Semi-automated Simulations: Know Your Schedules.

Nilesh Bakshi^{1,2}, Michael Donn¹, Emily Newmarch¹

¹Victoria University of Wellington, Wellington, New Zealand

²Studio of Pacific Architecture, Wellington, New Zealand

Abstract

This study tests semi-automated simulation measures such as schedules and occupancy profiles in BIM software packages to establish energy performance predictions for the purposes of providing evidence of compliance. These predictions are tested against an archetypal range of household operation figures that are based on the data collected of approximately 400 households monitored for 11 months each. This study identifies that standardising the simulations by using the archetypal range of dwelling occupation predictions produces a more consistent outcome in energy evaluation across both software packages. However, both of the BIM software packages tested in this study are unable to establish energy performance predictions that align with the real-world measured data. This suggests that in-built semi-automated simulation measures, beyond the optimised schedules and occupancy profiles, investigated in this study, need to be examined in greater detail.

Introduction

57 per cent of New Zealand construction projects adopt the Building Information Modelling (BIM) approach (BRANZ, 2017). ArchiCAD® and Revit® are the widely-used software packages (Thompson, 2012). Many firms have bought into this workflow by buying licenses for either ArchiCAD® or Revit®, with their most common use being 3D visualisation, 80 per cent, and design review, 75 per cent. However, both software programs have either built-in (ArchiCAD®) or connection function (Revit® to Green Building Studio®), which allow energy evaluation. Yet, in New Zealand, this function is one of the least used of the tools, with only 13 per cent of users adopting this and 0 per cent using it for New Zealand Building Code (NZBC) compliance. Under New Zealand standard NZS4218, NZBC compliance can be demonstrated using these tools through the 'Modelling Method', which requires the software to be validated against ASHRAE 140, an international energy simulation standard. ArchiCAD® and Revit® both claim validation against this standard.

Due to the large uptake of ArchiCAD® or Revit® by architectural firms and the low adoption of the energy evaluation tools, this study explores the viability of their semi-automated building energy performance simulation capability. BIM software packages like ArchiCAD® and Revit® aim to eliminate inappropriate human

intervention that could cause results to be untrustworthy (Bazjanac, 2008). This is done using a predetermined set of simulation inputs that are automatically assigned to increase workflow productivity.

These inputs include a set of predictions around the behavioural patterns of dwelling occupants. However, this set of predictions differs from program to program and they often do not match the required assumptions in the building code Modelling Method. This paper evaluates the effect on performance of these pre-set default assumptions of occupancy and energy use using as a baseline an archetypal range of household operation figures developed in recent Ph.D. research (Bakshi, 2017). The goal is to develop an occupancy modelling framework for the different types of residential housing that can: create consistency between software packages; provide appropriate code compliance results; and document a range of schedules that can be used to establish the risk of non-compliance with the code should occupancy be significantly lower or higher than the 'typical'.

Background

Globally, over the last 40 years, theoretical frameworks have attempted to capture the complexities of human behaviour by defining the connection between the external environmental factors (actions and events) and the internal human factors (drivers and needs) (Hong et al., 2015). Yet, aside from all of this research, occupation predictions are still one of the major weaknesses in building simulation for energy efficiency (Hong et al., 2015).

This issue has gained even more importance as building simulation shifts from a specialised task, using software that provides full manual control, towards semi-automation or BIM methods. This shift has increased the difficulty of creating trustworthy energy simulation results. This is in part because the detailed simulation building specific inputs that were once defined by engineers are now substituted by semi-automated simulation measures that are based on one-size-fits-all assumptions.

In the context of residential housing within New Zealand, the building code loosely defines appropriate occupancy prediction parameters and leaves itself open for interpretation and adjustment.

A recent doctoral thesis established a number of operational formulae based on dwelling size, household size and number of household appliances (Bakshi, 2017). Using data from the monitoring of approximately 400 households for 11 months each, and these formulae, an archetypal range of more accurate dwelling occupancy predictions can be incorporated into semi-automation software packages for building energy performance simulation.

