SM3570/5

Design Criteria for Retrofit Windows and New Walls

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About This Report

Title

Design Criteria for Retrofit Windows and New Walls

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Reviewer

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Abstract

This report outlines a suggested approach for establishing design criteria by which various systems can be assessed, to determine key performance parameters for solutions to improve the system towards better meeting the HSS High Standard of Sustainability®. Product development techniques such as Quality Function Deployment and Product System Assessment were used to identify and prioritise key technical requirements for exterior walls for new homes and windows for existing homes, and to verify suitability of the methodology developed.

Key criteria for the development of windows of existing homes are ability to regulate the indoor environment, installation ease and environmental aspects. For wall systems durability, the provision in the system for easy of upgrade and installation and key performance indicators are shelter, security, longevity and thermal insulation are important design criteria. Key performance requirements for a new wall system also include optimising thermal mass, glazing and insulation elements and designing in adaptability using prefinished componentry and easy connections.

While the goal of the systems strategy initially was to develop novel solutions, the results, especially for windows for existing homes, showed that the development of a new solution may not always be essential, and particularly in the case of window systems and wall systems, it was clear that their high ranking was influenced in many respects by 'uptake' related issues, i.e., not necessarily technological issues.

Reference

Bayne. K.M ; Allan, T.; Baker, K. July 2008. Design Criteria for Retrofit Windows and New Walls. Report SM3570/5 for Beacon Pathway Limited.

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1. Executive Summary

The Systems component of Beacon's work programme is relatively new and has been funded as a means of accelerating the uptake of innovative systems and technologies into the building process, thereby improving the sustainability of the housing stock for both retrofit and new build situations.

This report outlines a suggested approach for establishing Design Criteria by which various Systems can be assessed, to determine key performance parameters with which to develop solutions to improve the system towards better meeting Beacon's HSS High Standard of Sustainability® (HSS®).

Firstly, the project aims to find a methodology that can be used for any system, and then applies this methodology to two systems to develop design criteria for these systems that can be used in further research to move the system towards a better match with the HSS®. These case studies were also used to verify suitability of the methodology developed. The purpose of this report is therefore twofold:

- Firstly to introduce the method by which any system can be reviewed and assessed
- Secondly develop design criteria for 'windows for existing homes' and 'exterior walls for new homes'

The original intention of the Systems workstream was to create novel product and material technologies. However, to best achieve the HSS®, the research team had to consider that the system under review may not require a new solution, but the answer could be a specification framework for industry, an installation guideline, a revision to a standard, or a guide for consumers. Investigating 'systems', instead of specific products, requires the development of more generalised indicators rather than specific product criteria. This investigation was therefore was broad and investigative with a focus on identifying potential system development criteria. This research used two different approaches to investigate and apply the Beacon HSS™ criteria in the development of design criteria and performance indicators.

The research established an assessment methodology that incorporates elements of Quality Function Deployment and product life cycle thinking (Product System Assessment). This method can be applied to any building 'system' to establish the important design criteria for improving the system towards meeting the HSS High Standard of Sustainability®.

The research case studies also indicate that, for Retrofit Window systems, improving weathertightness (particularly air infiltration) when shut, the operability of the window and lifespan of the system were important design criteria, with key performance indicators being visibility, structural integrity, heat loss/gain regulation; while for New Wall systems, important design criteria are the length of time the wall system is designed for, as well as the provision in the system for easy of upgrade and installation and key performance indicators are shelter, security, longevity and thermal insulation.

2. Introduction

2.1. Beacon context

2.1.1 Operating strategy

Beacon Pathway Limited (Beacon) is a research consortium aimed at raising the standards of New Zealand residential housing to achieve greater levels of sustainability. Beacon's operating strategy is underpinned by market pull occurring within each of three priority research areas (Sustainable Neighbourhoods, Sustainable Existing Homes and Sustainable New Homes). Beacon will engage with key stakeholders across central, regional and local government, infrastructure, industry and consumers to identify what is required to maximise uptake within each priority area. This information will be used to determine the sequence and priorities of protocols, tools, guidelines and other Beacon outputs. This information will be "signalled back" to the research parts of Beacon to drive priorities and to also provide guidelines for how to best "package" the research (Figure 1).

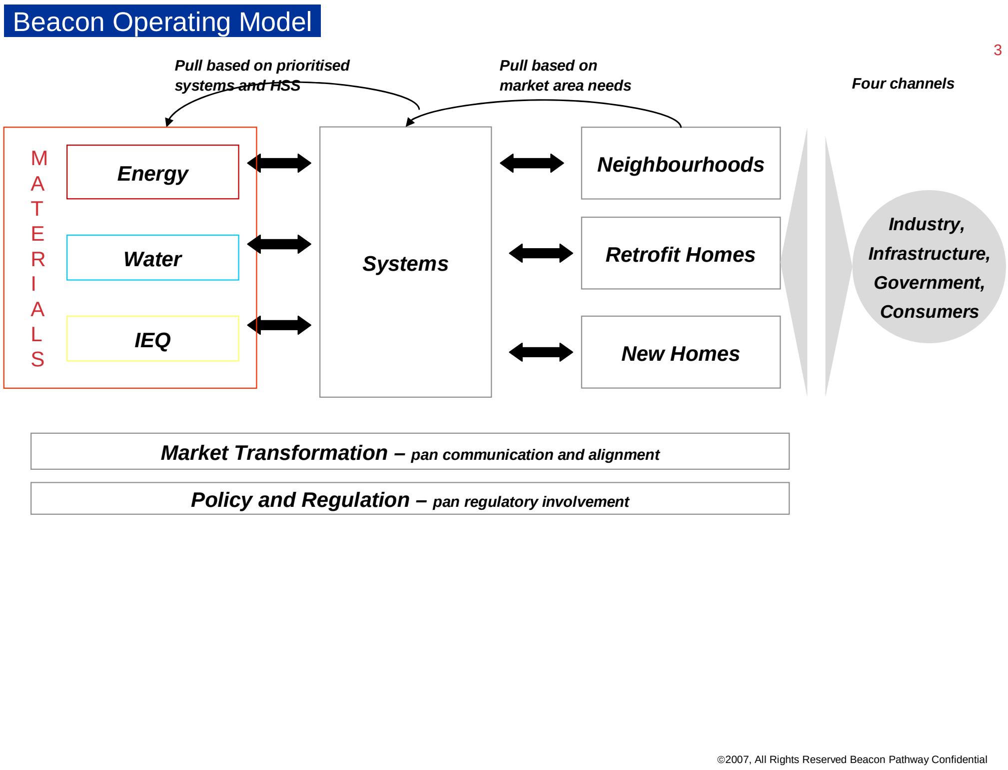

Figure 1: Beacon Operating Model

The Systems component of Beacon's work programme is relatively new and is intended as a means of accelerating the uptake of innovative systems and technologies into the building process, thereby improving the sustainability of the housing stock for both retrofit and new build situations.

The underlying principle of the "Systems strategy" is that specific materials or technologies are part of the whole house or neighbourhood and cannot therefore be seen in isolation. The principles and frameworks developed in this research stream will therefore be essential for the work undertaken in other research streams.

Of particular relevance to the project integration within Beacon is the HSS High Standard of Sustainability® (HSS®). The results of the Systems work will inform the HSS®, and targets defined in the HSS® will be incorporated into the design criteria developed in this research.

2.2 Systems strategy context

2.2.1 Definitions

A number of relevant terms have been defined within the systems strategy as below.

In this context '**Systems**' are the smallest part of a building where function (functional unit) can be appropriately prescribed. The function can be one or several relevant properties (e.g., static properties, heat and sound transfer or insulation). Within a certain system with a predefined function, different design options with different environmental outcomes can be described and compared. This provides a context for improving the standard of sustainability of the system. For example a retrofit window system can be defined as the system which improves the sustainability of the window performance, and may include the components of frames, sills, glazing, accessories, shading/ shutters, drapes/blinds and pelmets.

In this project '**Categories**' have been created within each system. This enables the system to be broken down and grouped into solutions that have similarity. For example in the retrofit windows system case study, the category of 'additions' enabled the grouping together of a range of solutions such as blinds, drapes and external shades whereas 'complete replacement' allowed the grouping of double and single replacement window solutions.

Within each system, a range of generic **'Solutions'** can be provided to aid in providing the required function(s). For each system, there will be a number of categorised 'solutions' to choose between. For example: retrofit window solutions include blinds and drapes; secondary glazing; films, IGUs and draught-stopping devices.

For every solution, specific **'Designs'** can be achieved which comprise of a particular package of materials and components. For example within the solution of 'blinds' there are Roman blinds, Venetian blinds; Thermal backed pencil pleat curtaining, etc.

'Products' are company specific products.

2.3 Goal of this report

This report is part of the research described in the Systems Research Workplan - "*Systems Phase 1: Criteria Development and Embedding Systems*" and will apply the concept of Life Cycle Assessment into the design process of specific prioritised systems to design building systems which have both a reduced environmental impact and improved service performance (by ensuring that systems meet specific targets set in the HSS High Standard of Sustainability®). The project focuses on the development of systems that can be applied to both retrofit and new build situations to substantially improve their ability to perform to a high standard of sustainability.

The components of the project are:

- An LCA of the NOW Home® and two homes from the Papakowhai Renovation project;
- Development of a prioritised list of systems for further research;
- Development of design criteria for two systems; and
- Development of an LCA based systems calculator.

This report presents the development of design criteria for two systems:

- Exterior wall solutions suitable for new residential buildings. (This includes the claddings, internal linings, structure, membranes and any insulating components, but not coatings)
- Window solutions suitable for retrofitting existing housing. (This includes the frames, sills, glazing, accessories, shading/shutters, drapes/blinds and pelmets)

The selected systems of 'Retrofit Windows' and 'New Exterior Walls' were investigated with two different approaches based on Quality Function Deployment (QFD) and Product System Assessment (PSA) for establishing design criteria and to test the validity and robustness of the approach as case studies.

This report outlines the approach used for establishing Design Criteria by which various systems can be assessed. Assessment is in order to determine key performance parameters with which to develop solutions to improve the system towards better meeting the HSS High Standard of Sustainability® (HSS®). The study reports on the testing of the approach and provides specific results from the approach's application to windows for existing houses, and walls for new houses.

This report lists the customer and technical requirements for the two top priority systems and ranks the technical requirements through the QFD process. The paper clarifies and defines each 'system' to establish key development directions for potential products and solutions.

This work investigates the key end user and technical needs from the systems, asking:

- Who are the main users and what are their key requirements for each solution?, and
- What are the key technical parameters and which are the most important?

Just as Beacon recognises that specific materials or technologies are part of the whole house or neighbourhood and cannot therefore be seen in isolation, neither can single products and components of a system be seen in isolation. Therefore a lifecycle approach using a Product System Assessment (PSAw has been used as a basis for assessing each system.

The purpose of this report is therefore twofold:

- Firstly to introduce the method by which any system can be reviewed and assessed
- Secondly to show how this method can be used, via case studies of two systems. These two case studies assess retrofit window systems and new wall systems. The case studies test the methodology and also provide guidance for the second stage of the Systems workstream.

As part of the Beacon systems project *"Criteria development and embedding systems"* this project also aims to establish priority areas for the development and uptake of the initial phase systems choice of innovative window retrofits and novel wall systems. The building solutions to be developed in the next phase of the programme will aid achievement of Beacon's goal of *"bringing the vast majority of New Zealand homes to a high standard of sustainability by 2012"* by "*developing systems that can be applied to both retrofit and new build situations to substantially improve their ability to perform to a high standard of sustainability*."

2.3.1 Structure of this report

Following an introduction which outlines the context and purpose of the study, the methodological approach is outlined in Section 3. This has been developed from the field of product development and has been modified for use at a systems level, so that it can be applied to any system under investigation.

The results for 'windows for existing homes' are described in Section 4, followed by the results for 'exterior walls for new homes' in Section 5. These sections also illustrate and explain each system and the key outcomes that are relevant for future research. A summary and recommendations section is provided at the end of the report, before references and appendices.

3. Background

The original intention of the Systems workstream was to create novel product and material technologies. However, to best achieve the HSS®, the research team had to consider that the system under review may not require a complete new solution, but the answer could be a specification framework for industry, an installation guideline, a revision to a standard, or a guide for consumers.

Typically, design parameters are established at a detailed, specific product level which makes defining them a simple analytical exercise. The problem that arises from this approach is that different parts that make up a system, can be designed in isolation. This project called for a higher level systems investigation, so the choice of which aspect of the system (category/solution/ component) required further investigation was not yet determined. Investigating systems requires the development of more generalised indicators rather than specific product criteria. This research was therefore broad and investigative with a focus on identifying potential systems design criteria.

The research investigated a range of solutions for each system, in order to define and prioritise the context and key performance indicators for both retrofitting of existing build residential window systems and wall systems in new houses. Investigating and establishing design parameters at a systems level was a key challenge. The research presented in this report adapted and modified, where necessary, two different product development methods to define design performance at a systems level.

3.1.1 Two approaches

This research used two different approaches to investigate and apply the HSS® criteria in the development of design criteria and performance indicators.

1. **Quality Function Deployment** – resulting in a set of prioritised technical criteria.
2. **Product System Assessment –** resulting in a set of key performance indicators.

Qualitative research was used in both assessment methods to determine key design criteria, however each assessment method used the information in differing ways to provide two different perspectives on the selected systems. Having two complementary approaches provided a broader base of information, and also allowed differing insight into the systems.

3.1.2 Choice of two systems

The approach that was applied to the choice of two systems for further research in this project is described in detail in the Prioritisation Working Paper of 16 June 2008 (Nebel et al. 2008). A summary of the choice of systems follows:

The top priority systems identified for **new built homes** were:

1. Windows
1. External walls
2. Ground floor foundations

The need for research on window systems and external wall systems for new built homes has been identified as equally important. However, only one system could be chosen for this part of the project. The external wall system was chosen as the system to study during these initial phases, and to focus on window systems in any future systems development work. It should be noted that significant learning from retrofit windows will be applicable to new windows and equally from new wall to retrofit walls[1].

