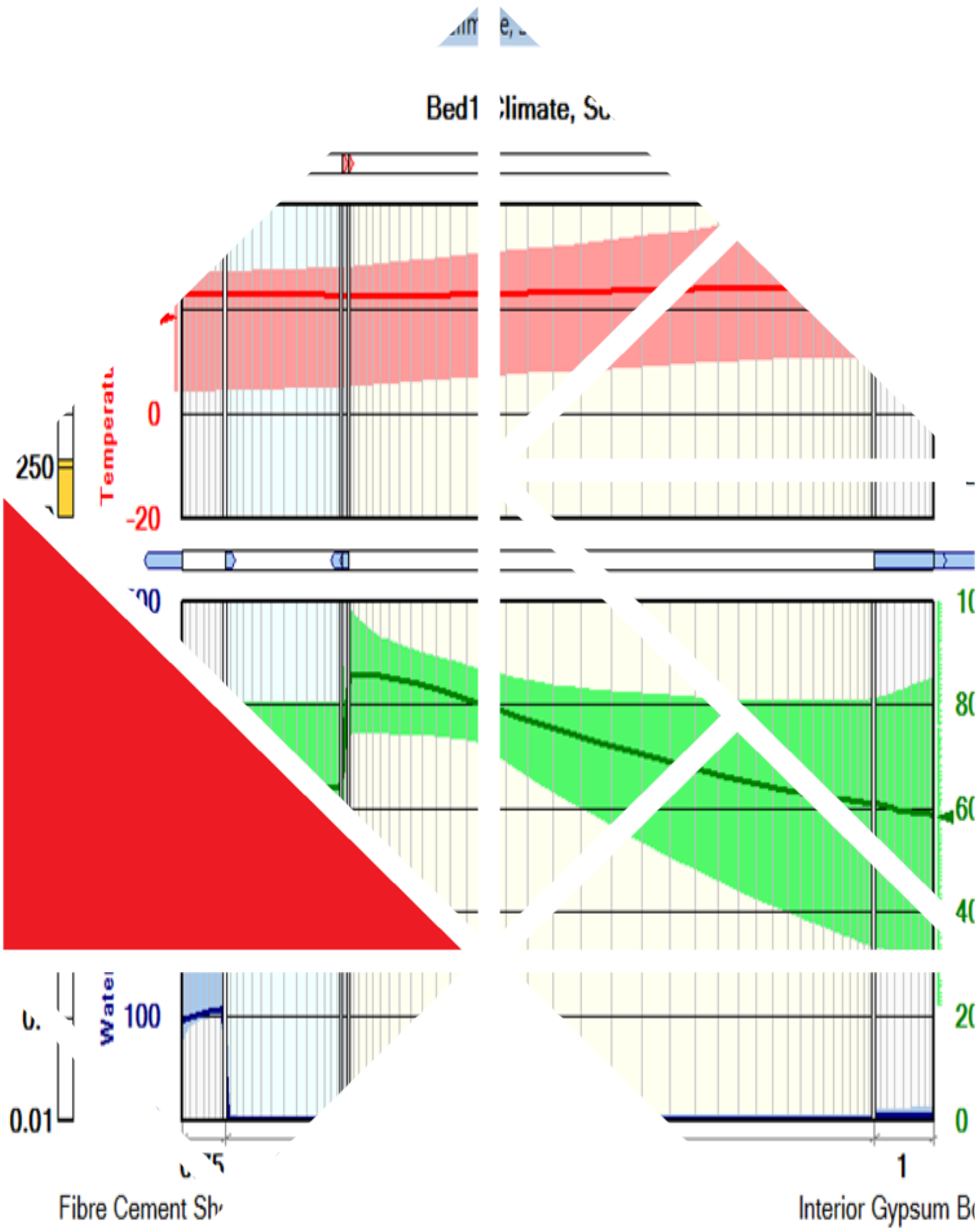
Study Report

SR361 [2016]

# The selection and hygro-thermal modelling of new New Zealand dwellings (pilot)

Roman Jaques, Brian Berg and Stephen McNeil



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# Preface

This pilot study is the first of a series of reports examining background issues around the current settings for clause H1 *Energy efficiency* and the related clauses of E3 *Internal moisture* and G4 *Ventilation* in the New Zealand Building Code (NZBC). It is part of a multi-year collaborative project between BRANZ and the Ministry of Business, Innovation and Employment (MBIE).

This pilot study focuses on two aspects: a) the selection of popular recently built dwellings covering all the major typologies, and b) the proof-of-concept hygro-thermal modelling of two diverse representative dwellings.

This report is the precursor to the main comprehensive BRANZ study: *New Zealand Internal Environment Project* (2017).

# Acknowledgements

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# Note

This report is intended for policy-makers, building technologists and building scientists with particular interests in the modelling of energy efficiency, thermal comfort, ventilation and moisture management in dwellings.

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## BRANZ Study Report SR361


### Authors

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### Reference

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### Abstract

This pilot study provides a proof of concept for effectively and robustly selecting and examining a variety of recently consented dwellings reflective of new New Zealand housing. The project is driven by the recognition that three associated clauses of the New Zealand Building Code (NZBC) – H1 *Energy efficiency*, E3 *Internal moisture* and G4 *Ventilation* – have not been updated for some time and, consequently, may not be providing an optimum internal environment. A simple, iterative housing typology selection process is detailed, which results in dividing dwellings into six main types: detached single storey, detached double storey, attached single storey, townhouses, mid-rise apartments and retirement villages. These types may be refined as knowledge about their differing hygro-thermal behaviours becomes apparent in the next project stage. The hygro-thermal simulation developed in this pilot combines several computer modelling tools (SketchUp, EnergyPlus and WUFI), resulting in a far more comprehensive insight into how dwellings perform hygro-thermally than has been available previously. This methodology is also described in some detail.

This pilot study is part of a wider BRANZ-MBIE investigation to better understand the internal environment of recently consented dwellings – both as individual built units and in terms of the housing stock as a whole – from an energy use, environmental health, comfort and lifetime cost perspective. This report is the precursor to the main comprehensive BRANZ study: *New Zealand Internal Environment Project* (2017).



### Keywords

Energy efficiency, hygro-thermal, New Zealand, new dwellings, typologies

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# 1. Background

The three main New Zealand Building Code (NZBC) clauses that influence the performance of the indoor environment of New Zealand's new homes are E3 *Internal moisture*, G4 *Ventilation* and H1 *Energy efficiency*. It has been between 8 and 18 years since the last substantial revisions of these three clauses. During this time, there have been a number of significant economic, social, technical and knowledge changes in the industry regarding how dwellings are being built, being operated and performing.

Some key changes since the last reviews of E3, G4 and H1 include:

- higher public expectations of the indoor performance of new homes
- substantial changes to the real costs of energy and some building materials that influence the internal environment
- increased understanding of the links between the quality of the internal environment and physiological and psychological health
- a growing awareness of the benefits of integrated building modelling to help test the wide range of assumptions being used to evaluate possible pathways to reach a low-carbon New Zealand economy (Royal Society of New Zealand, 2016)
- rising popularity of multi-unit dwellings
- possible mismanagement of internal moisture because of insufficient understanding of the complex hygro-thermal interactivity in a wide range of new-build scenarios.

In addition, there is awareness that inconsistent performance outcomes are delivered for the coldest climates when NZBC Schedule Method solutions are compared to the Building Performance Index in the Verification Method.

Consequently, this project aims to explore these topics through hygro-thermal-energy-ventilation simulation of typical new-build designs. This will provide information on how different types of dwellings are likely to perform under the current settings and whether these settings are optimal in terms of health, energy, cost and durability outcomes. Given the complex relationship between the thermal performance of a building envelope, ventilation and internal moisture and air quality, the internal environment aspects covered by clauses E3, G4 and H1 will be considered together to avoid unintended consequences and optimise the performance of the internal environment.

This report is the precursor to the main comprehensive BRANZ study: *New Zealand Internal Environment Project* (2017).

# 2. Project goals

The overarching goals of the *Internal Environment* project, which provides a background to understanding the current settings for clauses H1, E3 and G4, are to:

- better understand what we are achieving with new NZBC-compliant residential buildings in terms of indoor environmental performance, energy end use, financial and (ideally) non-energy impacts
- explore the impact of various scenarios on both typical NZBC-minimum dwellings and above-code minimum dwellings, in terms of hygro-thermal performance, cost and energy use, to better understand the consequences of potential changes to the NZBC and supporting documents.

The goals of this pilot study are to:

a) establish an efficient sampling methodology for selecting New Zealand dwellings of a range of typologies, reflective of those most commonly built today
b) determine a practical means of collecting and storing material and other key characteristics of each representative dwelling, in a succinct manner, which can be easily interrogated.

Then, on two very dissimilar virtual (computer simulated) dwellings taken from actual dwelling plans:

c) provide three-dimensional wireframe models in a flexible format that can be imported/exported into other key software
d) develop a translation algorithm that enables the importation of the building geometry into internal moisture/ventilation/air quality modelling software.

Ideally, the pilot will develop a minimum set of representative typology models that embody the majority of recent New Zealand dwelling stock, on which hygro-thermal simulation can be carried out. These typologies include, for example, single detached, semi-detached, terrace, top floor unit, middle apartment and so on. In addition, the pilot will develop a streamlined methodology that can be used for a follow-on large scale study, so that robust, consistent and simplified hygro-thermal modelling can be applied to a variety of parametric studies on the current and possible future new dwelling stock.

**In essence, this pilot is about providing a proof-of-concept modelling and hygro-thermal simulation process, so that variants of recently built New Zealand dwellings can be comprehensively interrogated to determine the performance of their internal environments.**

# 3. Methodology

## 3.1 Introduction

It should be noted that to some degree, because both this pilot and the proposed main project are breaking new ground (even when considered on an international scale), the methodology is exploratory and iterative in nature.

The pilot methodology can be spilt into five distinct parts:

- An overview of previous stock models
- The selection approach used for finding representative dwellings
- Prioritising what hygro-thermal-energy-ventilation questions to explore
- EnergyPlus simulation development
- WUFI interstitial moisture modelling.

## 3.2 Previous stock model approaches

There are two common approaches to modelling housing stock energy models – so-called 'top down' and 'bottom up'. Top-down approaches are macro-economic methods that represent an aggregated energy demand indirectly through economic or technical variables such as price indices or technology ownership. Bottom-up models can be generally classified into statistical and engineering approaches (McKenna, Merkel, Fehrenbach, Mehne and Fichtner, 2013). Statistical approaches data mine historical data to identify the relationships between total energy demand and energy end-use. Engineering approaches explicitly determine the end-use energy demands based on physical and/or thermodynamic relationships and are most suitable for the analysis of the impacts of technologies and/or policy measures (McKenna et al., 2013). One issue with bottom-up models based on building physics is they highlight the severe lack of publically available data that can be used to help identify social trends within the building stock (Kavgic et al., 2010). This limitation is true for New Zealand as well, with few exceptions. Given the goal of this study, which is focusing on the enviro-technical aspects of the new housing stock by typology, applying the engineering bottom-up approach better meets the study needs. Where appropriate, other BRANZ historic studies – such as the Weathertightness, Air Quality and Ventilation Engineering (WAVE) programme[1] – will be used to inform this (and the follow-on) project.

There are many examples of bottom-up energy stock models for houses internationally (for example, Snakin, 2000, Johnston, 2003 and TABULA Project Team, 2012). There appears to be little harmonisation or replication between individual international stock models. It has been suggested that the lack of harmonisation is because each has its own very specific goals, which are unlikely to be exactly the same as any other stock model[2]. It appears that the choice of the set of representative buildings has a significant impact on the results and conclusions drawn from bottom-up methods (Gendebien, Georges, Bertagnolio and Lemort, 2014), reinforcing the need for a careful selection process.

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[1] www.branz.co.nz/wave

[2] Personal communication. Pavia, M. (2016). EnergyConsult Pty, Australia. 31 March 2016.

Detailed bottom-up energy stock models can be broken down into two approaches – representative dwellings or typical dwellings. A 2011 study (Cyx, Renders, Van Holm and Verbeke, 2011) defines the two different approaches as:

> *The* ***representative*** *dwelling types approach involves modelling a set of fictional buildings based on average values. This set of fictional buildings is used to model the entire building stock. The established parameters are then iteratively adjusted to correspond to energy consumption for the total building stock known e.g. from energy balances. The* ***typical*** *dwellings approach involves composing a set of typical dwellings closely related to existing buildings and existing building components, chosen for their reference value compared to the examined stock. Considering that actual buildings and building characteristics are used as a basis, it is possible to examine the impact of various saving measures on a specific individual dwelling type.*

Some international studies even use a hybrid approach, which is a mix between the typical and representative (Gendebien et al., 2014) approaches. Whatever approach is used, examining a range of international stock models, it appears that in almost all cases only a very few building types are examined – for example, detached, apartment and semi-detached houses.

For this pilot study, it is suggested that a hybrid approach be used, to combine the strengths of each approach. In this, the geometry characteristics of some key buildings can be extended to a set of buildings to represent the different typologies. A tree structure is then developed to examine the different cases of construction characteristics, external environments and whatever variables/scenarios need exploring. The final defined building combines all these typical geometries, construction characteristics and environmental influences leading to a set of representative but fictional buildings. This approach was carried out successfully in the Gendebien et al. (2014) study.

