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Developments in Closed Panel Timber Frame Connection

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Timber frame construction has remained as one of the most environmentally friendly and sustainable methods of construction. The evolution of the closed panel system of timber framing has developed the practice into a form of modular construction whereby pre-fabrication of wall and roof panels can take place prior to site installation. With pre-fabrication reducing the risk of defective workmanship in panel production, increased focus is shifted to the performance of the junction between panels when they are assembled on site. As part of an overall research investigation into the improvement of a modular construction method, this paper focuses on the systematic evaluation of a new connection detail used in the assembly of walls in closed panel timber frame structures. The detail offers the potential to increase the airtight capabilities between the wall panels thus improving the thermal performance of the structure. The research outlined is concerned with the application of the detail in two trial phases. Each phase was assessed as part of an action research methodology contributing to the further refinement of the detail. It is envisaged that the trials will lead to the establishment of a functioning and sustainable method of connection that can be applied in future timber frame construction.

Key Words: Airtight, Energy Performance, Sustainability, Timber frame construction

Introduction

Presently, timber frame construction is one of the most sustainable and economically viable methods of modular construction (Pitts, 2011). The change from traditional 'open panel' timber frame construction to 'closed panel' is still an on-going process. The research outlined in this paper has the potential to be of benefit to both open and closed panel timber frame construction however, given the modular construction properties of the closed panel method, the detail will be focused on this discipline. Closed panel timber frame construction or 'panelized construction' involves the total pre-fabrication of timber frame structural walls in a factory setting before assembly on-site. This method of platform timber framing incorporates all components of a typical timber frame construction including, timber studs, insulation, external breather membrane, internal vapor barrier and external finish. Closed panel construction differs from Structural Insulted panels (SIPS) as it offers a completed timber frame wall structure from inside to outside including the presence of a cavity (Hairstans, 2010).

While the closed panel method has contributed significantly to the evolution of timber framing, many of the connection methods used in assembly are of a traditional background. The connection detail researched and presented in this paper is primarily concerned in the joining of wall panels to each other and the ability to provide a robust detail which will improve the construction time of a structure. The developed detail is also aimed at improving the airtight capabilities of modular buildings in the area of retrofit. This will have the potential to offer a direct influence on thermal performance by way of reducing heat loss through any gaps or spaces in the connection points of the wall panels.

This paper presents two phases of action research which are used to demonstrate the application and evolution of the connection detail. Working closely with an Irish timber frame construction company (Company A), the phases are a follow on from an initial feasibility stage of trialling the connectors and are aimed at refining the process as well as further assessing how the connection method can contribute to modular construction detailing. It is envisaged that the highlighted connection detail will ultimately provide an efficient, cost effective and performance enhancing alternative to traditional methods of assembly.

Methodology

The exploratory nature of the research has led to the application of an action research methodology in the context of assessing the connection methods on home extension projects. Action research is best applied to identify areas of concern, develop and test alternatives and experiment with new approaches (Kumar, 2005). This form of research lends itself to the refinement process as it is a way of learning from and through one's practice by working through a series of reflective stages (Riel, 2012). Each trial will have an individual action research phase in order to capture similar data relating to each project. The progression of action research can best be described in cycles incorporating a plan, action, analysis of evidence and reflection stages. Each project was independently investigated and monitored for the performance of the connection detail during the construction phase.

As outlined in Figure 12; Project 1 served as a means of assessing the suitability of the connection detail for use in a closed panel timber frame project. Following the evaluation of Project 1 and its cohesiveness in a modular construction environment, the progression to trial phases 1 and 2 was initiated. Trial 3 (as shown in Figure 12) is a future trial phase of the connection detail which, as part of the action research methodology, will be prepared for using the data and results of trial 1 and 2.

