External Research Report

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Measuring the Extent of Thermal Bridging in External Timber-Framed Walls in New Zealand

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About This Report

Title

Measuring the Extent of Thermal Bridging in External Timber-Framed Walls in New Zealand

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Abstract

This report shares the results and findings of a project to investigate the extent of thermal bridging in external timber-framed walls of new builds. The research methodology has evolved as the team gathered information, and is detailed. The Wall Project took a case study approach to investigate the percentage of framing in 47 newly constructed dwellings from Auckland, Christchurch, Wellington and Hamilton. The results show that the average percentage of timber framing compared to the area of the wall is above 34%. This is much higher than the 14 – 18% framing content generally assumed by both regulators and the industry. The results strongly indicate that the content of timber framing in external walls in residential new builds is at such high levels that the increased thermal bridging compromises the performance of walls and may mean that designed R-values are not being achieved. There is evidence that increasing framing content is being driven by the requirements of various regulations, mostly in relation to structure and weathertightness. In addition, there is also evidence that the definitions used in current construction R-value calculation methods for achieving energy efficiency and internal moisture, ignore significant areas of thermal bridging in wall framing. The report includes the results of measuring framing in the 47 individual case study dwellings, and what the research team have learned from both interviews with industry members, as well as through measurement and analysis of the case study houses. In concluding, the report highlights opportunities for further suggested research activity that could assist in improving the thermal performance of walls in New Zealand.

Reference

Ryan, V., Penny, G., Cuming, J., Baker, G and Mayes, I. (2019). Measuring the Extent of Thermal Bridging in External Timber-Framed Walls in New Zealand. Final Report – Building Levy Project LR11092. Report Wall/3 from Beacon Pathway Inc.

Disclaimer

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1 Executive summary

The case for having a well-insulated house with a minimum of thermal bridges is now well established; there are proven health, energy efficiency, and financial benefits. However, significant housing-related health and energy inefficiency issues persist in New Zealand. The thermal performance of a wall depends, in part, on the content of framing because framing has a significantly lower R-value than the bulk insulation materials typically used in walls of new houses. As framing content increases, wall R-value, as a whole, decreases accordingly.

The Building Research Levy-funded project, **LR11092 Measuring the extent of thermal bridging in external timber-framed walls** assessed a case study sample of 47 new residential houses under construction in New Zealand to determine the as-built framing content and extent of thermal bridging in exterior walls. The aim was to deliver insights into:

- The scale of the issue of high percentages of framing in New Zealand residential construction
- The effect that high percentages of framing has on as-built R-values
- The causes/reasons why high percentages of framing might be occurring.

The research has collected primary data from new builds under construction, including case study houses in the major house construction areas of Auckland and Christchurch, Hamilton and Wellington.

Initial research and informed industry knowledge indicated that Frame and Truss (F&T) manufacturers supply in excess of 90% of the framing to new residential builds in New Zealand[1]. This helped to evolve a major new aspect of the research approach which utilises hard copies of F&T panel elevations and plan layouts on site to assist with data gathering. The team also undertook a series of interviews with major suppliers to industry, cladding manufacturers, and representatives from F&T, which ensured the trust and cooperation of the F&T sector in obtaining framing plans, and has proved crucial to understanding how the design process worked and what drove design decisions.

Final results are based on a survey of **1103 wall panels** (across **71 levels and 47 dwellings**) and indicate the following key aspects:

- The average percentage of framing in walls was 34% (over the net wall area) varying from 24% to 57% (by level).
- Some individual wall panels have very high percentages of framing (50-100%); for example, smaller wall panels that are part of a larger overall wall can have higher percentages of framing - up as high as 70-100% per panel.
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[1] This figure was provided as an estimate from a number of different F&T manufacturers and representatives from the Frame and Truss Manufacturers Association or FTMA who quoted figures as high as 96% of supply to the residential sector

- There is little additional framing added on site. Around a quarter of all panels (291/1103) have added full depth framing, with the average for panels with added framing being just under 2% of net wall area, varying between 0.04% and 8% across the case study sample. The average additional site-added, full-depth framing timber by level is just 0.7% (range 0.1 – 4.0%)
- The average percentage by level of un-insulated areas (gaps or spaces in the wall cavity and including additional blocking installed typically for fixing linings, cladding, fixtures and services) was 3% with the lowest being 0.5% and the highest 10% across the sample.

The research also delivered insights across a number of key areas including:

Sector/industry findings

A number of design requirements in regulations have led to increased framing. This includes changes to E2/AS1 requirements for cladding as part of addressing weathertightness, structural requirements of NZS3604, council wind zone requirements, and structural requirements for multi storey buildings. Other factors include: designer preferences e.g. for cladding trends; less than optimal placement of windows in relation to studs during design; and design trends for double height vestibules impacting stud spacing. The research team also noted that F&T design software, which drives the design of panels, does not assess thermal performance, and although it is efficient in not using unnecessary timber, can result in double studs where panels meet. Additionally, the timing of sub-trades can mean walls are not fully insulated, especially at corners and internal wall junctions. These un-insulatable areas appear to be a commonly found and important weakness of the thermal envelope that is not currently considered in H1 calculations.

Regulatory findings

Different aspects of the Building Code appear to have been developed, or updated, without reference to other important features of the Code. For example, cavity construction has resulted in extra framing. Even though NZBC Clause H1 (Energy Efficiency) was amended in 2007 (after development of E2/AS1), it did not appear to take into account the corresponding increase in framing percentages required. Importantly, definitions of construction R-value in NZS 4218, which informs schedule and calculation methods, allows users to exclude a significant percentage of the framing when assessing framed walls, and therefore effectively ignore the real effect of thermal bridging. This means the deemed-to-comply compliance methods set out in H1/AS1 and E3/AS1 may not be achieving the minimum R-values assigned/claimed. This is evidenced by the fact that the average framing percentages of the case study dwellings appear significantly higher than those assumed in R-value calculations used to establish compliance with H1 (Energy Efficiency) and E3 (Internal Moisture). There is an opportunity for the results of this research to contribute to MBIE's Building Code review currently underway.

Findings outside the research brief

The team has noted a number of issues during their site visits, particularly around the lack of insulation in or around external corners, confined stud/nog work, half depth framing, 'high and dry' packers, a lack of insulation around the perimeter of midfloor sections, and the perimeter of concrete slabs. In addition, there were examples of poorly installed insulation and the structural integrity of some framing was compromised due to additional work on site.

The project has raised further questions and indicated areas worthy of further investigation. Additional research would usefully deepen our understanding of the variables contributing to higher or lower percentages of framing identified in the initial phase of this work. Further activity could aim to examine the impacts of these higher framing percentages on resultant R-values as well as describe weak points and blind spots identified in the case study houses which are likely to reduce the thermal performance of walls. Investigations could explore practical and buildable solutions to the identified thermal bridging challenges through examination of advanced framing techniques.

Findings from the current and suggested research have the potential to inform changes to building regulation and the codes governing the design and construction of external walls in New Zealand's residential sector. Given New Zealand has an extensive residential building programme underway that is likely to continue for many decades, it is prudent and smart to ensure new builds are compliant with NZBC requirements for energy efficiency, thermal resistance and moisture management, rather than continue to embed a systemic problem that will incur costs for subsequent generations.

2 Introduction

This report provides results from the Building Research Levy-funded project, **LR11092 Measuring the extent of thermal bridging in external timber-framed walls.** The report starts with background to the project and a synopsis of the methodology employed to undertake the case studies. It then goes on to provide final results from the 47 case studies which have been undertaken as part of this work, and provides a discussion of some of the main sector findings illustrated with case study examples. The report ends with a set of conclusions and opportunities for further work.

2.1 Project background

The case for having a well-insulated house with a minimum of thermal bridges is now well established; there are proven health, energy efficiency, and financial benefits. However, significant housing-related health and energy inefficiency issues persist in New Zealand. The thermal performance of a wall is influenced by the amount of framing present as framing has a significantly lower R-value than bulk insulation materials typically used in walls of new houses. As the percentage of framing increases compared to the insulation, wall R-value, as a whole, decreases accordingly.

In addition, anecdotal evidence over recent years suggests the percentage of timber framing in external walls in residential new builds has increased to such an extent that the increased thermal bridging compromises the requirements of NZBC Clauses H1 (Energy Efficiency) and E3 (Internal Moisture). Recent research conducted under the Building Research Levy prior to the commencement of this piece of work added weight to these concerns[2].

Naturally, the more framing that is used in walls, the less space remains for bulk insulation, thereby lowering the overall performance and resultant R-value of the wall. Standard 90mm timber framing has a much lower R-value than fibrous bulk insulation products commonly used in residential construction i.e. R-value of 0.7 m^2K/W vs an R-value of 1.9 - 2.8 m^2K/W. The overall R-value is also degraded as a result of the framing design around junctions such as windows and corner details, where double and triple stud configurations are becoming more common.

Investigation of the negative effects of thermal bridging on housing performance is not a new concept. Research undertaken by Harry Trethowen, head of Components Research at BRANZ in the 1980s, emphasised the need to mitigate thermal bridging. This is clearly articulated in the statement below by Trethowen[3] showing how important thermal bridging is to 'realised R-values' (i.e. system or construction R-values).

[2] *Bakshi et al. (2018)*
[3] *Trethowen (1986)*

"The principal factors causing R-values to vary from ideal are argued to be the well-known and widely ignored trio of thermal bridging, gaps in insulant, and moisture… Thermal bridging is shown to reduce realized R-values by up to 50% in common cases, even with timber framing, and the reduction becomes even more severe with increasing R-value."

This report provides the results from a programme of work which examines the core issues of thermal bridging in New Zealand walls and aims to deliver key insights into:

- The scale of the issue of high percentages of framing in New Zealand residential construction
- The effect that high percentages of framing has on as-built R-values
- The causes/reasons why high percentages of framing might be occurring.

The intention of this research was to assist in better defining the size of the problem in New Zealand by undertaking examination of houses under construction. The research question(s) stated at the outset of the project were:

1. *What is the percentage of framing in external walls in a sample of new builds across New Zealand and is the as-built framing percentage now typically above that assumed in H1 and E3 calculations? (i.e. are high framing percentages a real and definitive issue?)*
2. *What insights can be highlighted as to the causes of high framing percentages in New Zealand?*

In undertaking this research, Beacon has examined a total of 47 separate dwellings under construction in Auckland, Hamilton, Wellington and Christchurch.

3 Methodology

This research project assessed a case study sample of 47 new residential houses under construction in New Zealand to determine the **as-built framing content** in the exterior walls of the sample houses and **to identify and describe the primary drivers of the framing content observed**.

The 'as-built framing content' is expressed as: *the area of framing as a percentage of the wall area* (i.e. height x length). This has been calculated on a 'per level' basis and is based on **net wall area**, where net wall area excludes openings such as doors and glazing.

The research methodology and the approach employed during the fieldwork were developed with an understanding that little or no significant empirical research has ever been undertaken on the framing content of external walls of built residential houses in New Zealand. This presented a challenge to the research team in as much that accurate knowledge of as-built framing content in external walls in contemporary New Zealand houses is not available. This research was therefore 'deductive' and sought baseline empirical data to determine framing percentages in external walls and to identify and appraise the factors contributing to the framing percentages observed. Furthermore, the project team were also aware of previous research from a Victoria University study (Bakshi et al., 2018), which had established that recruiting suitable dwellings for a case study sample could be very challenging. These challenges led to the research team employing **an adaptive case study approach** in which recruitment criteria was not restrictive.

