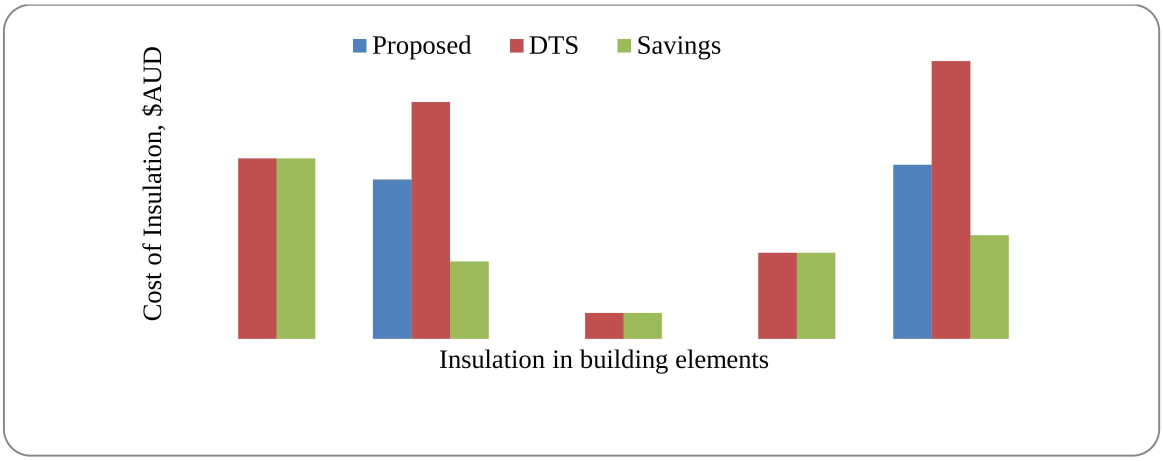


Figure 5. Insulation cost analysis between proposed approach and DTS calculation

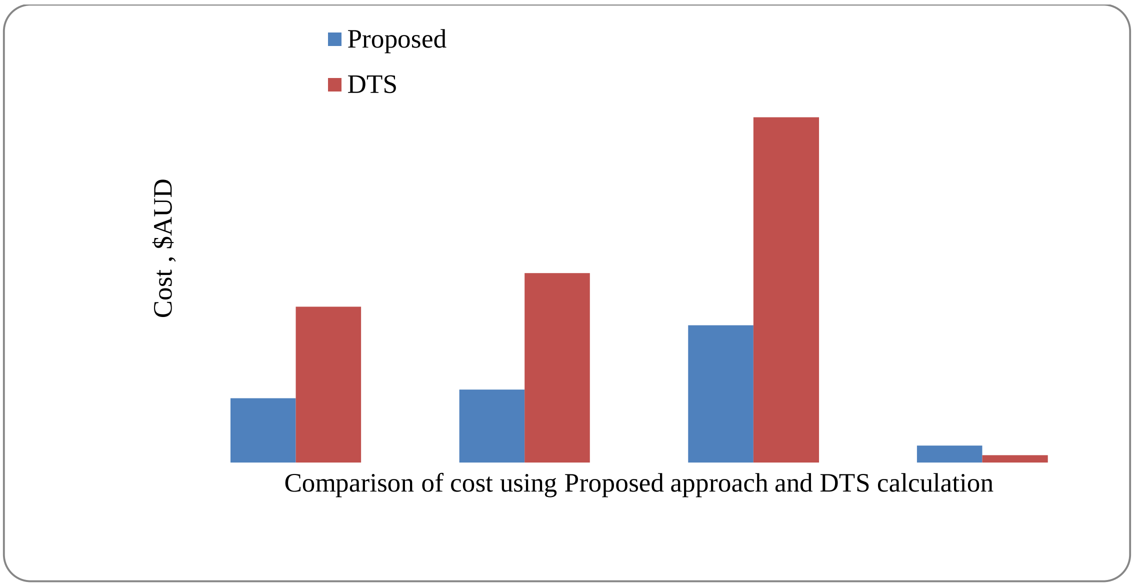


Figure 6. Analysis of costs between constructions and consultation at the design stage

**Single storey Restaurant building in a temperate climate**

For the single storey restaurant building in a temperate climate (Climate zone 7), the optimised building elements are presented in Table 3. There were three combinations of the building elements. The annual energy consumption numbers were less than DTS compliant Reference building as shown in Figure 7. All of the combinations achieved NCC compliance, when the proposed integrated simulation approach was used. Then the cost of insulation, glazing and total cost was calculated. Out of three options, the option 1 was selected later on as it was a cost effective in terms of minimum insulation value and cost of glazing.