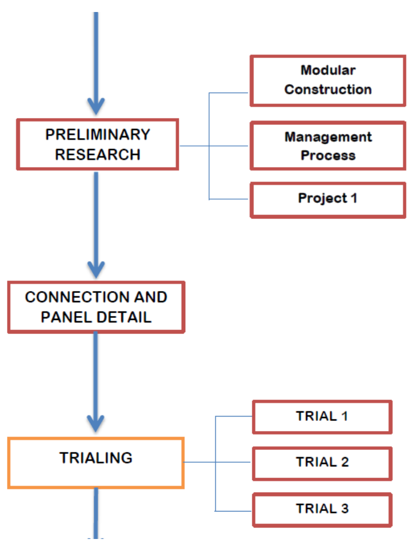

Figure 12: Section of Overall Research Progress Highlighting Trial Phases

Purpose of Research

The energy performance of buildings is becoming the most essential aspect of construction today. In Ireland, directives handed down by the European Union (EU) are directly influencing the construction sector in terms of being energy conscious. In 2002 the European parliament and the council of the EU issued the Energy Performance of Buildings Directive (EPBD), this document contained a range of provisions and requirements aimed at the improvement of the energy performance of residential and non-residential buildings (SEAI, 2012).

The directive outlines factors which are to be included in the general frame work for the calculation of energy performance of buildings, these factors range from the ventilation available in the building to the type of heating

system used. Of particular importance to the research outlined in this paper is the mention of air-tightness to be included in the thermal characteristics of all buildings to be assessed (European Union, 2002). This highlights the fact that air-tightness within a buildings fabric is a vital part when determining the buildings energy rating. The method of connecting closed panel timber frame walls as detailed in this paper has the potential to improve the air tightness between modular panels thus increasing the overall energy performance of the structure.
To date, there has been little research carried out on the airtight performance of the joint between modular panels. Instead airtight testing is more commonly carried out in a whole building scenario rather than specifically concentrating on one structural aspect. Research carried out by the structural Insulated Panel Association in the United States of America compared the airtight capabilities of 3 similar sized houses. Two of the houses were built using SIP's whilst a third house was constructed using conventional timber framing. An assessment of the houses was carried out using a blower door with digital pressure gauges. It was found that the average building air leakage of the two SIP houses was 31% lower than the building leakage of the standard timber frame house. It is also key to note that the SIP houses were tested for airtightness of 1.8 air changes per hour at 50 Pa compared to 3.9 for the timber frame house (Rudd, 1998).

Although the timber frame house in question was not built in a panelized format, the effective completion of the structure is identical to that of a modular built house. With this in mind, the data presented illustrates that there is far more potential for leaks to occur in a timber frame house than there is in a SIP built house. It is inconclusive if this can be contributed to the system of panel connection used in a closed panel timber frame structure however, as depicted in **Error! Reference source not found.**, it is clear that the system of connection used in a SIP structure is much more established and robust when dealing with airtight capabilities.

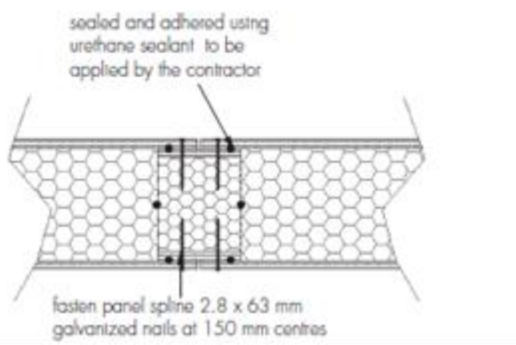

Figure 2: Connection detail between SIP panels (BBA, 2007)

Part L of the Technical Guidance Documents Building Regulations issued in Ireland deals with the conservation of fuel and energy in relation to domestic and non-domestic buildings. Part L was first published in 1997 and has been updated regularly. The biggest change in Part L's requirements came with the publication of the 2007 regulations. This document contained a principal requirement for a 40% reduction in energy demand and carbon dioxide emissions associated with heating, domestic hot water and lighting this was a direct result of Irelands's obligations under the EPBD (Colley 2007). The 2007 publication is also the first instance of air permeability testing becoming mandatory in all new builds. This is carried out by pressure testing the building prior to completion (TGD, 2007).