This methodology was adopted early in the research planning stage reinforced by an initial scoping meeting with stakeholders from MBIE, BRANZ, and EECA. It was chosen over a representative sample approach which was considered too difficult to implement effectively because of perceived problems in recruiting enough houses with specific characteristics or variables. A representative sample approach would be appropriate in a more advanced study that assessed the framing content of houses with specific variables and/or evaluated the presence, absence, roles and relationships between specific variables within and between samples. Furthermore, as this is an empirically unresearched area in New Zealand, there is little existing advice regarding which variables would be most meaningful for a representative sample approach.

The adaptive case study framework was therefore a pragmatic and flexible approach to the recruitment of houses that prioritised 'availability' and 'inclusivity of data' within the constraints of the project, rather than the requirement for any specific variable(s). This approach also guided the research team's interactions with industry players, which increased throughout the study as researchers sought to build a sound understanding of the dynamics and drivers of framing content in contemporary houses in New Zealand. For example, discussions with a number of key stakeholders and other framing experts (i.e. BRANZ, MBIE, EECA, KiwiBuild representatives, and a limited number of stakeholders from industry) following presentation of preliminary framing percentages, resulted in a widening of the **research scope** to look in more depth at the factors driving framing content and implications for the NZ Building Code.

Whilst 'availability' and 'inclusivity' were the primary drivers for the recruitment of houses and industry participants in the survey, it was considered ideal for the sample of houses surveyed to cover a reasonable spread of:

- typology (single/double storey, standalone, duplex, terrace, MDH)
- location/climate (region, temperatures and high wind influence)
- framing type - 90mm / 140mm (if available)
- builder market segment and any other key variables.

The case study survey was conducted over a period of nine months (March 2019 – November 2019) and collected primary data from new builds under construction. The research case study framework included samples from locations in the major house building areas of:

- Auckland – 28 houses consisting of 49 levels and 683 panels
- Hamilton – 4 houses consisting of 6 levels and 86 panels
- Wellington - 4 houses consisting of 4 levels and 86 panels
- Christchurch - 11 houses consisting of 12 levels and 248 panels

In total, 47 separate dwellings were assessed consisting of 71 separate levels and made up of a total of 1,103 separate framing panels.

3.1 Describing walls and framing elements

The **external walls** of residential dwellings are typically defined by the direction they face (e.g. a south facing wall or a north-east facing wall). External walls greater than a few meters in length usually consist of a number of individual **prefabricated frame and truss wall panels**, as indicated on the framing plan below (Figure 1) by the labels E9H, E10H etc. The longest single wall panels can be up to 6m in length (typically restricted by transportation and safe handling requirements). As an example, on the simple illustration below of a **single dwelling level,** there are 6 external walls and these are made up of a total of 12 separate wall panels.

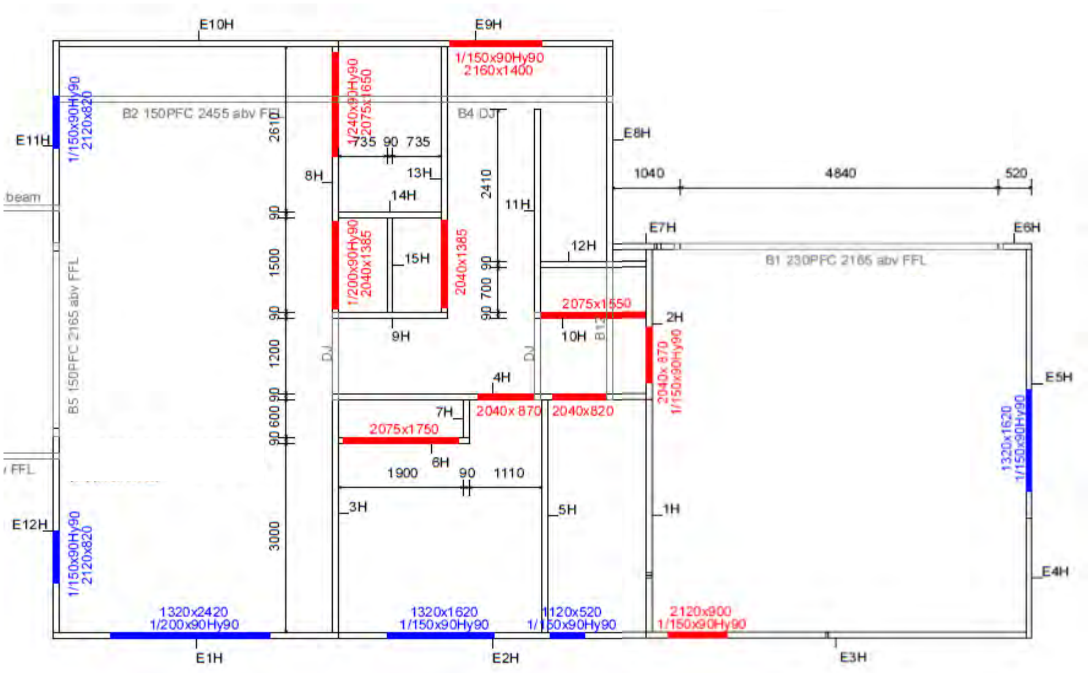

Figure 1: Illustration of a typical framing layout diagram showing labelled wall panels

In undertaking this research, the team adopted definitions used by F&T companies to describe the different **framing elements** whose dimensions (e.g. length and face-width) are recorded during the site assessments. The following diagram, based on an example of a typical F&T panel elevation, identifies common elements of wall framing noted during the site assessments:

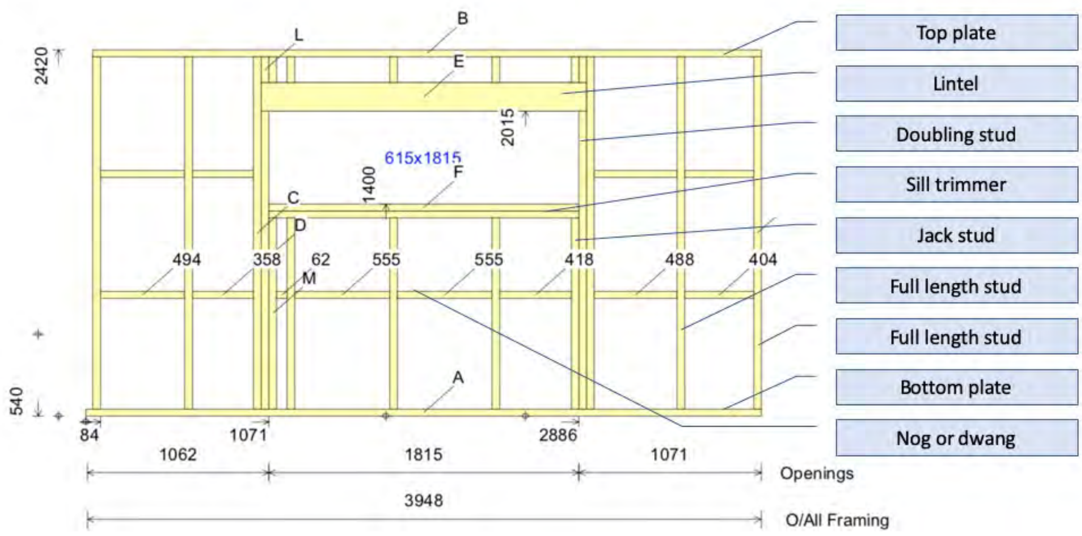

Figure 2: Common elements of wall framing

The framing elements noted for measurement on site include any/all of the following:

- Full length studs
- Trim studs
- Doubling studs (or understud)
- Jack studs (and 'top jacks' or 'overs')
- Top plate
- Bottom plate
- Lintels
- Sill or still trimmer
- Nogs or dwangs
- Blocking or packers (added at F&T)
- Blocking (added on site and not shown above)
- Blocking on edge (added on site and not shown above)
- Other

3.2 Calculating the percentage of framing in walls

The framing percentage of walls can be calculated at the unit of a panel, a wall, a level, or a house. Once individual panel data is collected, it can be used to calculate percentages for each panel then aggregated to determine the percentages for walls, levels or the whole house. Panel data consists of the dimensions (height and length) of the overall panel, openings such as doors and windows and all the framing elements (i.e. see Figure 1 above), including any framing added or altered on site (also noted and measured by the research team).

Framing percentages can be calculated based on 'Gross' wall panel area or 'Net' wall panel area, as defined below (see Figure 3 and Figure 4). In the net area approach, door openings and glazed areas are not included in a calculation of the framing percentages, whereas the gross wall panel area approach does include all openings (i.e. the overall wall area).

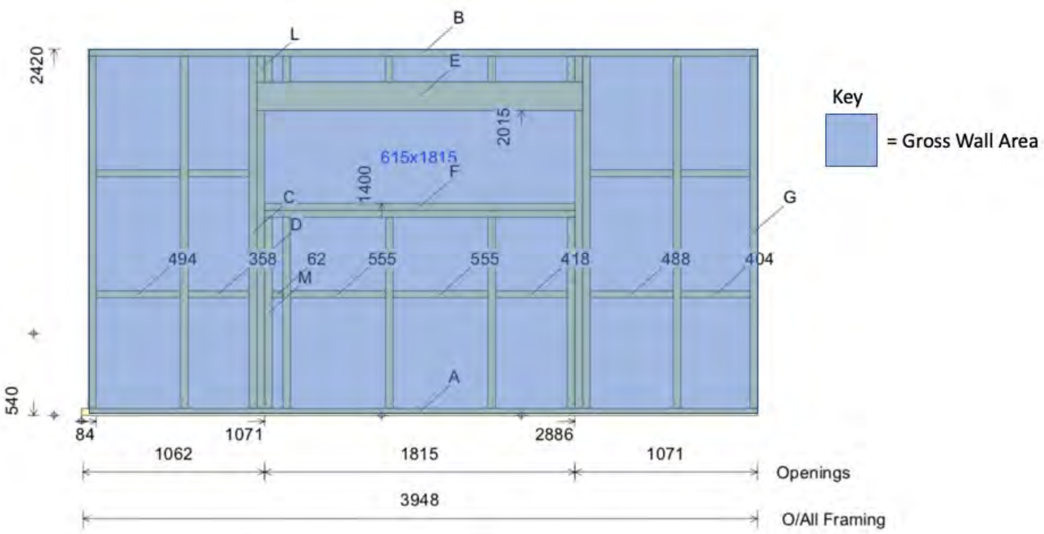

Figure 3: Calculating the Percentage of Framing based on Gross Wall Panel Area (GWPA)

Notes to the diagram: The diagram above indicates the area of framing in a wall panel as a percentage (%) of the total area wall panel including all openings. In the case above the GWPA is 3.948 x 2.420 = 9.554m²

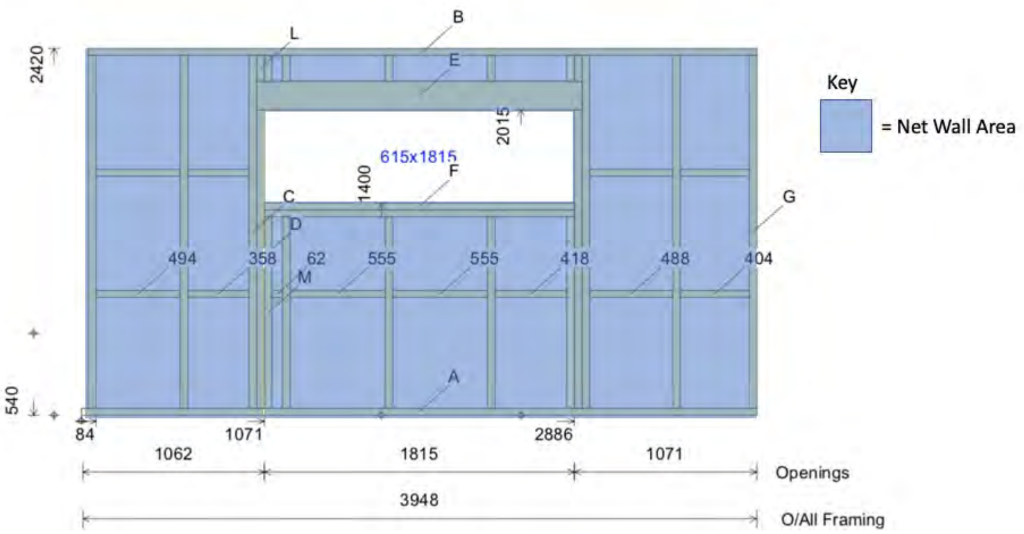

Figure 4: Calculating the Percentage of Framing based on Net Wall Panel Area (NWPA)

Notes to the diagram: The diagram above shows the area of framing in a wall as a percentage (%) of the total area of wall panel area excluding all openings. In the case above the NWPA is (3.948 x 2.420) - (0.615 x 1.815) = 9.554m² – 1.12 m² = 8.434 m²

From the outset of the research, the percentage of framing was calculated for both gross and net wall area. However, figures presented here are only reported based on **net wall area**. The percentage of framing of the '**net wall area' is of most relevance** as this is the same approach used by the New Zealand Building Code clause H1, which considers doors, glazed areas and other openings separately to the framed and insulated sections of the wall. However, it is important to note that some framing elements are excluded from the percentage of framing estimates used for H1 compliance (this is discussed later in this report in the section dealing with definitions under NZS 4218).