Methods

Newmarch et al., (2018) identify that in order to meet compliance in New Zealand the NZBC “Modelling Method” requires the a compliance report comparing the performance of a simulated model with against a reference model. The reference model is built to the compliance requirements outlined in NZS 4218. This model applies the minimum construction R-values based on the climate zone and is the measure of the minimum required level of performance.

In order to tests semi-automated simulation measures to establish energy performance predictions that can demonstrate evidence of compliance, this paper adapts this process and presents the building energy performance results of a reference case study model that uses software inputs for materials. As a measure of quality assurance all models use the same geometry and glazing ratio.

The case study model (Fig. 1), a typical mass built three-bedroom residential house, is simulated using the simple R-values specified in the NZS4218 (New Zealand Standards, 2019).

Figure 1: Case study model elevations of a typical mass built three-bedroom residential house. An example of the cases studies archetype monitored in Bakshi (2017).

The semi-automated simulation measures for schedules and occupancy profiles are examined for both ArchiCAD© and Revit© and optimised to reflect the measured energy use of a range of case studies from Bakshi (2017). To represent the full range of similar case studies for which data was measured, this study tests two semi-automated simulation measures of schedules and occupancy profiles that present the highest and lowest energy households. The result of these high and low energy household measures are then presented

comparatively against the measured or expected range of energy use.

To process case study data, the following five steps must be completed for the mechanics part of this methodology. All five steps must be completed the first time an analysis is done. Steps 1 to 3 for the first investigation area took four days of modelling for the initial simulation, each subsequent simulation was much quicker (half a day) as the built up model required minor tweaks to test different occupancy profiles. Step 4 took 1-1.5 days for each separate analysis. Step 5 typically took 2-3 days to evaluate, graph and summarise the results.

1. Prepare the architectural ‘Building Information Model’.
2. Define all ‘thermal blocks’ and set environmental inputs.
3. Automatic model geometry and material property analysis.
4. Assign and input additional data to complete ‘Building Energy Model’ (BEM).
5. Evaluate energy performance.

In total, a single case study with multiple investigation areas should take approximately 7 to 11.5 days to complete. This is considering modelling from scratch. In practice, where an existing 3D model already exists with zones, set up of all the simulation inputs could be done in 1 day.

On top of this, the level of energy evaluation is likely to be significantly less thorough due to a practice-based analysis being more targeted at finding a specific thing. For example:

- Does it meet NZBC?
- Does it overheat in summer?
- Is it too cold in winter?

These questions can be answered quickly by looking at the summary report exported as a PDF. There would be no need for analysing the raw data (as a CSV export) in Excel, which is where the time was spent in the energy evaluation for this research. This five step process potentially highlights a significant barrier to the viability using BIM’s semi-automated building energy performance simulation capabilities in practice. Educating professionals in the use of tools like these to a point that the time required to complete the analysis is less than the time that is currently required. This also calls into question the value provided is worth the considerable extra expenditure of time.

In both software packages, models were built using material descriptions that align closely with the building’s consent specifications. For example, Pink Batts©, a glass fibre batt insulation product commonly used in New Zealand construction, has been matched with the glass fibre batt insulation option in both ArchiCAD© and Revit©.

The building modelling strategy adopts the same modelling approach as Newmarch et al., (2018). All construction assemblies were made using materials present within the inbuilt library. Each material layer was

given the same thickness to match the case study construction specification.

However, as both inbuilt calculators were homogenous, for heterogeneous layers the most prevalent material properties were taken. In the context of this case study, in an insulated timber wall with a timber structure and insulation infill between the vertical timber studs, a single insulation material “layer” was defined. As a combination of the two materials’ R-values. (Newmarch et al., 2018). The methodology for R-value inputs for the reference and proposed models differ slightly in each software due to their interface and settings.

For ArchiCAD®, the construction R-values were input using the override setting within the energy model evaluation settings and a “Structure Heat Storage Mass” was applied. In Revit® the construction R-values were input by creating a new material with thermal properties that generated the reference and proposed construction R-values.