The top priority systems identified for **existing homes** were:

1. Windows
2. External walls
2. Space conditioning (covering space heating, space cooling, and ventilation) = HCV

Window systems have been identified as the highest priority for retrofit and Table 1 and Table 2 show the prioritised lists for new and retrofit homes.

[1] ***At the outset of this programme a decision was made to have one retrofit and one new build system as initial case studies. However as a result of the WIP meeting of 15 August 2008, the interactions between walls and windows were seen to be very important to the success of the system solution so that although this research stream is looking at them as discrete and separate units, the results of all the various case studies need to be seen in light of a 'whole house', and particularly a 'whole thermal envelope'. To enable the systems work to be researched however, the house needed to be broken down into artificially discrete 'system' units.***

Table 1: Prioritised list for new homes

1	*Windows*
1	*External walls*
2	*Ground floor/foundations*
3	*Ceiling and roof system*
4	*Space conditioning (covering space cooling, space heating and ventilation) = HCV*
5	*Integrated water systems*
5	*Water heating*
6	*Ceiling/floor (e.g. between first and second story)*
6	*Internal walls and partitions (including finishing systems (mouldings, paint, wallpaper, etc.))*
6	*Lighting (natural and electrical)*
6	*Reticulated energy systems (covering electrical supply and gas supply)*
7	*Access (steps and stairs)*
7	*Doors (external)*
7	*Doors (internal)*
7	*Solid household waste*

Table 2: Prioritised list for existing homes

1	*Windows*
2	*External walls*
2	*Space conditioning (covering space cooling, space heating and ventilation) = HCV*
3	*Ceiling and roof system*
3	*Integrated water systems*
4	*Ground floor/foundations*
5	*Lighting (natural and electrical)*
6	*Water heating*
6	*Access (steps and stairs)*
7	*ceiling/floor (e.g. between first and second story)*
7	*Internal walls and partitions (including Finishing systems (mouldings, paint, wallpaper, etc.)*
7	*Doors (external)*
7	*Doors (internal)*
7	*Reticulated Energy Systems (Covering Electrical supply and Gas supply)*
7	*Solid household waste*

4. Methodology

4.1 Overview

This section outlines the approach used for the qualitative research, and the two methods employed to define the design criteria for building systems.

The qualitative research is based on a literature review and expert interviews. In addition, key stakeholders and relevant codes were identified.

The two methodologies for the development of design criteria were based on Quality Function Deployment (QFD) and Product System Assessment (PSA).

4.2 Qualitative research

The qualitative research incorporated a literature search and structured interviews with building industry experts including researchers in the field of structural engineering and window systems research, building components manufacturers, building practitioners, and professionals from local energy agencies who interact with the public via requests for window retrofits and insulation.

The results of the qualitative research were analysed with regard to the following aspects:

- Market environment;
- Categorisation of systems;
- Assessment of competing solutions;
- System life cycle and key stakeholders;
- Codes and compliance.

Environmental impacts are also a key consideration in the development of sustainable solutions for building systems. However they are not discussed in this report. A prototype of an LCA window calculator has therefore been developed in a separate project (Kellenberger, 2008) and will be used in the second stage of this programme. A wall calculator developed previously by Scion (Kellenberger 2007) will be available to the research team for the second stage of the programme. The results of those calculators provide an environmental assessment of window systems and wall systems respectively over their life span and take all materials used for those systems, into account.

4.2.1 Literature review

A qualitative approach to reviewing the academic, trade, and public domain literature (looking for underlying issues and needs of the existing window systems and retrofit solutions for windows; and wall systems) identified core functions and functional attributes, and end-user needs. These findings are outlined in the case studies' background sections of this report (*see sections 5 and 6*).

The literature research focussed on the following aspects:

- NZ best practice in the building sector
- Current trade practices
- Recent advances in building science

The following databases were used for the literature review:

- Scopus
- Science Direct
- SB02; 05 and 08 conference proceedings
- BRANZ website for research reports and Build Magazine index
- DBH website
- Yellow Pages online (which led to relevant individual manufacturer websites also)
- Internet

Semi-Structured interviews with experts

Telephone conversations with experts working in the field of window retrofits and wall systems were conducted to identify end-user needs, and the current market environment. The following industry personnel were consulted for their views regarding the availability of retrofit solutions, ease of installation of systems and issues with current performance:

- Trevor Pringle, Technical writer and Architect (BRANZ)
- John Burgess, Building scientist working in field of windows, particularly IGUs (BRANZ)
- Kevin Golding, Senior executive of major NZ wall board manufacturer (WWB)
- Bryan Walford, Structural engineer and senior scientist in timber engineering (Scion)
- Phil Hancock, Project leader of the Beacon home retrofits at Papakowhai, (Energy Smart)
- Katie Nimmo, Community outreach officer for retrofitting installation and education service (Community Energy Action)
- Alan Howlett, General Manager of store selling retrofit window systems (Window Shoppe)

The following questions were used as trigger questions in the interviews:

Windows for existing homes:

1 Current issues with existing windows?
2 Which do you see as main issue? Why?
3 My observations so far in the study have revealed…….?
(Record reaction/ verification/ disagreement etc)
4 What are customers/ end users looking for from retrofitting system?
5 What currently available retrofitting window systems are you aware of?
6 What do you provide to end users currently?
Popularity of these?
Pricing of these?

7 Suggestions for further information/ contacts I could go to?

Walls for new homes:

1 Current issues with existing building systems for walls?
2 My observations so far in the study have revealed…….?
(Record reaction/ verification/ disagreement etc)?
3 What are customers/ end users looking for from new wall system?
4 What current advances in wall systems are you aware of?
5 Suggestions for further information/ contacts I could go to?

Market Environment

Based on the literature review and feedback from the structured interviews, the market environment for both systems was analysed and provided an initial scoping stage, prior to the definition of requirements, that provides context to the assessment. Reviewing academic, trade, and public domain literature enabled an analysis of the context in which the system operated within the building sector. The market environment established key solutions currently in use, emerging issues and concerns of the sector, and building science advances and research regarding systems performance. This provided background context for interpreting the quantitative results from the QFD analysis. This phase established the current solutions on offer, any issues or research directions, and comparable performance in core function.

System Categorisation and Competing Solution Assessment

In order to provide further insight, alternative or competing solutions were assessed. Adequately assessing the various solutions that contribute to achieving certain functions in a system, is more difficult, however, given the wide range of solutions available. As this research investigates a system rather than a specific product or product context, the system solutions were categorised in solution-based terms in order to be comparatively assessed. For example, you cannot directly compare a double glazed window against a drape, although they are both competitive solutions for a retrofit window system, so the categories of ‘addition’, ‘complete replacement’ and ‘partial replacement’ were made.

Using the system categories, a comparative assessment was undertaken by analysing each category against the attributes, in order to provide a generic description of the available solutions (see Addendum reports 1 and 2).

Determining the System Life Cycle (SLC)

The System Life Cycle (SLC) is modelled to investigate the interactions between the system and the user, over the life span of the system. The SLC provides a mechanism for investigating the interactions and identifying the key life cycle phases of the users/actors, rather than an environmental assessment. The SLC selects the area which is likely to be the most important. This is often done at a stage in the development process where total proof of this is still required downstream. The life cycle strategies approach developed at TU Delft (Brezet and van Hemel, 1997) in the United Nations Environment Programme PROMISE Manual also provides guidance on selection of the key life cycle stage on general principles.

Codes and Compliance

In any product or process development, codes and compliance can form an important consideration and in the building sector this is definitely so. Anything that is developed or introduced that falls outside standard accepted practice and has to be considered as an acceptable solution, needs to prove its efficacy. In addition to this, there can be the requirement for a range of product declarations from regional and local authorities, which can directly impact on time and cost of product development and subsequent introduction.

The relevant standards (*refer Appendix A*) relating to the two systems have been identified to form a boundary for development. If designs fall outside of these parameters, it would have to be accepted that this would incur additional cost and time to provide proof of product efficacy and protection against liability costs.

4.3 Methodological approaches employed for the development of design criteria

The methodologies applied in this project need to fulfil the following requirements:

- Can be applied to 'systems' and are not restricted to the more traditional product design
- HSS® can be incorporated
- Based on user needs and converts those into quantifiable technical criteria
- Structured methodologies that are repeatable with experts and consumers

Quality Function Deployment as a proven and mainstream methodology in combination with the Product Systems Assessment (described in section 4.3.2) approach fulfils these criteria.

4.3.1 Quality Function Deployment

Quality Function Deployment (QFD) is a product development methodology originally designed to 'engineer quality' into a product by embedding the customer requirements in, during the early research stages. Established in 1966 as a quality design system by Drs Mizuno and Akao (Mazur, 2004), this is a methodology for taking the 'voice of the customer' and using that information to drive aspects of product development. It marries systems thinking with consumer psychology. It is used primarily in the development and upgrade of engineering design and consumer products, and usually incorporates the 'House of Quality' matrix (Hauser and Clausing, 1988).

To prioritise which aspects of the retrofit window systems and new wall systems should have further solutions developed, the QFD process was used. QFD is a well established method to provide guidance on how to engineer or 'design in' aspects of the solution that will address what the customer wants or is seeking from a product. This would result in an answer to the key project question of "*Which technical / uptake aspects of these systems should be improved or modified for greater fit with both Beacon's sustainability requirements, and also to get a better match with customer needs and thus increase the chances of uptake occurring?* "

The approach has been utilised and adapted to a system level in this project. In a traditional QFD process, the team would be looking to either:

- create a new product that meets consumer requirements, or
- modify an existing product to better suit the needs of the consumer.

The question is then focussed on which of the technical requirements are most critical to meet the end user needs. In this project the QFD approach has been applied on a systems level to determine the area within the system requiring greatest development focus.

For example: Is it the insulation or the structure of a new wall system, or perhaps it is an existing solution that hasn't been well implemented to date i.e. is there a new procedure or accepted technique required for replacement of single glazed units with IGUs, or perhaps the solution that would best achieve the goal is to install pelmets on every window?

The QFD process has therefore been used to highlight which mix of technical requirements has the greatest impact. These will be developed into performance targets to get the best capacity for a desirable solutions development in the subsequent stages of development work.

The QFD process has four classic stages:

- Defining the requirements via the 'voice of the customer'
- Identifying the highest priority breakthrough areas for better quality delivery (via the House of Quality)
- Developing representations of the delivery breakthrough
- Improvements in quality of the new technology solution to meet the highest quality standards (Geng, 2004)

This part of the project (Part A of the Systems workstream) involves research in the first two stages of the QFD process; the following two stages will be undertaken during Part B of the Systems workstream. To undertake these initial two phases of the QFD process, an understanding of the 'voice of the customer' in terms of end user needs; and also key technical requirements of the solution, need to be developed for input into a 'House of Quality' style scoring matrix.

Defining the Requirements

The QFD method involves the research and creation of two sets of requirements:

1. **Technical Requirements:** these are measurable requirements which are usually provided by the company undertaking the process, as key variables of their production process. In this case this is Beacon, and the HSS® criteria were adapted to be used as technical requirements.

2. **Customer Requirements:** these are the intangible requirements projected by customers. These are defined through research with customers during the market research phase, and by literary findings and trade literature.

The customer requirements were determined by the research team through the qualitative research.

The technical requirements were based on the HSS® criteria (Table 3). However, the technical requirements need to be measurable and therefore sub-criteria were developed. The results of the market environment analysis were also assessed alongside the Hierarchy of Criteria during the development of technical requirements. Both the technical requirement list and sub-criteria were modified further during the Product System Assessment (PSA) process of defining the functional attributes, and again refined during a QFD workshop on 17 July.

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Table 3: Hierarchy of Criteria developed for prioritisation of systems based on Beacon's HSS® (Nebel, 2008)

Criteria	Sub-criteria
Sustainability	Energy
	Water
	Indoor Environment Quality
	Materials and Waste
Uptake	Future Flexibility
	Buildability
	Affordability
	Desirability

Defining the Relationships

Once the customer requirements and the technical measures were defined, the QFD matrix was created.

Figure 2 briefly illustrates the process of using the QFD matrix. The customer requirements are listed on the left hand side, and the technical requirements along the top. Note that the interactions between various technical requirements can be seen as a trade-off in the 'roof' of the matrix. This, however, was not seen as a necessary requirement of the design team when assessing at a systems level. It is at this point a relationship is created between the customer requirements and the technical requirements. The sum of each technical requirement score across all customer requirements is recorded at the base of the matrix; those with the highest scores indicate key performance areas to consider during development. A workshop to complete a QFD matrix was held on 17 July 2008 in Rotorua with a range of technical experts[2] (building industry; building scientists; structural engineers; building products manufacturers; product designers) where a relationship was created between each requirement.

The strength of the relationship is important to the outcome, so a scale needs to be used. The scale chosen to establish the linkages (Table 4) is advocated by experienced researchers in this field (e.g. Mazur, 2004; Tapke et al, 2004). The stronger the absolute relationship value that a technical requirement has with the customer requirements, the higher the score and the level of development priority. Logically this would signal an area where a development team should concentrate.

Table 4: Relationship scale for QFD

Relationship	None	Weak	Medium	Strong
Scale	0	1	3	9

2 Workshop attendees were: Bryan Walford (Scion) (facilitator); Karen Bayne, Barbara Nebel and Doug Gaunt (Scion); Timothy Allan and Kylie Baker (Locus Research); Trevor Pringle and John Burgess (BRANZ); Kevin Golding (WWB); John Jamieson (Fletcher Aluminium); and Bob Greenbury (GJ Gardner Homes). Bryan Walford facilitated the event, with guidance on how to complete the matrix, and leading a discussion of results with attendees.