A maximum air permeability rate of $10M^3/(h.m^2)$ was required by the 2007 regulations (TGD, 2007). This has been further reduced to $7M^3/\ (h.m^2)$ by the 2011 revision of Part L representing the likelihood that this figure will continue to drop over the nest number of years. Unlike Ireland and the UK, there is no requirement for mandatory air tight permeability testing in the United States building codes. Presently, air tight testing in the US is a performance requirement enforced by designers rather than by regulations (ABAA, 2012). As already mentioned, closed panel timber framing is the method of construction used in conjunction with the connection detail research presented in this paper. This form of construction allows for careful attention to detail regarding the fabric of each panel and factory sealing around components such as windows and doors. When constructed correctly, closed panel timber frame homes have the ability to achieve 1.87 air changes per hour (Antonelli, 2010).

The Connection Detail

The managing directors of Company A had an underlying idea of using existing connection systems in the construction market to work in compliance with the wall panels. Initial research into the types of timber connector's available yielded large amounts, however refining the search to connection systems that would be robust enough to be fixed to the joint faces of each panel provided one company which has a range of fixing mechanisms for use in timber construction. Sherpa™ are an Austrian based company specializing in timber connection systems.

The Sherpa ™ Company was first established in 1995 by Austrian Vinzenz Harrer, since then the company has expanded through research and development and now offers the world's largest 'slide-in' connection systems (Harrer, 2010). The range of connectors can support loads of 5 to 280kN and are available in a wide selection of sizes. For Project 1, the "Type B' connector was used. Given the success of this connector, it was decided to continue to use the 'Type B' for Trial 1 and Trial 2. The 'Type B' connectors are typically used in the fixing of large structural members such as glue-laminated or solid timber beams. The connectors are made from cast aluminum with dimensions of 4.7 Inches by 2.5 Inches allowing them to easily fit between the two most common sized panels of 4 Inches to 6 inches thickness. According to Sherpa™ the 'Type B' connector can support a horizontal force of 12kN which is more than adequate to deal with any lateral forces applied to walls after installation (Harrer 2010).

In order to provide extra assurance regarding air permability of the joint, a self adhesive, self expanding tape was used in conjunction with the Sherpa™ connectors. The most suitable tape available is the Compriband TP600 impregnated joint sealing tape. This tape has British Board of Agrement testing approval and has an air permeability factor of $< 0.1m^3$ / [h.m.(daPa)n], a U-value of 0.055 W/m/K and a 25 year life expectancy (Illbruck, 2011). The tape has an overall width of 20mm ensuring that it can be applied beside the Sherpa™ connector on the end face of each panel. The tape can expand up to 15mm after application, filling any uneven gaps or spaces between the panels and forming an effective moisture and air tight seal. The use and positioning of the Sherpa™ and the Compriband tape is illistrated in Figure 3. The external to internal build up of the wall is; ½ inch concrete board, 1½ inch batten, ½ inch OSB board, 6 inch vertical stud (containing 6 inch thick fibreglass insulation), 1 inch ridged insulation, 1½ inch batten and ½ inch internal plasterboard. This wall build up was used in both Trial 1 and 2 and provides an overall U-Value of $0.21W/M^2K$.