Analysis of Simulation Inputs

In ArchiCAD® the default values reflect the operation profile specifications of the DIN 18599 Standard - Energy Efficiency of Buildings. However, this standard states that this operation profile is not made for residential buildings.

Additionally, as the standards are native to Germany, it is not clear where the NZ Residential Profile (Fig. 2), is generated from.

Figure 2: ArchiCAD® operation profile semi-automated simulation measures list.

Table 1 lists details about the assumptions used for each building type during energy analysis or heating and cooling loads analysis in Revit®. These assumptions are based on ASHRAE 90.1-2010, ASHRAE 90.2-2010, ASHRAE 62.1, CBECS data, and other building surveys.

The Autodesk Revit® manual specifically notes that these assumptions are used for the purpose of providing reasonable energy usage estimates and not for the purpose of code compliance (Autodesk, 2019).

Table 1: Revit® operation and energy load profile semi-automated simulation measures list, Autodesk (2019).

Parameter	Values
Occupancy Schedule	Residential
People/100 sq. M.	0.945
People Sensible Heat Gain (W/person)	70
People Latent Heat Gain (W/person)	45
Lighting Load Density (W/sq. M.)	4.8
Equipment Load Density (W/sq. M.)	4.6
Infiltration Flow (ACH)	0.5
Outside Air (ventilation air) Flow Per Person (litres per second)	Null
Outside Air (ventilation air) Flow Per Area (cubic meters per hour per square meter)	1.1
Unoccupied Cooling Set Point (C)	29.4

What Fig. 2 and table 1 identify is that both software packages establish their specific set of assumptions for building performance evaluation from within their country/continent of origin. Although this is a logical step for their relative local markets, it quickly reduces the applicability to other international markets where they are also being sold.

In New Zealand the regulations provide assumption parameters for the ‘Modelling Method’ that are loosely defined, which means that externally developed software doesn’t have to redo the information being applied to case study-specific building components. Very literally the ‘Information’ aspect in ‘Building Information Model’ quickly becomes inaccurate, leaving the user with a building model that lacks crucial information. This missing link becomes important as this missing information is used to create a Building Energy Model (BEM), which in turn generates results that can be used for compliance against the NZBC.

Figures 3 and 4 are graphs of the different occupancy assumptions from ArchiCAD®, Revit® and NZS4218. They represent two different periods; weekdays and weekends, as defined in NZS4218. However, both ArchiCAD® and Revit® keep the same set of assumptions across all these periods. Occupancy schedules follow the same trend with differences noticeable during the day.

Figure 3: Weekday occupancy profile comparison.

This could be due to the behaviour predictions originating from different behaviour patterns. For example, Revit®

define their occupancy schedule as “single family” which suggests occupancy assumptions based around work and school daily patterns. This definition of the name appears to be reflected in the schedule not turning completely off during the middle of the day and starting to increase at 3pm, a typical school finishing time, and again at 5pm, a typical end to the workday.

In contrast, ArchiCAD© only specifies the schedule as “Residential NZ” which is a term more loosely defined than what is used in Revit©. However, as the schedule is inactive from 9am until 6pm. It can be assumed that this behaviour prediction appears to be based on occupants with a professional lifestyle and not children. The behaviour prediction assumptions are not stipulated in the user manual.

Figure 4: Weekend occupancy profile comparison.

For both ArchiCAD© and Revit© there are a notable differences, beyond the Graphic User Interface (GUI) for running an energy simulation. These differences pertain to the assumption of occupancy (Fig. 5) and internal heat gains (Fig. 6).

Figure 5: Comparison of occupancy figures between code and ArchiCAD© and Revit©.

Both ArchiCAD© and Revit© are drastically different in comparison to the suggested parameters from the NZS 4218 as part of the New Zealand Building Code.

The code compliance methods allowed in the NZS4218 means of compliance with Clause H1 of the building code allows any calculation tool that complies with ASHRAE Standard 140 to be used to prove compliance.