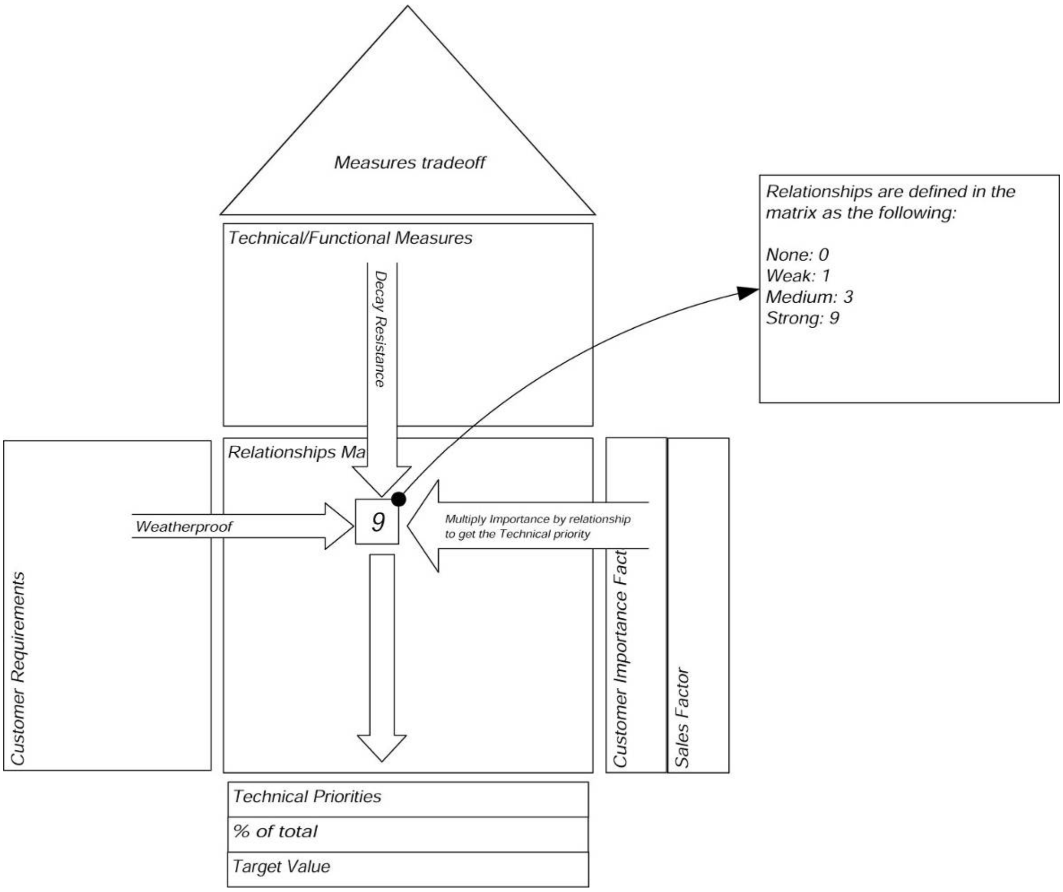

Figure 2: QFD matrix illustration *(Source: Allan, 2005)*

4.3.2 Product System Assessment

Investigating the product system is considered essential to the integration of a life cycle thinking approach into product development. Goedkoop (1999) describes the product system as "*a set of material products needed to jointly fulfil a user's needs*". Emerging systems thinking realises the need to set product-service relationships into a life cycle system to enable the appropriate context. Product service systems using the product system approach to incorporate the aspects of manufacturing, distribution, retail, use, and disposal over the product life cycle, in conjunction with 'voice of the customer' and LCA requirements, is an emerging field. The research team has used this approach previously (Allan, 2005) and both Scion and Locus Research are enhancing the method through recent research work. In this regard, the following diagram broadly illustrates the research team's interpretation of a product system (Figure 3).

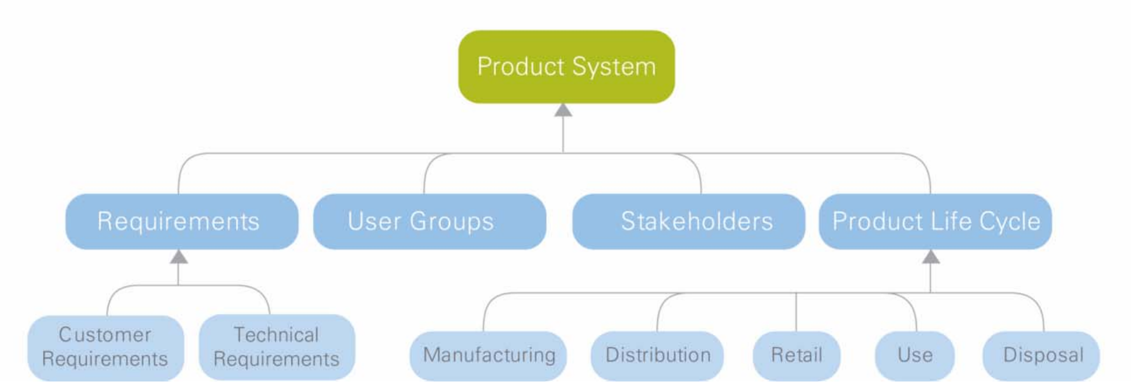

Figure 3: Product System Diagram (Locus Research 2008)

The Product System Assessment (PSA) method aims to create a clear and defined understanding of the system by focusing on functions and attributes, and the interactions of these. This section details the investigation and establishment of the following components:

1. **Core Function:** captures the system function in a single concise statement.
2. **Attributes:** describe the system function in more detail.
3. **Criteria:** broad performance-based criteria grouped using attributes.
4. **Key performance indicator:** specific performance indicators based on criteria and HSS^{TM} criteria

The relationship between Core Function, Attributes, Criteria and Key performance indicators is outlined in Figure 4.

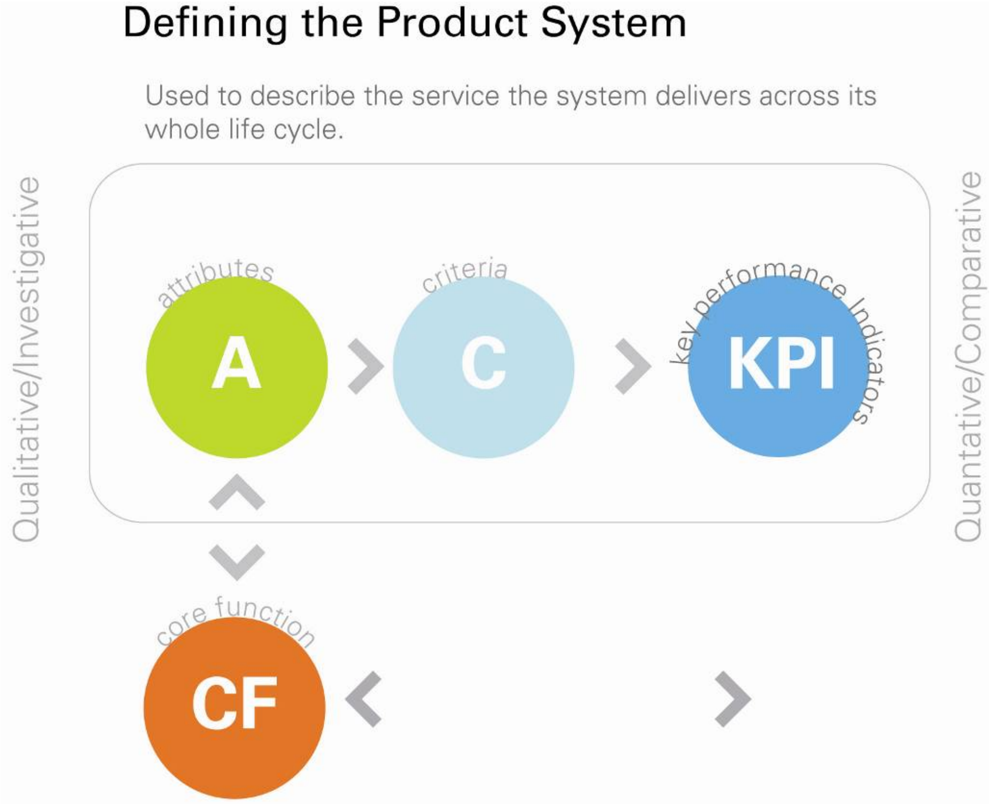

Figure 4: Relationship between Core function, Attributes, Criteria and Key performance indicators

Defining the System Core Function

The development of the Core Function, Attributes and Criteria were based on the literature review and qualitative research undertaken for the QFD approach. Learnings from the QFD workshop and discussions held with the experts at this workshop were also taken into account.

In order to create a 'system oriented' view, the 'core function' needs to be defined. The system's core function effectively defines a product system, rather than just the object itself. It is conceptually similar to a 'Functional Unit' which is used in life cycle assessment (LCA). A 'Core Function' statement was developed for each of the two selected systems. This statement encapsulates the functional attributes of a system including the service being provided by the product system during its life-span.

Define the Attributes and Criteria

The attributes express all the essential functions of the system elaborating on the core function by providing qualitative values, whilst the criteria are performance based, more specific, and are grouped under each attribute. This is expanded further to provide a list of parameters which are measurable and are grouped under criteria.

Key Performance Indicators

Specific performance targets for functional attributes are required to enable designers to improve product systems. These parameters have been crafted into Key Performance Indicators (KPI's) which provide guidance for any subsequent solution development. They are based on the following rankings

- Ranking of solutions against criteria
- Ranking design criteria against the HSS®

5. Windows for existing homes

The results presented in this section provide the background for the development of design criteria for windows for existing homes as well as the results of the development of the design criteria.

5.1 Background

This section sets the context and also provides the results of the qualitative research that was used in the development of the design criteria.
Included are the following aspects
- market environment
- the categorisation of solutions for windows in existing homes
- an assessment of existing solutions
- system life cycle and key stakeholders
- a brief overview of relevant code and compliance documents

5.1.1 Market environment

Window systems have evolved in response to technology advances, architectural styles and interior fashion trends. Similarly, fashion has dictated what various window treatments (blinds, drapes, pelmets etc.) are available, while textile technologies have allowed thermal backed curtains with reduced porosity and light penetration.

Improved technologies are available on the marketplace, but are not yet being adopted in any great numbers by New Zealand households. Windows are also seen as a fairly permanent housing fixture rather than a commodity item. However, John Burgess of BRANZ[3] predicts that window trends will go the way of Europe, where windows are replaced more frequently and seen as a commodity item of fashion. Installation of double glazing in a retrofit context appears to still have a number of issues to address. Some of these concerns are due to the combination of consenting for retrofit with tradesperson inexperience in the systems. Additionally, there is a sense that there is nothing wrong with the existing glass systems – it is the increased energy costs that need to be combated – and that these window systems have served us well for many years and thus will continue to do so with only minor alterations (Burgess, 2006). New Zealand norms with regard to window systems (having internal window sills, being able to open their windows outwards, having internal drapes and curtains and relaxed security) have prevented market acceptance of some of the more common Northern hemisphere systems, such as turn-tilt designs and five-point locking mechanisms. That they are not usually available in aluminium also deters uptake of imported systems, and the exceptional range of colours and sizes available in aluminium supports the monopoly market share of aluminium-based systems.

[3] ***John Burgess pers. comm., July 2008.***

Burgess (2006) shows the new window market is dominated by aluminium framing (~96%), with less than 5 % market share of non- aluminium systems, and 1% for thermally broken aluminium framing. However, the market size for retrofit shows a slightly different picture, where a number of older residences have retained single-glazed, timber framed joinery. Storey et al. (2004)—cited in Ryan (2008)— estimates 1,040,000 housing units aged pre-1979, and Burgess (2006) estimates there are over 800,000 residences in NZ with single-glazed, timber framed joinery. This figure is derived from an estimate of the likely window-frames in residences from pre-1970 before the introduction of aluminium joinery had a significant impact, and is slightly greater than the estimate of Storey which gives 738,000 pre-1970 houses.

Existing windows breakdown

A recent estimate of the housing stock by decade[4] (Figure 5) coupled with the types of window framing present in that era (Shaw, 1997; Hill, 1976) shows that though there is still a significant number of timber-framing units (~ 755,000), the bulk of housing stock are likely to be represented by single-glazed early aluminium window systems (around 850,000). The photo images in Figure 4 represent the housing typologies outlined in Ryan (2008) (*For a further breakdown of window types currently in the housing stock by Beacon typology, refer to Appendix B).*

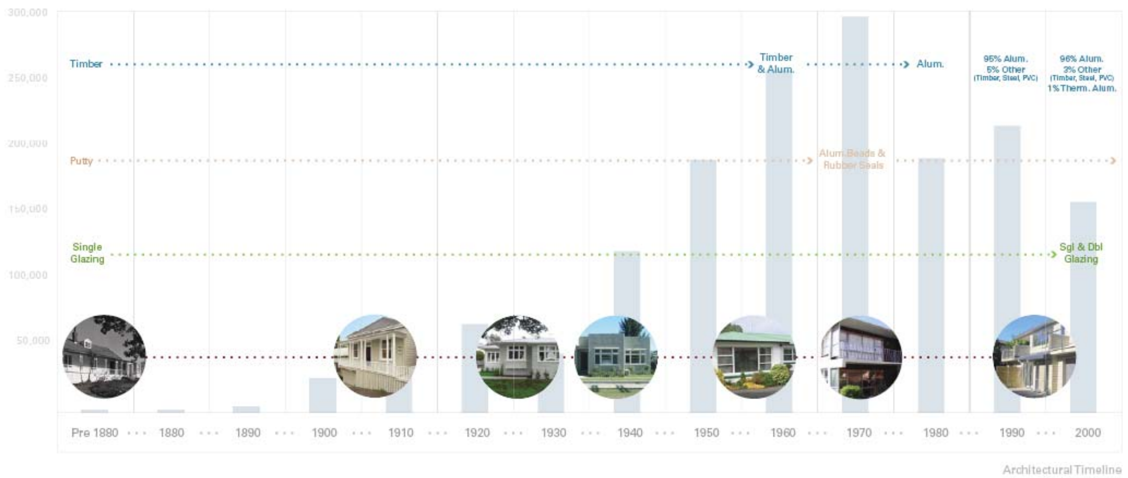

Figure 5: Timeline of window styles and current housing units in building stock

Additionally, there are a small but growing number of homes from the pre-1960 era that are replacing the traditional timber frames for double-glazed aluminium units.