In addition to the lack of standardised approach to developing stock models is the lack of standardisation in the selection of the individual representative dwelling. Often, even within journal papers, little information is provided on how the models were developed so that others can duplicate them. Also, no hygro-thermal stock models seem to have been developed internationally that this pilot study can leverage off. The majority of stock model studies encompass just thermal and (other end-use) energy needs. It is not known why this is the case, but it may be due to the added complexity of combining moisture-specific issues or moisture being recognised to be of lesser importance in terms of performance indicators. There is also a fair amount of 'ad-hockery' – for example, a USA study (Bluestein and DeLima, 1985) aimed to develop a database of 'standard' single family homes and associated heating and cooling load data for analysis. In determining how to distribute windows on their dwellings, they settled on "…apportioning the window area according to the exposed wall area on each side"! This does not provide a good representation of reality, and such assumptions can significantly distort the results.

## 3.3 Selection of representative dwellings

### 3.3.1 Overview

The goal for this part of the pilot project was to establish a smart sampling method for selecting typical dwellings, reflective of the bulk of those commonly built in New

Zealand in the last 5 or so years. In terms of the selection procedure, two processes needed to happen in parallel to acknowledge the main study:

- selecting typical dwelling(s) representing a specific typology, and
- selecting likely outlier[3] dwellings for stress and sensitivity testing.

In essence, this pilot project has relied on a combination of approaches in the selection of reference dwellings:

- Where the typology was reasonably well defined, dwellings (i.e. consent documentation) were chosen on the basis of their size. In addition to the average sized archetypical model, one very small and one very large sized dwelling and diverse form (i.e. room geometry and placement complexities) were selected to ensure that a range of hygro-thermal responses were covered, as part of the sensitivity testing in the main project.
- By analysing over 100 selected new dwelling designs from around New Zealand, common patterns in shape/complexity emerged. Consequently, it became apparent which dwellings would be good representatives for this pilot project.
- It became obvious that representing diverse typologies (such as 'single storey, detached homes') with just one or two buildings would probably lead to a very narrow set of hygro-thermal outcomes. However, just how diverse the subset of representative dwellings needs to be can only be realised in a follow-on study. It is highly likely that there will be some filtering of the representative houses provided by this pilot in the follow-on study.

In all, some 21 reference dwellings (refer Table 2) were selected for detailed hygro-thermal simulation studies to be carried out in the follow-on study. A summary of some key building element statistics, mainly sourced from the latest BRANZ New Dwelling Survey (Curtis, 2015), are detailed in Appendix A1.

### 3.3.2 What is being built in New Zealand now?

The first step was to define the various residential building types currently being built in New Zealand. In most international energy studies, housing types were limited to very few variants: typically, single-flat homes, two-family homes, small and large multi-family homes and, at the most, two sub-categories within these.

One of the complications that needed resolving was the lack of a clear definition for the various dwelling typologies. Given their distinct function and form and, therefore, likely performance aspects, this needed resolving early on. For this pilot, the following typologies and their definitions were used. They cover all the major dwelling types currently constructed and reflect the definition used by the BRANZ economics team. As building consent authorities (BCAs) use a variety of definitions, there is only a partial agreement with them.

1. **Detached, single and double storey** – the prototypical stand-alone New Zealand house. New examples are almost all built in smaller towns, fringe

[3] In other words, dwellings that are likely to exhibit extremes of hygro-thermal performance. Two important contributory factors are thought to be dwelling size and form/shape.

suburbs of larger cities, and rural areas. They can take a wide variety of forms and sizes.

2. **Attached, single storey** – usually two small houses with a common shared (garage) wall – often in the suburbs of cities or in larger towns. Only horizontally attached (i.e. having a common wall) to adjacent dwelling.
3. **Multi-level, townhouses** – usually consisting of many repeated forms with little variation, almost always two (counting the mezzanine) or three levels. Only horizontally attached (i.e. having a common wall) to adjacent dwelling. Becoming increasingly popular in urban areas where space is at a premium. Two market extremes – the spacious/luxury or the small/modest. Includes terraces.
4. **Multi-rise, apartments** – where dwellings are both vertically (i.e. having a ceiling/floor in common) and horizontally (i.e. having a common wall) attached to an adjacent dwelling. Huge size and quality range available, from the spacious/luxury to the small/modest options. Two heights considered – low rise (2–4 storeys) and medium rise (5 or more storeys), each with either low or high quality options.
5. **Retirement villages** – three main formats are most common: single stand alone or attached units; 2 storey, attached, townhouse-style; and a long linear 'attached, 2 storey all under one roof' design. As the first two formats have considerable cross-over (in terms of thermal envelope, size, layout and construction methods) with other dwelling typologies, only the last type is examined in this pilot study.

### 3.3.3 Which dwelling typologies to select?

The next step was to examine the individual typology proportions, to better understand their (likely) impact on the overall stock now or in the near future.

Early discussion with MBIE decided that the year 2014 was to be used as the reference year for this pilot study due to it being recent and easily accessible. The following Statistics New Zealand information[4] provided the figures split into the various dwelling types in Table 1.

**Table 1. Actual New Zealand consented dwelling numbers (in 2014)[3]**

| Dwelling Type | Number |
|---|---|
| Houses | 18,359 |
| Apartments | 1,721 |
| Retirement village unit | 1,917 |
| Townhouses, flats, units | 2,720 |

The dwelling types, as defined by Statistics New Zealand (2015), are described as:

- **House:** house not attached to others.

[4] Source: www.stats.govt.nz/browse_for_stats/industry_sectors/Construction/building-consents-issued-info-releases.aspx

- **Townhouse**, flat, unit and other dwellings: granny flat, minor dwelling.
- **Apartment:** apartment, excluding those in retirement villages.
- **Retirement village unit:** villa, townhouse, apartment, or other dwelling within a retirement village…Excludes care apartments.

The Statistics New Zealand figures provided some useful insights:

a) Their classification is open to some interpretation, given the unclear nature of the descriptions. In particular, the aggregation of townhouses, units and flats provides no granularity about the individual contributions.
b) Retirement villages are an important part of the overall stock and will undoubtedly grow as our population ages. However, due to some of their stock solutions being highly likely to be closely related (in hygro-thermal terms) to townhouses, only a portion of their stock will need to be modelled.
c) Dwelling consent information received by Statistics New Zealand does not contain the number of floors. Therefore, it can be difficult to ascertain whether a multi-unit dwelling is a (horizontally attached) townhouse or a (vertically attached) apartment block (personal communication, BRANZ Economist Matthew Curtis, 2016).

Ideally, the selection and examination of consent data would be carried out directly from individual BCAs, but BCAs' characterisation of buildings doesn't provide the granularity necessary for this pilot. Taking Auckland Council BCA as an example, the dwelling consent information between the various old (non-unified) council BCAs has yet to be amalgamated into their new unified system, necessary for the varied reporting structures. Therefore, the records of each former BCA would need to be individually sampled. Even if individually sampling 'dwelling units' constructed in the last quarter of 2014 (i.e. some 2,188 dwellings), the method would be too time intensive to manually examine.

Conversely, the BRANZ New Dwelling Survey 2014 (NDS) (Curtis, 2015) examined some 1,200 dwellings, providing a reasonable amount of easily accessible data that is applicable to this pilot study. Data collected included dwelling size, number of levels (indicating dwelling type), materials used for claddings, foundation system, framing type, insulation type and R-value, window frame type and internal linings. All this data is traceable back to a specific building consent. It selects the houses/builders randomly, but the feedback is optional. Consequently, the NDS became the chief source for initially selecting possible reference buildings by typology. The most recent BRANZ House Condition Survey (Buckett, Jones and Marston, 2010) was also queried as a possible information source, but proved limited as only 45 houses were from the 2000's stock.

### 3.3.4 How to best capture new-built archetypes

One of the goals of the stock model was to contain enough variety of built forms to have some confidence that sensitivity tests would highlight performance issues of concern (within reasonable parameters). As part of this, representative dwellings in each typology were examined for duplication of key variables that might impact on hygro-thermal simulation. It is anticipated that the selected dwellings within each typology are sufficiently different to provide an appropriately wide range of simulated hygro-thermal performance. Only through careful simulation can this hypothesis be confirmed.

BRANZ experts in the disciplines of moisture, construction, economics and architecture provided guidance for the selection of representative dwelling models. The selection process was driven by two variables that cannot easily be changed as the result of parametric modelling:

- The known influence of overall conditioned area (size) on thermal comfort and energy use
- The possible influence of building geometric complexity on hygro-thermal performance.

The other choices that are likely to impact on building performance (such as insulation levels, cladding options, ventilation options etc) will be examined parametrically in the main study. The relationship between conditioned area (or more specifically volume) and space conditioning energy use is elaborated on in Appendix A2.

The initial NDS-selected homes were then traced back to their respective 10 BCAs. These BCAs were approached for the necessary consent documentation. In all, just under 70 consents of various typologies were provided. This was more than the number of dwelling categories because of the need to capture a good range of dwellings within each classification. Once documentation for each dwelling was received and examined, a much better understanding of key building details became evident. One issue was that even with careful pre-selection, it became obvious that there were some gaps within the sub-categories – mainly in terms of size. To fill these gaps, a range of recently consented drawings were sought. Therefore, a further filtering process was executed, so that:

- the conditioned area was either representative (where known) or at the ends of the spectrum in what is often built (as far as can be determined) for a particular dwelling type
- a mix of complexities in geometric form were included within a dwelling type category
- similar designs were discarded, either within or across categories, as they would add little value to the study
- very unusual designs were also discarded, as their combination of anticipated performance characteristics were unlikely to be replicated elsewhere in the housing stock.

This filtering process resulted in a shortlist of typical dwellings by typology. The key metrics are shown in Table 2. The first alpha in the ID code references either the size (small, medium, large) or the style (1, 2, 3) while the second references the dwelling type. The **red-font** indicates the two dwellings selected for hygro-thermal modelling proof-of-concept aspects, for this pilot. Their detailed plans can be found in Appendix A3 and A4 while Appendix A5 provides wireframe models of them. An example of the EXCEL catalogue of the dwellings' physical characteristics can be found in Appendix A6.

**Table 2. Listing of selected dwellings representing various typologies**

| Dwelling types | ID code | Size ($m^2$) | Short description |
|---|---|---|---|
| Detached, single storey | 1_S_SS | 110 | Small sized, but complex form |
| | 2_S_SS | 151 | Small sized, but simple form |
| | 3_M_SS | 186 | Linear form |
| | 4_M_SS | 210 | Complex form |
| | 5_L_SS | 232 | Simple design |
| | 6_L_SS | 260 | Complex design |
| Detached, double storey | **7_S_DS** | **211** | **Small sized, but complex form** |
| | 8_S_DS | 206 | Small sized, but simple form |
| | 9_M_DS | 230 | Medium sized, simple form |
| | 10_M_DS | 260 | Medium sized, complex form |
| | 11_L_DS | 290 | Large, simple form |
| | 12_L_DS | 290 | Large, complex form |
| Attached, single storey | 13_T1_SS | 130 | Simple form |
| | 14_T2_SS | 126 | Complex form |
| Townhouses – multi-level | 15_T1_DS | 43 | Modest design (with small mezzanine) |
| | 16_T2_DS | 120 | Luxury design (over 3 storeys) |
| Multi-rise, apartments[5] | 17_T1_AP | Avg= | Low rise, modest sized |
| | **18_T2_AP** | **Avg=** | **Medium rise, modest sized** |
| | 19_T1_AP | Avg= | Low rise, luxury sized |
| | 20_T2_AP | Avg= | Medium rise, luxury sized |
| Retirement village | 21_T1_RV | Avg= | One long linear, 2-storey formation, with all units under one roof |

As can be seen, detached houses have a large number of representatives. This was thought prudent given that approximately 75% of new dwellings consented in 2014 were detached (according to Statistics New Zealand) and the range of size and shape options are wider than most other building typologies.

Only through hygro-thermal modelling will the extent of the performance variation *within* the various dwelling typologies become apparent and thus (potentially) be able to be further filtered and simplified (or perhaps even extended). This is one of the objectives of the proposed follow-on study which, if funded, is expected to be completed in 2017.

[5] Note that all the multi-rise apartments will have several sub-dwellings to investigate, according to unit positioning – e.g. mid-storey, central; top storey, corner, ground floor, end unit, etc.

## 3.4 Key hygro-thermal-energy-ventilation questions

A set of questions was drafted up by the broader project team during the model-making process, to inform the proposed follow-on study. This was performed so that the most useful areas for exploration were targeted (given the potentially large number of questions possible) and also to:

- ensure that key questions didn't get overlooked
- ensure that the combination of variables simulated were likely to have a substantial impact on the internal environment and related energy issues
- reduce the likelihood of having to continuously rebuild the three-dimensional digital wireframe models and parametric programs iteratively throughout the main project.

The questions were then prioritised to provide a way of sensibly filtering the possible modelling iterations that could be carried out in a study of this nature. The complete listing is shown in Table 3. It should be noted that these questions are only in a draft form and will be refined and clarified at the start of the proposed follow-on project. Also, it should be noted that not every question may be able to be accommodated using the simulation techniques proposed in this pilot.

