Parametric Energy simulation in concept design phase: A dynamic simulation case study

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Abstract. This paper presents a framework for the development of early-design guidance to inform architects and policy-makers using parametric whole-building energy simulation. The emphasis of the study was to identify and assess the benefit of energy efficiency alternatives primarily focused on the building’s thermal envelope. The energy efficiency alternatives included performance adjustments to the external glazing, wall, roof, floor properties. The result indicated the glazing selection should look to achieve the highest thermal resistance (R-value) and best solar control (lowest shading coefficient value) within budget. Ideally a solar control low-e IGU system could be installed. Solar control glazing also reduced the required development cooling capacity by ~17%.

1. Introduction

Emissions from burning fossil fuels are the primary cause of the rapid growth in atmospheric carbon dioxide (CO\textsubscript{2}) \textsuperscript{[1]} and natural gas and oil that are primarily used for heating and cooling as well as electricity generation in buildings play an important role in CO\textsubscript{2} emissions (U.S. Congress Office, 1992). Energy usage in buildings is responsible for approximately 33\% of the total of final energy consumption and an important source of energy-related CO\textsubscript{2} emissions worldwide \textsuperscript{[2]}. In OECD countries, buildings cause about 30\% of national CO\textsubscript{2} emissions from the consumption of fossil fuels \textsuperscript{[3]}. One of the ways of improving energy sustainability is increasing energy efficiency in existing buildings. However, investment costs for installing and/or replacing technologies with more efficient ones can be seen by the building owners an obstacle to achieve improvements in energy consumption. Consequently, this change affects both future CO\textsubscript{2} emissions and future energy expenditures. Therefore, the initial investment decision for the new technologies should be given by taking future energy expenditure savings and reductions in CO\textsubscript{2} emissions into account. This study is motivated by the need to use an analytical approach to select the right energy efficiency measures for improving energy efficiency in existing buildings with both environmental and financial considerations.

Designing energy efficient buildings with good indoor environment involves elements of expertise deriving from multiple disciplines such as architects, civil, mechanical and electrical engineers. With current emphasis on sustainability, including building energy and indoor environment, design requirements from the involved disciplines have become more important in the early design stages \textsuperscript{[4]}. Therefore, building performance simulations (BPSs) are increasingly used to design buildings in early concept phase.
Studies have reported that energy savings of up to 30% can be achieved through retrofit options in existing office and commercial buildings without compromising the indoor comfort [5] [6]. The greatest potential for optimizing the energy efficiency of buildings is in the early design stages [7] [8] [9] [10].

Early concept design study has been done in this paper. The emphasis of the study was to identify and assess the benefit of energy efficiency alternatives primarily focused on the building’s thermal envelope. Specialized building performance modelling software (IES-VE 2015) provided a platform for the energy modelling process.

The proposed building geometry was translated into IES-VE to create a 3-dimensional model, other modelling inputs into IES-VE included;

- lighting, equipment & occupancy gains,
- operating profiles,
- plant efficiencies,
- thermal performance of constructions

A “Baseline” energy model was defined to an equivalent New Zealand Building Code (NZBC) H1 model and the baseline annual energy use calculated. Proposed energy efficiency alternatives were assessed based on comparative performance to this baseline model.

The energy efficiency alternatives included performance adjustments to the external glazing, wall, roof, floor properties.

2. Building and site information

The development included office Pods spread over three levels, a Gym and Café with a gross floor area of approximately 5600 m2. Basement car parking provisions are also provided.

2.1. Building geometry

The geometry of both the proposed building was input in IES-VE to create the 3-dimensional computer model shown in Figure. 1.

![Modelled Geometry - view from the South East](image)

2.2. Simulation weather file and climate

2.2.1. Climate. New Zealand has a largely temperate climate. While the far north has subtropical weather during summer, and inland alpine areas of the South Island can be as cold as -10 C in winter, most of the country lies close to the coast, which means mild temperatures, moderate rainfall, and abundant sunshine.

2.2.2. Weather file. The simulation weather file was derived from historic weather observations and represents an average or typical meteorological year. The simulation weather file was an International Weather for Energy Calculations (IWEC) file and contained hourly weather data including dry bulb temperature, dew point temperature, wind speed, wind direction, hourly solar radiation and illuminance data.
3. Baseline energy model

The baseline thermal envelope performance figures Table 1 and Table 2 are based on the climate zone one requirements as defined by the NZBC H1 clause.

**Table 1. Baseline Model – Thermal Envelope Assumptions**

| Thermal Envelope Element | Construction Notes | R-value (m².K/W) |
|--------------------------|--------------------|-----------------|
| Walls                    | Pre-Cast Concrete Panel Timber Framing Gib Lining | 0.3             |
| Floors                   | Suspended Concrete Slab Carpet & Underlay         | 0.4             |
| Roofs                    | Steel Roofing & Underlay Framing & Insulation Ceiling Tiles | 1.9             |
| Glazing                  | Clear Single Glazed (shading co-efficient 0.94)   | 0.18            |

The modelled building façade, roof and floor areas are displayed in Table 2. Any glazed spandrels are included within the solid wall area figures.