Feedback during the 2008 Canterbury Home Show[5] confirms that undertaking window retrofits effectively is a major concern to homeowners in Canterbury, and that there is presently an unfulfilled demand for a low-cost solution (or solutions package) to reduce heat-loss through

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[4] ***From statistical datasets obtained from BRANZ via personal communication with Ian Page, June 2008***

[5] ***Personal communication with Community Energy Action, July 2008***

glazing[6]. The majority of the enquiries at the Home Show were from homeowners wanting a secondary glazing system to fit existing aluminium windows.

Any system or solution would require ‘simple steps’ and messages for uptake and DIY installation – as an example, the Community Energy Action clients are having enough trouble getting their heads around the a) need for and b) science behind, insulation – let alone a double glazing system.

Current solutions

Homeowners are seeking to retrofit their window systems primarily for:

- heat loss reduction
- noise control
- to control condensation
- prevention of UV damage to furnishings in summertime

There is a scale of options for homeowners to consider, with new thermal drapes and draughtstoppers at one end, and triple+ glazing at the other end of the spectrum. Depending on budget, skills, and the property’s unique characteristics, there are existing options to suit.

There are a range of agencies who are stakeholders in the retrofit windows market, including:

- Double glazing manufacturers
- Window joiners
- Secondary glazing suppliers (e.g. Magic Seal™)
- Energy retrofit agencies such as Community Energy Action (CEA)

The seven generic ‘stepwise’ retrofit solutions already in existence include:

- Heavy drapes and pelmets
- Films
- Draughtstopping
- Secondary glazing
- Resetting of windows
- Retrofitting of existing timber frames
- Installation of insulated glass units (IGUs) in place of single glazing

Heavy drapes and pelmets

In addition to thermal-backed materials and textiles, plain ‘blackout’ curtaining can be obtained for fitting either as a backing to non-thermally backed curtains, or as an additional drape for an extra thermal heat prevention and light prevention layer. A number of studies indicate that simply employing heavy drapes and pelmets can have significant benefits for the price. The Sustainable Energy Agency of Victoria, Australia (Sustainability Victoria, 2008) show that heavy drapes and pelmets are very effective in reducing heat loss through the window (See Figure 4).

[6] *Personal comm.. Katie Nimmo, July 2008*

The University of Texas (2008) also calculates that adding drapes to a bare window could reduce the heat loss by 37% on a single glazed window, and thermally backed or insulated drapes would reduce heat loss by 56%. However, this is calculated on a still air environment. If a pelmet is not used to stop the convective flow of air behind the curtain, then the effect of the curtains can actually increase condensation occurring on the windows.

Lloyd (2007) retrofitted a number of homes and found "*the use of drapes ($3,960) or window plastic reduced heat loss by around 25 W/K, which is equivalent to a window thermal conductivity reduction of 3.8 W/m2K. This result is better than the reduction expected for aluminium framed double glazed windows ($10,925), and is similar to the reduction in heat loss if double glazed windows with wooden frames had been used, but at much less cost*".

Films

Recent treatments (such as 3M's Scotch Tint™ and Prestige Window Films™) are able to significantly reduce UV while providing clear non-tinted viewing. Films can reduce glare and tints allow privacy during the daytime, however at night the tinting allows less privacy as the occupants find it difficult to see out the window, while it is much easier to see inside the home. Reflective heat can also damage vegetation near the windows.

Draught stopping

Draught stopping works to seal draughts coming from older windows (usually non-aluminium) which are caused by movement of the timber over the years, poor-fitting catches, and non-sealed components. Sealing doors and windows provides energy cost savings of up to $40 per year, giving a payback period of 1.25 years[7]. Lloyd (2007) in a study of retrofitted homes for air tightness found that "a 25% reduction [in heat loss] can be obtained by using mostly foam strip materials on doors and opening windows". Using temporary measures Bassett (1996) found it was possible to improve the average building airtightness by 50%. Adhesion of foam seals can be hampered due to damp sills from condensation and mould, and peeling or flaking paint (Howden-Chapman, 2005; Bassett, 1996).

Secondary glazing

These units sit in front of the pane of glass on the interior of the window frame, and provide an air gap for insulation purposes. These are usually plastic or acrylic in nature, and come in three forms:

- A permanent sealed fixture which lasts in place up to five years. These are professionally installed with magnetic sealing systems, and have cutting templates to deal with handles and window hardware for a tight and secure fit. Most units do not inhibit the view, and have very few failures due to condensation and moisture ingress.
- A semi-permanent framed fixture which can be removed in the summer time. The seals are sometimes magnetic, or taped, and provide an effective seal, but can only be used for two seasons or so.
- A plastic 'kit' which is a DIY option for homeowners, and provides a single-season solution.

[7] ***Pers. Comm. Katie Nimmo, CEA, July 2008***

Plastic window insulation kits are most effective when the window frame is at least 10-20 millimetres (mm) thick. About 12 mm thickness is the optimum insulating value for the distance between panes. Some aluminium window frames are thinner than 10 mm, and plastic secondary window insulation may not be effective on these very thin frames. The plastic self-DIY kits require a 10 mm gap in the frame, and there is insufficient gap for this in many aluminium frames. CEA are aware of one secondary glazing unit from the UK that fits aluminium frames. They have tried unsuccessfully to source this unit, and have therefore been unable to determine if this would be feasible to use on existing aluminium windows[8].

Because getting the air-gap in place is most important, not the extra panel of glass, secondary glazing in many cases is a more economical and simpler option to the installation of IGUs. The cost of installing Scotch-tint™ and Magic Seal™ in a typical house (about 35 panels) is around $6,000-$7,000, which is about a third the price of double glazing a home. Window Shoppe has not experienced any major issues with professional installation, only recalling two failures on about 2000 jobs[9]. Secondary glazing also offers benefits over IGU replacement in historical or decorative windows – particularly those with colonial small transom panes and dividing muntins, as the look can be retained.

Resetting of windows

Sealing and resetting windows will lead to a reduction in heat loss caused by cold outdoor air infiltration and will reduce the heat loss of a house. Bassett (1996) states "*In a pilot trial on one house, 83% of the target airtightness was achieved using standard carpentry practices of re-setting windows and doors, and caulking leakage openings in the interior lining with a sealant*" and estimates that a 50% reduction in air infiltration can be expected in most houses by resetting windows and doors, and caulking leakage.

Retrofitting of existing timber frames

Timber or PVC frames increase the thermal value by 30% over a non-broken aluminium frame, significantly reducing condensation (Burgess, 1999b). BRANZ has developed a fully commercialised technology (TRIG) for upgrading timber single-glazed units to incorporate IGU inserts (Burgess, 2006). Standard timber window sashes don't have a wide enough (10mm) rebate to accept IGUs, neither may older aluminium windows.

Installation of IGUs in place of single glazing

Various issues have evolved in relation to the ability of the industry to successfully install these units. A series of innovative solutions have been developed, which include: a sloped rebate for timber window installations; specification and technical solutions for the installation practice; and packers and wand support bars for taking the additional size and weight of the windows. BRANZ-introduced innovations in IGU for New Zealand conditions include the 'blue' sloped setting block, and also 15 degree sloped primed timber rebates (Burgess, 2000; Burgess, 1999). A gap between panes can double the R value of the timber window, or increase it by 30% for an aluminium framed window without thermal breaks (Burgess, 1999b).

[8] Katie Nimmo, pers. Comm., July 2008.
[9] ***Pers. Comm Alan Howlett, July 2008.***

While triple glazing is becoming more popular in Europe, Burgess (2006) warns that there are physical and economic limits to the use of multi layer glazing. Additionally, triple glazing does not increase sound performance over double glazing with a significant air gap (BRANZ, 1998). The increased weight of the new IGU windows could potentially cause structural issues to the surrounding wall frame and structural loadings, although there is little evidence of recent upgrades having this problem (Burgess, 2008). The issue is complicated in that usually it isn't a builder or architect that specifies the IGU replacement unit, it is the homeowner, and they fail to appreciate these aspects. A potential issue for future upgrades would be the new requirement for a weathertightness cavity in walls with monolithic claddings – this could cause structural issues if used in combination with more weighty double glazed units than the originally specified single glazed unit.

Installing retrofitted window systems effectively still has a number of issues. These are based around six main problems:

1. The existing space and walls not being adequately plumb, or leaving sufficient tolerance to install another unit.
2. Insufficient knowledge and experience by the building fraternity in what is required to install modern window systems. This is further complicated by the idiosyncrasies of double glazed units, and the need for compliance, permits, consents and window standard revisions.
3. The weight and size of IGU units.
4. The ability to extract existing window frames without damaging surrounding cladding and linings; and to install IGU units with wider sills.
5. Insufficient frame thickness on some aluminium framing systems to allow secondary glazing to be installed; and insufficient rebate thickness of timber and aluminium sash to allow for IGUs to be installed.
6. There is currently no standard for installation of IGUs in a retrofit situation.

Performance comparisons for heat loss across various window system solutions

Both the Tasmanian Environmental Centre(2008) and Sustainability Victoria (2008) show that the most important aspect in retrofitting is to create a still air space, and to improve the overall 'R' value of the window system from room to exterior. The studies show that, while double glazing with heavy drapes and pelmets is the most efficient solution, this may not be the most cost-effective or easily achievable option. Interestingly, in Table 5 below (Tasmanian Environment Centre, 2008), heavy drapes and a pelmet or fixing the top of the drape to the wall (such as Roman blinds) achieve similar results to installing double glazing units but at significantly cheaper cost and greater installation ease.

Polystyrene shutters are also very effective, but may not be culturally appropriate or acceptable to New Zealanders. Lloyd (2007) supports this opinion, and found that "*External shutters, as used in many other places in the world, were also considered but again this option was outside the comfort zone of suppliers in New Zealand and a suitable contractor was not found to offer such a product*." Figure 6 indicates performance in summertime conditions for Australia, showing awnings and shutters offer good protection from heat gain, while double glazing without further shading devices offers limited additional protection from heat gains.

Table 5: Winter heat loss compared to bare glazing for different window retrofits

Heat loss relative to single glazing

Bare window, single glazed	100%
Vertical or ventian blinds	100%
Holland blinds, no pelmet	92%
Heavy lined drapes, no pelmet	87%
Double glazing	69%
Heavy lined drapes, with pelmet	63%
Double glazing with low e-coating	57%
Polystyrene shutters, good air seal	50%
Double glazing, heavy drapes and pelmets	47%

Source: http://www.tasmanianenvironmentcentre.org.au/content/documents/WebWindows.pdf

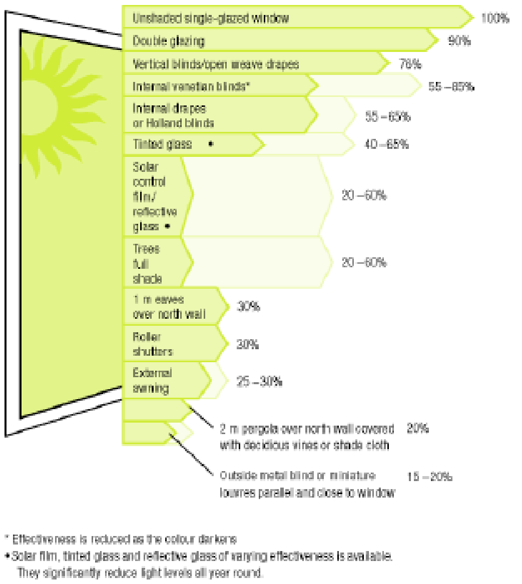


Figure 5.13: Comparison of heat gains through different window treatments in summer

Source: http://www.sustainability.vic.gov.au/resources/documents/Window_protection.pdf

Figure 6: Summertime heat gains compared to single glazing for different window retrofits

Cost benefits of the systems

Lloyd's 2007 study of retrofitted homes in Dunedin, Otago, gives a cost comparison for drapes and double glazing: initial cost of $3,960 for window drapes compared to $10,925 for double glazing. The additional heat saving for the added cost of double glazing was just 258KWh per annum, the drapes providing 4.2% energy savings, and the double glazing 6.5% energy savings.

The retrofitting process for installing IGUs is expensive (in the region of $20,000-30,000), and does not guarantee a repayment from resale value. This contrasts with similar costs for upgrading a kitchen and bathroom, with almost guaranteed return on investment from resale. The expense to replace single glazing units is outside the current budget of most homeowners. According to Katie Nimmo from the Community Energy Action (CEA) in Christchurch, an agency that aids low-income householders and homeowners with retrofitting for energy efficiency, expecting people to replace existing window systems with new IGU double glazing is "*a joke… if people cannot afford to install a heat pump, there is no way they will be able to afford to double glaze even part of their homes*."[10] Katie Nimmo told of a woman who was quoted $22,000 for the replacement of all the windows in her house with double glazing. This compared to using plastic kits that cost less than $200 and achieved considerable heat loss advantages. There is a large market for a cheaper but fairly effective solution rather than IGUs.