Questions are prioritised into three streams:

**Tier 1 [Dark-green]:** essential to the project (17)

**Tier 2 [Mid-green]:** definitely interesting/useful to have answered (1)

**Tier 3 [Light-green]:** of lesser interest but might be useful (1).

**Table 3. Prioritised list of thermal, ventilation and moisture questions**

| # | Questions | Clauses affected |
|---|---|---|
| **1** | **What are the appropriate airtightness benchmarks to use in thermal and moisture modelling?** | **H1, G4, E3** |
| 2 | What are the appropriate ventilation schedules to use in thermal and moisture modelling to reflect the range of "typical" occupant behaviours and schedules? | H1, G4, E3 |
| **3** | **What is/are the appropriate heating setpoints and schedules for thermal and moisture modelling?** | **H1, G4, E3** |
| 4 | What are the thermal, internal moisture, and indoor air quality implications of different types of "next gen"construction types/methods that are in the market? How do these compare to traditional contruction types in terms of thermal efficiency, and airtightness? | H1, G4, E3 |
| **5** | **What is the current NZBC baseline energy consumption for all the dwelling typologies, and particularly for apartments, if built to the Schedule Method minimum requirements, how much energy would be required to keep the homes at minimum healthy indoor temperatures/link to heating setpoints from question 3) throughout the year?** | **H1** |
| 6 | What is the current NZBC baseline energy consumption for detached dwelling typologies, if built to meet the minimum BPI requirements, how much energy would be required to keep the homes at comfortable indoor temperatures throughout the year? | H1 |
| **7** | **What are the passive temperature and humidity profiles of all of the dwelling typologies when free-running?** | **H1, G5** |
| 8 | What is the internal moisture profile of NZBC Acceptable Solution conforming new dwellings? Where does occupant behaviour begin to cause issues that may affect occupant health, material durability etc? | E3, G4, H1 |
| **9** | **As above, but for climate change scenarios.** | **H1** |
| 10 | How thermally comfortable are new homes built to the minimum requirements of the Schedule Method? | H1 |
| **11** | **What are the internal moisture, energy efficiency, and indoor air quality implications of varied occupant behaviours on the performance of different types of dwellings? Consider family type, occupancy schedule, occupant-driven natural ventilation, occupant-influenced mechanical ventilation (e.g. extraction fans).** | **H1, G4, E3** |
| 12 | What are the implications of varying mass, envelope insulation levels, airtightness on energy efficiency and internal moisture? | H1, G4, E3 |
| **13** | **What are the effects of different glazing ratios on thermal performance? Does this differ by dwelling type? Particularly look at dwellings with small proportions of external wall area.** | **H1** |
| 14 | What are the effects of different glazing ratios, including the G4 natural ventilation minimum requirements, on indoor moisture and indoor air quality? Focus on types of dwellings with small proportions of external wall area - e.g. terraces, apartments. | G4 |
| **15** | **What are the implications of the provision of different levels (including the minimum Acceptable Solution) of ventilation through natural and mechanical means on energy use, internal moisture, internal temperatures. Look at positive pressure type systems and balanced ventilation systems.** | **H1, G4, E3** |
| 16 | Where is the tipping point between thermal insulation, air tightness, internal moisture loads and occupant behaviour under current Acceptable Solution minimum requirements? Particularly look at health and durability, including problematic interstitial moisture. | H1, G4, E3 |
| **17** | **What are the optimal performance combinations for thermal insulation, air tightness, and ventilation in light of thermal comfort, internal moisture, and indoor air quality? Natural (where applicable) and mechanical ventilation.** | **H1, G4, E3** |
| 18 | What is the impact of particular occupant behaviours which have a perverse impact on energy, efficiency, indoor moisture, and/or ventilation? E.g. drying clothes inside, unflued gas heating, not airing out the house in cold/poor weather? | H1, G4, E3 |
| 19 | How much difference does curtains and carpet have on the thermal performance of a home? | H1 |

## 3.5 EnergyPlus simulation development

### 3.5.1 Introduction

The purpose of this modelling in a wider sense is to better understand the performance of a wide range of recently constructed New Zealand dwellings via hygro-thermal simulation. The focus is on the interrelated building performance areas of indoor thermal comfort (temperature), ventilation, infiltration (air tightness), heating energy use, internal moisture (relative humidity) and interstitial moisture.

Simulation simultaneously focusing on all these building performance areas is beyond the scope of typical NZBC clause H1 simulation verification methods. Typically, each of these areas of building performance is simulated independently of one another in separate specialist software. This is despite their interconnected nature in both performance and in the H1 compliance clause. The purpose of this pilot study from a simulation perspective was to demonstrate by proof of concept that it could be done efficiently and provide the quality of data required for analysis. Two residential-type buildings consented in 2014 were selected for this pilot. The first model is a stand-alone 2-storey 4-bedroom house. The second is a multi-storey apartment building. For this building, the unique individual apartments (premises) were simulated, rather than the whole building. This decision was made to reduce modelling time and effort, as the modelling of the other apartments is simply a replication of these unique individual apartments.

NZBC clause H1 has three ways (which increase in complexity) of demonstrating compliance. Firstly, by the use of the schedule method. The schedule method is an Acceptable Solution under H1. Using this method, compliance is demonstrated by ensuring the building's thermal envelope exceeds the minimum R-values specified in the relevant H1 clauses. Not all buildings can use the schedule method to demonstrate compliance. Some fall outside its scope. For example:

- If the building's total net lettable area is greater than 300 m².
- If the building's total glazing area is greater than 30% of the total wall area.
- If the combined east, south and west glazing areas is greater than 30% of the total east, south and west wall area.
- If skylight area is greater than 1.5 m² or 1.5% of the total roof area (whichever is smaller).
- If the total area of decorative glazing and louvres is greater than 3 m².

In the instances where the building design does not meet these scope criteria, the second method of compliance, the calculation method, may be used. The calculation method is a simple series of manual algorithms that calculate the sum total of the thermal envelope element area divided by the R-value of that element for each element.

$$HL_{Proposed} = \frac{A_{Roof}}{R_{Roof}} + \frac{A_{Wall}}{R_{Wall}} + \frac{A_{Floor}}{R_{Floor}} + \frac{A_{Glazing}}{R_{Window}} + \frac{A_{Door}}{R_{Door}} + \frac{A_{Skylight}}{R_{Skylight}}$$

Compliance is demonstrated by comparing the sum of the total heat loss of a building design (referred to as the proposed) to the sum of the total heat loss of the same building design (referred to as the reference) but with the schedule method's R-values. The design passes if the heat loss of the proposed is less than the heat loss of the reference. Building design can only use the calculation method if the building design's total glazing area is 40% or less than the total wall area.

The third and final method of demonstrating H1 compliance is the modelling method. The modelling method involves using a dynamic whole-building energy simulation tool to calculate (also referred to as simulate) the annual energy consumption of the building. This method is defined as a Verification Method by H1, specifically clause 1.1.1. This clause empowers NZS 4218 as the standard that defines the methodology for how to model a building (if less than 300 m² net lettable area) in order to satisfy on reasonable ground that the building design meets the requirements of the building code. Compliance is shown by comparing the energy consumption required to service the heating and cooling loads between the proposed (as-documented) building and the reference building (the same building but with the thermal envelope R-values applied). If the proposed building's energy use is less than the reference, the building passes.

NZS 4218 exists as two versions, a 2004 and a 2009 version. This research has referenced NZS 4218:2009 *Thermal insulation – Housing and small buildings*, as it is the most recent.

### 3.5.2 General approach

Simultaneous simulation of indoor temperature, natural ventilation, infiltration, thermal mass, passive solar gain, heating energy use, internal moisture and interstitial moisture is not common. NREL's *Moisture Penetration Depth Model for Estimating Moisture Buffering in Buildings* (Woods, Winkler and Christensen, 2013) and Oak Ridge National Laboratory's *Indoor Climate and Moisture Durability Performance of Houses with Unvented Attic Roof Constructions in a Mixed Humid Climate* (Pallin, Boudreaux and Jackson, 2014) are two examples of this form of building simulation. Both use the simulation program EnergyPlus to calculate the internal environment conditions and space conditioning energy consumption. EnergyPlus was selected for the BRANZ study for three primary reasons. First, EnergyPlus is one of the most detailed and advanced whole-building simulation tools available (see Appendix A7 for details on tools used). It is maintained by the US Department of Energy (US DoE) and validated to standards such as BESTest (Building Energy Simulation Test). Second, it is a free program. Therefore, these models can be used in future without licensing capex costs and are more accessible to a wider audience. Third, the previously mentioned research studies by Pallin et al. (2014) and Woods et al. (2013) also used EnergyPlus. This provides a useful reference and, where appropriate, their methodologies have been used to inform this BRANZ pilot study.

Figure 1 shows the general modelling workflow used in this study. Firstly, a 3D geometric representation of the building is constructed using OpenStudio (a SketchUp plugin for EnergyPlus). This includes defining thermal zones and assigning construction systems to the constructed building surfaces. Secondly, this OpenStudio model is saved as a text-based .IDF file type and is imported into EnergyPlus version 8.5. Using a text editing tool called the IDF Editor (freely downloadable with EnergyPlus), simulation inputs for sensible and latent heat gains by zone, zone heating and cooling types and operational schedules and zone natural ventilation and infiltration rates are defined and assigned. This completes the basic construction of the combined energy/thermal/ventilation models. The outputs of these simulations are hourly outdoor and indoor air temperatures and relative humidity (RH), zone ventilation and air exchange rates (measured in air changes per hour, or ACH) and space conditioning energy use results. The outputs for the outdoor and indoor temperatures and RH are then used to create the indoor environment used in the WUFI simulations to calculate interstitial moisture levels.

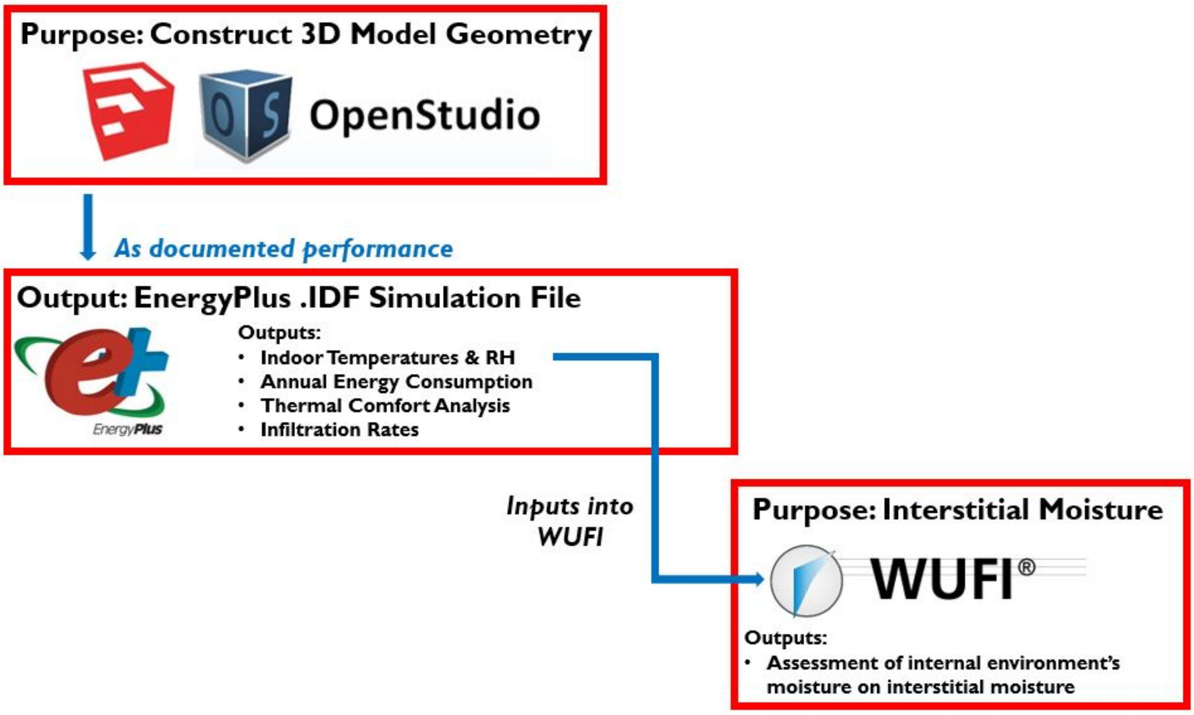


**Figure 1. Modelling workflow from SketchUp to EnergyPlus and WUFI**

To calculate these outputs, various simulation assumptions must be made. The following sections detail this process.

#### 3.5.2.1 Thermal zone rules

The first step is to translate the building's design into a combined thermal/airflow model. Thermal zoning rules are applied to ensure the model is zoned to accurately calculate the energy and thermal performance. These rules work on a common approach – zone the building to divide or combine building spaces into separate zones based on:

- how different areas are likely to exchange heat energy (e.g. through conduction, convention and radiation)
- their orientation, often if greater than a 45º difference
- their HVAC equipment systems, set points and schedules
- the different internal loads within spaces, such as occupant usage activities, occupied time schedules and different plug and lighting loads and schedules.