In addition to the percentage of timber framing making up the net wall panel area, the researchers have also calculated and reported the **added percentage of framing** and the **percentage of the wall that cannot easily be insulated and is typically left un-insulated**, as described below:

- **Added Percentage of Framing -** The percentage of **full depth framing** (e.g. blocking, nogs, studs, packers, trimmers) that has been added on site by the builder and/or other trades and is not shown on the Frame & Truss drawings. Added framing that is not full depth is included in the percentage of un-insulatable area.
- **Un-insulatable Area Percentage -** The percentage of the net wall panel area that is left uninsulated, either because: A) it cannot be insulated from inside the room as the building wrap (and often cladding) is installed prior to insulation installation; or B) it is difficult (or considered too time consuming) to insulate effectively due to access, size and/or shape of the uninsulated gap. Almost all walls in the assessed dwellings had some un-insulated

spaces including areas such as external corners, interwall junctions, mid-depth blocking for services and narrow gaps between studs that are not insulated. Un-insulatable areas appear to be a commonly found and important weakness of the thermal envelope that is not currently considered in H1 calculations.

Other key variables potentially useful for additional and more in depth analysis of the sample houses, were also gathered during the site assessment or taken off the F&T drawings, including:

- **Wall orientation (per wall)**: which is useful when exploring and/or modelling wall performance. A pragmatic approach was taken to labelling the orientation following standard compass notation (e.g. N, NE, E, SE, S, SW, W, NW)
- **Room type (per wall)**: which is useful in more detailed analysis to highlight instances where additional timber is added by trades (e.g. plumbers and electricians) as well as being potentially useful in further analysis of the likelihood for condensation risk (e.g. bathrooms, laundry, toilet etc).
- **Cladding type for each wall panel**: This is important as framing requirements change depending on cladding type, wind zone and cavity batten requirements.

In addition to the lengths, widths and types of timber included as part of the F&T framing elevations, these drawings also contain other useful information. This differs depending on the version of the software that the F&T company is using (usually one of the two dominant software licensees - MiTek or Pryda). One potentially useful variable is provided by the total volumetric amount (m^3) of timber used in each of the F&T framing elevations provided for each job (it also includes process wastage nominated by the individual F&T plant). This data may be a useful indication of the amount of timber included within each frame. It may be of benefit in the future to ascertain a linear measurement of timber used in each framing panel, with the possibility to deduct reasonably accurate percentages of framing from this higher-level data.

3.3 Methods

The **recruitment phase** of the project initially involved the research team identifying houses through their existing industry contacts. Given that the ideal time for assessment of framing on site is at the pre-line inspection point (i.e. when roof and wall cladding is complete, all additional framing has been installed and the walls are ready for insulation and lining), several houses were initially recruited via an insulation company to test both the recruitment process and the data collection process.

The insulation company provided a selection of houses to choose from and the research team were able to make pragmatic choices of which to assess with a broad case study framework in mind, and were able to line up inspections at suitable times. In some instances, properties were recruited from a different insulation company and/or through other industry contacts such as builders or developers. The research team sought permission from the builder or housing company to visit the site and to obtain the panel elevations and wall layouts from their respective Frame &Truss supplier.

Once on site, the researcher(s) was met by the site supervisor and went through the site health and safety induction before conducting the framing survey which took 2-4 hrs per level depending on complexity.

3.3.1 The percentage of framing - data collection and analysis methods

The research team initially developed a **framing survey template** and **procedures for onsite data collection,** and these were tested on the houses that were initially recruited in the pilot phase. This included a procedure to manually record the dimensions of all as-built external walls, openings, individual pieces of framing, un-insulatable[4] areas and any on-site changes or additions to the framing by contractors, builders and/or sub-trades (i.e. compared to the framing drawings supplied by the Frame and Truss company). The research team documented the site visits through photographs and measurements and gathered key data relating to the construction including wall orientation, cladding types, room types; frame sizes, frame layouts, house typology, number of storeys etc. Off site, this data was entered into a **custom-built database for analysis.**

The data collection process was revised following two findings from the initial data collection process: 1) collecting framing data accurately on site was very time consuming due to the amount and complexity of framing and; 2) Frame and Truss (F&T) manufacturers supply in excess of 90% of the framing to new residential builds in New Zealand[5] and could provide hardcopy elevations and plans that included dimensions of each wall panel and every piece of framing. Accordingly, the research approach was modified from the collection of on-site framing measurements and data to a process of **recording exceptions** from the hard copy framing panel elevations, plan layouts, and frame schedules (list of framing with dimensions) supplied by the F& T companies. This made on-site collection of wall and framing data, and the calculations of the percentages of framing quicker and more efficient, resulting in a more robust data set. It also meant greater collaboration and engagement with the F&T industry which also proved important for building an understanding of the drivers of framing content.

As the research progressed, the team continued to recruit most of the sample houses via insulation company contacts as they were able to refer the team to houses across a wide range of sizes, typologies, builders, F&T companies and locations.

Over the course of the 9 months of field work, the research team conducted on site **data collection surveys of 47 houses.** This process included:

- Planning visits (including development of information sheets, ethical procedures, data collection processes)
- Liaison with builders – ensuring verbal agreement is granted to gather data and cc'ing the builder in the email request to F&T.
-

[4] ***Un-insulatable means as area of an external wall that is assumed to be insulated but is not because it cannot be accessed by the insulation installers (i.e. internal wall junctions, external corners)***

[5] ***This figure was provided as an estimate from a number of different F&T manufacturers and representatives from the Frame and Truss Manufacturers Association or FTMA who quoted figures as high as 96% of supply to the residential sector***

- Liaison with the appropriate frame and truss plants to get panel elevation drawings and plan layouts.
- Conducting site visits and gathering data. This involved comparing F&T layouts and plans with as-built framing set out and noting any differences, photographing walls, taking measurements and in some instances enquiring with the builders or sub-trades on site to ascertain reasons for any additional framing noted (not always possible due to availability of contractors and sub-trades)

Following the site surveys, **data for each wall panel was cleaned and entered into the framing database** for data analysis. The database consisted of an Excel spreadsheet template or worksheet into which the dimensions of each wall panel, framing and openings from the F&T elevations and layouts for each level was entered The dimensions of framing added on site (full depth and mid-depth) or changes from the F&T drawings were also entered into the worksheet along with the dimensions of areas of the wall that could not be insulated (i.e. un-insulatable areas). Each level has its own workbook which contains dozens of separate worksheets, with one worksheet for each wall panel and a summary worksheet where information from all panels is summarised.

An example of a single wall panel worksheet developed by the research team is set out below:

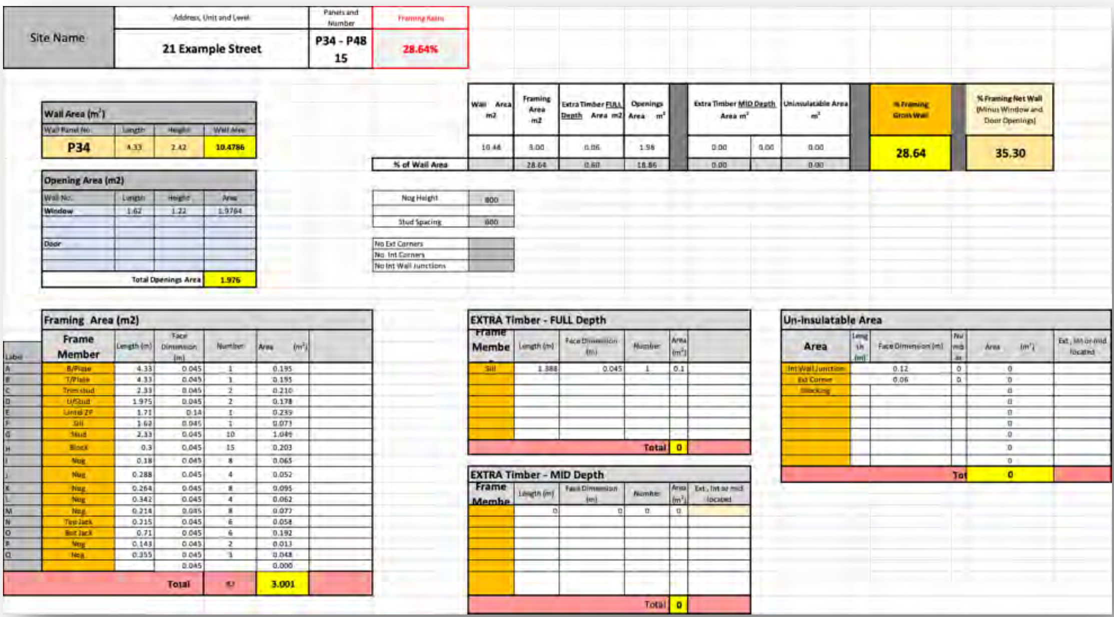

Figure 5: Illustration of single wall panel worksheet

Formulae embedded in the worksheets calculated the gross and net wall area (m^2), added framing area (m^2), and un-insulatable area (m^2) <u>for each panel</u>. Individual wall panel data in the separate worksheets is summed (in a summary worksheet) <u>for each level</u> to enable the overall net wall percentage of framing, percentage of framing added-on site and percentage of un-insulatable area to be calculated for that level. These are presented in the main results provided Table 1 on page

16 for each of the 71 levels surveyed, along with the average, standard deviation, maximum and minimum for the case study data set of 71 levels.

Based on these results, and with a range of framing data and house/site attributes held in the database, further analysis could be undertaken to compare case studies with one another to provide insights into individual variables that appear to be affecting higher than expected percentages of framing. However, this is out of scope for this stage of the research study and may be explored in future work.

3.3.2. Drivers of framing content

One of the objectives of the study was to understand what was driving the framing content in external walls. Early interactions with industry contacts suggested that a **series of interviews** with major suppliers to industry, cladding manufacturers and representatives from F&T companies would be the best method to achieve this.