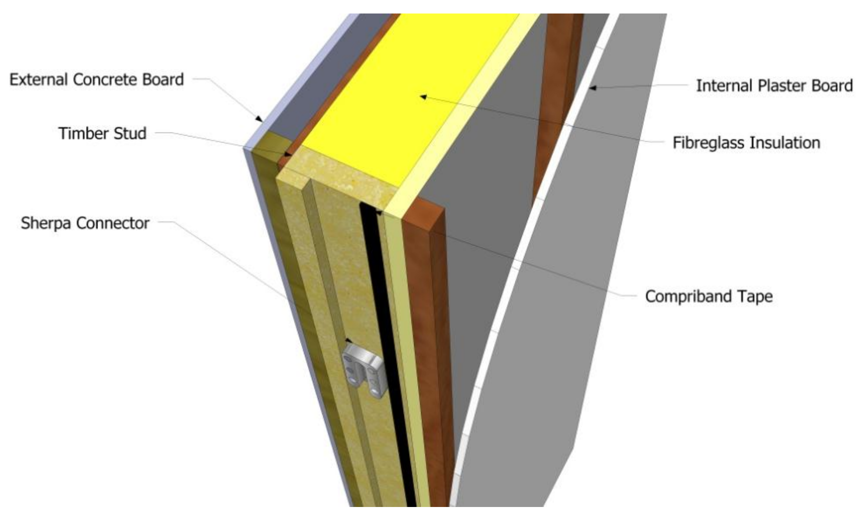

Figure 3: Section of wall showing location of Sherpa and Compriband Tape

Development since Project 1

Research into the improvement of the connection method between closed panel timber frame wall panels has progressed from an initial test project titled Project 1. Project 1 was the first extension project constructed using the connection methods as described. The pre-fabrication and on-site assembly aspects of the project were carried out by Company A. Efficient construction of the project was significantly aided by the use of the improved connection detail in conjunction with traditional methods of assembly. Project 1 paved the way for further refinement and research into the use of the connection details. A full assessment of Project 1 yielded encouraging factors for further trialling of the connection detail. These factors include the speed of erection afforded by the connectors, the opportunity to complete each panel in terms of insulation and membrane placement in a factory setting rather than on-site and the tighter connection between each closed panel. Two further extension projects constructed by Company A provided opportunities to conduct two trial phases of research to further assess the benefit and potential of the connection detail.

Trial 1

Trial 1 provided the first trial test for the complete use of the connection system. The end result of the project was a single storey extension to an existing two storey, mid-terrace house located in Dublin, Ireland. Before the extension was constructed at the client's home however, it was entirely pre-constructed by Company A as a showpiece home extension at a leading Irish

home expo show. Using this marketing opportunity, Company A decided to construct the clients extension for the duration of the show and to then dismantle the building, bring to the actual site and reconstruct. This presented an ideal opportunity to test the Connection details in their application to assembly, disassembly and reassembly phases in the project.

Trial 1 was an extension design adding 430 Sq. Ft onto an existing house. The extension is single storey and will be used as a new kitchen/living room (see figure 4). The project consisted of five wall panels and four roof panels which were all completely pre-fabricated in Company A's factory prior to being transported to site.

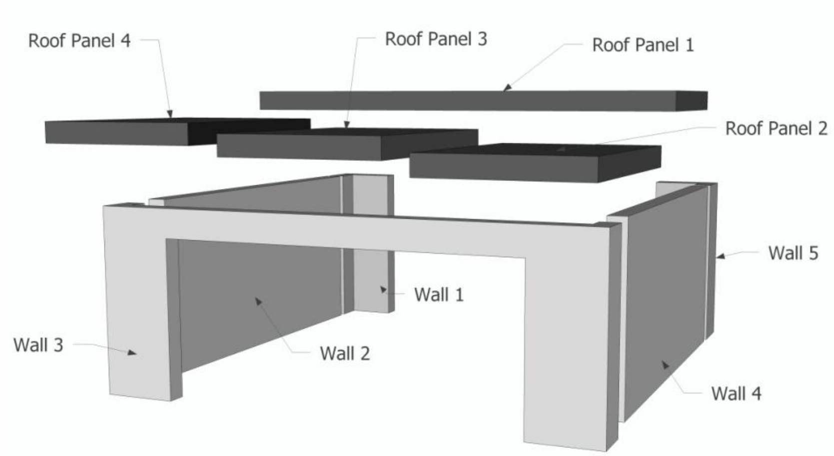

Figure 4: Exploded view of Trial 1 showing locations of wall and roof panels

Connection Details

Trial 1 was first assembled at the Expo show and because the extension was not in its final positioned place, the Compriband tape was omitted from the construction detail. This allowed sole focus on the ease of connection between the Sherpa's™. Following the previous project (Project 1), an addition was made to the connection detail; a single 1½ x ¾ inch batten was placed beside the Sherpa™ connectors, this was to ensure the connectors remained in line with each other, it also offered a means of achieving a flush joint face between two panels as the batten fitted neatly into the ¾ inch gap left by the connectors. Each wall panel had two Sherpa's™ in position, one located 16 inches from the top of the panel and the second located 16 inches up from the bottom.