Heat losses from window systems

To reduce heat losses through a window, a sufficiently sealed air gap is required to ensure that heat flows are minimal. The main issue with present windows is: a) glass has low thermal resistance and b) the window system (including curtains/ blinds/ drapes) isn't air-tight. This means that:

- Any secondary glazed units must have sufficient seal attachments to the frame
- Curtain and drapes are close fitting, and have a pelmet or seal at the top to stop conduction and condensation forming on the window.
- The air in the gap between the drapes and the panes should be as still as possible (see Figure 7) to prevent a convective loop forming.

[10] ***Katie Nimmo, personal communication, June 2008.***

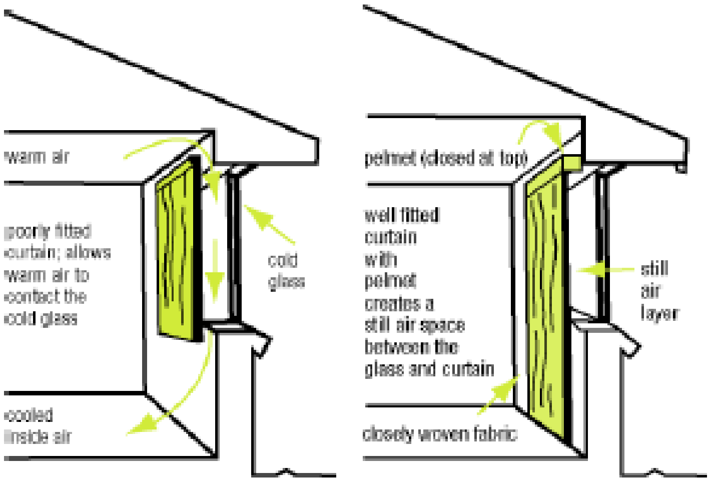


Figure 7: Convective loop due to poorly, and well-fitted, curtaining solutions[11]

5.1.2 System categorisation

To analyse the retrofit window system, it was necessary to 'categorise' the solutions for this system. For example it would not be feasible to compare an 'aluminium window frame' with a 'drape' or an IGU with a frame. The categories had to allow effective and fair cross-category comparison in a way that was meaningful for retrofit windows.

The windows were compared using three major categories:

1. **Addition:** elements that could effectively be added without replacing existing component parts.
2. **Partial Replacement:** elements that could replace existing elements in the system (such as glass) providing a performance improvement pathway.
3. **Complete Replacement:** these solutions required complete replacement of the existing window unit.

More developed characterisation is included in Appendix D with further divisions under the three major divisions. The Window Energy Rating System (WERS[12]) indicates there is a much greater difference between single and double glazing in general energy performance, than there is between alloy, timber and PVC frames (see Table 6). This has resulted in any specific framing material types being excluded from the characterisation, and subsequent competing solution assessments.

11 Source: www.sustainability.vic.gov.au/resources/documents/Window_protection.pdf
See movies showing heat flows at:
http://utwired.engr.utexas.edu/conservationMyths/heatingCooling/drapeDefense.cfm
12 Refer: http://www.design-navigator.co.nz/WERS2.html; http://www.wers.net/

Table 6: WERS rating of systems (WERS 1995)

		Glazing			
		Single Glazing (Clear)	Double Glazing - Standard (Clear)	Double Glazing - Standard + Low E	Double Glazing - Argon + Low E
Window Frame	Alloy	2	3.5	4	4.5
	Thermally Broken	2.5	3.5	4.5	5
	Vinyl (uPVC)	2.5	4	4.5	5
	Timber	2.5	4	4.5	5
	Composite	2	4	4.5	5

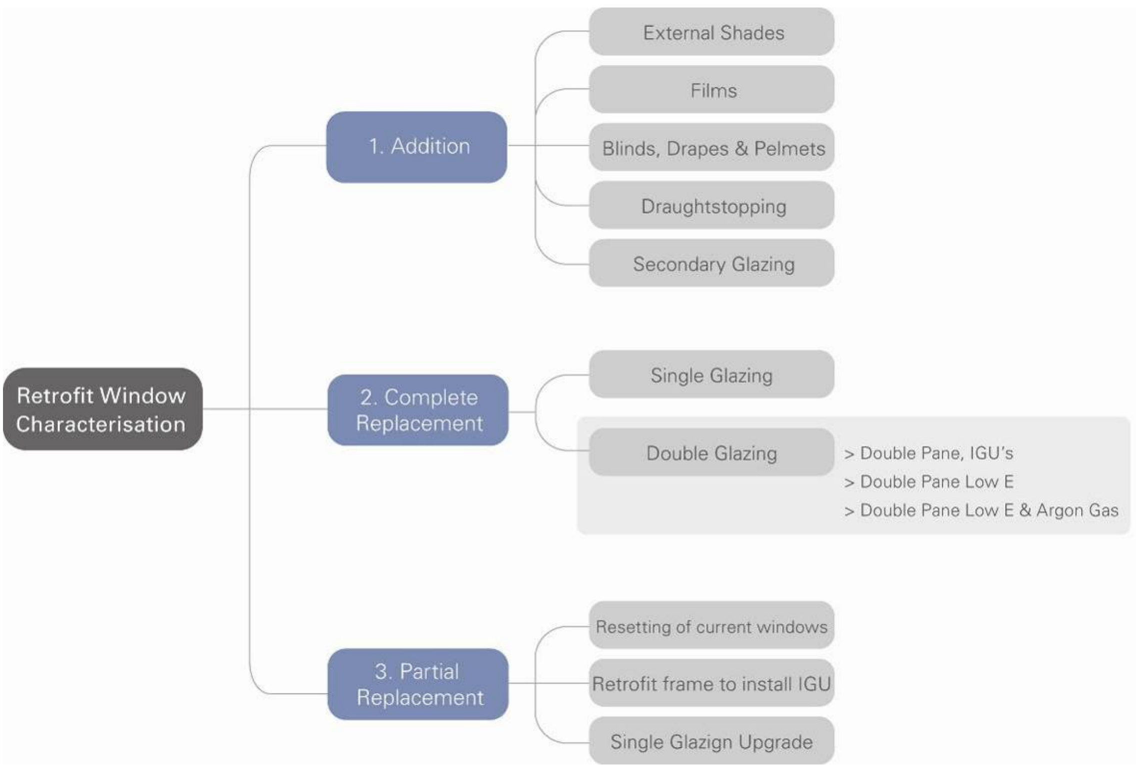


Figure 8: Retrofit Window System Categorisation

5.1.3 Competing solution assessment

The product characterisations are used to group the solution being assessed and the criteria for the assessment are the key attributes drawn from the development of the core function. Together these provide a systemic overview of the retrofit window context.

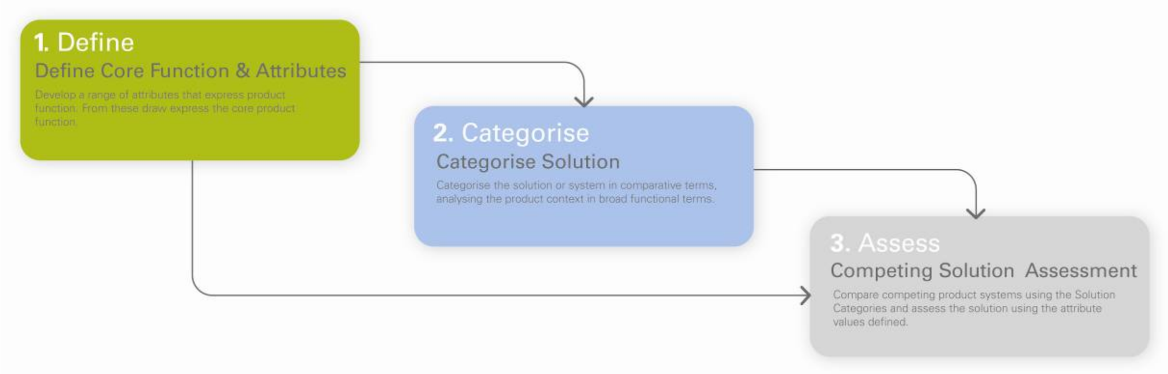


Figure 9: Product System Assessment steps

The competing solutions were investigated at a 'categorised' level to prevent getting drawn into micro-detail and cover a wide range of solutions. The visual summary investigated the products using the attributes established in Table 14. An example sheet is shown in Figure 10. The full assessment form is included in Addendum Report 1.

Figure 10: Competing solution assessment sheet

5.1.4 System Life Cycle (SLC) and key stakeholders

The system life cycle was developed in order to identify who the key users/actors are over the life of the system. Key life cycle stages and the stakeholders involved at the various stages over the life of the system are shown in Table 7

Table 7: System life cycle and key stakeholders

Lifecycle Stages	Description	User/Actor	Notes
1. Manufacturing	Solution components	Product Manufacturers	
		(Framing, Glazing, Textiles, etc.)	
2. Fabrication	Prefabrication of components	Window/Material Fabricators	
3. Specification & Sales	System specified	Specifiers	Cost and compatibility with the existing home must be considered when choosing or specifying the best system for the context. The cost must be relative to the gains or savings provided by the retrofit.
	Distribution	Architects	
	Retail of products	Builders	
		Merchant/Retailer	
4. Installation	Addition and/or Replacement	Builder	Retrofitting of a new system includes the partial or complete replacement of existing window/framing components, or the addition of furnishings to the interior or exterior of the window to increase its thermal performance. Once again, context should be considered to provide an appropriate level of performance.
		Installer	
		Home Owner	
5.Product Lifespan	Use	Home Owner	Retrofitting of the system aims to provide increased performance of the thermal envelope, including regulation of temperature, acoustics, and humidity. Maintenance of the system is to factor in the lifespan of the system, this will include cleaning, refinishing, and replacement of components over its life.
	Maintenance	Tradesman	
6. End of Life	Disassembly of system	Home Owner	The system may be dispersed across more than one aspect at the end of its life. Some components will be disposed of to landfill, others utilised in another context, and some remanufactured into new materials.
	Reuse	Builder	
	Recycle	Manufacturer	

5.1.5 Codes and compliance

Retrofitting a new window system will require compliance with structural, durability and performance requirements of the New Zealand Building Code (NZBC) along with the relevant New Zealand Standards (NZS4223) for glazing. A full outline of the requirements for clauses of the NZBC is given in Appendix A.

Adherence to any additional principles or rating schemes is not compulsory but will provide measurable aspects on the environmental and functional performance of the system.

Mandatory Compliance

The retrofit window system must comply with various aspects of the NZBC that cover installation and performance of the window. These have been outlined in the Level Series on Windows that is produced by BRANZ[13] and covers clauses on the following:

- Structure
- Durability
- Fire Safety
- External Moisture
- Internal Moisture
- Hazardous Building Materials
- Safety from falling
- Ventilation
- Airborne and impact sound
- Natural light
- Energy Efficiency

A building consent is required for alterations (replacement of a window) and must comply with other provisions of the Building Code to at least the same extent as was present previously. This has been described as substituting 'like for like', fulfilling the requirements/ compliance of the replaced component or element. This could be leveraged to reduce the barriers to retrofit the new window system.

WANZ WIS

The Window Association of New Zealand (WANZ) Window Installation System[14] is certified alternative solution under the NZBC for the installation of windows and doors.

[13] *Refer* www.level.org.nz

[14] *Refer:* http://www.wanz.co.nz/

Weathertightness Testing

To determine the weathertightness of the system against external moisture (NZBC Clause E2 External Moisture) the following testing methods have been outlined by the Window Association of New Zealand (WANZ):

- *E2/VM1* The Verification Method E2/VM1 (NZBC: Schedule1) is only applicable for testing the weathertightness of windows in a cavity construction.
- *AS/NZS 4284:1995* A modified version of the testing procedure from AS/NZS 4284:1995 could be used for testing weathertightness of the window in a direct fix cladding system

NZS 4223

All glazing must comply with NZS 4223 Part 3 *Human Impact Safety* and all possible provisions of NZS 4223.

Optional Principles and Ratings

The HSS High Standard of Sustainability® (HSS®) covers the measurable aspects of the system that will improve the health of the home and the environment. Passive design makes the most of free, natural sources of energy, such as the sun and the wind, to provide heating, cooling, ventilation and lighting and to contribute to responsible energy use.[15].

The Window Energy Rating System (WERS) (WERS 1995) is a government supported rating system for window performance that uses a simple 5-star system to tell you how various window frame and glass options will perform. It advises you the best windows to use for keeping your house warm in winter, cool in summer, and for minimising fading damage. Window size, type and orientation is assessed through the home energy rating system (HERS) so WERS may only be applicable in the prescription of which pre-rated window is to be used at each particular site

[15] ***Refer BRANZ 'Level' series. http://www.level.org.nz/passive-design/***

5.2 Design criteria for windows in existing homes

5.2.1 Quality Function Deployment

The results of the workshop held on 17th July 2008 to complete a QFD 'House of Quality Matrix' for retrofit window systems are outlined in this section. Prior to the workshop technical and customer requirements were identified and then relationships between these requirements established at the workshop.

Requirements

Technical

The HSS High Standard of Sustainability® (HSS®) covers the main aspects of energy, indoor environment quality, water, materials underpinned by future flexibility, buildability, and affordability. Any retrofit window system developed by Beacon will address the aspects of the HSS® in each of these areas, for the home into which it is installed. A list of technical requirements were developed from the HSS® with sub-criteria to explain the criteria (as per the AHP process, refer Bayne, 2008). These were distributed to workshop participants prior to the July 17 workshop, and discussed and modified accordingly at the workshop before the QFD assessment was undertaken. This process ensured that the experts involved in the workshop had input into the technical criteria process, and also that the criteria were properly understood by participants such that they were able to undertake the assessment exercise. The technical requirements listed in Table 8 were assessed against the end user requirements during the QFD workshop.