The process allows a wall R-value to be smaller than the minimum required in the Schedule Method. What it requires is that a building's performance is simulated to demonstrate it is better than a baseline design using the

Schedule Method's R-values. As with most building energy performance software, both software packages 'validate' themselves against the same international computer modelling standard, ASHRAE 140.

Figure 6: Comparison of heat gains per person between code and ArchiCAD© and Revit©.

In this initial analysis (Fig. 3 to 6) any potential similarities in energy predictions seems implausible for an identical building modelled in these two software packages. This appears to be primarily driven by the differing occupancy predictions for a residential building in ArchiCAD© and in Revit©.

As these occupancy predictions are also different to those recommended by the building code for energy simulation, they cannot 'out-of-the-box' be easily used to demonstrate compliance with the building code energy performance specification. With an increasing trend to create these 'semi-automated' and apparently validated (ASHRAE 140) simulation packages there is a level of unreliability in the results which precludes any possible approval of their use for code compliance and increases the probability that they could be a cause of future 'performance gap' problems.

Measured Data

A doctoral thesis completed in 2017, titled, *A lifecycle analysis of living*, focused specifically on measuring household behaviour and the impact associated with the act of dwelling rather than simply looking at the dwelling alone (Bakshi, 2017).

This doctoral thesis, first established the fundamental gap of knowledge surrounding our understanding of human behaviour in the operation of a household. Among other things, like potential environmental impact reduction measures in the energy generation sector, Bakshi (2017) identified the existence of *Hidden Emissions* (Bakshi, 2017, p.223) that are currently not considered in international CO₂ accounts.

This work postulated a an unprecedented theoretical framework for establishing impact resulting from human behaviour at the household level, making it possible to understand how behaviour in the home effects household occupancy and operation.

Using data from the monitoring of approximately 400 households for 11 months each and operational formulae based on dwelling size, household size and number of

household appliances, Bakshi (2017) identified three occupancy and energy user groups.

For the purposes of this study the measured household operation and occupancy data from Bakshi (2017) is used as it provides the only measure of actual occupancy in household operation to date. Figure 7 shows the data graph produced by Bakshi (2017) These were classified as low, medium and high users which translated into occupancy and energy load figures for this study.

Figure 7: Low, medium and high occupancy and energy user groups Bakshi (2017, page 204).

For the purposes of this investigation, only the 'high user' households and 'low user' households are tested in ArchiCAD© and Revit©. This made it possible to comparatively assess the comprehensive range of expected results against the simulations from each semi-automated simulation software.

Results

The measured data of 'high user' and 'low user' households were presented in average kilo-watt hours (kWh) per month. For this reason all simulation outputs will be converted to monthly averages so that the results can be comparatively analysed.

Figure 8: Expected range based on Bakshi (2017)

The expected range data (Fig. 8) suggests that the lowest user group profile energy figure is approximately 470kWh per month. The highest user group profile energy figure is approximately 760kWh per month. (Bakshi, 2017). This is the targeted average monthly kWh range that each software simulation will need to replicate so that the simulation results can be trusted as a measure of quality against the measured data collected.

Figure 9: ArchiCAD© results range

In order to establish how the semi-automated simulation schedules and occupancy profile measures in ArchiCAD© establish energy performance predictions, the user group profile energy results for both the low and high user groups are plotted in Figure 9. This data shows that when simulated in ArchiCAD©, the lowest user group profile energy figure is approximately 390kWh per month and the highest figure is approximately 521kWh per month. Both the lowest and highest figures are well below the expected range figures. This suggests a consistent downward trend for both simulation outputs from ArchiCAD© in comparison to the measured figures.

Figure 10: Revit© Results range.

The results of the semi-automated simulation of schedules and occupancy profile measures in Revit© are plotted in Figure 10. This data does not follow the same trend for both simulation outputs as observed in the outputs from ArchiCAD©. The lowest user group profile energy figure is approximately 320kWh per month, which like the lowest figure from ArchiCAD© is much smaller than the 'expected range' figure. However, the highest user group profile energy figure is approximately 960kWh per month. These figures have the biggest range of simulation results that is outside of the highest and lowest 'expected range' results (Fig. 8).