Over the course of the study, the research team held a number of in-depth discussions with a range of industry players (listed below) about their views on framing design process, relevant rules and regulations, framing trends, perceptions of framing added on site. As the research team gathered more data, the framing configurations and percentages of framing that had been observed, was also discussed. Industry participants were drawn from a variety of sectors involved in the delivery of framing in residential construction and included:

- **Frame and Truss manufacturers:** Akarana Timber, Auckland Frame and Truss, Central Frame and Truss, Wiri Timber
- **F &T software designers:** MiTek and Pryda
- **Timber and cladding suppliers:** Hermpac, James Hardie
- **Merchants:** Bunnings, Carters, ITM, Mitre 10, PlaceMakers
- **Industry organisations:** Frame and Truss Manufacturers Association.

Interviews also assisted the project team in gaining the cooperation of the frame and truss sector which has proved crucial to gaining a better understanding of industry's approach to the delivery of framing as well as obtaining panel elevation and layouts.

Collaboration and engagement with the F&T manufacturers and their experienced detailing staff enabled more in-depth analysis of the different demands of the New Zealand Building Code clauses B1 Structural, E2 weathertightness framing requirements, and the insulation components of H1 and E3 code clauses.

4 Results

The following results are based on a survey of 1,103 panels across 71 levels and 47 dwellings that were assessed and analysed via site visits and follow up.

4.1.1 Wall panel statistics

- The average number of framed panels from the Frame and Truss plant that make up each level of the dwelling is 15.5 with a range from 6 to 41.
- Ground levels almost always have more wall panels than second and third levels.

4.1.2 Percentages of framing

- The 71 case study **levels** from the 47 dwellings have an **average percentage of framing in walls** of just over **34%** - based on the **net wall area** method. This varies from levels with the lowest percentage of framing recorded at **24 %** to the highest of **57%** (by level). In some instances, smaller individual wall panels can have percentages of framing up as high as 70-100% while a small number of individual wall panels were below 20%. However, the majority of individual wall panels have percentages of framing between 20-50%.

4.1.3 Additional timber (full depth)

- This research indicates there is **little additional framing added on site**. Around a quarter of all panels (291/1103) have added full depth framing, with the average for panels with added framing being **just under 2% of the net wall area, and varying between 0.04% and 8%** across the case study sample. The average additional site-added, full-depth framing timber by level was just **0.7% (range 0.1 – 4%)**.

- Where framing has been added on site, it is mostly in the following areas:
  - Kitchens – to take linings, for pipework, electrical and plumbing.
  - Bathrooms – linings, fittings, baths etc.
  - Apron flashing – and other roof flashing etc.
  - Stairs – to take stair rails and to provide fixing points for linings
  - Bedrooms – for example in built in wardrobes to take shelving

- Un-Insulated Areas, which includes added framing which does not fully fill the wall cavity depth. The average percentage (by level) of un-insulated areas, including **additional blocking** (typically for fixing linings, cladding, fixtures and services), was **3%, with the lowest being 0.5% and the highest 10%.**

4.1.4 Results table

The following table provides a summary of results for the 71 separate levels analysed from the 47 case study dwellings examined.

Table 1: Summary of results for the 47 case study dwellings showing individual levels

Id #	Level		No. of panels	No. of panels with framing added on-site	Percentage of framing* (net area method)	Added percentage of framing** only panels with framing added on-site	Percentage of un-insulated area ***
1	First	1a	13	2	35.53	1.40	0.78
	Second	1b	11	7	35.78	1.57	4.61
2	First	2a	19	5	36.43	0.52	1.91
	Second	2b	15	7	36.68	1.27	5.50
3	First	3a	10	0	32.23	_	1.86
	Second	3b	10	0	34.88	_	7.60
4	First	4a	9	1	33.66	2.19	3.14
	Second	4b	9	6	32.00	1.34	3.41
5	First	5a	9	1	34.45	2.15	3.05
	Second	5b	9	3	31.27	0.34	3.11
6	First	6	15	2	31.77	0.55	2.90
7	First	7	15	2	31.43	0.37	3.15
8	First	8	21	5	29.60	1.07	3.08
9	First	9	20	5	27.61	0.82	1.75
10	First	10	19	3	29.89	0.55	3.17
11	First	11a	15	0	41.61	_	2.14
	Second	11b	7	0	39.24	_	3.41
12	First	12a	16	1	36.83	0.21	2.16
	Second	12b	10	6	40.46	1.51	4.35
13	First	13a	9	2	42.45	1.79	8.25
	Second	13b	13	6	30.98	1.89	0.51
	Third	13c	11	2	30.18	3.23	1.51
14	First	14a	10	3	30.92	1.19	3.87
	Second	14b	8	2	28.96	2.56	2.18
15	First	15a	10	4	31.47	1.59	3.97
	Second	15b	8	2	29.15	2.10	2.25
16	First	16	18	2	31.79	0.04	1.26

Id #	Level		No. of panels	No. of panels with framing added on-site	Percentage of framing* (net area method)	Added percentage of framing** only panels with framing added on-site	Percentage of un-insulated area ***
17	First	17	10	2	28.16	0.31	3.59
18	First	18a	14	3	27.51	1.25	2.35
	Second	18b	10	0	29.76	_	6.85
19	First	19a	19	0	34.83	_	3.47
	Second	19b	12	1	32.27	0.42	4.39
20	First	20a	23	5	33.70	1.50	6.22
	Second	20b	20	8	37.18	1.96	1.54
21	First	21a	19	3	57.34	5.50	0.82
	Second	21b	14	3	42.81	1.01	2.76
	Third	21c	10	4	49.12	2.48	4.44
22	First	22a	6	2	24.26	0.67	2.68
	Second	22b	17	11	41.32	3.40	2.32
23	First	23	13	0	26.02	_	1.60
24	First	24	13	2	24.03	1.10	2.33
25	First	25a	8	5	47.68	3.79	3.17
	Second	25b	14	8	44.40	3.70	2.03
26	First	26a	33	19	41.19	2.52	2.27
	Second	26b	29	10	47.11	2.38	3.73
27	First	27a	16	3	36.52	0.74	2.37
	Second	27b	13	4	29.63	3.57	1.85
28	First	28a	17	3	37.20	0.68	2.56
	Second	28b	14	3	31.15	3.79	1.94
29	First	29	9	0	32.93	_	0.95
30	First	30	33	5	32.27	2.96	2.42
31	First	31a	12	7	29.80	5.41	1.94
	Second	31b	10	5	31.81	3.48	4.19
32	First	32a	12	6	30.42	7.98	2.57
	Second	32b	10	2	31.57	2.07	5.21

Id #	Level		No. of panels	No. of panels with framing added on-site	Percentage of framing* (net area method)	Added percentage of framing** only panels with framing added on-site	Percentage of un-insulated area ***
33	First	33	17	7	32.39	1.46	3.86
34	First	43	15	2	26.44	0.11	2.86
35	First	35	15	0	26.43	_	2.84
36	First	36	16	0	26.17	_	2.01
37	First	37	24	1	27.38	1.08	1.88
38	First	38a	30	2	29.30	2.22	8.92
	Second	38b	31	14	39.70	1.33	10.12
39	First	39	41	18	37.13	4.62	4.28
40	First	40	15	13	32.00	1.54	3.48
41	First	41	15	2	29.69	1.34	2.14
42	First	42	15	1	29.05	5.01	2.12
43	First	42	14	1	32.53	0.89	1.29
44	First	44	18	1	35.65	0.12	1.91
45	First	45	19	3	32.76	0.74	2.96
46	First	46	28	11	37.31	4.42	2.06
47	First	47	21	12	40.95	1.70	1.15

Notes to the table:

* Includes full-depth framing added on site

** Only full-depth framing added on site

*** Includes mid-depth framing added on site

In addition to the results in Table 1 above, the following tables also highlight summary information:

Table 2: Survey details (summary)

Survey Details	
Number of Properties Surveyed	**47**
Number of Levels	**71**
Number of Panels	**1103**
Number of Panels with framing added on site	**291**

Table 3: Number of panels per level (summary)

Number of panels per level	
Average	**15.5**
Standard Deviation	**6.9**
Maximum	**41**
Minimum	**6**

Table 4: Percentage of framing by level (summary)

Percentage of Framing (by level)	
Average %	**34**
Standard Deviation %	**6.2**
Maximum %	**57.3**
Minimum %	**24**

Table 5: Percentage of added framing by level (summary)

Percentage of Added Framing (panels with framing added)	
Average %	**2**
Standard Deviation %	**1.6**
Maximum %	**8**
Minimum %	**0.04**

Table 6: Percentage of uninsulated area by level (summary)

Percentage of Uninsulated Area (by level)	
Average %	**3.1**
Standard Deviation %	**1.8**
Maximum %	**10.1**
Minimum %	**0.5**

5 Illustrated issues

During the course of the research, and especially during case study site visits, the research team became aware of a number of significant issues that are worthy of illustration. Some of these were distinctly related to framing and the overall thermal performance of the resulting wall – these are covered in Section 5.1 below. Other issues were worthy of note but were deemed out of scope in a study primarily focussed on framing percentages. These are covered in Section 5.1.8 below. In both areas, the issues are illustrated with pictures from the case study site visits. These images have been modified where necessary to remove identifying characteristics and to retain case study confidentiality. The images help to explain the issues that were encountered and point to the value of being on site and seeing what is actually occurring during the process of construction.

5.1 Framing/wall related issues

Several key issues that are directly related to the overall framing layout and final performance of the wall (from a thermal perspective) were encountered during site visits. In a few instances, this may have been the result of an error in design or an oversight during construction from the personnel involved (builders, trades, contractors and service providers etc). However, many of the issues that were encountered appeared regularly and some are of significant concern in relation to final thermal performance and construction R-values. These included the following:

- Absence of insulation in external corners
- Absence of insulation where internal walls meet external walls (external wall junctions)
- Poorly installed or problematic installation of insulation. It should be noted that standards for insulation install varied greatly, with some appearing to be very good and others with clear issues that should be picked up during pre-line inspection and compliance checks. It should be noted that the quality of insulation installation *was not* part of the project scope and is not specifically addressed in this report. A number of the buildings examined were not at the point of insulation installation or were only part-way through the process at the time of survey. Therefore, no specific commentary regarding the general state of insulation installation is provided in the illustrations that follow (except where it relates to framing).
- Missing insulation – especially around confined stud/nog work and blocking/packing where gaps are too small to insert correctly oriented insulation.
- Added half-depth framing e.g. nogging for flashings, pipework and electrical fittings, is often left uninsulated. This negatively impacts the thermal performance of the wall (e.g. when occurring as a result of an apron roof being flashed around an upper floor wall junction - as seen in several of the photographs below).
- The midfloor sections of almost all multi-storey dwellings assessed appeared to be completely uninsulated, leaving a large band (200 - 300mm+) of uninsulated timber around the perimeter of every midfloor junction (between ground and all upper floors).
- The use of plastic packers under the bottom plate which, in some instances, were left poorly insulated, therefore potentially allowing a pathway for draughts and heat loss at the wall-floor junction.