The wall and roof panels were positioned by mobile crane. The construction sequence was straight forward; all walls were assembled as shown in figure 4 (sequence of Wall 1 to Wall 5). Wall 1 and Wall 2 connected together easily however, difficulties arose when aligning and connecting Wall 3 to Wall 2 and Wall 4. The panels were separated and assessed individually, it was found that there were some dimensional differences between the adjoining faces of the wall panels, although this difference was less than 5mm, it was enough to prevent the connectors from joining together. A solution was provided in the shape of removing the top and bottom fixing screws from one of the Sherpa™ plates, leaving the middle fixing intact. This was permitted because the structure was being assembled for the Expo show and was not being used as a functional building. Removing both fixings allowed the Sherpa™ to pivot slightly in order for a smooth connection to be established. The final connection of Wall 4 to Wall 5 proceeded without the need to make any adjustments. This connection, much like the one between Wall 1 and 2, was a joint between smaller walls which could be easily adjusted during alignment. Construction of the roof Panels preceded without any hindrance as each panel slotted into the pre-designed positions. It took a total of four hours to assemble the extension.

De-construction and Reassembly

The complete extension was disassembled in the reverse order that it had been built. The disassembly of the wall panels took place without any damage being caused to the wall panels. The extension was erected in the exact same sequence as it had been for the Expo show. As with the first erection of the structure, Wall 1 and 2 connected together easily, however the joint between Wall 2 and 3 proved difficult but, with persistence, the wall panels slid into position. Unlike the Expo show assembly, the fixings in the Sherpa's™ were not removed and so a solid connection between the panels was maintained. Difficulty again arouse when connecting Wall 3 to Wall 4 but the connection was eventually made. The delay in forming a solid connection between the panels was further hindered by the expansion of the Compriband tape. As the tape was thicker during the connection process, the unseen snagging and tearing of the tape is a possibility. From start to finish assembly took six hours to complete, the extra time taken, when compared to the first assembly, mostly related to the aligning and positing of walls to establish a solid connection.

Trial 1 Analysis

As this project was the second time of using the Sherpa™ type B connectors, there was a keen interest to see if they could function to the best of their ability during the erection of the extension at the Expo Show. Ultimately the details proved to be difficult to connect even with a guide batten attached to the end of each panel. As highlighted earlier, Wall 3 was the largest of all the wall panels and so was the most difficult to connect as the sheer size and weight of the wall prevented manoeuvring during positioning. This difficulty was repeated again during the erection of the extension on the actual site.

Although Wall 3 was large, future projects will no doubt contain similar size wall panels and so the incompatibility of the Sherpa's™ is a concern for the progression of this detail. It is obvious that the precision of the connectors does not comply with the level of precision used to cut the timber studs and this is a problem that will face every extension fabricated using timber. The positive to be taken from this trial is the execution of a complete construction, disassembly and re-assembly. The connectors allowed for an easy dis-assemble without any snags. A further positive is undoubtedly the time taken to construct the extension each time was relatively short including the time taken to align the connectors properly. It is recommended that the next trial should ensure all connectors are set in each wall at perfect alignment and will slide into each other without hindrance. This can be improved somewhat by placing the connector at a higher level resulting in an earlier alignment and connection as the wall panels are being dropped in place. A quicker connection time will also work best with the Compriband tape as it will not get the sufficient time to expand before the panels are joined.

Trial 2

Trial 2 involved the pre-fabrication and construction of a one-room, a single storey extension approximately 226 Sq. Ft in area. There was no pre-assembly of the project before bringing to site and so dimensions and panel positions were of utmost importance to ensure a fast construction time. The existing house had recently been acquired by the project clients and they wanted to construct the extension to their new home before moving into the property. The purpose of the extension was to add more space and light to the existing living/sitting room of the house.