Table 3: Optimised building element options for the single storey Restaurant

| **Insulation/Glazing options** | **1** | **2** | **3** |
|---|---|---|---|
| External walls (Cavity or Brick walls) | R1.5 to Cavity panels | R1.0 to Brick walls | R1.0 to Brick walls |
| Roof+ceiling | R1.0 | R1.5 | R2.0 |
| Ground floor | Nil | Nil | R1.0 |
| Colour (α) | 0.4 | 0.7 | 0.6 |
| Glass | Low e clear | Low e clear | Low e clear |
| U value, SHGC, VT | 3.6, 0.68, 0.82 | 3.6, 0.68, 0.82 | 3.6, 0.68, 0.82 |

From Figure 8, it was demonstrated that there was no insulation cost required for internal walls and floors of the building, when the integrated approach was used rather than using DTS calculation method. The insulation cost savings were achieved in these elements including external walls and ceiling-roof. It was observed that the difference between integrated approach and DTS calculation for the total cost of insulation and glazing were significant as illustrated in Figure 9. It was approximately $10,000. Compared to simulation procurement (Approximately $990) it was 12 times higher. This means a simple investment in simulation during the early design stage can save at least 10 times higher cost of construction compared to initial investment. Similar to the first case studied building, there was no savings for the insulation and glazing using the DTS approach can be achieved, except the reduced consultation fees.