When zoning residential buildings, the modelling methodology outlined in NZS 4218:2009 states:

G1.6.2 Spaces that are likely to have significantly different space conditioning requirements shall be modelled as separate zones.

G1.6.3 The conditioned space shall be divided into a minimum of three separate zones.

G1.6.4 Roof spaces and enclosed subfloor spaces shall be modelled as thermal zones.

NZS 4218:2009 defines a conditioned space as:

spaces within the building envelope that is expected to be conditioned. This includes all habitable spaces and for housing includes kitchen, lounge, dining room, bedroom, hallways and bathrooms. Unconditioned space shall be separated from unconditioned space by building elements (walls, glazing, skylights, doors, roof and floor), to limit uncontrolled airflow and heat loss.

By comparison, unconditioned spaces are:

spaces within the building envelope that are not conditioned (for example, this may include a garage, conservatory, atrium, attic, subfloor and so on). However, where a garage, conservatory or atrium is expected to be heated or cooled these spaces shall be included in the conditioned space.

Other useful zoning rules used in building thermal simulation include:

- "If any resulting thermal zone is less than 3 m wide, absorb it within surrounding zones" (Department for Communities and Local Government, 2010, p. 29).
- "If any resulting thermal zones overlap, use your discretion to allocate the overlap to one or more of the zones" (Department for Communities and Local Government, 2010, p. 29).
- "Naturally ventilated zones shall be permanently open to and within 8 m of operable wall or roof openings to the outdoors" (ASHRAE Standards Committee, 2007, p. 5). Note CFD modelling of airflow can be used to demonstrate natural ventilation design's effectiveness exceeds 8 m.
- Limitations in simulation software. For example, zones should be simple triangles or rectangles. Complex polygons such as L shapes cannot be calculated. They should be divided into two zones.

Zones used in energy calculations are based on the similarity and differences between their thermal loads, while the zones used in airflow modelling are based on pressure relationships and differences in ventilation airflows (Ng, Persily, Emmerich and Musser, 2012).

The zoning rules used for this pilot study need to be a combination of those used for simulation of energy/thermal/ventilation (e.g. NZS 4218:2009) and airflow performance. In addition, this project is focused on assessing the performance of as-documented building designs. Therefore, the models in this research must be a closer match in terms of space geometry and zoning to the actual as-documented spaces than what may result from following the NZS 4218:2009 rules.

Due to limitations in simulation software and such factors such as modelling time, buildings cannot be modelled to be an exact representation of their real life counterparts. As a result, concessions in the zoning must be made.

In response to these concessions and the simulation demands of combining both energy/thermal/ventilation and airflow ventilation modelling, this pilot study has developed a hierarchy to ensure certain spaces are modelled to the detail they require to have their performance assessed, while other spaces identified as less important are adapted to fit.

This divides spaces into four categories, of decreasing importance.

1. Spaces that are conditioned and defined as habitable by NZS 4218:2009 but are typically occupied in periods greater than 15 minutes in duration. This includes bedrooms, lounges, kitchens and dining rooms.
2. Spaces that are conditioned by mechanical ventilation only and are habitable but typically occupied in periods less than 15 minutes. This includes bathrooms and toilets.
3. Spaces that are unconditioned and are habitable but typically occupied in periods less than 15 minutes. This includes spaces such as hallways, corridors and stairs.
4. Spaces that are unconditioned and are uninhabited. This is typically limited to garages.

The 15 minute occupied rule is derived from ASHRAE Standard 55-2004: *Thermal environmental conditions of occupancy* (ASHRAE, 2004, p. 2). This standard defines 15 minutes as the minimum amount of time a space must be occupied for the standard to be applied to that space. This is to account and allow for the time delay it takes for people to acclimatise to the space they just entered and then occupy, as it can take up to an hour for people to acclimatise to the new indoor environment (ASHRAE, 2004, p. 2).

In many building designs, the heating is not specified (Jaques, 2015). Built-in (e.g. heat pumps or fires) are not consistently shown on the building consent documentation from which the models are being constructed. Therefore, in future research into different heating systems types, to ensure comparable results across different buildings and typologies, this pilot methodology has made the assumption that habitable, occupied bathrooms and hallways do not contain a heating appliance, and no spaces have mechanical cooling.

#### 3.5.2.2 Modelling construction systems

The construction systems – that is, the combination of building materials making up a wall, ceiling or floor element – are modelled in two different ways. In EnergyPlus, they are pre-calculated to account for non-homogeneous thermal bridging. For example, the material exposed to the ambient environment is modelled in detail using the EnergyPlus Material Object. Variables such as surface roughness, thickness, thermal conductivity, density, specific heat, and thermal, solar and visible absorptance are defined. All the materials within the wall cavity (e.g. between the interior face of the external material and the wall cavity face of the internal lining) have had their R-values calculated to be expressed as a single homogeneous material. The interior material is modelled in detail to ensure the thermal mass effects of its specific heat gain properties are accounted for due to their influence on indoor air temperatures. Other properties include:

1. Surface resistance values are calculated by the programme on the basis of building height and outdoor ambient environment.

2. The BRANZ *House Insulation Guide* (referenced in NZBC clause H1 as providing compliant thermal resistant calculations) has been used to define construction system R-values for wall, floor and roofs.
3. Windows are modelled as whole unit R-values using the LBNL Window 7 tool and the 1989 WERS Report: *Generic Window System Geometry and Frame R-values*. Window geometry is defined as 1800 mm unit width, 1500 mm unit height, 2.7 m² area and one horizontal transom.

#### 3.5.2.3 Modelling air flow

##### Interzone airflow

Interzone airflow is the air exchange between two thermal zones.

NZS 4218:2009 section G1.6.5 states "the model shall have a representation of internal conductive heat flows between thermal zones." However, no requirement is defined for convective (airflow) heat flow. This pilot study excludes convection airflow between zones unless it is mechanically driven.

##### Complex zones

In many cases, a building simulation model requires zones that are complex in shape (e.g. L shaped) to be simplified into multiple neighbouring rectangular zones. The conductive heat transfer throughout the combined zone is accounted for by defining the separating surface as an AirWall. However, the convective heat transfer (which is commonly excluded) is modelled using the EnergyPlus Cross Zone Mixing Object. Cross zone mixing is where two zones exchange air, affecting both the sending and receiving zone. Mixing availability can be controlled by temperature difference or by a time-based schedule. When a temperature difference is positive, air from the sending zone flows to the receiving zone. When the temperature difference is set to zero, mixing occurs regardless of air temperature.

##### Natural ventilation

Simple methods of simulating natural ventilation are limited. Often, their approach is to specify a number of air changes per hour (ACH) for the zone and then apply this during specific times when the internal temperature exceeds defined comfort parameters. It is then up to the building designer to design openable windows to achieve these ACH values. This technique is useful for generic building design but it does not assess the overall effectiveness of the ventilation strategy, including wind effects. Computational fluid dynamics (CFD) is the current best practice method for the simulation of natural ventilation airflow. However, due to the scale of this project, this methodology requires something less precise and time intensive than CFD, which can be linked to a whole-building dynamic simulation. EnergyPlus' Airflow Network meets this requirement.

##### Infiltration

Building infiltration is traditionally modelled as a constant air changes per hour (ACH) rate. However, when using the EnergyPlus Airflow Network, the Zone Infiltration Design Flow Rate cannot be used. This requires more detailed infiltration calculations. The Airflow Network requires the infiltration to be calculated by entering an effective leakage area (ELA) for the surfaces within a zone. The following steps outline this study's approach for calculating the ELA values based on whole-building level ACH rates and blower door test results. This way, building level infiltration results are converted into an equivalent ELA for each surface. A similar methodology was used by Pallin et al. (2014).

1. Assume a building level infiltration level of 3.5 ACH at 50 Pa is one appropriate value for new residential construction in New Zealand.
2. Convert this ACH infiltration at 50 Pa into an ELA (m²) at 4 Pa, using www.residentialenergydynamics.com/REDCalcFree/Tools/AirLeakageMetrics.aspx
3. Distribute the calculated ELA value (which is the size of the opening that provides the ACH infiltration spread out throughout the whole house) across all the building's exterior surfaces. Divide the ELA m² by the total surface area to get a ELA per m² figure. This is then multiplied by the surface area of each surface it is applied to. A separate ELA object is created for each surface as specified ELA is in m² and is dependent on the surface area of the surface it is being applied to.
4. Apply the following values:
   a) Discharge coefficient: 1.0 is a default assumption (Ghiaus and Allard, 2005, p. 73).
   b) Reference pressure difference (Pa): 4 Pa pressure difference.
   c) Air mass flow exponent: 0.6–0.8 depending on blower door test results.

### 3.5.2.4 Schedules/internal heat gains

#### Number of people

The following modelling assumptions are used in this pilot study:

1. Two people per master bedroom, then one per bedroom. Occupied 9pm–6am (sleeping).
2. All intermittently occupied spaces (see 3.5.2.1) are excluded from occupation.
3. All habitable rooms (excluding bedrooms) follow the NZS 4218:2009 schedule in Table G2, where the total number of occupants is evenly distributed across these areas.
4. Activity watts per person: sleeping = 40 W/m² and seated quiet = 60 W/m².
5. Sensible and latent heating fraction is auto calculated. Sensible is divided into radiant and convective: 30% radiant, 70% convective.

#### Moisture loads

Modelling internal moisture gains within EnergyPlus is limited. There is no specific object that allows the direct input of moisture generation rates. However, workaround methods exist to approximate the effect. Woods et al. (2013) simulated internal moisture gains by expressing them as a latent heat gain based on the evaporation of water – for example, 347 watts 100% latent heat gain at a constant 20ºC indoor temperature distributed over 48 m² (7.23 W/m²). This equals 0.5 kg/h or 12 L/day, which equates to a two-bedroom house with three occupants (Table 4.3.2 of ASHRAE 160-2009 *Criteria for moisture-control design analysis in buildings*, ASHRAE 2009). Based on this methodology, the figure of 7.23 W/m² can be scaled to match the requirements from ASHRAE 160 Table 4.3.2.

#### Lighting

NZS 4218:2009 states interior lighting heat gain and electricity end-use calculations are optional modelling parameters. This is probably due to the lack of data regarding installed lighting levels and occupancy controlled lighting behaviour.

#### Electric equipment/plug loads

NZS 4218:2009 specifies an internal gain of 24.5 W/m² at 100% sensible heat gain for equipment plug loads in conditioned zones and 100 W at 100% sensible heat gain for the domestic hot water divided by the floor area of conditioned zones. Neither of these are electricity consumption figures.

### 3.5.2.5 EnergyPlus outputs

#### Output meter

This is the sum of the building's total meter and sub meter energy consumption. It does not break down to per-zone level of detail. The meter calculates:

1. Fans: Electricity
2. Heating: Electricity
3. Cooling: Electricity
4. Interior lighting: Electricity
5. Electricity: Zone

#### Output variable

Using this object, the outputs that are summed for the output meter results can be specified individually. This allows results to be calculated for individual zones – for example, the electricity used for heating per zone.

## 3.6 WUFI interstitial moisture modelling

### 3.6.1 Background

WUFI (**W**ärme **U**nd **F**euchte **I**nstationär, which loosely translates to 'Warm and moist transients') simulates heat and mass flows in building components. WUFI is available in several versions:

- WUFIPro (the 1Dimensional WUFI variant)
- WUFI2D for two-dimensional analysis
- WUFI plus, a whole-house simulation package, similar in capability to EnergyPlus
- WUFI Passive (new) for passive house certification.

WUFIPro has been used for this pilot project as it is fast and ideally suited to quickly simulating multiple wall sections. BRANZ has a collaboration going back many years with the Fraunhofer Institute for Building Physics (FIBP) on the development and benchmarking of WUFI. The software has an extensive history in BRANZ's research programs, particularly with the Foundation for Research, Science and Technology-funded weathertightness research (McNeil and Bassett, 2007) and, more recently, vapour control in walls (Overton, 2016).

During the weathertightness project, BRANZ developed a cavity ventilation model that allowed the realistic simulation of the performance of cavity walls (Bassett, McNeil and Overton, 2012), which was key to quantifying the performance of these wall systems when it came to the management of moisture. All modelling was benchmarked against experiments in BRANZ's test building to provide confidence in the outputs.

### 3.6.2 Possible questions able to be answered with WUFI

A few basic applications of WUFI that are pertinent to this project (both this pilot and the proposed follow-on) are listed below:

- Assessing the risk of moisture accumulation inside the construction due to operating conditions (this is more important as insulation levels increase)
- A sensitivity analysis of this to indoor conditions
- Assessment of ability of walls to recover after a wetting event (a leak or flood etc)
- Mould growth potential on surfaces throughout the construction
- Corrosion potential of fasteners inside wet building elements (possible for masonry, under development for timber).

At this stage, the assessment of risk of timber decay is not possible as insufficient data is available on the various decay species. However, projects are underway that will start to fill this gap, at Lund University and others. In addition, a related BRANZ Levy proposal is being considered.

### 3.6.3 Proposed model setup

Each of the different proposed constructions from the main project can be created in WUFI, thereby building a library that the different climate files can be run against. For this pilot, one construction geometry has been created (shown in Figure 2 below), where the materials are assigned (from left to right) as:

**[exterior]** Cement sheet – Air Layer – Building wrap – Insulation – Interior lining **[interior]**

Note that material properties are taken from the WUFI database in conjunction with the BRANZ material property database. This is actively being expanded and will be transferable into a more recent version of WUFI.