These, and other issues, are illustrated in the following site photographs:

5.1.1 Uninsulated external corners

	
Light coming through from an un-clad external corner – this results in a significant uninsulated cold spot in the thermal envelope (on every corner of most dwellings surveyed)	An external corner junction (uninsulated) showing the light coming through the external wrap
	
Uninsulated corner – note that in the lower section of this gap insulation offcuts have been inserted into this difficult to access space.	Uninsulated corner showing mixture of 140mm and 90mm framing

5.1.2 Uninsulated internal to external wall junctions

Two internal wall junctions required to support this cupboard (and the wall between the two bedrooms). Both full height and wide gaps in the thermal envelope that will remain uninsulated

Light can be seen shining through the building paper at the left hand side of the image where the internal wall meets the external wall

A small internal wall for a cupboard opening intersects with the external wall – timing of the insulation install means that this void is now impossible to insulate

The internal to external wall junction showing the absence of insulation and also the poor seal which may lead to heat loss and moisture ingress through condensation

	An example of an internal wall to external wall junction prior to building paper going on – note the large voids which, in all likelihood, will remain uninsulated

5.1.3 Problematic gaps in framing affecting installation of insulation

	
An example of timber fillet packing in the framing which leaves an uninsulated gap in the thermal envelope	An example of packing in the framing which mitigates against getting insulation into these small and inaccessible spaces. Spray in expanding foam may be the only solution in these areas
	
Added framing on site to take fixings – note the gaps at the tops and bottoms of these pieces of added timber which cannot be insulated	This gap between these two studs will be hard to fill with insulation and will be a significant source of heat loss in this section of the wall

5.1.4 Added half depth framing / blocking and missing insulation

140mm blocking on edge to support flashing for the apron roof – noting that the 45mm face remains uninsulated as well as the awkward gap left behind in the space above it

90mm blocking on edge to take plumbing pipe fixtures – the 45mm space behind this edge fitted timber remains uninsulated

The effect of added blocking to support shelving in a cupboard space – note also the uninsulated internal to external wall junctions

Photograph taken looking up the stairs and showing a large expanse of added blocking to take a handrail

	
140mm blocking on edge to support flashing for the apron roofing – note that the remaining 45mm X 140 mm gap on the face remains uninsulated	A large area of blocking added across several wall panels to take an apron roof flashing
	Image showing added framing for fixing handrail (on diagonal) as well as framing at 300mm centres despite 140mm timber sizing

5.1.5 Uninsulated midfloor sections

	
A midfloor section (photographed from within the stairwell) indicating the large uninsulated 'ribbon' right around the house between the two floors	A built up section of midfloor indicating the extent of the uninsulated solid timber thermal bridge (approximately 410mm) created between the two levels
	
A midfloor 'ribbon' photographed half way up the stairs	A midfloor junction in the open void of a large stairwell

5.1.6 High concentrations of framing and areas of solid timber

	
An example of a five-stud corner next to multiple trim studs to account for the window opening	High concentration of corner framing leaves this external corner almost completely uninsulated
	
A high percentage of framing with close nogging, blocking and multiple studs next to a large window	Two internal wall junctions in a small toilet wall next to an opening. This results in a high percentage of framing in this wall – in an area that may be prone to condensation

5.1.7 *Other framing related issues of note*

	
An uninsulated wall behind a bath – in this case the timing of the trades works against this being insulated properly	Large steel portal (uninsulated) around door and adjacent to a wall with a high percentage of framing
	
High concentration of framing and a combination of difficult shapes making insulation difficult	The plastic packer under the bottom plate – in this instance with gaps and less than adequate expanding foam under the full width of the bottom plate

5.1.8 Other non-framing related issues of note

During the site assessments, the research team also noted several issues that were unrelated to framing but worth capturing from the point of view of the overall performance of the final dwelling. These include the following:

- Absence of perimeter insulation around concrete slabs; though not a requirement under current standards, this will be a source of heat loss from the thermal envelope.
- Compromised structural integrity of some framing due to additional work on site.
- ‘Siloed’ building trades (such as cladding teams or insulation installers) being separated from an integrated understanding of other elements of the build process. This has implications for aspects such as the installation of insulation at the right time or the correct installation of cladding when framing set outs may have changed.

	
Large raised and uninsulated concrete slab perimeter.	Typical concrete slab – uninsulated around the perimeter.
	
Wiring and pipework in external walls made insulation installation challenging	An example of cutting away supporting stud work to affix a hold down bolt

6 Framing and construction R-values

As part of the background research for understanding the effect of timber framing in walls, the research team explored current processes for compliance with H1 and E3 under the current regulatory system. It is worth noting that the instructions for calculating construction R-values under NZS 4218 are somewhat ambiguous and do not sufficiently account for the full effects of thermal bridging within the building envelope. Crucially, when applied to modern frame and truss wall panels, the definitions of what needs to be counted exclude a significant number of the framing elements that contribute to thermal bridging and heat loss. This is seen in two main sections of NZS 4218 that deal with construction R-values in Section 3.2 and linked to Section 2 dealing with the definitions; as per the following:

Construction R-value

The construction R-values of building elements shall be calculated using the typical area described in the definitions.

The construction R-value for walls, roofs, floors, and doors may instead be calculated including the effect of openings and corners, lintels, sills, additional studs, and so on.

Figure 6: Text relating to the definition of Construction R-value - S3.2 of NZS 4218 (2009)

Construction R-value	The R-value of a typical area of a building element (for further information see 3.2)
For walls and roofs	The R-value of a typical area of the building element excluding the effects of openings and corners
For framed walls	This includes studs, dwangs, top plates, and bottom plates, but excludes lintels, additional studs that support lintels, and additional studs at corners and junctions

Figure 7: Text relating to the definition of walls (excluding key framing elements) - S2: Definitions of NZS 4218 (2009)

The text referring to ‘framed walls’ above specifically **excludes** lintels, supporting studs, and studs at corners and junctions. With these elements removed from the equation, the resulting calculation provides **a version** of a construction R-value that is likely to appear significantly higher than the **actual** construction R-value of the ‘as built’ wall (which have those framing elements and resulting thermal bridging present).

Toward the conclusion of the research, BRANZ suggested undertaking some modelling using a recently developed R-value calculation tool and utilising results from a number of examples of the collected case study data to ascertain how overall wall R-values might be affected by higher percentages of framing. This was useful to the research team in determining the difference between the actual framing encountered on site when compared to NZS 4218 definitions.

The drawing below[6] illustrates the difference between the actual framing installed on site from a single case study wall panel when compared to how the wall is set out in the definition provided in NZS 4218 - which effectively allows the user to ignore the thermal bridging of lintels, trimming and double studs etc.

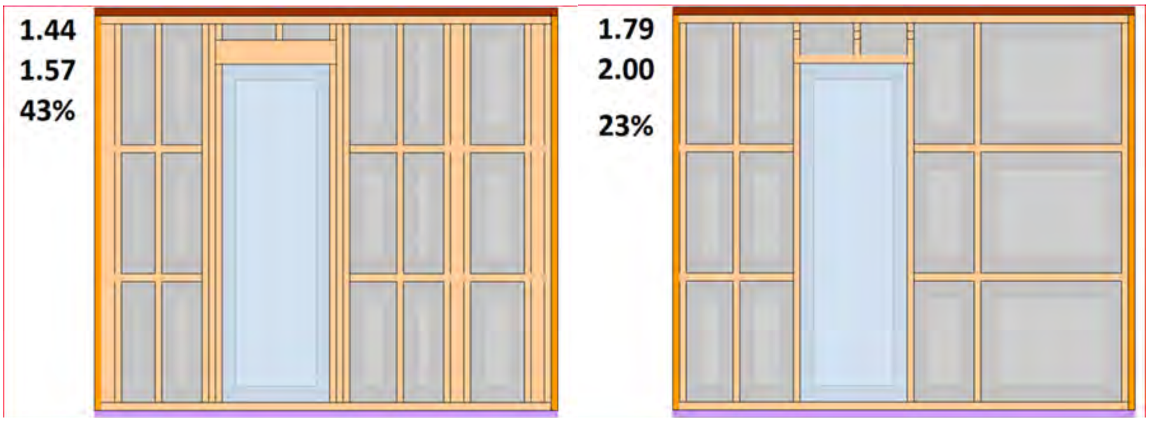

Figure 8: Actual timber framing (left) compared to allowable definitions under NZS 4218 (right)

The figures shown in the top left of each drawing indicate the following; firstly the achieved R-value with R2.0 insulation in the voids, then the achieved R-value with R2.8 insulation installed (the maximum that is currently achievable in a 90mm cavity), and then the third figure describes the percentage of framing that make up that wall panel.

In this single example, the first illustrated panel (left hand side), is a realistic representation of what was installed on site, has a net percentage of framing of 43% (the opening has been removed from the calculation). With R 2.0 insulation in the wall, the wall would only deliver a construction R-value of R1.44 (due to the effects of thermal bridging). With higher R 2.8 insulation in the wall the construction R-value only marginally exceeds the required minimum construction R-value of R 1.5 set out in clause E3 of the NZ Building Code. It is worth noting that, even with the higher R-value of insulation installed (R2.8), the construction R-value is below the minimum required construction R-value of R1.9 for walls in the Auckland climate zone.

The second illustration (right hand side) is of the same wall panel but only shows framing that is required to be counted using the definition outlined in NZS 4218 when calculating wall R-values. In relation to thermal bridging, the simplified approach set out in NZS 4218 states "*This includes studs, dwangs, top plates, and bottom plates, but excludes lintels, additional studs that support lintels, and additional studs at corners and junctions*". Using this definition, the wall can be

[6] ***R-value modelling and images courtesy of Ian Cox-Smith, BRANZ***

redrawn as per the image on the right and this then indicates a percentage of framing of only 23%. Interestingly, even with this definition, the required resulting minimum construction R-value of R1.9 for Auckland is only just achieved with the addition of R2.8 insulation in the voids. With the R2.0 insulation it only achieves a construction R-value of R1.79. It is also important to note that these calculations and models do not account for any losses due to poorly installed insulation or uninsulated spaces, uninsulated corners etc. Were these weak points to be accounted for, this would further reduce the actual construction R-value of the specified walls.

This is only a single example and it is recommended that future research explore this in more detail – ideally, calculating the effective construction R-value in a direct comparison between the actual timber installed on site and the NZS 4218 definition.

In addition to the example outlined above, three sets of measurements from three different case study dwellings were chosen to compare the actual 'as built' framing with an expected construction R-value for the wall panels selected. This element of the research sits outside the original scope of this first phase of the wall project research, but it has informed the development of a useful approach suggested for future work (outlined in the concluding section).

The following diagrams provide a summary of some of the modelled case study data from one of the case study dwellings. Each diagram is segmented into quadrants as follows:

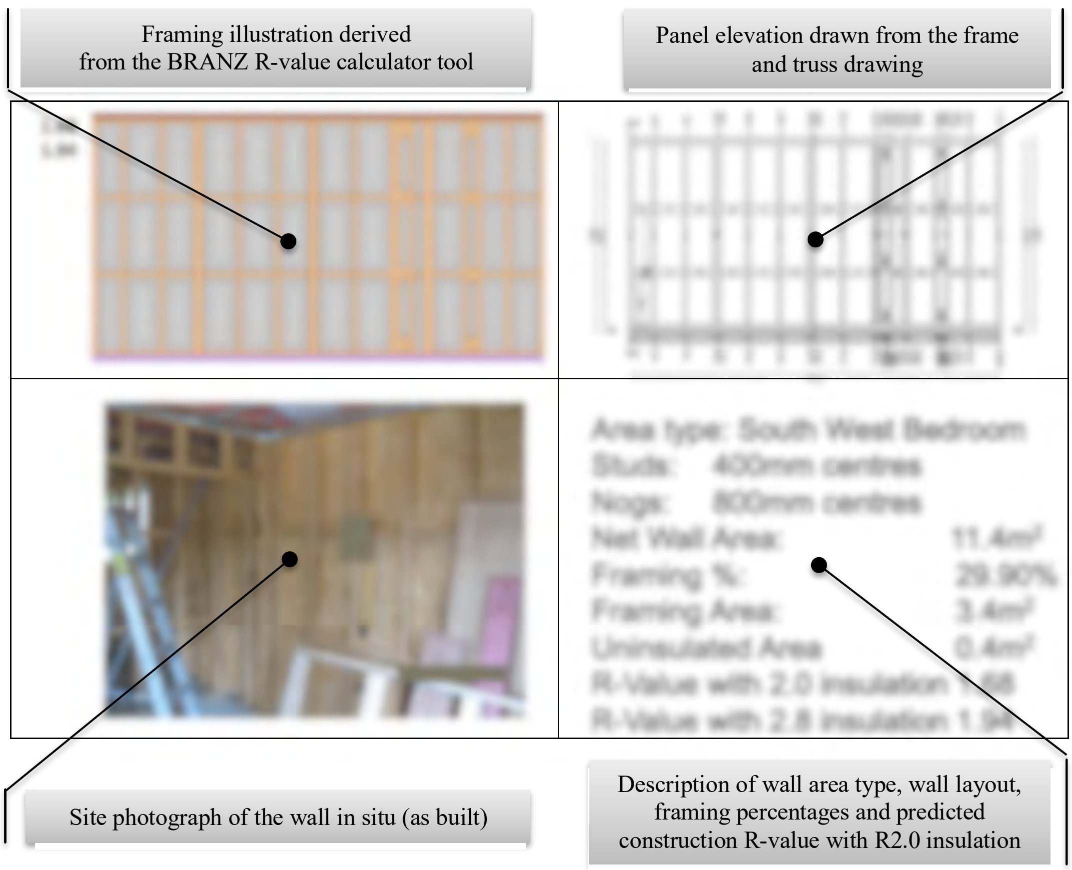

Figure 9: Diagram showing the key quadrants explored in the summary illustrations to follow

The diagrams are not specifically representative of the sample of case study dwellings, but help to inform readers of achieved R-values from a series of typical wall configurations. These are included here as an illustration of the dynamic at play between framing percentages, wall layout and resulting construction R-values.