As can be seen in figure 4, Trial 2 is comprised of a total of 3 pre-fabricated wall panels and 3 pre-fabricated roof panels. This results in two points of connection between Panel 1 and Panel 2 and between Panel 2 and Panel 3. The construction sequence would be the placing of Wall 1, then Wall 3 with the final placement of Wall 2 completing the structure. As outlined in the recommendations of Trial 1, extra emphasis was placed on the location of the Sherpa™ connectors. Attention to detail at pre-fabrication stage was paramount to ensure the connectors would go together and not be prevented from sliding into place by slight dimensional inaccuracy. In reality, there was only one complete large joint between wall panels in the project. This was between Wall 1 and Wall 2 as the joint between Wall 2 and 3 was only above the large corner door.

In terms of the joint between the wall panels, the Sherpa™ connectors were counter sunk into the vertical studs, this insured there was no gaps between the panels as both end studs came face to face as seen in figure 5. In order to develop the connection detail further, the external breather membrane was wrapped around the end of each wall panel; the Compriband tape was then installed in line with the outside edge of the vertical stud (figure 5). This detail was also used when connecting Wall 1 and 3 to the existing building.

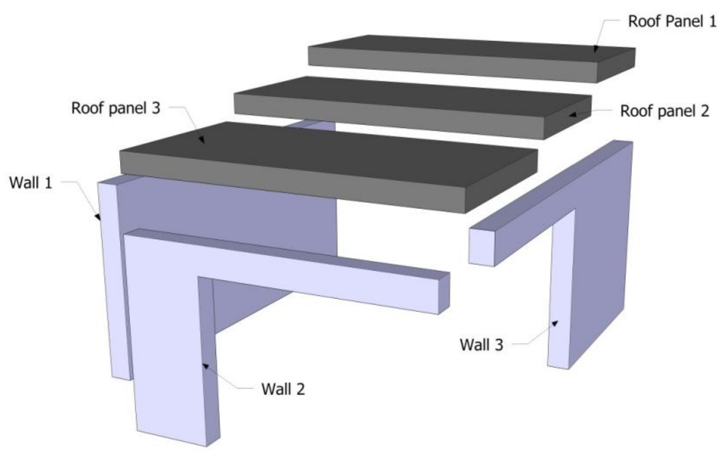

Figure 13: Exploded view of Trial 2 showing wall and roof panels

Applying the Compriband tape in the location shown (figure 5) results in the effective continuation of the external membrane and also ensures the joint between the wall panels remains moisture proof and airtight. The same principal can also be applied when connecting two wall panels together, for Trial 2, this could only be properly tested in the joint between Wall 1 and Wall 2. A detail had to be designed for using the Compriband tape in conjunction with the Sherpa's™ and also in conjunction with sealing the external breather membrane. As can be seen in figure 5, the external membrane is wrapped around to the end face of the wall before being taped into position; the Compriband tape is then applied to provide an effective seal between both breather membranes. The

Sherpa™ connector is countersunk in position at the top of the wall panel, this positional change was to effectively guide the wall and ensure that both the Sherpa™ at the top and bottom of the wall connected properly.

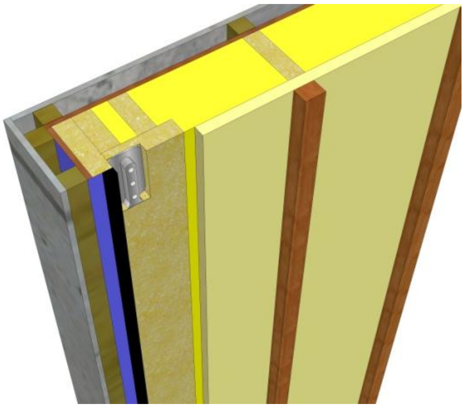

Figure 5: Image on Left depicts the counter sunk position of the connector whilst the image on right shows the application of the Compriband tape completing the detail