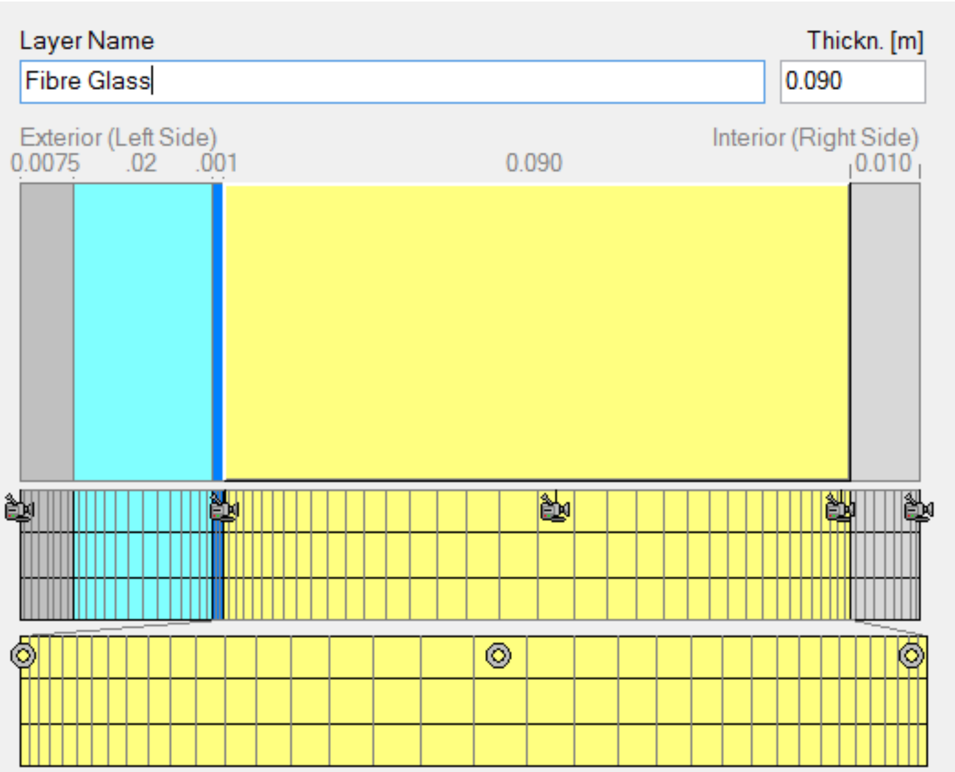


**Figure 2. WUFI screenshot of 20 mm cavity wall, FCB clad, R2.2 insulation, with plasterboard internal lining**

Once a geometric model is built, it can easily be subjected to multiple climates with a batch process, with no rework of the model required.

### 3.6.4 Climate files

As WUFI has its own file format for boundary conditions (.WAC), the climate files required are generated from the EnergyPlus outputs using a script and can be taken from any of the modelled zones. The required parameters are temperature and relative humidity (RH) (both indoors and outdoors), as well as solar radiation (both direct and diffuse) outdoors. This script has the capability to be expanded to automatically generate a set of climate files for each dwelling modelled in EnergyPlus. This means simulation of hygro-thermal conditions can be done for each zone of the building as modelled by EnergyPlus.

### 3.6.5 Outputs/scenarios

Due to the BRANZ relationship with FIBP, BRANZ has the ability to perform customised analysis of the model results. A few basic outputs are presented below, to illustrate the sort of data able to be generated.

The most basic outputs include time history plots of water contents in materials, RH and temperature over the course of the simulation. These can be of a whole layer or a specific point inside a material. This is illustrated below for the model shown in Figure 2 subjected to a south-facing climate and taking the interior conditions for a bedroom on the south side of the building. Figure 3 shows the moisture content history of the (entire) interior lining of the course of the 3-year simulation, and Figure 4 shows the projected temperature and RH history in the 3 mm of insulation closest to the exterior.

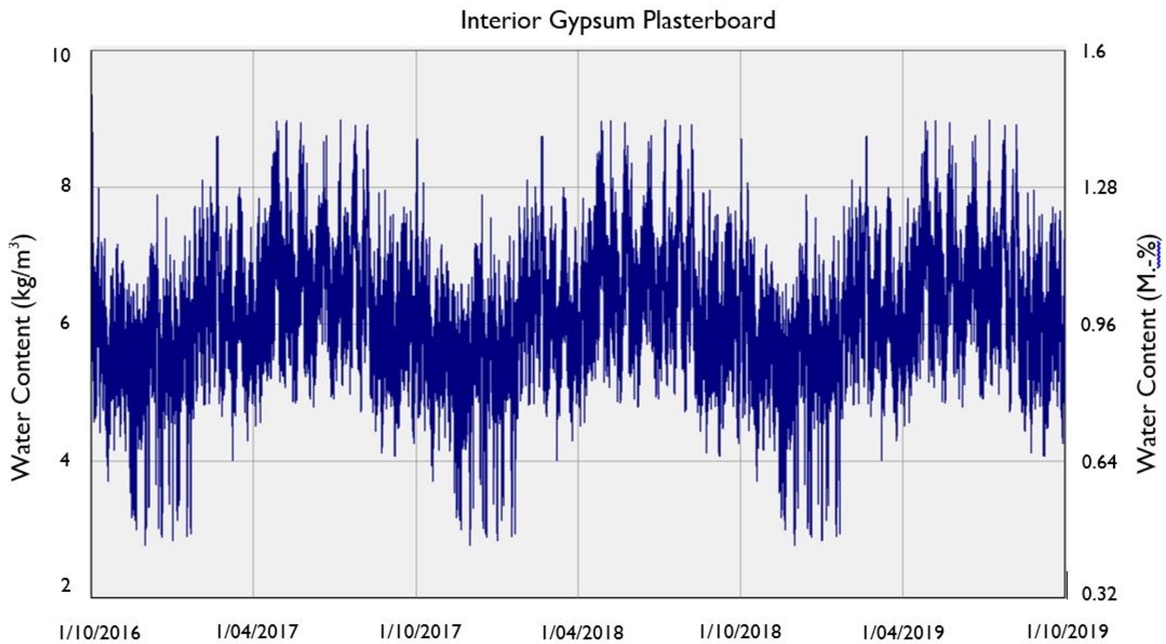


**Figure 3. Moisture content of interior wall lining**

Figure 3 demonstrates a time history plot of moisture content of the gypsum lining of the model in Figure 2. Three years of data are presented, with the water content on the left axis and this as a calculated mass percentage on the right axis. For this plot, the mean moisture content is of the order of 6 kg/m$^3$, which equates to an average RH of 70% inside the material.

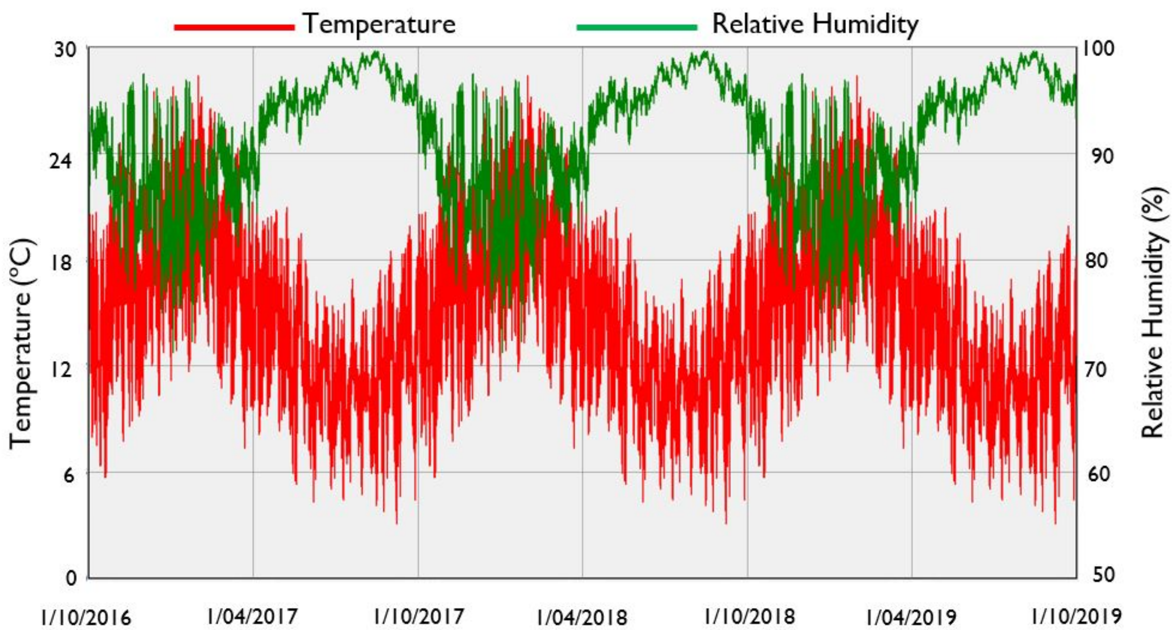


**Figure 4. Temperature and relative humidity at position of wall underlay**

Figure 4 plots the temperature (red) and humidity (green) over the same measurement period, this time for the last few millimetres of insulation directly below the wall underlay. The typical summer/winter seasonal variation of both variables is evident, with wintertime RH levels exceeding 90%, whereas in summertime RH levels fall below 60%. In the model above, a higher humidity is simulated than might be observed in reality. This is because ventilation was not modelled in the cavity, which typically lowers the RH.

Also available as an output is an animation of the RH and temperature profiles in the wall over the course of the simulation – a screenshot is shown in Figure 5. The animation is a useful tool to illustrate the dynamic nature of heat and mass transfer in wall elements. It also shows that simple steady-state models do not consider all the variables at play. In terms of identifying any issues, the animation can be used to narrow the focus for further exploration.

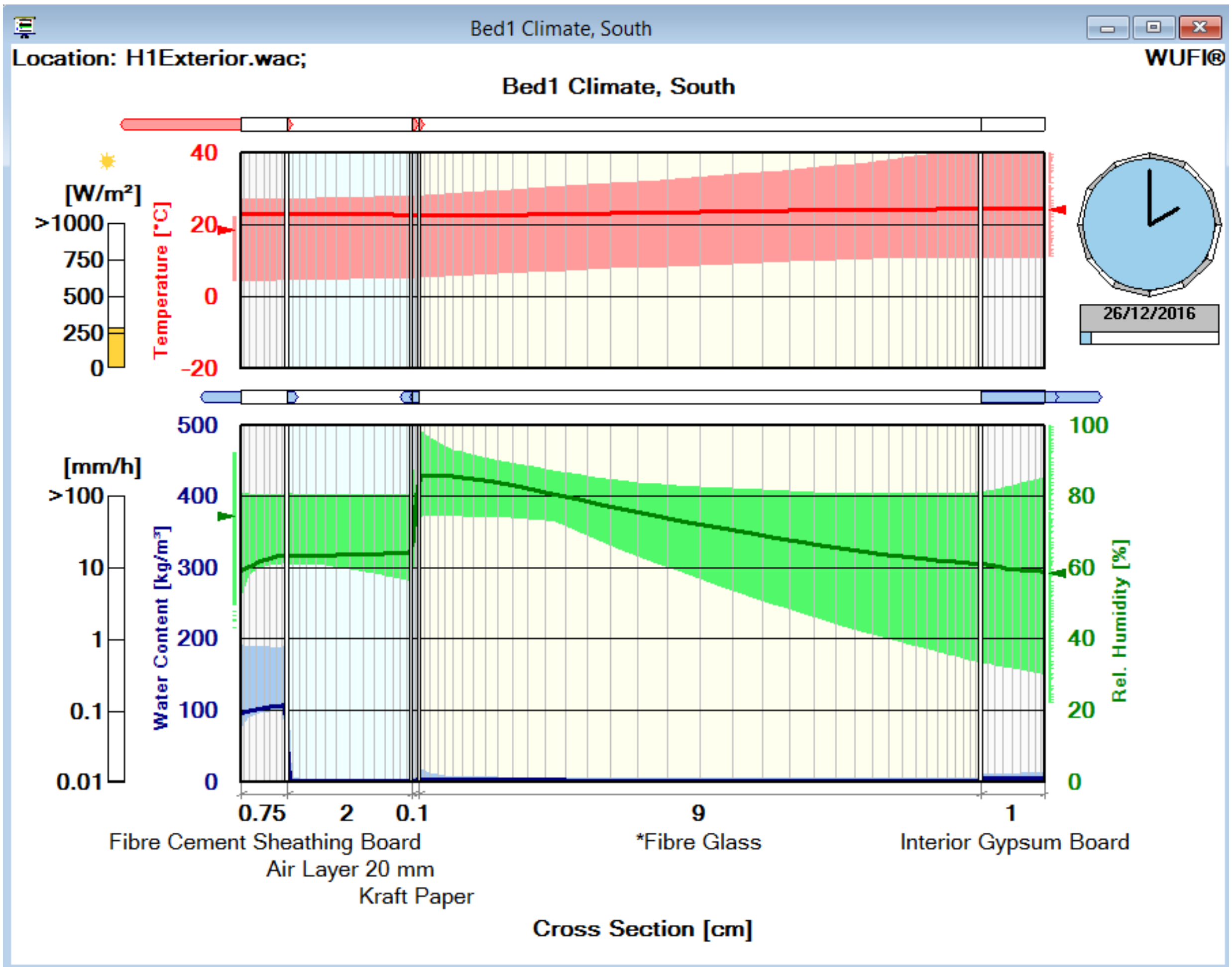


**Figure 5. Screenshot of WUFI calculation animation**

## 3.6.6 Further analysis

While useful for a simplified look at the conditions in a wall, these outputs are limited by the user's interpretation of what constitutes a problem. To that end, a set of postprocessors are under development at FIBP, which allow a more rigorous approach to assessing wall performance. The first of these to be released is WUFI Bio, which aims to help make design decisions based on simulated mould growth.