**Table 2. Thermal Envelope Areas.**

| Envelope Orientation | Total Area | Glazed Area | Solid Element Area | WWR |
|----------------------|------------|-------------|--------------------|-----|
|                      | m²         | m²          | m²                  | %   |
| Facades              | 3.664      | 1.706       | 1.958              | 47% |
| North                | 1.268      | 457         | 811                | 36% |
| South                | 944        | 599         | 345                | 64% |
| East Total           | 699        | 283         | 416                | 41% |
| West Total           | 753        | 367         | 386                | 49% |
| Roofs                | 2.450      | 0           | 2.450              | n/a |
| Floors               | 2.457      | 0           | 2.457              | n/a |

The modelled building façade, roof and floor areas are displayed in Table 2. Any glazed spandrels are included within the solid wall area figures.

3.1. Building services assumptions

Several building services assumptions were made when generating the Baseline energy model and these assumptions were kept constant when assessing the proposed energy efficiency alternatives. A summary of assumptions relating to the modelled building services/systems are provided in Table 3.
### Table 3. Building Services Assumptions

| Building Service          | Performance                                                                 |
|---------------------------|-----------------------------------------------------------------------------|
| Temperature Set-Points    | Heating 21°C                                                                 |
|                           | Cooling 22°C                                                                 |
| Heating Source            | Electric heat pump with an average COP of 3                                 |
| Cooling Source            | Electric heat pump with an average Energy Efficiency Rating of 2.5          |
| Outdoor Air Ventilation   | Constant Volume System                                                      |
|                           | 1.5l/s/m² outdoor air to office areas                                       |
|                           | Specific Fan Power (SFP) 1.8 W/l/s                                           |
| Toilet & General Extract Fans | 0.5l/s/m² total extract air flow rate                                      |
|                           | SFP 0.6 W/l/s                                                               |
| FCU Fans                  | Supply Air Flow Rate based of a Delta T 10°C                                 |
|                           | SFP 0.9 W/l/s                                                               |
| Operating Profiles        | Adapted ASHRAE office profiles with plant operating for one late night per week refer to Error! Reference source not found, for details. |
| Occupancy                 | 10m²/person                                                                 |
| Lighting Power Density    | Office – 8W/m²                                                              |
|                           | Circulation – 10 W/m²                                                       |
|                           | Toilets – 10 W/m²                                                           |
| Equipment Gains           | Office – 12W/m²                                                             |
| Domestic Hot Water        | Standard WELLS 2-Star flow rate fitting installed,                          |
|                           | DHW/Cold Water Ration 50%                                                   |
|                           | System Efficiency 80%                                                       |
| Fuel Costs                | Electricity – 20c/kWh                                                        |

Given the large number of small business pods and that each pod had a separate title it was very likely small dedicated HVAC systems would be installed for each pod. Baseline Model 1A reflects this assumption where each pod was modelled with an efficient heat pump system providing both space heating and cooling.

Given the efficient space heating & cooling system of Baseline Model 1A, achieving the energy savings target was more difficult when compared to a more traditional chilled water system with electric heating elements.

#### 3.2. Annual energy use (Baseline1A)

The SIM 01a baseline model was calculated to have an annual energy consumption of 140 KWh/m² across the Gross Floor Area (GFA). The annual energy consumption by end use for the baseline model is displayed in Figure. 2 with percentages.
The energy end use categories which are directly influenced by the performance of the building thermal envelope (space heating systems, space cooling systems and indoor FCU fans) accounts for approximately 43% (61.0 KWhm²/yr) of the baseline annual energy use. The remaining energy end use categories account for 57% of annual energy use and are not directly influenced by the performance of the thermal envelope.

3.3. Energy efficiency alternatives
An indicative square meter cost for each energy efficiency alternative was obtained from product suppliers, the glazing and opaque construction alternatives are displayed in Table 4 and 5 respectively. The indicative per square meter costs were multiplied by the relevant construction areas and a total cost was estimated for each energy efficiency alternative. 