The trends, or lack thereof in the case of the ArchiCAD© results that are observed in Figures 8 to 10 are collectively plotted on a single axis (Fig. 11). This makes it possible to compare the 'low user' and 'high user' range of each simulation package with the expected range data.

Figure 11: Comparison of high and low simulation results – Expected Range vs ArchiCAD® vs Revit®. (Figures 8, 9 and 10 merged in order to see a better comparison between the results).

The comparison of high and low simulation results (Fig. 11) identifies that although the simulation results overlap and in some instances fall within the ‘expected range’, the highest and lowest figures for both do not replicate the simulation results and hence cannot be quality assured against the measured data collected by the preceding doctoral research (Bakshi, 2017). Although it is possible to use this data to create more consistent occupancy profiles for both BIM software packages, this does not establish reliable energy performance predictions for the purposes of providing evidence of compliance in practice. This could potentially be resolved by examining in greater detail the other in-built semi-automated simulation measures, beyond the optimised schedules and occupancy profiles. These can potentially include the material properties and libraries, how both software packages deal with thermal bridging and also how heterogeneous and homogenous construction layers are modelled as identified by Newmarch et al. (2018).

Conclusion

This study tested semi-automated simulation measures that specifically deal with the building schedules and occupancy profiles in BIM software packages to establish energy performance predictions. These predictions were tested against an archetypal range of household operation figures that are based on the monitoring data of 400 households for 11 months each.

This study identifies that standardising the simulations by using the archetypal range of dwelling occupation predictions can produce some consistent inputs for semi-automated simulation measures such as schedules and occupancy profiles. Although this has potential to produce more consistency in the outcome in energy evaluation across both software packages, both BIM software packages are unable to establish energy performance predictions that align with the real-world measured data. The semi-automated measures incorporated in each software package both use input data that cannot be used for the purpose of code compliance. It is therefore unsurprising that the occupancy profiles tested in this study based on measured data produce more consistent results between the software packages tested. This is also a predictable outcome when one considers the

default occupancy profile comparison presented in Figures 3 and 4.

Limitations and Further Research

It should be noted that this research is not without limitations. First, in order to test the simulation viability and process, this study only analyses one type of case study that was examined in the preceding doctoral research. Although the data from this doctoral research was extensive and representative of the residential housing stock in New Zealand, simply looking at one housing typology here inherently means that the results presented are restricted to this single housing typology.

Second, the data that these results are based on were collected in the Household Energy End-use Project (HEEP) over ten years ago (BRANZ, 2013). Therefore this data may not represent current design technologies and practices.

Third, this study only tests semi-automated simulation measures that focus on schedules and occupancy profiles in two BIM software packages.

Fourth, although this study identifies the need to incorporate accurate energy simulation in the BIM process, neither the demand nor the viability of using BIM’s semi-automated building energy performance simulation capabilities in practice have been tested. This has both economic and accuracy concerns. The simulation time-frame identified in this study alone suggested this is a potentially grave concern. Especially considering the simulations here were conducted by a team of simulation experts and researchers. Therefore, it is expected that the most significant barriers to being able to provide accurate energy performance predictions using the BIM software packages tested in this study will likely be:

- educating professionals in the use of these tools to a point that the time required to complete the analysis is less than the time that is currently required – or the value provided is worth the considerable extra expenditure of time;
- providing reliable and trusted data on materials and example details that can be easily used by industry;
- providing tools that are improvements on the interfaces tested here that enable design professionals to understand energy simulation in existing practice and to develop designs that optimise building efficiency and performance.

These four limitations are the basis for the logical next steps in this research which will need to focus on:

- Developing a statistically representative sample of simulations.
- Measuring contemporary projects in industry to establish occupancy and energy profiles.
- Examining other in-built semi-automated simulation measures not examined in this study.

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