By default, WUFI Bio is geared towards mould on interior surfaces, but with appreciation of limitations, can be applied to other locations in the wall.

WUFI Bio requires a user to specify the substrate class of the building material of interest. Several are available to choose from, but a typical painted gypsum lining will be of class 1. The description of a class 1 substrate is:

> Bio-utilizable substrates, such as wall paper, plaster board, building products made of biologically degradable materials, materials for permanently elastic joints, strongly contaminated surfaces (Sedlbauer, 2001).

A 'Class K' exists, which is aimed at mould species that are known to pose a risk to health such as *Stachybotrys*. This, however, is fairly experimental and is still under development.

Figure 6 is a screenshot of the WUFI Bio output for the surface of the interior lining of the model above, with the red line illustrating the critical water content of a mould spore, where growth would occur given the conditions. The blue line indicates the modelled moisture content of a mould spore at the condition of the gypsum surface. Provided the blue line does not exceed the red line, little mould growth can be expected.

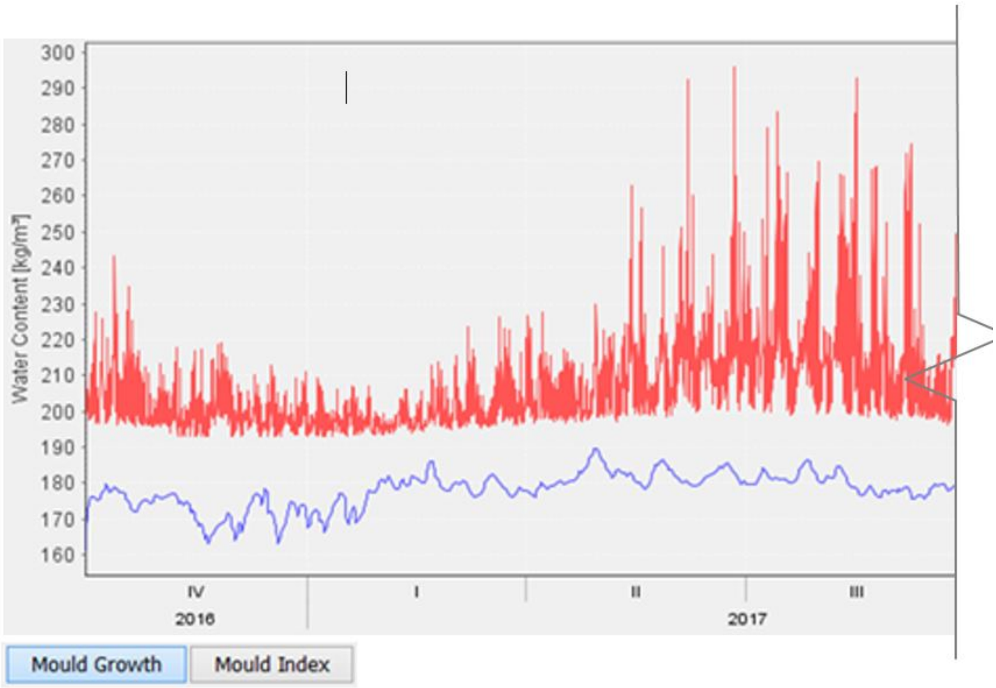


**Figure 6. WUFI Bio output**

As Figure 6 demonstrates (with the spore moisture content never exceeding the critical moisture content), the risk of mould growth on the interior surface for this model is minimal.

Other post-processors are available for WUFI, which include:

- The MRD model from Lund University, which performs a similar function to WUFI Bio, and is also being further developed, with a view to incorporating some degree of decay model in the future.
- A corrosion postprocessor for steel corrosion in masonry materials.
- BRANZ is considering assisting on expanding the corrosion postprocessor to include timber materials, also including the effect of different treatment options on corrosion performance of fasteners.

### 3.6.7 Summary

In relation to outputs for the pilot project, the following have been accomplished:

- A script (i.e. algorithm) has been created that will generate a WUFI .WAC climate file from EnergyPlus outputs.
- A method for the creation of a library of construction models has been created.
- A method for batch processing has been designed, for running each climate over the correct wall type to create the WUFI output files.

Currently, no consideration can be given to decay of timber due to insufficient data being available, but the use of WUFI Bio or the MRD post processor from Lund will enable the assessment of mould growth potential on wall surfaces and inside the construction.

# 4. Discussion and recommendations

## 4.1 Discussion

The aim of this pilot project was to establish a proof-of-concept methodology for effectively and robustly selecting and modelling the performance of a variety of recently consented dwellings reflective of new New Zealand housing.

If successful, the methodology would then be used in a larger stage 2 project to examine the settings of three associated clauses of the New Zealand Building Code (NZBC) – H1 *Energy efficiency*, E3 *Internal moisture* and G4 *Ventilation*.

The pilot study has:

a) established a smart sampling methodology for selecting New Zealand dwellings of a range of typologies, reflective of those most commonly built today
b) determined a practical means of collecting and storing material and other key characteristics of each representative dwelling, in a succinct manner, which can be easily interrogated
c) provided two three-dimensional wireframe models in a flexible format that can be imported/exported into other key software
d) developed a translation algorithm that enables the importation of the building geometry into internal moisture/ventilation/air quality modelling software.

The next stage of the project, simulating the reference buildings to represent the new-build stock, can now be accomplished.

## 4.2 Recommendations

That stage two of this project be initiated, so that:

a) what is being achieved with the new dwellings (largely) built to minimum requirements for clauses H1, G4 and/or E3, in terms of indoor environmental performance, energy end use and (ideally) non-energy impacts, is better understood for typical residential dwelling typologies
b) the implications of dwellings with above minimum specification for H1, G4 and/or E3, in terms of hygro-thermal performance, cost and energy use, are explored.

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# Appendix A1: Key statistics of new New Zealand dwellings from previous studies

Below is a summary of some key building element statistics, from various sources but mainly the BRANZ New Dwelling Survey carried out in 2014 (Curtis, 2015) which is carried out biennially. This data was required to develop the simulation runs as well as being part of BRANZ's contractual requirement for this pilot.

## Common new-dwelling cladding and insulation data

The most common roof cladding types in dwellings, listed by popularity, can be seen in Table 4.

**Table 4. Common roof cladding types (in 2014)**

| ROOF CLADDING TYPES Market share 2014 | |
|---|---|
| **PRODUCT** | **% share** |
| Long-run profiled steel | 54 |
| Metal tiles | 36 |
| Concrete tiles | 8 |

The most common wall cladding types in dwellings, listed by popularity, can be seen in Table 5.

**Table 5. Common wall cladding types (in 2014)**

| WALL CLADDING TYPES Market share 2014 | |
|---|---|
| **PRODUCT** | **% share** |
| Clay brick | 34.4 |
| Radiata WB | 20.1 |
| Cement board | 10.0 |
| Cedar WB | 5.8 |
| EIFS | 3.0 |
| Concrete brick | 2.7 |
| Plywood sheet | 2.4 |
| Steel zincalum | 2.2 |

Note that structural insulated panels will be added to this list for the hygro-thermal simulations and all those that are similar will be amalgamated (such as *pinus radiata* and cedar weatherboard). The most common ceiling insulation types in new dwellings, listed by popularity, can be seen in .

**Table 6. Common ceiling insulation products (in 2014)**

| ROOF INSULATION PRODUCT Market share 2014 | |
|---|---|
| **PRODUCT** | **% share** |
| Fibreglass | 97 |
| Polystyrene | 1 |

The most common wall insulation types in new dwellings, listed by popularity, can be seen in .

**Table 7. Common wall insulation types (in 2014)**

| WALL INSULATION PRODUCT Market share 2014 | |
|---|---|
| **PRODUCT** | **% share** |
| Fibreglass | 95 |
| Polystyrene | 2 |
| Polyester | 1 |

The most common wall insulation types in new dwellings, listed by popularity, can be seen in .

**Table 8. Common floor insulation products (in 2014)**

| UNDERFLOOR INSULATION PRODUCT Market share 2014 | |
|---|---|
| **PRODUCT** | **% share** |
| Polystyrene under slab | 49 |
| Pod style | 35 |
| Polystyrene between joists | 10 |
| Foil | 2 |
| Other | 4 |

The averaged thermal envelope R-values in new dwellings can be seen in .

**Table 9. Averaged elemental R-values (in 2014)**

| R-VALUES FOR THERMAL ENVELOPE Market share 2014 | | | | |
|---|---|---|---|---|
| | Ceiling/Roof | Wall | Floor* | Windows* |
| Climate Zone 1 | 3.2 | 2.4 | Self reported results too inconsistent - pod-style and uninsulated main flooring types | Extrapolating: approximately 93% simple aluminium double glazed (R0.26); remaining improved IGU with thermally broken, low-e or argon (R0.31–R0.33) |
| Climate Zone 2 | 3.5 | 2.4 | | |
| Climate Zone 3 | 3.7 | 2.7 | | |

As can be seen in , the figures obtained from the BRANZ New Dwellings Survey are indicative at best, given the evidence that the specified R-values are only meeting the minimum requirements of clause H1 Schedule Method. It is thought by experts[6] that the self-reported R-values are inconsistent and highly likely to be over-estimated. The flooring self-reporting is probably the most inaccurate of all the elements and should be ignored. Note that in the benchmarking study (Jaques, 2015) and the 100-odd consents of the dwellings sampled for this typology study almost all were only just reaching the minimum requirements of clause H1 Schedule Method. So, it is a reasonable assumption that this is the case for the majority of new homes constructed.

[6] BRANZ Principal Economist Ian Page and BRANZ Economist Matthew Curtis (in 2016)

## Common new-dwelling space conditioning systems

The most common space conditioning types in dwellings, listed by popularity, can be seen in  following. Note that 43% of the sample had a heat pump, which has the ability to cool.

**Table 10. Common space heating systems (in 2012)**

| SPACE CONDITIONING SYSTEM TYPE Market share 2012 | |
|---|---|
| **TYPE** | **% share** |
| Heat pump | 34 |
| Gas fire | 18 |
| Gas fire and heat pump | 9 |
| Wood burner | 6 |
| Gas fire and underfloor | 1 |
| Unknown | 32 |

Note: This market share was for stand-alone homes (Jaques, 2015), rather than all dwelling typologies. For the main follow-on study, it is suggested that perhaps a larger sample of dwelling consents, by type, is sampled to get a better representation. However, as demonstrated by the percentage of "unknown" space conditioning types in , not all consents provide detailed information on just how much of the overall floor area is heated by a point-source heater (and what energy source is used) and therefore how the remaining spaces are heated. Another complication is that the efficiencies of various heater types vary considerably, so converting the energy figures to primary energy requires some guesswork.

# Appendix A2: The thermal implications of dwelling size

Because of the usually observable high correlation between floor space (or more correctly, the 'conditioned volume'[7]) and the heat consumption for comfort of buildings, it makes sense to distinguish building sizes (McKenna, Merkel, Fehrenbach, Mehne and Fichtner, 2013) in the selection of representative houses. As a rule, current New Zealand specification[8] practice for new dwellings – at least for stand-alone houses – is to default to the Schedule Method look-up minimums for insulation levels (Jaques, 2015). Using the coefficient of determination to measure how a random selection of 2012 stand-alone New Zealand houses from Hamilton can be explained by their floor areas alone, we can see that it explains 85%.

Other relationships were examined – such as varying the window areas, house orientation etc – but considerably weaker relationships were found. Note that the impact of varying insulation values could not be explored due to the similarity in specification levels between houses in the random selection.