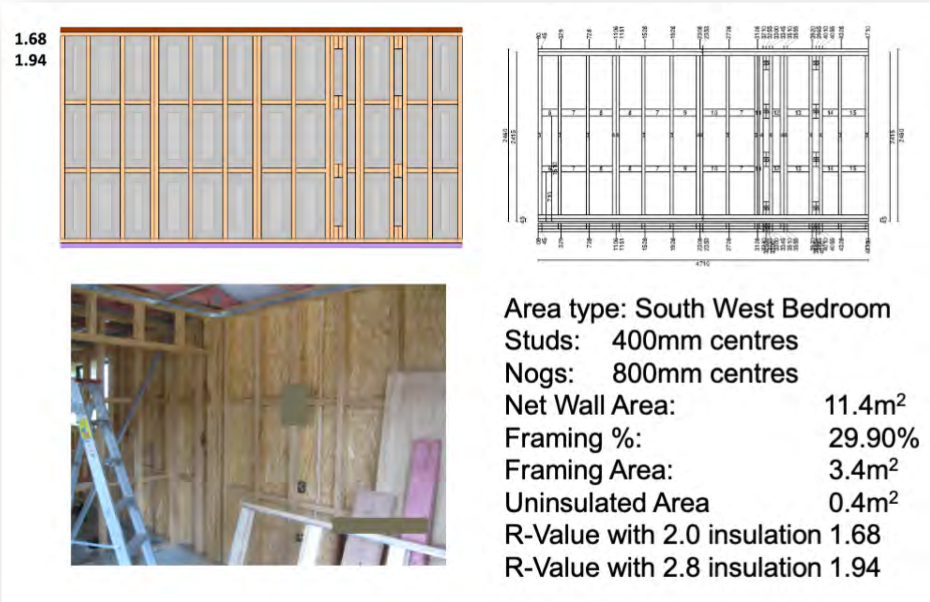

Figure 10: Southwest bedroom wall showing wall area, layout and resulting R-value

Figure 11: Northwest kitchen wall showing wall area, layout and resulting R-value

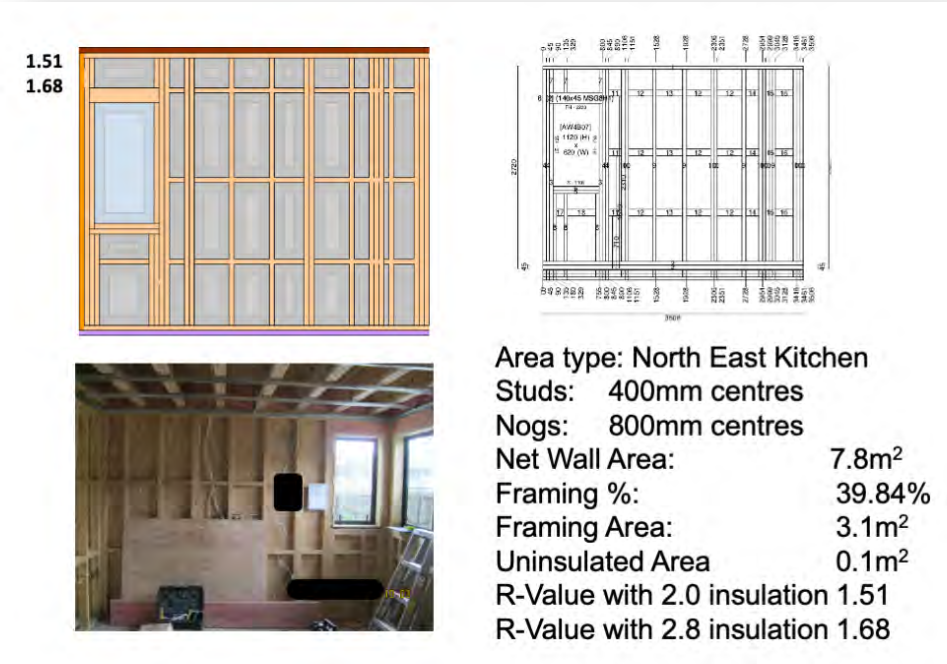

Figure 12: Northeast kitchen wall showing wall area, layout and resulting R-value

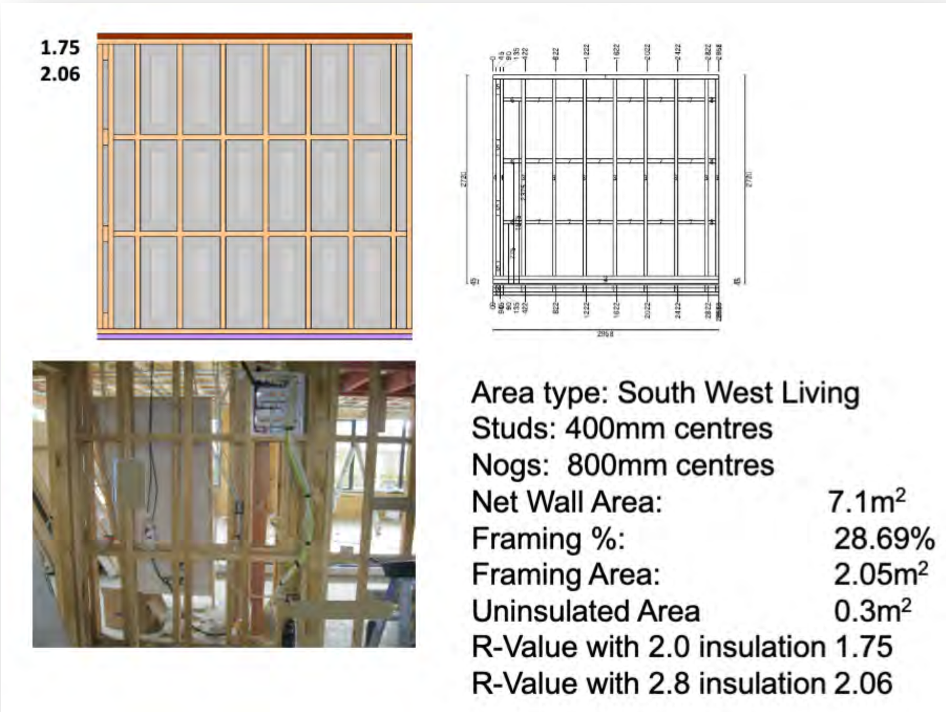

Figure 13: Southwest living room wall showing wall area, layout and resulting R-value

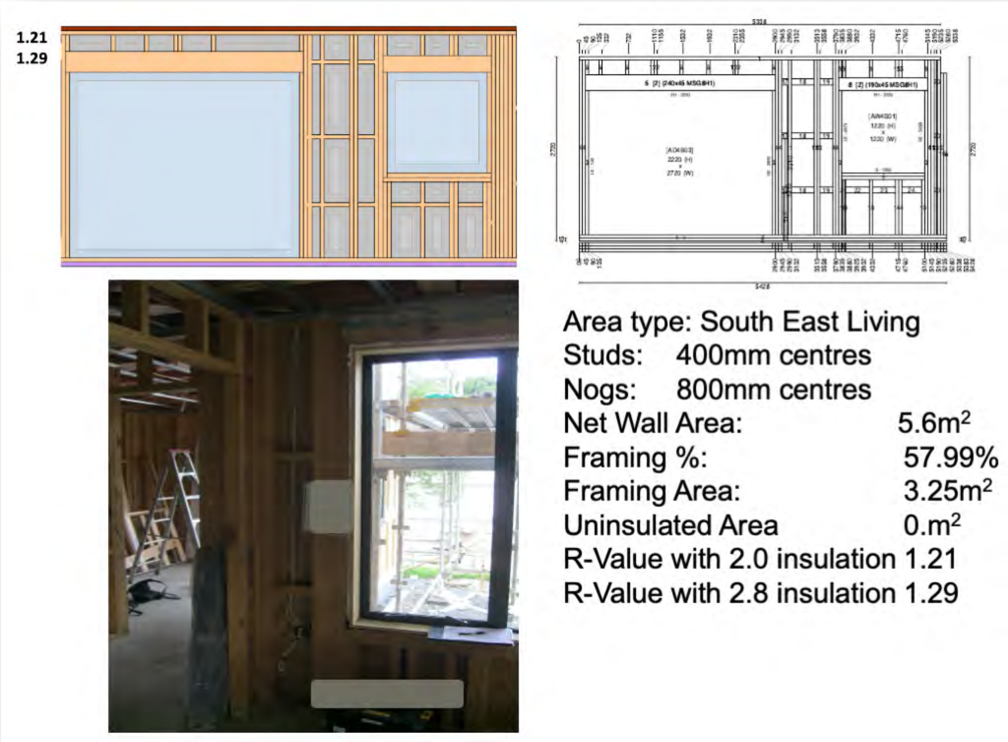

Figure 14: Southeast living room wall showing wall area, layout and resulting R-value

7 Key findings

The following section provides a summary of the key findings arising from the research. These have been informed through a variety of research methods including site visits, data analysis, stakeholder interviews/meetings, desktop research and informed research team discussions. Findings have been categorised into the following key areas:

1) **Research process findings:** learning the team has made in undertaking the research which informs the process that was used and may be useful for similar studies.
2) **Sector / industry findings:** learning about the key issues relating to the residential construction sector, framing and the resulting thermal performance of walls.
3) **Regulatory findings:** insights into how the regulatory environment may be contributing to higher than assumed framing percentages (i.e. in excess of that which is assumed by industry and regulators, and also the impacts that recent changes in regulation have made to the level of framing required (including cavity construction and recent updates to NZS3604).

These three key areas are explored in the three main sections below.

7.1 Research process findings

The research team embarked on this work with an open mind about how best to set up the case studies and gather data. As part of that process, considerable learning was made along the way including the following:

7.1.1 High industry interest

Early engagement with the Frame and Truss industry proved very beneficial to the project and the robustness of the results. Members of this sector have been highly intrigued by the research. It is worth noting how interested the frame and truss manufacturers are in the potential for the results to inform building practice in New Zealand. Many have voiced surprise in the growing amount of timber in the framing elevations that they are producing, and they have also expressed an interest in finding out what variables might be driving this[7].

