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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 co-efficient 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_2) [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_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_2 emissions worldwide [2]. In OECD countries, buildings cause about 30% of nationalCO_2 emissions from the consumption of fossil fuels [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_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_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 [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-dimesional 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.

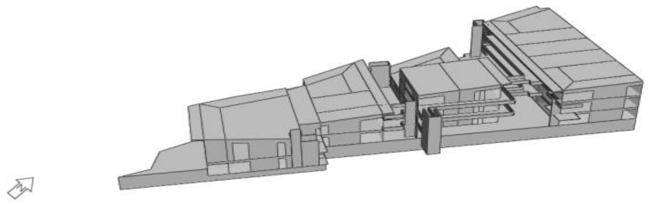

Figure 1. Modelled Geometry - view from the South East

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 (m^2.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/m^2 outdoor air to office areas Specific Fan Power (SFP) 1.8 W/l/s
Toilet & General Extract Fans	0.5l/s/m^2 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	10m^2/person
Lighting Power Density	Office – 8W/m^2 Circulation – 10 W/m^2 Toilets – 10 W/m^2
Equipment Gains	Office – 12W/m^2
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.

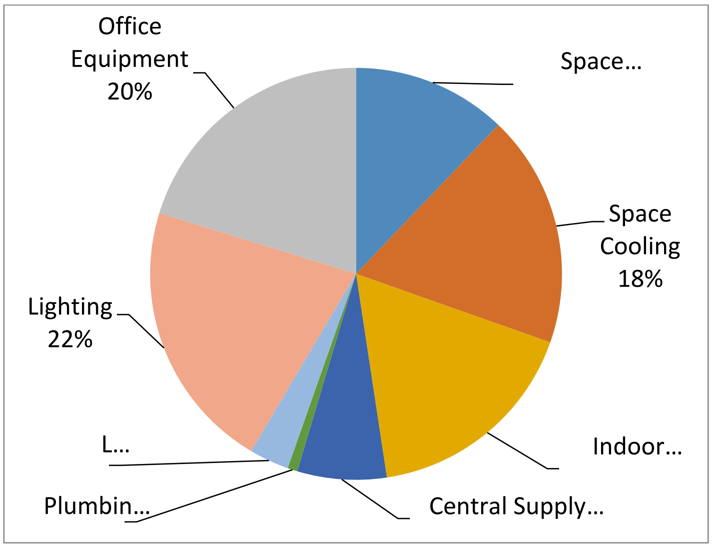

Figure 2. Baseline 1A Model – Energy End Use (% of total annual energy use)

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**	
		m^2.K/W	SC
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

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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: anuual energy use.

Simulation Ref.[1]	**Space Heating Source** kWh/m^2	**Space Cooling Source** kWh/m^2	**Indoor FCU Fans** kWh/m^2	**Central Supply & Extract Fan** kWh/m^2	**Domestic Hot Water** kWh/m^2	**Plumbing Pump** kWh/m^2	**Lighting** kWh/m^2	**Office Equip.** kWh/m^2	**Total Building Energy Use** kWh/m^2
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.

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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

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