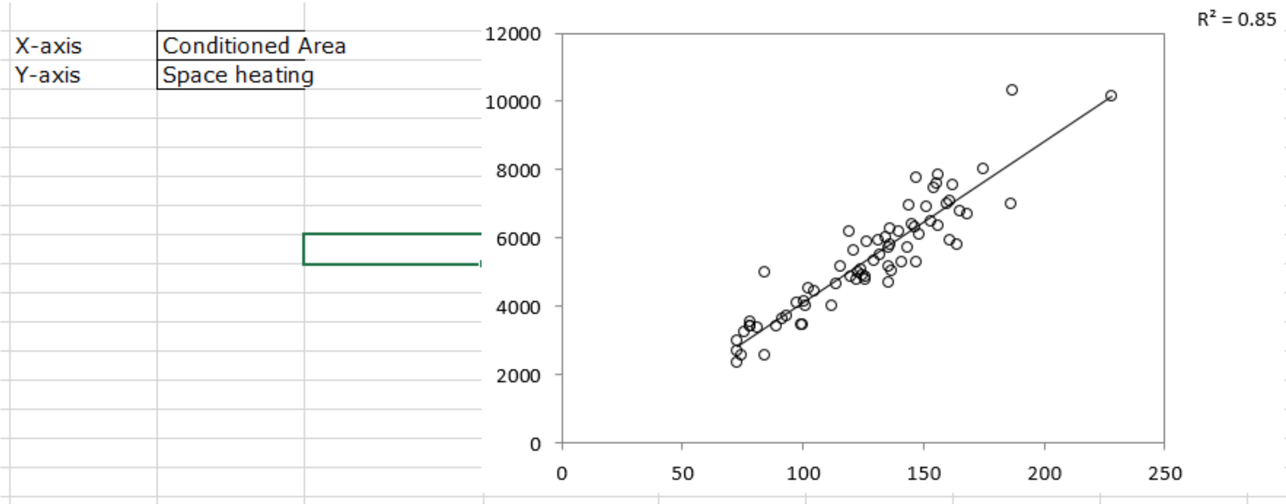



**Figure 7. $R^2$ relationship between heated area (in $m^2$ on x-axis) and space heating needs (in kWh on y-axis) for 70 randomly selected detached houses in Hamilton (Jaques, 2015)**

[7] 'Conditioned volume' is the area multiplied by the average height of all the spaces within a dwelling that are normally heated and/or cooled to keep thermally comfortable. Thus, they include bedrooms, lounges, kitchens and dining rooms but not garages. It is usually defined as all the space within the thermal envelope (or enclosure) of the dwelling.
[8] Note that this is what is specified and may not exactly equate with what is actually installed *in-situ*. Anecdotal evidence suggests that if anything, specified R-values are an over-estimation of what is installed.

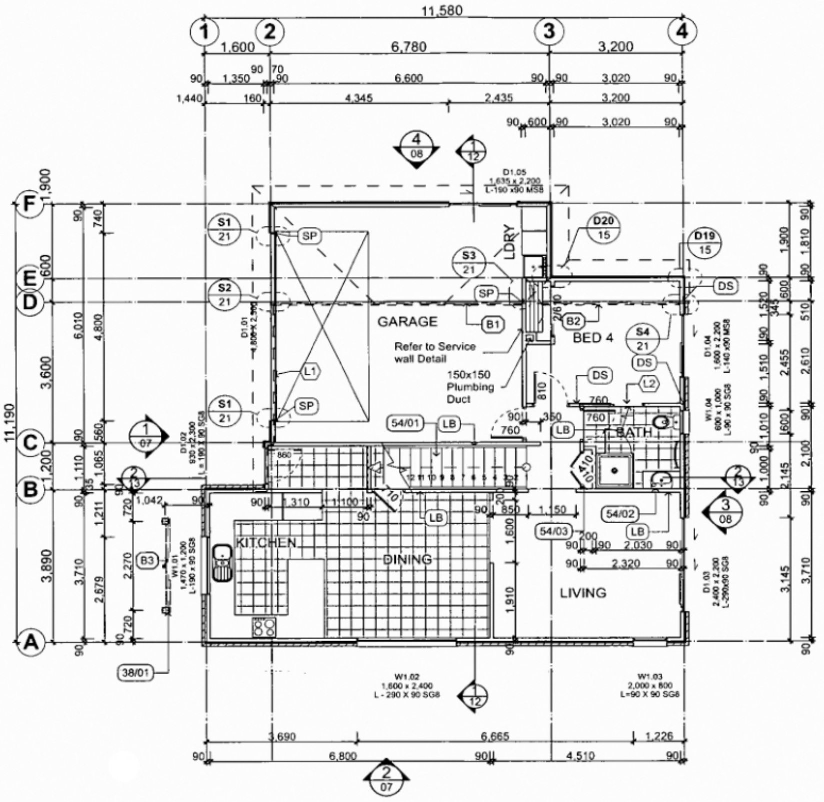
# Appendix A3: Reference dwelling #1 plans: Small-sized, 2 storey, detached

This house (Figure 8 and Figure 9) is a good representation[9] of many smaller sized, suburban, 2-storey dwellings commonly supplied by group home builders. They are typically orientated to face the road. Some key statistics:

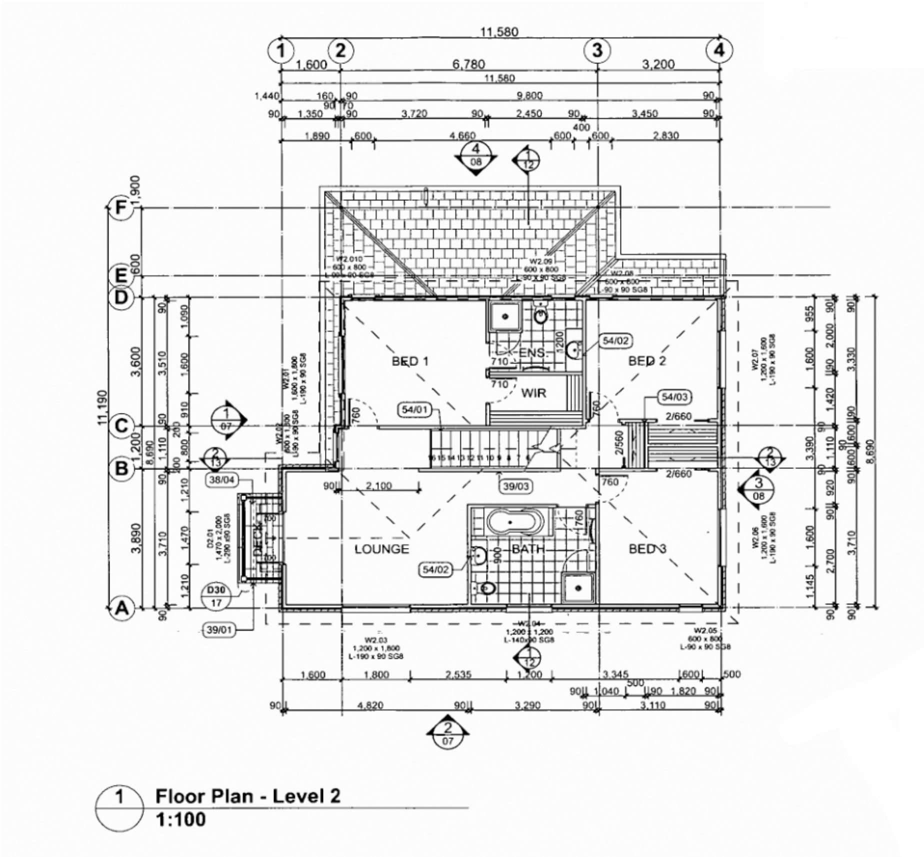
- Floor area: 211 $m^2$, including garage
- Timber frame construction – internal and external
- Combination of fibre-cement weatherboards and brick veneer external wall cladding
- Concrete roof tiles
- Non-thermally broken aluminium windows
- R2.6 ceiling and R2.2 wall insulation
- Raft-style concrete slab
- Combination of underfloor electric heating in main living areas and unspecified.

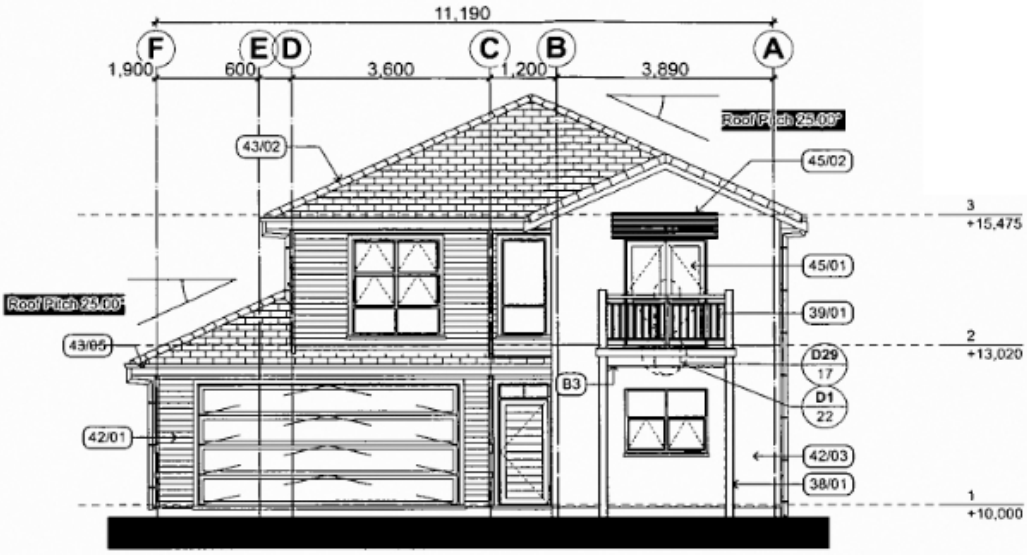
**Figure 8. Typical 2-storey detached house**

[9] Personal communication, BRANZ architect Trevor Pringle (ANZIA)