Table 8: Technical Criteria – HSS® Grouped

Criteria	Sub-Criteria	Sub-Criteria
Sustainability	Energy	Heat Generation
		Low Energy Production
		Embodied Energy - Material Selection
	Indoor Environment Quality	Thermal Insulation
		Humidity
		Ventilation
		Internal Moisture Dispersal
		Noise/Acoustics
		Pollution
	Materials	Carbon Footprint
		% Content Recycled
		% Content Disposed
		% Content Reused
		Low Material Waste - Production
		Lifespan of product
		Impact Resistance of Glass
Uptake	Future Flexibility	Cleaning of Surface
		Low Maintenance Cost
		Upgrades
	Buildability	Consented
		Light Weight
		Ease of Installation
		Easy Finish (coating)
		Construction Waste
		Weathertight
		Operation/Use
	Affordability	Purchase Cost
		Incentive
		Return on investment

Customer

From the qualitative analysis, user needs in terms of their interactions with the system were identified. The key messages from this analysis were that:

- Any window retrofit must ensure that the core functional performance of the window is not compromised:
- Opening to outside (light penetration and ability to access external environment)
- Weatherproof
- Maintaining character/style of the home (this is particularly important in houses with sash windows, and stained glass transom windows)
- Maintaining visual/optical performance (i.e. no condensation forming, peeling films or creased/warped secondary glazing sheets)
- Any secondary glazed units must have sufficient seal attachments to the frame

- Curtain and drapes are close fitting, and have a pelmet or seal at the top to stop conduction and condensation forming on the window.
- The installation of retrofit IGU requires standardisation and training for effective installation practices to occur.

To account for these end-user needs, in addition to the core functional performance needs from windows, the following list in Table 9 has been developed as being representative of the "voice of the customer" for assessment of retrofit windows in the Quality Function Deployment (QFD) process. These along with the descriptive sub-criteria were distributed to workshop participants prior to the July 17 workshop, and discussed and modified accordingly at the workshop before the QFD assessment was undertaken. This process ensured that the experts involved in the workshop had input into the process, and that the end user requirements were properly understood by participants so they were able to undertake the assessment.

Table 9: 'Voice of the customer' end user needs

End User Needs	Sub Criteria
Opening to outside	Light penetration
	Able to physically access exterior
Views	Optical performance retained if retrofitted
	Privacy
Ventilation	Air flow
	Shut-off 'valve'/no draughts
Shade provision	Glare resistance
	UV resistance - doesn't damage furnishings
Security	Prevents intrusion by pest or criminal elements
Weatherproof	Stops moisture penetration
	Doesn't leak
Sufficiently sealed air gap	Thermal resistance
	Air tight
	Pelmets
	Curtains to floor, close fitting to walls and sills
	Heavy curtains
	Tight seal around window frames
	Protects inner seal of IGU
Reduces Condensation	Thermally broken frames
Quiet	Reduces outside noise penetrating
Internal window sills	Placement for coffee cups, ornaments etc.
Cost effective	Good features for initial cost
	Good features for ongoing cost
Maintenance / Easy cleaning	Does not build up dust or cobwebs etc.
	Cleaning ease
Installation Ease / Handling	Can be installed in non-straight and twisted openings
	Can be installed in upper levels without crane
	Large tolerances for fitting of non-standard sizes
	Ease of replacement/ retrofit
	Consenting procedures
Architecture	Maintains style and character of home and streetscape
	Maintains aesthetic

Relationships

The QFD workshop held on July 17 resulted in the 'House of Quality' style matrix provided in Appendix C. The results indicate that the aspects of Beacon's HSS® that are significant in retrofit window solutions relate to affordability and buildability aspects, as well as material/system lifespan.

The priority technical requirements which would most impact on achieving customer requirements, as ranked by the QFD workshop, are listed in Table 10 as weathertightness and operation/use. The participants assessed the significance of the relationship between the end user needs and the technical criteria on an absolute scale of 1-3-9. The technical requirements with highest overall points are those which need to be given the most consideration in the design of a new 'solution' as they are what impact most significantly on achieving the customer requirements.

Table 10: Ranked technical requirements as result from QFD workshop

Rank	Technical Requirement	pts
1	Weathertight	108
2	Operation/ Use	99
3	Lifespan of product	86
4	Purchase cost	81
5	Incentive	75
6	Lightweight	70
7	Return on investment	63
8 =	Thermal conductivity / heat loss	61
8 =	Consented	61
9	Ventilation	59
10	Upgrades	57
11	Prefinished components	52
12	Noise / Acoustics	51
13	Ease of Installation	45
14	Heat Generation	42
15=	Humidity	36
15=	Low energy production	36
17	Cleaning of surface	31
18	Internal Moisture Dispersal	27
19	Carbon Footprint	25
20	Low maintenance cost	22
21	% Content Recycled	19
22	Pollution	18
23	Impact resistance of glass	17
24	Low material waste	6
25 =	Construction Waste	3
25 =	Embodied Energy	3

To utilise these criteria in solutions development, measures[16] would have to be attributed to the technical criteria and the design targets (preferably a measure or band) would have to be set for the design and engineering team. This phase of the project looks at identification of the most useful technical criteria, rather than attempting any improvement of solutions at this stage, so the measures are not yet necessary.

Because the technical criteria used were based on the HSS®, analysis of the matrix also indicates the end user needs that have the largest influence in terms of meeting Beacon's HSS®. The consumer requirements were ranked by their total scores in the matrix and are qualitatively outlined here for clarity. Table 11 gives the priority end user needs that have the largest influence in terms of meeting Beacon's HSS® (as these were the basis for the technical requirements).

Table 11: Priority end user needs

1. ***Ventilation*** (ensuring airflow provision while maintaining airtightness when closed)
2. ***Opening to the outside*** (with implications surrounding weathertightness and heat loss)
3. ***Cost effectiveness*** (this appears to be highly significant for all uptake HSS™ characteristics)
4. ***The architectural style and integrity of the visual appearance*** (this can significantly impact on what can be achieved, and the types of solutions which would be appropriate)
5. ***A sufficiently sealed air gap*** (which has significant technical impacts in achieving the Beacon HSS™)
6. ***Weatherproof*** (This has very significant impacts on uptake aspects of the Beacon HSS™, particularly relating to buildability and affordability)

Ensuring these customer requirements are met during the solutions development stage will have the most likelihood of meeting targets for Beacon's HSS® aspects related to the system. This result provides a complementary result to the standard QFD House of Quality assessment, and gives additional insight into means of achieving the HSS®. Thus Table 10 and Table 11 together provide the result of the QFD House of Quality matrix assessment in defining relationships.

[16] ***By measures this means parameters or units which can be designed to and the design assessed on e.g. a measure for ventilation would be air flow rate per hour/ air changes.***

5.2.2 Product System Assessment

This section outlines results of the Product System Assessment (PSA) for retrofit window systems, including the core function, attributes, criteria and the key performance indicators.

Core system function

The core function of retrofit windows has been defined as:

> *"Regulation of light and indoor environment through easily installed aperture control systems"*

This core function outlines the service being provided by a retrofit window. The core function expresses the system's requirement for regulation of light and indoor environmental quality, whilst referring to ease of installation and the provisions for controlling the aperture created by/through the presence of a window.

The functional unit in Table 12 was used as an initial reference. This was developed in the context of the Beacon criteria system selection phase AHP (Bayne, 2008). This is focused on the thermal value of the system through the expression of a window area and the required frame length against the R-value. This captures what is regarded as the significant environmental impact of the product over its life.

Table 12: Retrofit Window Functional Unit

Double glazed window including frame with a specific R-value	Double glazing	$1m^2$ of double glazing
	Plastic, timber or aluminium frame	Required length of framing[17]

Attributes of the core system function

The attributes that express essential functions provided by retro-fit windows are based on the qualitative research undertaken presented in section 5.1.1 (Context). The findings of the qualitative research are summarised in the mind map as outlined in Figure 11. This mind map was generated by the research team and explores the value in both functional and emotional attributes of the product; it is included here as a reference only. The initial mind map is an investigation, and is not something that is a constrained final list of elements. It rather attempts to establish a link from research to design and by synthesising research information into a qualitative view that can be used for design process. The attributes that were defined in the process are shown in Table 13.

[17] ***Note that framing perimeter depends on the shape of the window. If it is square of 1m sides it will have perimeter of 4m; if it is 0.5m x 2m, it will have perimeter of 5m.***

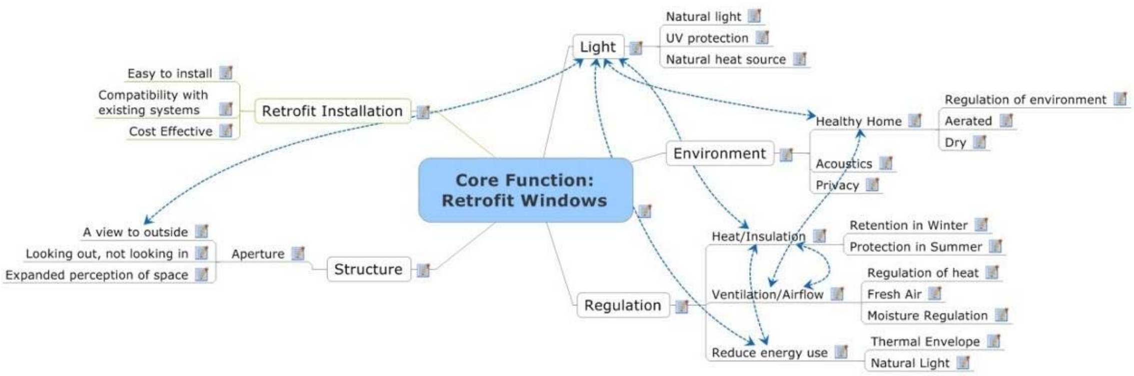


Figure 11: Core Function Mind Map

Table 13: Key Attributes of the retrofit window system core function

Light	Effectively capture visibility as well as the effects of light such as heat and UV damage.
Environment	With specific reference to the indoor environment.
Regulation	Needs to operate within other variables that cannot be controlled such as the exterior conditions and seasons (therefore cannot be 'controlled') but can be regulated.
Aperture	An aperture is an opening that can be either opened or permanently closed and encompasses the concept of the opening in a wall that a window requires.
Installation	A self evident attribute covers the installation; critically it should consider the compatibility of systems.

The functional attributes are grouped and explained in further detail to clarify their selection and relevance (refer to Appendix D for details). The definitions have been further developed by the research team to provide a qualitative basis for understanding the attributes. These definitions are not necessarily the same as those outlined in the New Zealand Building Code or relevant standards, but are provided to give context to the meaning of the 'attributes' as seen through the eyes of the design team. The attributes are then developed into criteria and then specific parameters. The attributes are a reference to the range of things they represent.

Design criteria

Specific design criteria were developed to describe the attributes in more detail (Table 14) These criteria were prioritised by the research team to form the key performance base indicators in the next step.

Table 14: Criteria grouped by attribute

Attribute	Criteria
Light	Visibility
	Protection
Environment	Heat
	Health
	Acoustic
	Privacy
Regulation	Heat/Insulation
	Air Quality
Aperture	Frame
	Structure
	Security
	Mechanical
Installation	Easy to Install
	Cost-effective
	Compatibility

Key performance indicators

Key performance indicators (KPI) were developed off the core function, key attributes and design criteria as described above to provide the basis for an analytical comparison of the current solution categories (i.e. additions, complete replacements, partial replacements) available for retrofitting windows. The KPIs illustrate how the system solutions (in the case of windows) performed against each attribute (and criteria) and the HSS® criteria.

Firstly the performance of different solutions was ranked against design criteria (Table 17). Secondly categorised solutions were assessed against the HSS® and then multiplied by the 'performance indicator' to obtain the 'key performance indicator' (Table 19). The results for all considered solutions are shown in Table 20. The key performance indicator is created by following the equation in Table 15.

Table 15: Creating key performance indicator

Performance Indicator	X HSS® weighted score	= Key Performance Indicator
Created by assessing solutions against design criteria (Table 17)	Created by assessing a solution against the HSS® criteria (Table 19)	The sum of taking the attribute performance indicator and multiplying it by the HSS® weighted score (total in Table 19)

Ranking of solutions against design criteria

In order to assist identifying the most relevant design focus, the solutions were scored against the attributes based on a scale as shown in Table 16 to develop performance indicators. The ranking is shown in Table 17. The following matrix was developed and used by the research team to assess attributes during the competing solution investigation. It could be also be used to get feedback from experts and end users to further solidify any downstream results (however this step was not undertaken during this research project due to time and budgetary constraint, and that the results required were indicative only). It is important to view this matrix in conjunction with the functional attributes to more fully comprehend the criteria.

Table 16: Attribute rating scale

Rating	Excellent	Very good	Good	Acceptable	Poor
Scale	5	4	3	2	1

Table 17: Design Criteria Ranking Matrix for Retrofit Windows

Solution		Light			Environment			Regulation		Aperture				Installation		
		Visibility	Protection	Heat	Health	Acoustic	Privacy	Heat/Insulation	Air Quality	Frame	Structure	Security	Mechanical	Easy to Install	Cost-effective	Compatibility
Addition	External Shades	4	4	2	4		1	3		2				4	3	1
	Films	1	1	3			3	2		4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
	Blinds, drapes, and pelmets	4	4	2	2	5	1	4	2	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
	Draughtstopping				3	1		3	2					5	4	5
	Secondary glazing	5	1	5	3	3		3	3	4	3	2	3	3	4	4
Complete Replacement	Single Glazing	5		5	3	2		2	2	4	5	2	5	2	5	4
	Double Glazing - Standard	5		5	4	4		4	4	4	5	3	5	2	3	4
	Double Glazing - Argon	5		5	4	4		4	4	4	5	3	5	2	3	4
	Double Glazing - Std + Low E	5	5	5	5	4	3	5	[illegible]	4	5	3	5	2	3	4
	Double Glazing - Argon + Low E	5	5	5	5	4	3	5	4	4	5	3	5	2	3	4
Partial Repl.	Resetting of current windows	5		5	2	2		1	2	4	3	1	5	1	1	5
	Retrofit frame to install IGU	5		5	4	4		4	4	3	[illegible]	3	4	2	4	4
	Single Glazing Upgrade	5	5	5	3	2	3	3	2	3		[illegible]		3	3	5
	Total	54	25	52	42	35	14	43	33	43	33	22	[illegible]	[illegible]	39	46

Attribute

Design Criteria

Weighting

System category Score used in Table 19.