7.1.2 Lead time needed for access to F&T plans

The process developed by the research team to access F&T layouts and panel elevations worked well, but required at least four days' notice to contact the parties and obtain documents. Frame and Truss manufacturers operate very efficient systems in a busy sector, and the research team was careful to map out an efficient process that did not overly tax them. In addition, it should be noted that the panel elevations and floor plan layouts are manufacturing drawings, generated during the manufacturing process and as such, are generally used in-house only (they belong to F&T manufacturer and are rarely released outside of the factory).

[7] ***Personal communication from FTMA members during a session organised to outline this research project at their regular board meeting***

7.1.3 Site assessments were time consuming

Site assessments take less time when additional framing added on site can be compared with accurate F&T panel elevations. Data entry of the information gleaned from site was a lengthy process, and no electronic version of the frame and truss elevations was easily available in a way that might speed this up (most are delivered as PDF files and/or hard copies and require separate entry into Microsoft Excel).

7.2 Sector / industry findings

During the research, interactions with industry players provided a number of key insights. Interviews were held in the early stages of the project with representatives from major frame and truss manufacturers as well as suppliers to the industry such as cladding manufacturers and software providers. The following key insights were identified:

7.2.1 Cladding requirements: impacts of E2/AS1 changes in 2005

The scope of E2/AS1 is aligned to NZS 3604. It is limited to timber-framed buildings up to three storeys high, with a maximum height from the ground to the highest point of the roof of 10m. It covers most traditional claddings i.e. masonry veneer, stucco, horizontal and vertical timber weatherboards, fibre cement weatherboards, profiled metal claddings, fibre cement sheet, plywood sheet and EIFS cladding. E2/AS1 provides details for common junctions and penetrations of the building envelope.

E2/AS1 also requires buildings to be scored according to weathertightness risk and, depending on the risk score and type of cladding, requires a cavity behind most claddings. Cavity battens require timber framing to be nogged at 800 centres compared with NZS 3604 minimum 1200 centres so, in effect, E2/AS1 added another line of nogging in standard height wall framing.

E2/AS1 generally shifted the internal corner junction from three-stud to five-stud as can be seen in the illustration below. This shows five studs even for direct fix cladding where the studs are supporting a 50 x 50 mm vertical corner flashing. Prior to leaky buildings, it was not usual to use a corner flashing so the weatherboard would have been direct fixed to a 3 stud internal corner.

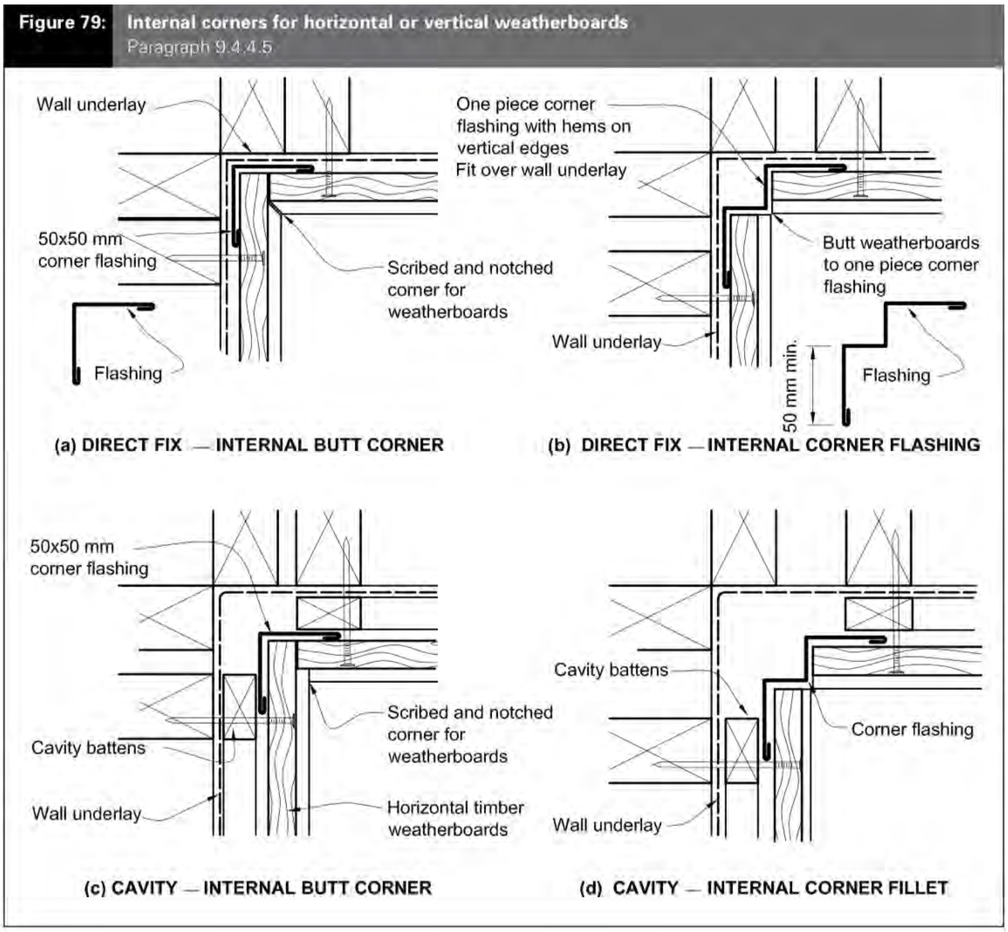

Figure 15: E2/AS1 requirements for internal corner junctions for weatherboards[8]

[8] *Images sourced from MBIE, 2016. Acceptable Solutions and Verification Methods For New Zealand Building Code Clause E2 External Moisture*

Figure 16 below (fibre cement sheet cladding) illustrates how the set out of the internal corner with cavity changes depending which way the sheets are lapped. It is entirely possible that the F&T detailer will make the decision to add a stud, so the builder has fixing either way.

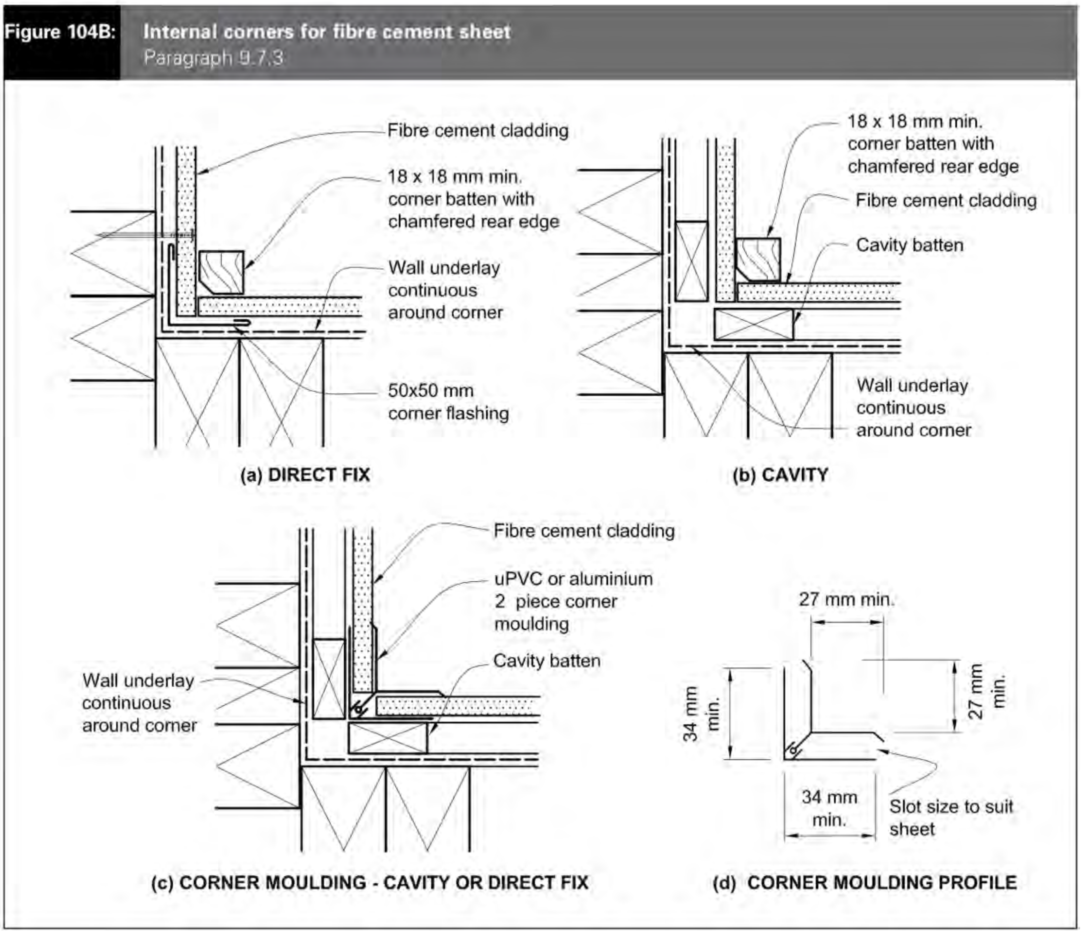

Figure 16: E2/AS1 requirements for internal corner junctions for fibre board[9]

It is recommended that further research is conducted into the extent to which cladding requirements dictate closer stud and nog centres than NZS 3604 structural requirements. For example, in instances where NZS 3604 could allow wider spacing of 140mm framing cladding requirements may dictate spacing i.e., even though wider stud spacings may be possible *structurally* with 140mm frames, the requirements of cladding fixings may still dictate studs at 400, 450 or 600 centres as per 90mm framing.

7.2.2 Designer preferences

In some situations, designers call for double sills, or double studs at smaller centres based on their personal preferences[10]. It should be noted that discussions with F&T detailers indicated that they think some of the requests are unnecessary (from a structural or fixing point of view), but in order

[9] ***Images sourced from MBIE, 2016. Acceptable Solutions and Verification Methods For New Zealand Building Code Clause E2 External Moisture***

[10] ***Personal communication from an interview with a F&T detailer, 2019***

to keep the client/customer happy, and to avoid potential liability issues, they do not overly question the preference. F&T detailers are contracted to produce drawings based on consented documentation and are not likely to remove specified items that are shown on the plans.

7.2.3 *Higher numbers of multi-storey dwellings*

As might be expected, the structural requirements for greater load bearing on lower floors appears to be a contributing factor to higher framing content on lower floors to carry the additional weights of upper storeys.

7.2.4 *Application of wind zones during design and consenting*

There was some evidence that varying interpretation of wind zone requirements by councils, as well as designers, may be contributing to higher than expected framing content in walls. This can occur where a designer opts to design for higher wind zones based on site assessment, rather than general wind zone, to make the design robust. In addition, some designers may choose site assessment and design for higher wind rating where a new proposed building is multi-storey in an otherwise low-rise subdivision (to account for higher wind speeds when sitting above the existing low rise structures).

7.2.5 *Less than optimal placement of windows, doors and openings (at the design stage)*

The placement of windows and doors does not appear currently to be well thought through in relation to the requirements for studs and accompanying fixing points for cladding or internal linings. For example, in some instances, shifting a window anywhere from a few mm to 300mm to one side or another could negate the need for additional studwork / nogs etc to carry fixings (with the window stud work operating as the fixing point). Importantly, there appears to be a lack of integrated 'design thinking' about how to **minimise** framing in the walls to achieve the goal of a better performing thermal envelope.