One single Sherpa™ connector was installed on the much smaller connection plane between Wall 2 and Wall 3. As Wall 2 was the last panel to be positioned, it was paramount that all the Sherpa™ connectors joined in cohesion with each other. As Wall 2 was lowered into position, it was noted that the connectors, although perfectly aligned, were not fitting together correctly. After assessing both corner joints it was determined that the connectors simply afforded too little tolerance in the connection sequence. Coupled with this, the delay in positioning Wall 2 allowed for expansion of the Compriband tape before the panels were joined together. This is a re-occurrence of a similar problem in Trial 1. For ease of construction, the Sherpa™ connector used in the smaller connection between Wall 2 and 3 was removed. This allowed Wall 1 and 2 to connect with minimal disruption. The connection between Wall 2 and 3 was then secured with a traditional nailed connection.

Trial 2 Analysis

Trial 2 allowed for further development of the connection detail with particular focus being placed on the continuation of the external breather membrane in a typical closed panel timber frame build. This element of the detail is crucial as in order to develop a self-contained panel system. Without doubt, the Sherpa™ connectors offer excellent strength and effectiveness when they connect, however they do not offer enough tolerance when being joined together. Rather than sliding into place in unison, the Sherpa's™ located in Walls 1, 2 and 3 did not join together smoothly. The early expansion of the Compriband tape further jeopardises the effectiveness of the connection between the panels as it is unknown if the tape remains intact once the panels are joined.

Conclusion

A number of key factors have been highlighted that require to be addressed for the further progression and refinement of the connection detail. The adoption of the action research methodology has outlined certain aspects of the detail which need to be re-examined. In both trials, difficulty with the alignment of the Sherpa™ connector prolonged the assembly process. There are a number of contributory factors to this delay including lifting position, accuracy of setting out the connectors and ability to adjust the position of the wall during lifting. All of these factors can contribute to a misalignment of the Wall panels but these are factors which are common to every construction project and so must be taken as standard practise.

Next Phase of Research

The Sherpa™ type B connector does not offer sufficient room to manoeuvre before a solid connection is formed. It is therefore necessary to opt for a connector which allows more movement and opportunity for alignment before the wall panels join properly. An alternative to the Compriband tape should be sought. Due to its nature, the tape can only be put in place prior to installation of each wall panel, this adds delay to the placing of each panel as the tape cannot be factory fitted. In addition to this the quick expansion of the tape calls into question its integrity once a connection is made between two panels.

The necessary adjustments are required to be made to the connection detail before the commencement of Trial 3. It is envisaged that the development and application of a commercially viable and energy efficient alternative method of panel connecting can have a major impact on the construction techniques of closed panel timber framing.

References

ABAA (2012) *Air Barrier Association of America | Whole Building Air Tightness Testing* [Online]. Available: http://www.airbarrier.org/whole_building/index_e.php [Accessed 05/05/2012]

European Union (2002) *Directive 2002/91/Ec of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings*, Brussels. Available.

Hairstans, R (2010) *Off-Site and Modern Methods of Timber Construction : A Sustainable Approach*, TRADA Technology, Buckinghamshire.

Harrer, V (2010) *Sherpa Timber Connectors*, Sherpa, Frohnleiten.

Illbruck, T (2011) *Compriband Tp 600*, Tyne & Wear. Available.

Kumar, R (2005) *Research Methodology : A Step-by-Step Guide for Beginners*, 2nd ed, SAGE, London.

Pitts, G (2011) *Low Energy Timber Frame Buildings Designing for High Performance*, Gardners Books.

Riel, M (2012) *Understanding Action Research* [Online]. Available: http://cadres.pepperdine.edu/ccar/define.html [Accessed 12/07/2012]

Rudd, A (1998) *Air Infiltration | Sips.Org*. Available.

SEAI (2012) *Seai - Ber Legislation and Background* [Online]. Available: http://www.seai.ie/Your_Building/BER/EPBD/ [Accessed 27/04/2012]

TGD (2007) *Part L - Conservation of Fuel and Energy - Dwellings*, Dublin. Available.