The results of the design criteria ranking are two fold, including the ranking of the design criteria (bottom line of Table 17) for the system ‘window for existing homes’ and individual performance indicators for each solution.

The ranking of the design criteria is summarised in Table 18. High scores indicate that these criteria can be addressed with current solutions. Low scores indicate areas which could be significantly improved through design intervention. For example, the low score for the criteria “easy to install”, indicates that this might be related to an uptake issue.

The performance indicators are used in the development of the key performance indicators which also take the HSS® into account.

In this instance, scoring was undertaken by the research team based on their understanding of the system criteria, and the importance of each of these to the core function.

Table 18: Ranked criteria for window systems

Criteria	Ranking
Visibility	54
Heat	52
Compatibility	46
Heat/Insulation	43
Frame	43
Health	42
Opening/closing	40
Cost-effective	39
Acoustic	35
Air Quality	33
Structure	33
Easy to Install	33
Protection	25
Security	22
Privacy	14

Ranking design criteria against the HSS®

The ranking of the attributes with regard to their contribution to the HSS High Standard of Sustainability® was done by the research team when deciding whether a design criteria affects a certain HSS® criteria (Table 19). A qualitative scaling of 1 (it affects criteria) or 0 (is does not affect criteria) was applied. There fore a score of 1 is added to each square if the attribute affects the HSS® criteria column. This scoring can be then used across all categories within the system being assessed. For this project, the scoring was subjectively undertaken by research team members.

This was done for each solution. An example for ‘single glazing replacement’ is shown in Table 19 (See Appendix E for rankings of other solutions). Note that the performance indicator column is based on the results for ‘single glazing replacement’ of the criteria ranking in Table 17.

Table 19: Example of KPI/HSS® Criteria Matrix – Windows (Single Glazing replacement)

	Single Glazing Replacement	**Performance Indicator**	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	**HSS Total**	**Performance Weighted**
Light	Visibility	5	1		1					1	3	15
	Protection				1		1			1	3	0
	Heat	5	1		1						2	10
Environment	Health	3	1		1					1	3	9
	Acoustic	2			1					1	2	4
	Privacy					1	1	1		1	4	0
Regulation	Heat/Insulation	2	1		1	1		1		1	5	10
	Air Quality	2			1			1		1	3	6
Aperture	Frame	4								1	1	4
	Structure	5				1		1			2	10
	Security	2			1					1	2	4
	Mechanical	5			1			1			2	10
Installation	Easy to Install	2					1	1		1	3	6
	Cost-effective	5							1	1	2	10
	Compatibility	4					1	1		1	3	12
								Total:			40	**110**

The KPIs for all solutions of the system ‘window for existing homes’ are shown Table 20.

Table 20: Retrofit Windows KPI's

		Key Performance Indicators
Addition	External Shades	82
	Films	48
	Blinds, drapes, and pelmets	100
	Draught stopping	70
	Secondary glazing	116
Complete Replacement	Single Glazing	110
	Double Glazing - Standard	131
	Double Glazing - Argon	131
	Double Glazing - Std + Low E	166
	Double Glazing - Argon + Low E	166
Partial Repl.	Resetting of current windows	88
	Retrofit frame to install IGU	124
	Single Glazing Upgrade	123

It should be noted that not all solutions address the same issues. However, the solutions are not ranked against each other, but ranked against design criteria and the HSS®. Table 20 provides a balanced scorecard because it considers all performance attributes and all HSS® criteria. The highest scoring system categories are highlighted in a darker colour for ease of reference. Double Glazed Low E (both STD and Argon) scored the most highly against the combined attributes and HSS® criteria.

Key performance indicators across the various solutions on offer showed that visibility and heat regulation were the most important indicators (Table 18). The lower cost 'additions' have lower performance levels across all attributes although score highly in the installation area due to a good cost/benefit ratio. More costly full replacement solutions have a high median score but rank in the mid-range for cost efficacy as a result of (life) performance and cost avoidance. The total scores of the attributes (which totals all solution scores) was ranked and used to identify current areas where performance scored lowly.

This method provides an analytical basis for understanding how solutions perform comparatively against others within the same system. However, it should be noted that these results do not constitute 'consumer preferences'. These were determined during the QFD analysis in the previous section.

5.2.3 Conclusions

The significant parameters to consider from an assessment of the performance criteria and highly-ranking technical requirements appear to be:

1. Regulation (particularly weathertightness and heat)
2. Ease of installation (including purchase cost, return on investment and maintenance costs)
3. Environment (including maintaining ease of core functional operations)

The key requirements for retrofit window systems solutions appear to be four-fold:

- Address the issues surrounding weathertightness and moisture/air infiltration by better sealing of the units, and sealing of the frames on closure.
- Provide all exterior windows in inactive locations where people use their rooms most (e.g. lounge/living; bedrooms; kitchens) with a system which seals the convective air flow behind curtains and drapes. This, in reality, would entail a programme of uptake of heavy drapes and pelmets, where the drapes are close fitting.
- Provide an affordable secondary glazing system which can be retrofitted to a majority of aluminium windows where there is often less than a 1cm space in which to fit these.
- Provision of installation guidelines or a revised New Zealand Standard for installation procedures during replacement of single glazing units with IGUs.

The assessment of key performance indicators shows that double glazing provides the best benefits for window retrofitting in terms of heat regulation while retaining visibility and light. However, due to the wide range of window types and current systems in place in New Zealand houses, payback and performance of IGU compared to simpler measures may determine more efficiency benefits on a case by case basis. Therefore, it appears there may also be an opportunity solution which takes the form of a flow diagram for householders to determine the most effective package of solutions for their given situation, and provides information on where the various components of the solutions 'package' can be obtained.

6. Exterior walls for new homes

The results presented in this section provide the background to the development of design criteria for exterior walls for new homes and the results of the development of the design criteria.

6.1 Background

This section sets the context and also provides the results of the qualitative research that was used in the development of the design criteria. Included are:

- market environment
- the categorisation of solutions for exterior walls for new homes
- an assessment of existing solutions
- system life cycle and key stakeholders
- a brief overview of relevant code and compliance documents

6.1.1 Market environment

In a comprehensive consumer study of builders of high-rise apartments in Auckland, Te Morenga (2001) identified user needs for wall systems as:

- **Structural functions:** resistance against loads; connection of roof to floor thus transferring loads
- **Separation functions:** weather resistance; privacy; prevention of excessive heat gain or loss between the internal and external environment; containment and exclusion of noise between occupancies; fire protection; external and internal moisture control.
- **Miscellaneous functions:** thermal storage; admission of sunlight (via window);containment of electrical wiring, plumbing, and other services; provision of surfaces which may be decorated; attachment of internal furniture and fittings

Some key trends in wall use, building science and fashion that impact on wall design needs were also elicited from the qualitative literature review:

- Wall-mounted appliances and fixtures (eg. vanities)
- Insufficient fixing ability in light-framed (particularly gypsum) wallboard
- Increasing cabling requirements, and concerns regarding growth in radio-frequency from wireless applications (this may lead to desire for wall systems that can temporarily prevent radio-band penetration)
- Prefabrication and modern methods of construction (MMC).
- The integration and interactions of thermal insulation, moisture buffering capacity and mass-in-wall performance.

Paevere and Mackenzie (2006) outline emerging technologies and the market environment for the low-rise building sector. The major drivers and challenges they found are:

- Environmental sustainability
- Process integration and off-site production

- Demographics and social change
- Workforce issues (lack of qualified tradespersons and ageing of tradespersons)
- Increasing awareness of the impacts on human health and wellbeing (IEQ and OSH)
- The risk averse nature of housing market customers and sensitivity to fashion trends
- Regulatory environment
- Innovation and technology adoption

The authors state " new technologies that satisfy consumer demands and that also offer significant economical benefit to both the consumer and the builder as well as having a sound technical and code basis are those most likely to succeed". Builders that are most likely to be early adopters are more concerned about being a leader in the industry than about the impact of new innovations on their profits. In particular, these leaders are seeking "increased quality" as a market edge. The major impediments to the uptake of innovations and technology in the building sector are due to cost, and their subcontractors' reluctance to adapt to new products and materials.

One of the increasing drivers for new housing is affordability, and the need for more affordable low cost housing options. Wall systems comprise a large proportion of the housing structure, and impact heavily on both the initial and ongoing maintenance costs.

Bayne and Page (2007) highlight the increasing drivers of time to erect, and the increasing safety benefits and imperatives of having cleaner worksites, reduced working at height and reduced personnel on the worksite. These impact significantly on aspects such as site work requirements, prefabrication, trim waste and offcuts, contractor downtime and the installation practices, and equipment requirements for erection of the system.

6.1.2 Current Solutions

Current wall system solutions come under the following generic headings:

- Light framing advances
- Panellised sandwich construction
- Heavy walls
- Thermal and acoustic insulation
- Improved linings and claddings
- Stay-in place formwork
- Connection, bonding and jointing technologies

A brief description of each of these types of wall solution follows, including information on emergent or novel solutions.

Light framing advances

Light timber or steel framing for housing is well established within New Zealand, with light timber framing holding in excess of 90% of the current residential wall market. Estimates of residential light steel framing share vary greatly (from 1% to 5% market share), but are increasing. Since the introduction of pre-cut and prenail framing, and advances in steel roll-forming, kiln-drying and preservation techniques for timber, limited new solutions have become available on the market.

Two timber solutions that sought to address the issue of stud straightness are laminated veneer studs (using laminated veneer lumber ripped to size) and laminated timber studs. Both solutions have not developed in the marketplace to date due to added costs, however, a similar laminated idea for internal wall that is commercial in Sweden is SodraSmart. The Sodrasmart system uses a non-nail system of insertion into the bottom stud, where the stud is twisted into place. The studs are also laminated for straightness, but have notches for inserting cables and pipes to minimise wall thickness.

A new wall system incorporating wider stud spacing and thicker studs was proposed during the development of the Waitakere NOW Home® project (Collins et al., 2003). The proposed system consisted of 900 mm exterior wall stud spacing together with wider studs of 125 mm or 150 mm nominal width. Combined with 15 mm plasterboard or bracing plywood, this could provide both thermal insulation and potential cost savings if the buildability and market resistance aspects could be overcome in a cost effective manner. However, issues surrounding the logistics of thicker walls, combined with resistance by the building fraternity to move towards thicker plasterboard were at the time, considered insurmountable in terms of achieving a commercial offering. The concept feasibility should probably be reviewed during the next phase of development.

Panellised sandwich construction

Structural insulated panels (SIPs) or stress skin panels create a strong and stable energy-efficient building envelope that is quick to erect. Their popularity in this market is due to the low cost, structural integrity, built in thermal performance and pre-sheathed construction. The ability to combine performance and affordability with prefabrication has been a large incentive to uptake. SIPs are not a new technology, and have failed to gain traction in the Australasian residential marketplace although industrial buildings have had some uptake. The reasons for this have been mainly attributed to the dominance of light timber framing systems and a lack of sheathing. More recently, the system has been reinvestigated on its environmental credentials (Rudd and Chandra,1994). BASF[18] claim the key contributors to the environmental performance of SIPs include:

- Reduced heating and cooling loads over the lifetime of the home due to reduce leakage through insulation gaps and high R-values from no thermal bridging
- Low environmental impact of materials
- Low maintenance requirements
- Lightweight materials which reduce transportation fuel use

The opportunity of using bio-based foam inserts in SIPs is also being explored in New Zealand (McIntosh and Harrington, 2007), and worldwide, new panel configurations are being developed.

[18] *From BASF corporate trade literature*

Heavy walls

Massive timber construction

The natural air filtering, moisture buffering and low thermal conductivity of timber can provide a healthy interior environment. Massive timber systems consist of planks of wood which are nailed together in a factory to make a large panel of lumber, between 120 and 200mm thick. By laminating timber planks in a cross-ply manner, the wall decreases the effects of swelling and shrinkage. One example is Finnforest Kerto in Leno system (Figure 12).

Figure 12: The Kerto in Leno system

Earth building

Earth building techniques, though ancient, are becoming more prevalent, and a New Zealand standard has been developed (NZS 4298). The methods commonly used include rammed earth, adobe and pressed earth blocks, and poured earth wall moulds. Earth building has been advocated for similar reasons to massive timber – the breathability of the earth and ability to regulate dampness and thermal comfort from a combination of thermal mass and breathable, natural materials. Earth building, however, is not factory-produced, and is highly labour intensive and time consuming.

Concrete

The major advances in concrete wall solutions are autoclaved aerated concrete systems, e.g. Hebel (Figure 13). These can be used both as a panel cladding system on light framed construction, and also as a structural panel wall system (still used mainly for commercial buildings). Hebel has sound and thermal benefits, as well as being about five times lighter than standard concrete. This allows significant embodied energy savings over standard concrete masonry wall systems, 64% less than brick veneer[19].