7.2.6 *Frame and Truss industry very efficient*

The Frame and Truss industry appear very efficient in their delivery of frames and work hard to remain cost competitive with one another. This suggests that every piece of timber in the framing layouts is there for a reason (i.e. they are not adding in any 'unnecessary' timber, but rather the amount of timber in the frames is being driven by structural requirements and/or cladding/lining requirements and/or designer preference).

7.2.7 *Timing of sub-trades can impact thermal envelope*

The timing of sub-trades as part of the construction process impacts the delivery of a good (or bad) thermal envelope. A clear example of this is the lack of insulation in external corners and internal to external wall junctions. Ideally, insulation is placed in these voids during construction (by the builder – or whomever is erecting the frames on site). In practice, insulation installation is often contracted out to an insulation installation team who arrives on site just before the internal linings are put on – and when it is too late to add insulation into these, now inaccessible spaces. This issue is clearly illustrated in the photographs in Section 5.1.

7.2.8 Typical F&T frames can result in double stud arrangements

F&T companies deliver maximum sized frames up to 6m in length – but more typically 3.6m and 4.8m and detail their own junctions between these panels. This typically results in a double stud where two panels join on a flat wall[11].

7.2.9 F&T design software does not assess thermal performance

F&T software is primarily concerned with truss design and allows the detailer to design the wall frame according to the plans supplied and their knowledge of NZS 3604 and cladding requirements. There is no current assessment of thermal performance within the software as it concentrates mainly on structural requirements with the thermal performance sitting outside of the manufacturer's current remit (up to this point)[12]. However, it may be possible to look at the addition of this functionality in future iterations of software. In general, design software is moving toward more BIM functionality. Given the right incentives, the industry may be able to incorporate this functionality with the right incentives in place, and this could be explored in future work.[13] There may also be scope for exploring interoperability between the F&T design software and other design programmes.

7.2.10 Ceiling heights impact stud spacings

NZS 3604 has wall frame tables for 2.4, 2.7 and 3 m high walls. Some industry experts pointed out that their customers who are using an intermediate stud height e.g. 2.5m are having to default to 2.7m high wall frame layout with commensurate increase in external framing, or they have to pay for specific engineering. It is worth noting the F&T industry is keen to see improvements to NZS 3604 and can see where there are gaps, anomalies and lack of flexibility in the current Standard. In addition (and related to the point about designer preferences above) design choices such as a double height entrance vestibules or stairwells mean the resulting exterior wall may be 5-6 metres high and must be stiff enough to withstand bending. Once again, this will add to higher percentages of timber in that wall.

7.3 Regulatory findings

As the project team developed more insights into the way that industry felt about the levels of framing in residential building, it opened up discussions and understanding about how key features of New Zealand Building Code and regulation either works - or doesn't work - in respect to the addition of framing in our housing stock. This can be the result of a number of actors in the building chain – from councils through to central government, from designers through to builders and how they implement different aspects of construction. A synopsis of these key insights is provided below:

[11] *Personal communication from an interview with a software company representative (MiTek), 2019*
[12] *Personal communication from an interview with software company representatives from MiTek and Pryda, 2019*
[13] *Personal communication from an interview with a software company representative (MiTek), 2019*

7.3.1 Unintended consequences of regulation

Different aspects of the Building Code appear to have been developed, or updated, without reference to other important features of the Code. An example would be the impact that cavity construction has had on external frames of houses (see Section 7.2.1 above). This results in extra framing. Even though H1 was amended in 2007 after E2/AS1, the standard framing percentage assumed in H1 does not appear to have been addressed. This potentially means that the deemed-to-comply compliance methods set out in H1/AS1 and E3/AS1 are not achieving the minimum R-values assigned/claimed. At an absolute minimum, E3/AS1 requires the R-value of the external walls of houses to be over R1.5 and the methods used to assess this should be up to date with changes instigated by amendments to other Code clauses or compliance methods. Leaky buildings, not surprisingly, led to very conservative behaviour with respect to compliance, so industry and councils may have inadvertently favoured compliance with E2 over H1. This type of 'siloed' Code amendment and development may be leading to some unexpected consequences for framing ratios.

7.3.2 Current structural requirements of NZS 3604 and recent changes

Structural requirements set out in NZS 3604 may also be contributing to an increase wall framing percentages: for example, the location of buildings in higher wind or earthquake zones; buildings which are 2 or 3 stories high; and choosing higher than 2.4 ceilings and larger windows will all have an impact.

Recent amendments to NZS 3604 were carried out in 2000 (amendment 1), 2006 (amendment 2) and 2011 (dealing with loadings). These, by themselves, were not step changes to the amount of timber required for framing, but each may have had a small contributory effect in the amount of timber required. Amendments included changes to look-up tables, framing sizes and timber grades as well as the consolidation of tables covering the weight of roofs (from three tables covering lightweight, medium and heavy weight roofs to two tables covering light and heavy roof typologies). There is evidence to suggest that these changes to NZS 3604 may have inadvertently contributed to an increase in the amount of timber used in wall framing. For example, the move to consolidated tables for roof weights might result in a requirement for slightly more structural timber than a lightweight steel roofing product actually requires.

7.3.3 Regulatory review opportunities

The timing of MBIE's Building Code review appears to be well aligned to the collection of data and the analysis undertaken by this research. There is potential for the results and data collected to assist both MBIE and BRANZ processes – ensuring the results can help to inform MBIE's code review and prioritise areas for action especially around the energy efficiency aspects of H1 and E3. Findings may, for example, inform an update to the current instructions for determining construction R-values in walls as stated in NZS 4218 (2009) Section 3.2 and explained in Section 6 above. There may also be suitable opportunities to utilise the findings to assist with industry education (e.g. builders, designers and trades to highlight the importance of framing set out, insulation install and the reduced performance from walls with percentages of framing that exceed those estimated by H1 and E3). Some of these opportunities are being explored in future work.

8 Conclusions

This report has provided final results from the BRANZ Levy funded project *"A Bridge Too Far: Measuring the extent of thermal bridging in timber-framed walls in New Zealand"* which became known as *'The Wall Project'*. The research specifically set out to answer the following two research questions:

1. *What is the percentage of framing in external walls in a sample of new builds across New Zealand and is the as-built percentage of framing now typically above that assumed in H1 and E3 calculations? (i.e. are high framing percentages a real and definitive issue?)*
2. *What insights can be highlighted as to the causes of high framing content in New Zealand?*

The Wall Project investigated the content of framing in modern construction through a case study approach of 47 newly constructed dwellings from Auckland, Christchurch, Wellington and Hamilton. The results show that the **average percentage of timber framing** compared to the area of the wall **is above 34%** based on the 47 dwelling case study sample. This is much higher than the 14 – 18% framing content generally assumed by both regulators and the industry. The results strongly indicate that the content of timber framing in external walls in residential new builds is at such high levels that the increased thermal bridging compromises the performance of walls and may mean that designed R-values are not being achieved.

The research has delivered key insights into how much framing is used in houses, how much extra framing is added on site as well as the reliability of Frame and Truss manufacturing data being used to calculate the percentage of framing. The project has established that there is a disconnect between what is assumed in New Zealand's current construction R-value calculation methods and what is actually being built in the real world.

The research has also highlighted significant weak points and blind spots in key aspects of current house construction. These 'defects' including un-insulated corner junctions, un-insulated mid-floors, un-insulated interior to exterior wall junctions and areas of timber flashing, timber packing and blocking all compromise the performance of the thermal envelope.

Although a small percentage of additional framing is added on site by builders and sub-trades (an average of just 0.7% of net wall area by level in the sample set), the majority of framing is predetermined, designed and delivered to site via the frame and truss manufacturing process. These pre-nailed frames already have a high percentage of timber framing in them based on specific design requirements.

A range of factors appear to be influencing the higher-than-assumed rates of framing including:

- Structural requirements of NZS3604 – the most recent change to this Standard was 2011 and advice to date is that it did not significantly change structural requirements. The location of buildings in higher wind or earthquake zones, buildings which are 2 or 3 stories high and choosing higher than 2.4 ceilings and larger windows could all increase the percentage of wall framing without any change to the standard.

- Building in higher wind zones (defined in NZS 3604) and the application of wind zone calculations / requirements by local authorities as well as design and building professionals.
- Changes to E2/AS1 after leaky buildings that resulted in an extra line of nogs to support the mid stud cavity batten and, in many cases, mandated five stud internal corners.
- Cladding trends such as increasing popularity of vertical profiles which require 400 or 480mm nog/dwang spacing depending on wind zone.
- Design choices such as a trend for double height entrance vestibules or stairwells mean the exterior wall may be 5-6 metres high and must be stiff enough to withstand bending.
- Designer and builder preferences – which occasionally result in higher framing content due to requirements such as double sills or double stud arrangements by request. It is noted that, to date, the research team has not investigated the specific minimum requirements of each case study or a series of typical dwellings from a structural or cladding point of view – and this may form part of future work.

8.1 Further research activity

The research outlined in this report has delivered key insights into how much framing is used in houses, how much extra framing is added on site and the reliability of Frame and Truss manufacturing data being used to calculate the percentage of framing. Robust case study data from 47 newly constructed dwellings indicates that there is a substantial disconnect between intended thermal performance of walls in new houses and what is achieved in reality in the 'as built'. There is potential for further work to explore this important aspect of New Zealand construction. Research questions raised at this stage in the research process include:

1. *Which of the identified key drivers for high percentages of framing are responsible for the largest amount of additional framing?*
2. *Can framing design be optimised to reduce framing content in walls and, subsequently, reduce the effects of thermal bridging?*
3. *What are the modelled thermal performance impacts of the higher percentages of framing encountered when compounded by the weak points and blind spots in the thermal envelope that have been identified in typical current construction practices?*
4. *What are the practical advanced framing solutions in new build construction that can improve thermal performance of timber frame walls?*
5. *Are these solutions buildable, cost effective and feasible from a compliance point of view?*

In answering these questions, additional research would usefully deepen our understanding of the variables contributing to higher or lower percentages of framing identified in the initial phase of this work, including an examination of the extent NZS 3604, E2/AS1 and cladding manufacturers requirements and builder preference may be driving higher timber content. Further activity could aim to examine the impacts of these higher framing percentages on resultant R-values as well as describe weak points and blind spots identified in the case study houses which are likely to reduce the thermal performance of walls. Investigations are also required to explore practical and buildable solutions to the identified thermal bridging challenges through examination of advanced framing techniques. Work might include:

- In situ tests using HFT panels to define performance levels of walls in typical existing and new build scenarios.
- Exploring cost effective advanced framing techniques to overcome typical thermal bridging issues identified by the research.
- Modelling using frame and truss industry suppliers/designers to explore the impacts of cladding, regulation, structure, wind zones etc as drivers of excessive framing on particular dwelling typologies.
- Undertaking calculations of construction R-values of modelled walls with detailed framing set up compared to what is assumed in both the current schedule and calculation methods under H1 and when using simplified NZS 4218 definitions.
- Exploring a larger sample size of built dwellings from frame and truss supplier information (framing layouts) to achieve a larger sample size and with the ability to further determine the impacts of key variables e.g. cladding, regionality, wind zones, structural requirements etc.

The activities described above will contribute to a greater understanding of framing content in external walls and how this might impact the means of compliance for thermal performance of walls in New Zealand's residential construction. Findings from the current and suggested research have the potential to inform changes to building regulation and the codes governing the design and construction of external walls in New Zealand's residential sector.

Given New Zealand has an extensive residential building programme underway that is likely to continue for many decades, it is prudent and smart to ensure new builds are compliant with NZBC requirements for energy efficiency, thermal resistance and moisture management, rather than continue to embed a systemic problem that will incur costs for subsequent generations.

9 References

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