Table 4. Thermal Envelope - Glazing Variations

| Modelled Glass | Glass description                     | Glazing performance |
|----------------|---------------------------------------|---------------------|
|                |                                       | R value  | SC         |
|                |                                       | m². K/W  |            |
| Glass 1        | Clear Single Glazed (NZBC)            | 0.18     | 0.94       |
| Glass 2        | Clear IGU                             | 0.35     | 0.80       |
| Glass 3        | Solar Control IGU                     | 0.34     | 0.33       |
| Glass 4        | Solar Control & Low-e IGU             | 0.51     | 0.30       |
Table 5. Thermal Envelope – Opaque Construction Variations & Costs

| Modelled constructions and insulation products | R-values | Construction references |
|-----------------------------------------------|----------|-------------------------|
| **Wall Variations**                           |          |                         |
| NZBCWall Construction                         | 0.30     | Wall (NZBC)             |
| 90mm Pink® Batts® R1.8 Wall                   | 2.00     | Wall Type 1             |
| **Roof Variations**                           |          |                         |
| NZBC Roof Construction                        | 2.10     | Roof (NZBC)             |
| 140mm Pink® Batts® Classic R2.6               | 2.92     | Roof Type 1             |
| 180mm Pink® Batts® Classic R3.6               | 3.48     | Roof Type 2             |

4. Results

The following Table 6 summarizes the modelled energy efficiency alternatives and details the associated energy and financial implications with respect to the Baseline Model 1A.

Table 6. Energy efficiency measures: annual energy use.

| Simulation Ref. ¹ | Space Heating Source kWh/m² | Space Cooling Source kWh/m² | Indoor FCU Fans kWh/m² | Central Supply & Extract Fan kWh/m² | Domestic Hot Water kWh/m² | Plumbing Pump kWh/m² | Lighting kWh/m² | Office Equip. kWh/m² | Total Building Energy Use kWh/m² |
|-------------------|-----------------------------|-----------------------------|------------------------|-------------------------------------|--------------------------|---------------------|------------------|---------------------|----------------------------------|
| SIM 01a           | 15.4                        | 23.1                        | 20.6                   | 9.0                                 | 11.9                     | 1.0                 | 27.3             | 25.9                | 140                             |
| SIM 02a           | 12.5                        | 23.9                        | 19.3                   | 9.0                                 | 11.9                     | 1.0                 | 27.3             | 25.9                | 137                             |
| SIM 02b           | 15.4                        | 14.7                        | 15.5                   | 9.0                                 | 11.9                     | 1.0                 | 27.3             | 25.9                | 127                             |
| SIM 02c           | 14.1                        | 14.9                        | 14.8                   | 9.0                                 | 11.9                     | 1.0                 | 27.3             | 25.9                | 125                             |
| SIM 03a           | 12.3                        | 26.4                        | 19.4                   | 9.0                                 | 11.9                     | 1.0                 | 27.3             | 25.9                | 139                             |
| SIM 04a           | 15.1                        | 21.9                        | 18.2                   | 9.0                                 | 11.9                     | 1.0                 | 27.3             | 25.9                | 136                             |
| SIM 04b           | 14.7                        | 21.9                        | 20.1                   | 9.0                                 | 11.9                     | 1.0                 | 27.3             | 25.9                | 138                             |
| SIM 05a           | 12.4                        | 25.1                        | 19.9                   | 9.0                                 | 11.9                     | 1.0                 | 27.3             | 25.9                | 139                             |
| SIM 06            | 6.1                         | 19.5                        | 11.9                   | 9.0                                 | 11.9                     | 1.0                 | 27.3             | 25.9                | 119                             |
| SIM 07            | 6.3                         | 19.5                        | 11.6                   | 9.0                                 | 11.9                     | 1.0                 | 27.3             | 25.9                | 118                             |

¹ For details on the energy efficiency alternative associated with each simulation reference refer to Table 6

4.1. Glazing

The simulated solar control glazing alternatives had significant benefits to overall building annual energy use with the largest gains coming from solar control attributes. In addition to the energy savings associated with solar control glazing the required development cooling load was reduced by ~17%.

4.2. Wall and Roof

Wall insulation is not required within the NZ building code baseline model. SIM 03a modelled the thermal resistance of a wall at R2.0 which performed well. Roof insulation was required in the NZ building code baseline model.
4.3. Combination of energy efficiency measures
The modelled SIM 05 which was a combination of the below energy efficiency alternatives provided energy saving of approximately 21.0 kWh/m²/yr

- SIM02c - Solar control low-e IGU,
- SIM3a - R2.0 wall insulation
- SIM04b - High performance roof insulation R3.5 (R3.6 batts 200mm deep)

The required development heating and cooling capacity for SIM 05 were both reduced by 34% and 28% respectively when compared to the Baseline Model 1A requirements.

5. Conclusion
The glazing selection should look to achieve the highest thermal resistance (R-value) and best solar control (lowest shading co-efficient value) within budget. Ideally a solar control low-e IGU system could be installed. The developed models in this paper provide an opportunity for MEP designers, owners, and facility managers to estimate energy consumption of the commercial office buildings at the earliest phase of the construction projects. It enables them to select energy consumption measures according to the goal of the project for saving energy.

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6. Acknowledgment
I would like to express my gratitude to the SEEC Pvt Ltd and GreenTree Pvt Ltd. for providing me the opportunity to work on this project.