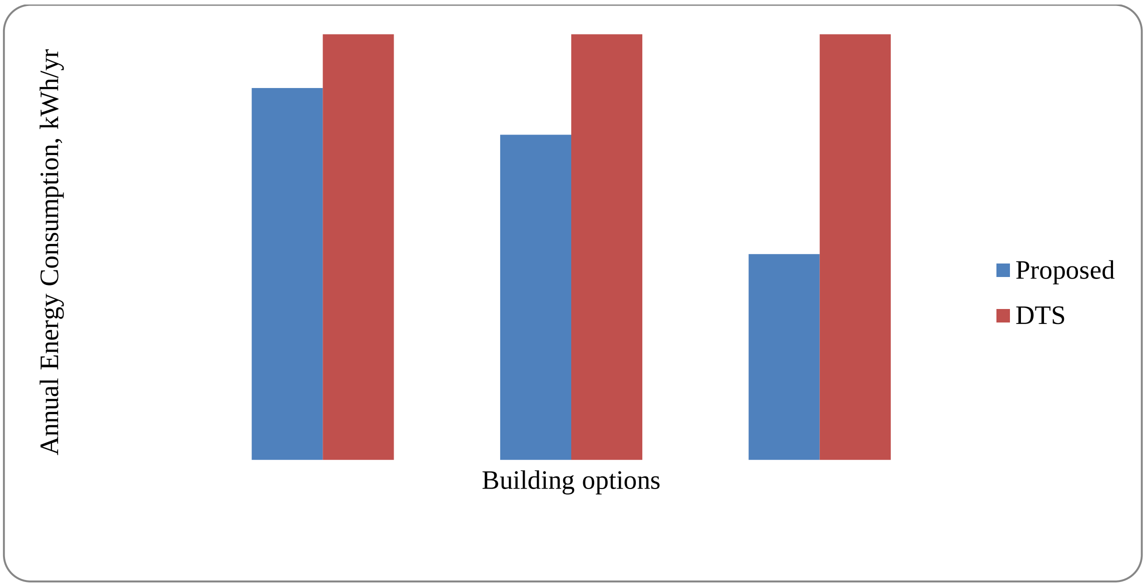


Figure 7. Three options and their compliance with Reference building of NCC

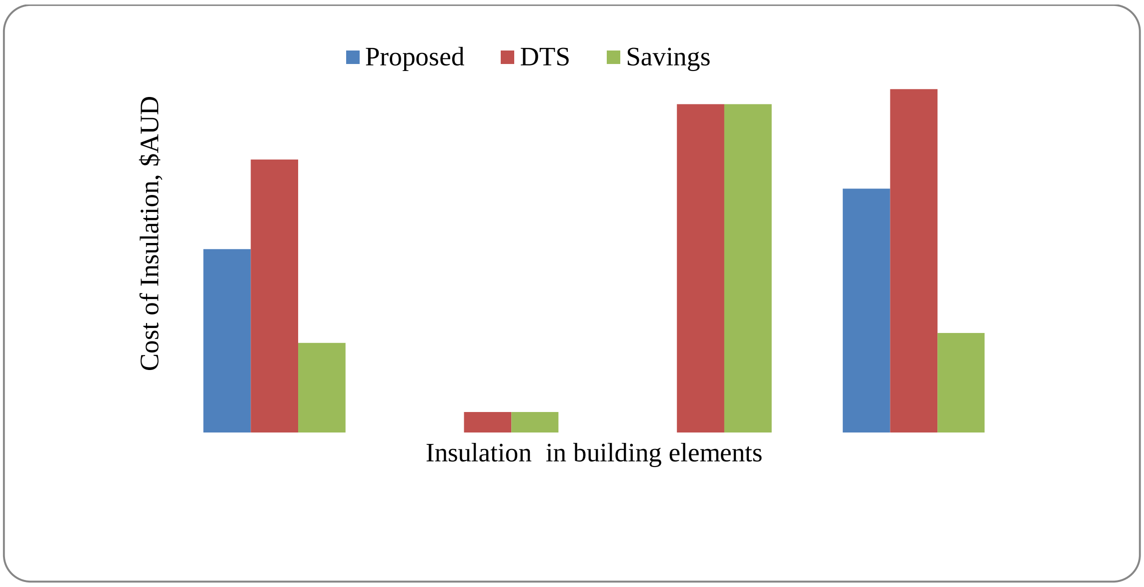


Figure 8. Insulation cost analysis between proposed approach and DTS calculation

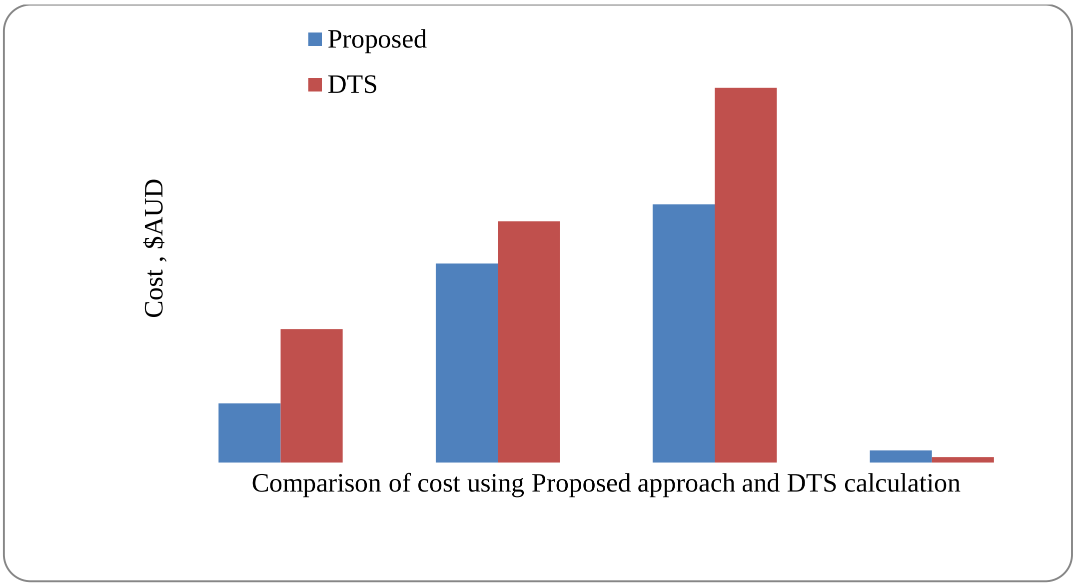


Figure 9. Cost analysis between construction and consultation

## Conclusions

The integrated approach adopted in this study, can be an appropriate way of investigating the optimised building options, energy performance investigation and cost savings of building elements. This approach can be followed at the pre-design, design, tendering, pre-construction overall in design phase for new commercial buildings projects and retrofit stage of the existing commercial buildings projects. Project Managers and Project leaders can consider this approach to save the constructions cost in their projects. From the application of integrated approach on the two case studied buildings, it can be concluded that, the civil construction cost saving was 10 to 12 times of initial investment for simulation procurement during the early stage of design phase of the project. Initial investment for simulation procurement from competent and reputed consultants may vary based on their skills and experiences. In this study, the cost of consultant was considered as an hourly basis ranging \$200/hr to \$250/hr to complete the simulation. In terms of insulation cost savings, it may vary from $\$4/m^2$ to $\$27/m^2$ whereas the glazing cost savings may vary from $\$98/m^2$ to $\$200/m^2$. The civil construction cost saving can be achieved up to 5% of the total construction value (total \$250k approximately) for case studied office building and 10% of the total construction value (\$125k approximately) for case studied Restaurant building. Depending on the type of construction, energy-efficient, optimised and sustainable design options, the cost savings can be more significant (>10%) than manually calculated building elements and cost options if this integrated approach is followed properly. However, the electrical, mechanical and hydraulic equipment purchasing and installation cost were not included in this study as these were not relevant to civil construction cost. To save the construction cost of a building, for a particular building fabric, insulation and glazing, is a complicated process. This process requires appropriate methodology, modelling and input in software by competent person, unknown number of simulations in software, trade in elements within a limited budget and finally agreement between energy efficiency consultants' recommendation and clients' approval. Builders and contractors demand to reduce the construction cost and want to use minimum insulation in building fabrics with low cost glazing. These are the challenges to building designers and energy efficiency consultants.

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