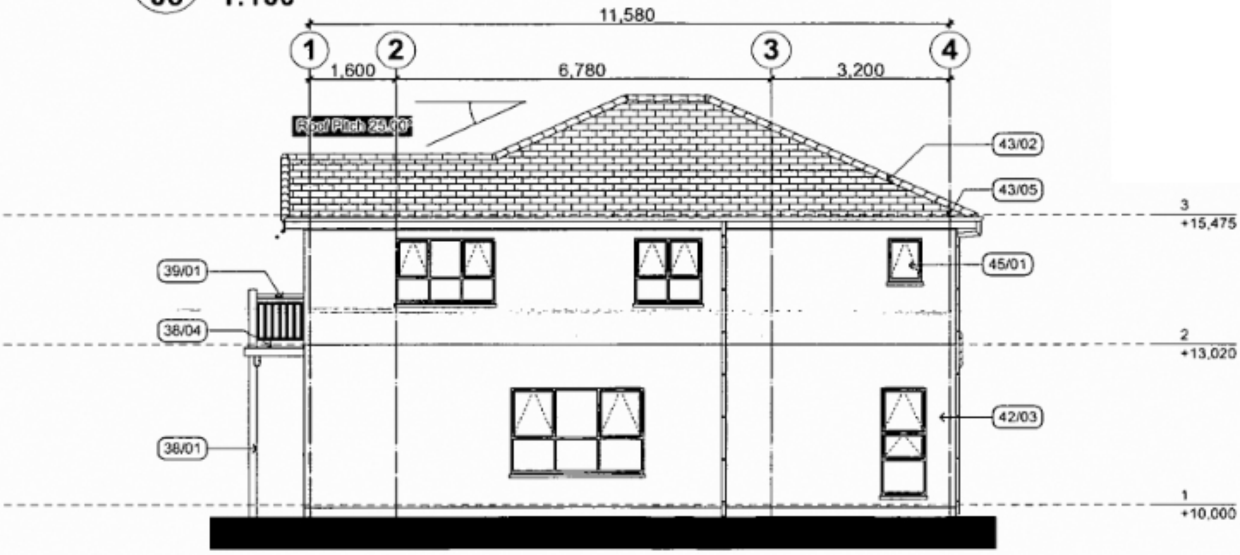



1 Floor Plan - Level 1
1:100


BED 1
ENS
WIR
BED 2
LOUNGE
BATH
BED 3
DECK
1 Floor Plan - Level 2
1:100




1 Elevation
06 1:100




2 Elevation
06 1:100

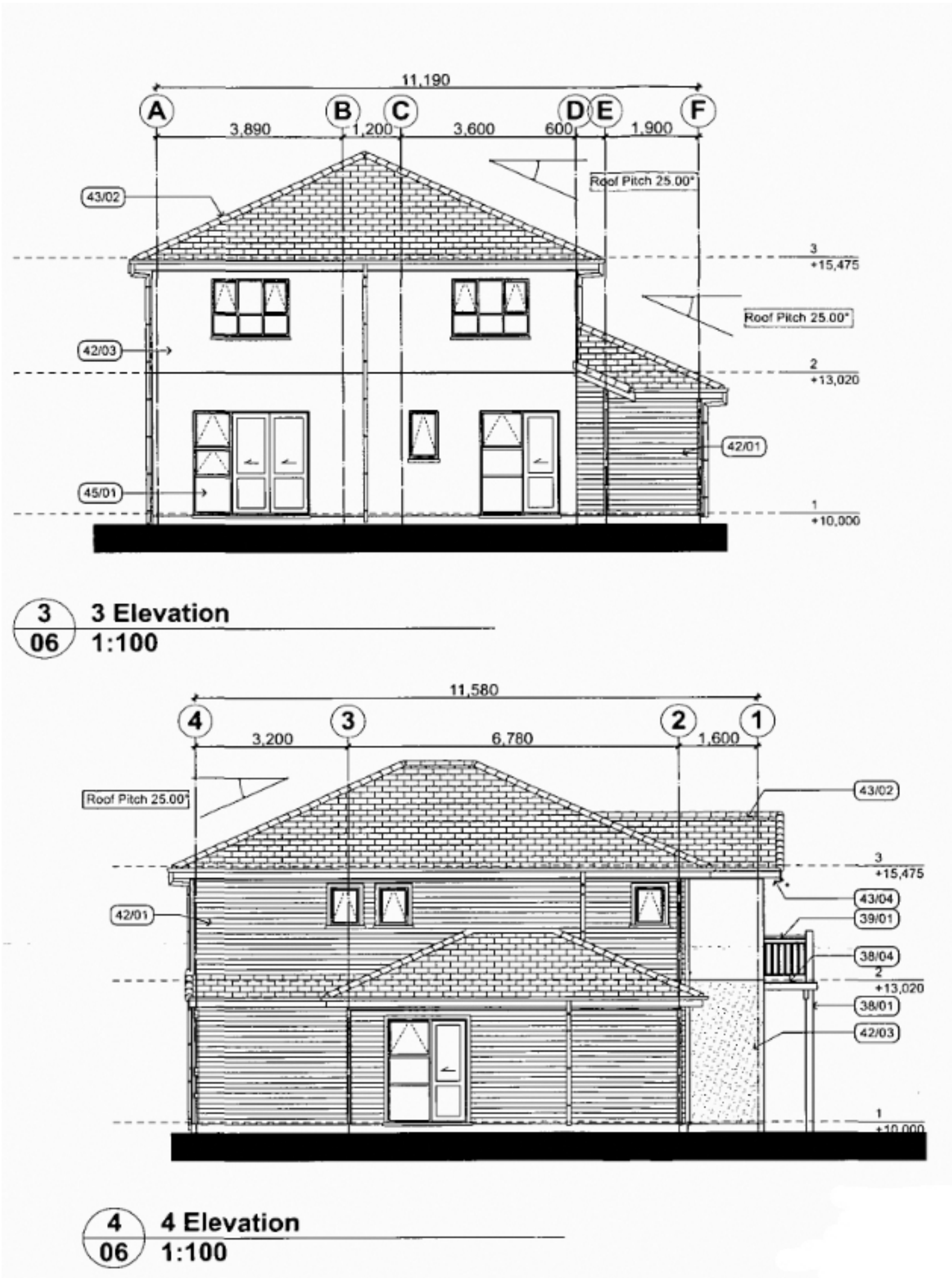



**Figure 9. Consent drawings of 2-storey detached house**

# Appendix A4: Reference dwelling #2 plans: Medium-rise apartment

This medium-rise apartment (Figure 10 and Figure 11) would typically be located within a larger city's CBD area. It is an 11-level tower comprising 80 residential units configured as a package of a one-bedroom unit combined with a self-contained studio.

This specific example was built in 2011.

**Figure 10. Medium rise apartment – 3D rendering**

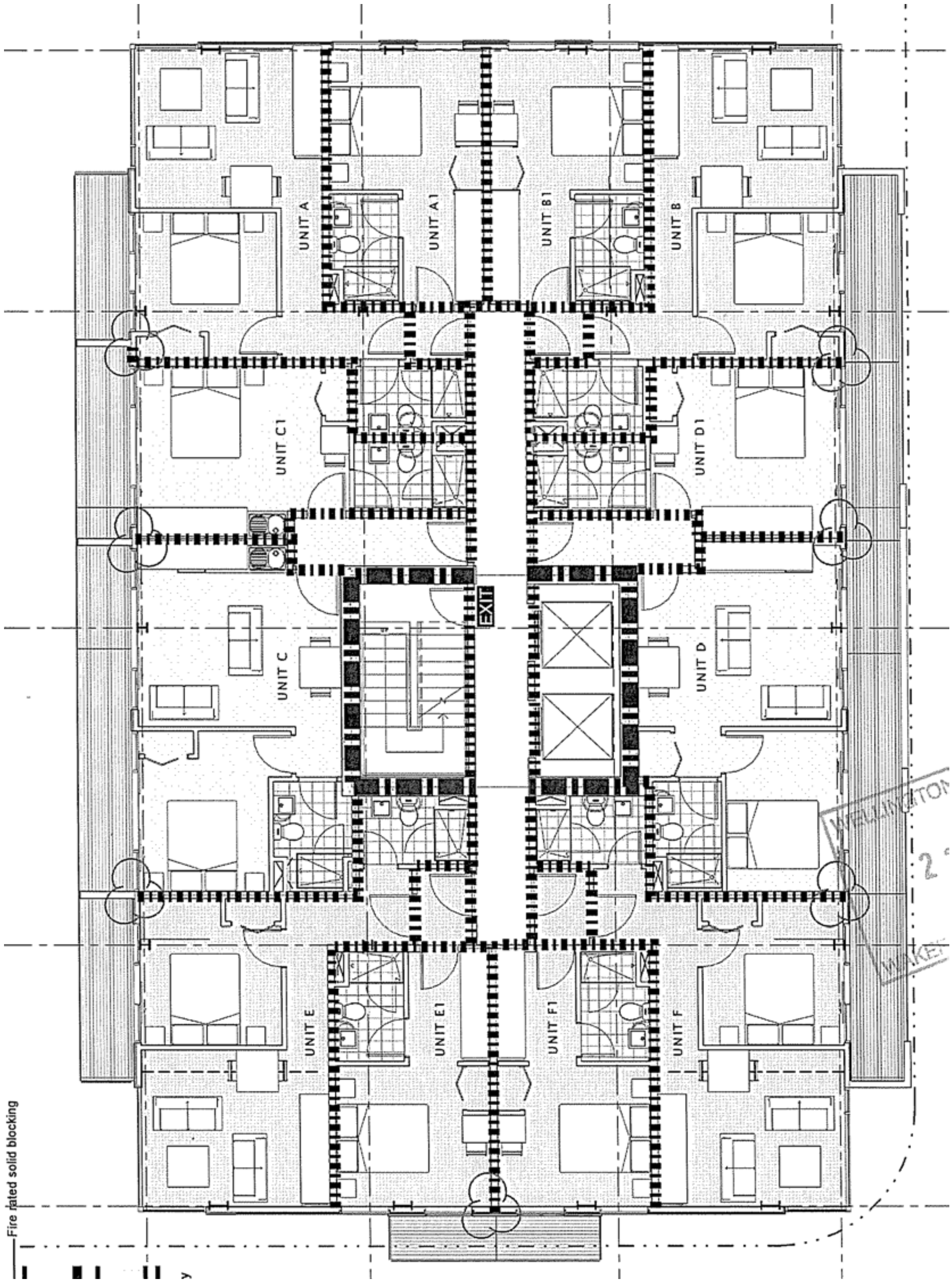



**Figure 11. Medium rise apartment – plan of typical floor layout**

# Appendix A5: 3D wireframe models of two reference buildings

The following wireframes (Figure 12 and Figure 13) model the two proof-of-concept buildings investigated – the double storey stand-alone and the multi-storey apartment.

As documented

As modelled

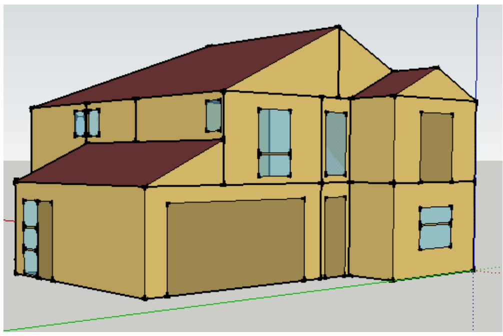


**Figure 12. Wireframes of double storey reference dwelling**

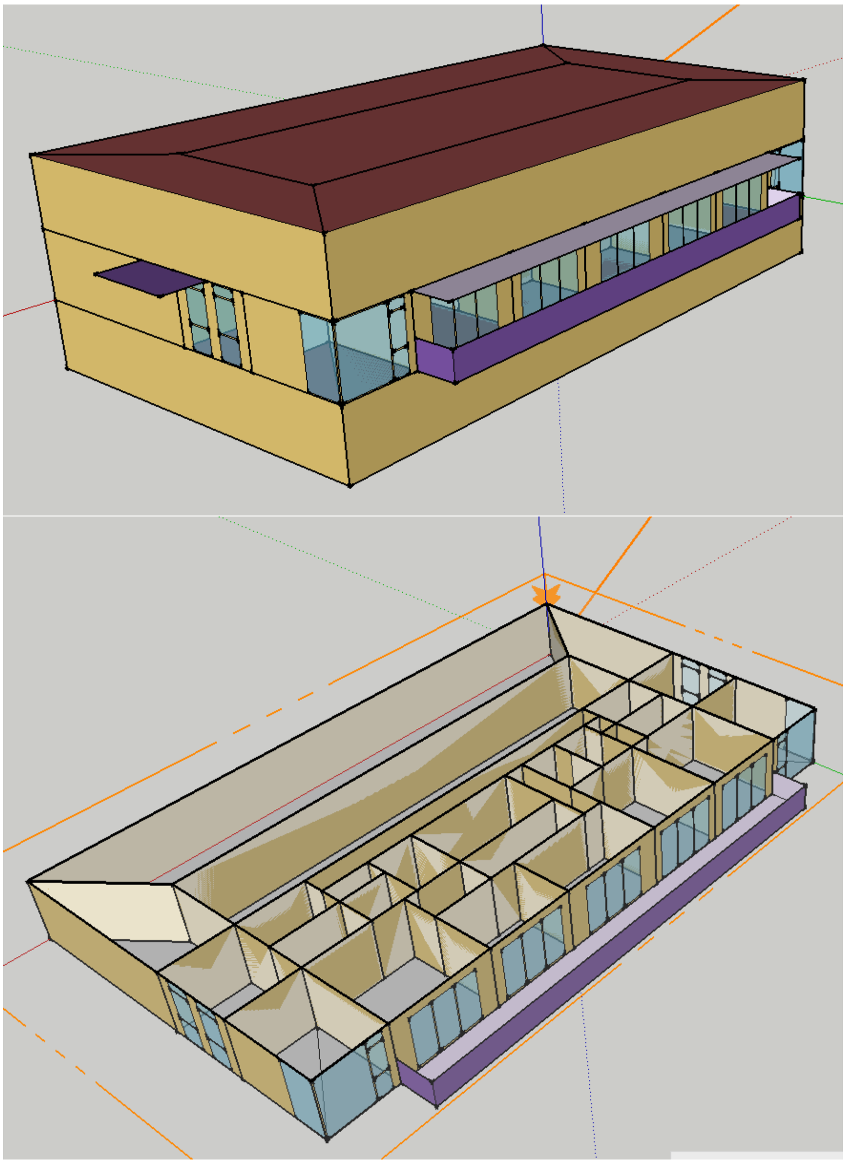


**Figure 13. Wireframes of multi-unit reference dwelling**

# Appendix A6: Catalogued typology characteristics

An MS Excel spreadsheet was constructed to identify and categorise the selected dwelling types by their various properties. The aim was to have an easily interrogatable database listing all dwellings that could be applied to the follow-on study.

The detail was arranged under the following headings, to give an idea of how the template could work:

- Dwelling ID
- Site characteristics
- Dwelling characteristics
- Installed systems
- Glazing metrics
- Building element metrics
- Ventilation/flooring metrics
- Variables examined
- Wireframe model.

A (partial only) spreadsheet snapshot is shown in Figure 14.

| *The following data will be provided for all the dwellings in the sample. For multi-units, only the unique dwelling units will be examined, to avoid repitition.* | *CELLS TO FILL IN* | *UNITS* |
|---|---|---|
| *Only the 'Cells to fill in' column should be populated. The grey cells are drop-downs.* | | |
| | | |
| **Dwelling identifier** | | |
| Dwelling ID # | e.g. SS_1 | alpha-numeric code |
| Dwelling location address | 14 Tesla Lane, Titirangi, Auckland | text |
| dwelling typology | multi-atorey apartment | |
| dwelling placement (if a multi-rise) | top unit end | |
| | | |
| **Site characteristics** | | |
| Climate (using NIWA 18 climate zones) | Whangarei | |
| | | |
| **Dwelling Characteristics** | | |
| floor area as defined by Council (includes garages, e.g.) | 156 | m2 |
| floor area within thermal envelope (excludes garage) | 134 | m2 |
| exposed mass floor | 22 | % of total floor area |
| number of storeys of dwelling being examined | 2 | |
| number of bedrooms in dwelling (including any studies) | 4 | |
| number of dwellings in whole building | 1 | |
| average ceiling height (of main living room) | | m |
| main water heater type | electric - storage | |
| | | |
| **Installed systems** | | |
| renewable energy sources (PV, solar thermal etc) | none specified | |

**Figure 14. Snapshot of partial EXCEL template of material properties and dwelling characteristics.**

# Appendix A7: Computer modelling tools used

A variety of computer modelling tools were used in this pilot – both separately and in combination. This was necessary as there is no one tool that is sufficiently broad, detailed and flexible enough for direct application.

The main modelling tools and their applications were:

**SKETCHUP:** a 3D modelling computer program for a wide range of drawing applications such as architectural, interior design. (www.sketchup.com)

**ENERGYPLUS:** a whole-building energy simulation program that engineers, architects and researchers use to model energy consumption and the thermal performance of buildings. Specifically, it can model heating, cooling, lighting, ventilating and other energy flows very accurately and is becoming the leading engine used in dynamic thermal modelling today. (https://energyplus.net)