[19] ***From Hebel trade literature and website www.hebel.co.nz***

Figure 13: Structural wall system using AAC from Hebel

Thermal and acoustic insulation

Improvements in foam/fibre insulation technologies are primarily to:

a) increase thermal performance by providing higher R-value
b) increase the acoustic STC rating
c) improve the ability to stay in place and fill the space using binders and spring-back technologies. For example, a gap of just 5 mm around the edges of insulation can reduce the overall wall thermal performance (R-value) by 50%, and leaving an unsealed gap between the cladding/ linings and the insulation can also have a detrimental effect on the wall thermal and acoustic performance. Several wool-batt and polyester-batt companies have developed novel binding systems to reduce sagging and slumping e.g. Latitude™ advanced resin bonding (www.woolbloc.co.nz).
d) improve the environmental performance by using recycled materials, natural fibres or bio-based polymers e.g. PinkBatts™ which use up to 80% recycled glass in their insulation product, Autex batts which use up to 85% recycled polyester fibre, and newer expanded bio-foams such as those developed by Scion for the Biopolymer Network using polylactic acid (PLA).

Stay-in-place (SIP) formwork

Stay-in-place (SIP) structural formwork consists of polymer based gridwork and insulation that works similar to insulated concrete formwork (ICF), allowing a concrete core to be poured in place. Early ICF technology did not offer a long-term cladding solution for the walls however, the newer SIP systems use interlocking PVC panels or steel V-ribs rather than expanded polystyrene as an outer cladding. The forms, made of concrete board (25 mm thick), reinforcing bars, galvanised steel and insulating material in the middle of the wall system surrounded by concrete, are separate panels connected together with concrete and reinforcing bars. The stay-in-place forms not only provide a continuous insulation and sound barrier, but also replace lining on the inside, and it replaces the first two steps of the stucco application process on the outside. One such system includes the Ultimate wall system from Nuform Building Solutions (Figure 14). There is also a foam-filled system, with a timber interior lining. These systems are usually used for light commercial buildings.

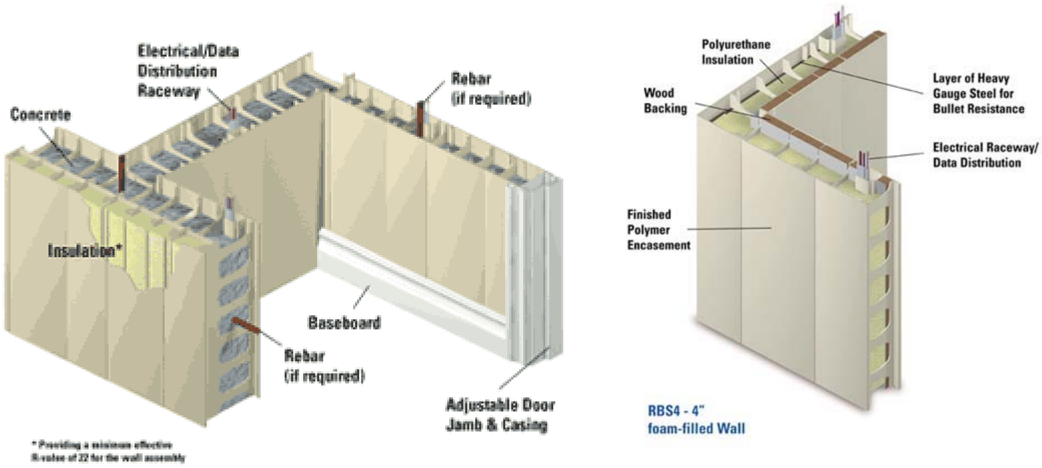


Figure 14: Ultimate building system

Connection, bonding and jointing technologies

Systems which have emerged to improve connection design include plastic nails, nail plates, and adhesive fastenings. Novel technologies include bioadhesives (e.g. use of plant and animal based tannins, chitin and other natural polymers), cam-lock systems and panel jointing systems. Additionally, a couple of innovations have emerged to aid installation of jambs and studs. The GRB jamb tie aids alignment and allows jamb-fixing without nail damage.

MMC

Modern Methods of Construction (MMC) consists of the offsite manufacture of panels and volumetric modules. The main benefits from MMC are in resource efficiency, speed of construction, high standards of design quality, improvement in onsite safety and overcoming skill shortages due to reduced labour requirements onsite (Bayne and Page, 2007). Although this prefabrication can add 7-10% to the overall build-cost, building with prefabricated components can significantly reduce the time to erect and therefore increase productivity in the building sector.

6.1.3 Performance considerations for wall systems

Thermal mass

R-values alone are not a good measure for thermal performance, due to the dynamic nature of thermal flows (Bellamy and Mackenzie, 2001; 2003). Heavy walls significantly improve thermal comfort for occupants during both day and night time by reducing over and under heating peaks, thus smoothing temperature peaks. Bellamy and Mackenzie (2001) found heavy walls could reduce annual heating energy by 7% and reduce overheating by 70%, by providing up to 3º C of cooling and improved cooling due to ventilation. Solar gain and insulation need to be carefully matched to the thermal mass of the walls for the energy savings to be realised. Thermal mass from solid massive timber systems have also been found to reduce purchased energy costs. Hameury (2005) states that the annual purchased energy is decreased by 10% with a massive wood construction relative to a lightweight construction of same U-value. It is important to also recognise the need to consider orientation, solar gains and window size, total mass, and how the various interactions between these elements impact on performance and requirements for increasing insulation CCANZ (2001).

Moisture buffering capacity

The ability of porous materials to 'breath', absorbing and releasing moisture while giving off and taking up thermal energy, and regulating the temperature and humidity of the indoor environment is potentially useful for indoor environmental quality. The heat of wetting and moisture buffering capacity of massive timber structures was measured in-situ for a massive timber building in Stockholm by Hameury (2005), showing significant smoothing of humidity within the indoor environment, similar to the impacts available from thermal mass for temperature.

A similar modelled study by Haque et al. (2006) indicated that while timber-lined walls would produce a heat of wetting effect, this was not enough to significantly impact the overall thermal comfort of occupants. The moisture buffering capacity of the timber-lined surfaces, however, could be better utilised in controlling indoor humidity and condensation.

These large timber systems have the ability to act as a passive system in keeping the indoor temperature and humidity within an acceptable range. Hameury (2004) points out that though other porous materials (plasterboard, AAC and wool) enable higher moisture uptake capacity, they are seldom left exposed as an interior or exterior surface, and are therefore barely activated.

6.1.4 System Categorisation

To analyse the new exterior wall system it was necessary to 'categorise' the system. Walls can be created using a wide range of material and component combinations. The categories had to allow effective inter-category comparison in a way that was meaningful for new exterior wall solutions. The categorisation of the walls was based on the major constituent parts of the wall which were defined as follows:

- **Cladding(C):** The part of a system that provides the weather resistance and protection from the elements, in effect this part encloses the wall system.
- **Structure(S):** The component parts within the system deemed to deliver the structural requirements of a wall including load bearing attributes.
- **Insulation(I):** The parts of a wall system that are largely responsible for the delivery of thermal resistance.
- **Lining(L):** The internal finishing surface of a wall that provides a visual finish and surface for decoration and attachment.

The analysis used the four component parts and the **degree of integration** as the major delineating factors in assessing the new walls. The conventional system (light timber frame, exterior cladding, insulation and plasterboard lining), which is termed the 'control', was assessed as having no component design integration. The parts are manufactured and delivered separately and can even be used by different trades.

Other systems analysed have differing levels and types of component integration. Figure 15 illustrates different levels and approaches to integrating components. An example of how this works is Solid Masonry, which is deemed by design, to integrate exterior cladding with structure, but still may require insulation and lining, whereas Structural Insulated Panels (SIP) integrate insulation with the provision of structure, but would require exterior cladding and lining.

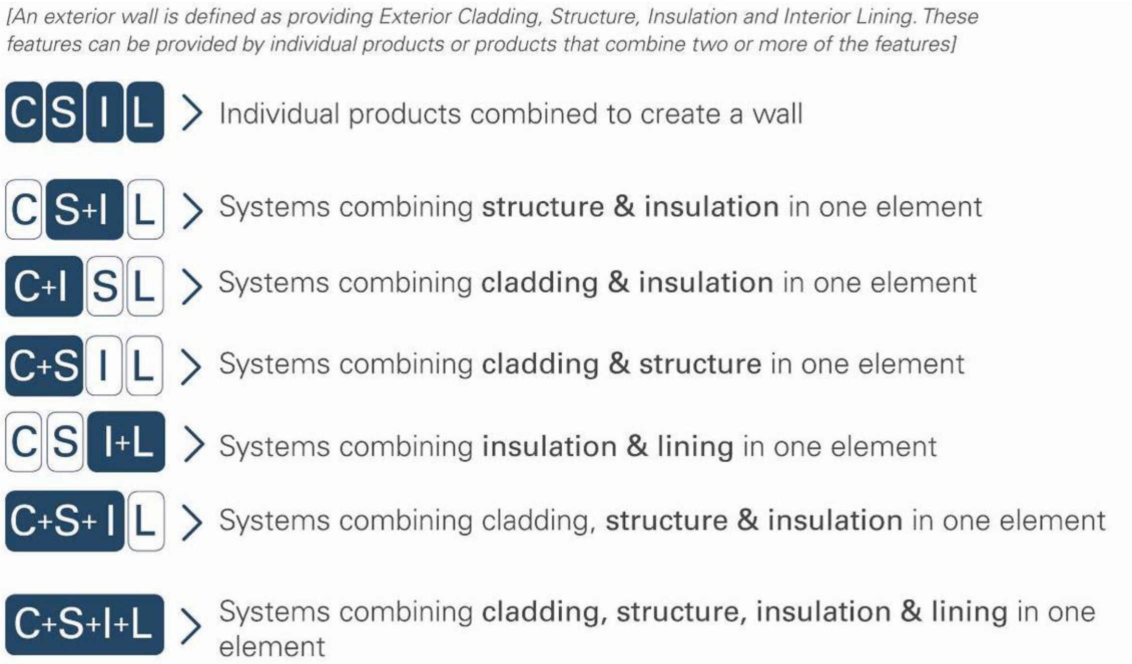


Figure 15: New Wall Category Key

Examples for the categories include:

CSIL	light timber framed with standard cladding and standard lining
C(S+I)L	structural insulated panels
(C+I)SL	exterior insulating foam panels (eifs) on light timber framed wall with standard internal lining
(C+S)IL	solid masonry
CS(I+L)	insulated drywall
(C+S+I)L	continuous insulated masonry
(C+S+I+L)	Lockwood

Many current systems fall into the CSIL category and don't have great variances in basic performance (although cost can vary significantly). Systems integration appears to have real potential in the New Exterior Wall space due to the lack of integration in current mainstream building systems.

6.1.5 Competing solution assessment

The competing solutions were investigated at a ‘categorised’ level to prevent getting drawn into micro-detail and cover a wide range of solutions. The visual summary investigated the products using the attributes established in Table 27. An example sheet is included in Figure 16 for reference here with a full copy provided in a separate Addendum Report 2.

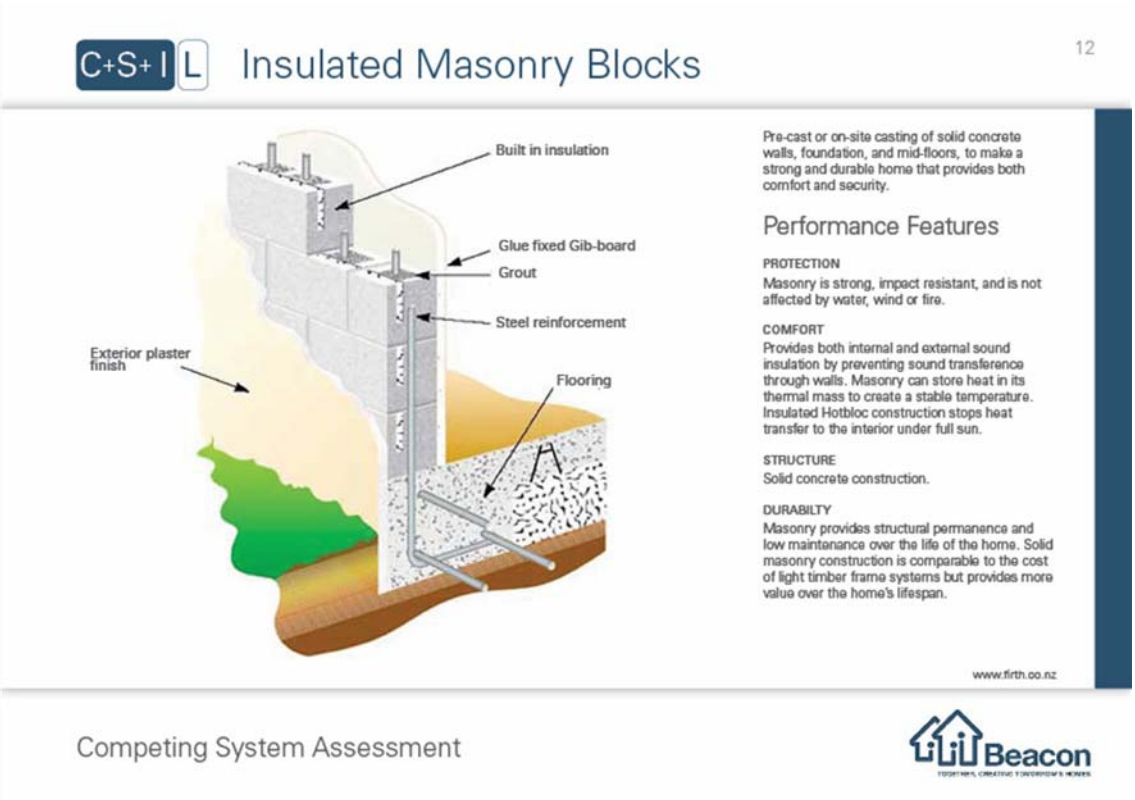


Figure 16: Competing solution assessment sheet

6.1.6 System Life Cycle (SLC) and key stakeholders

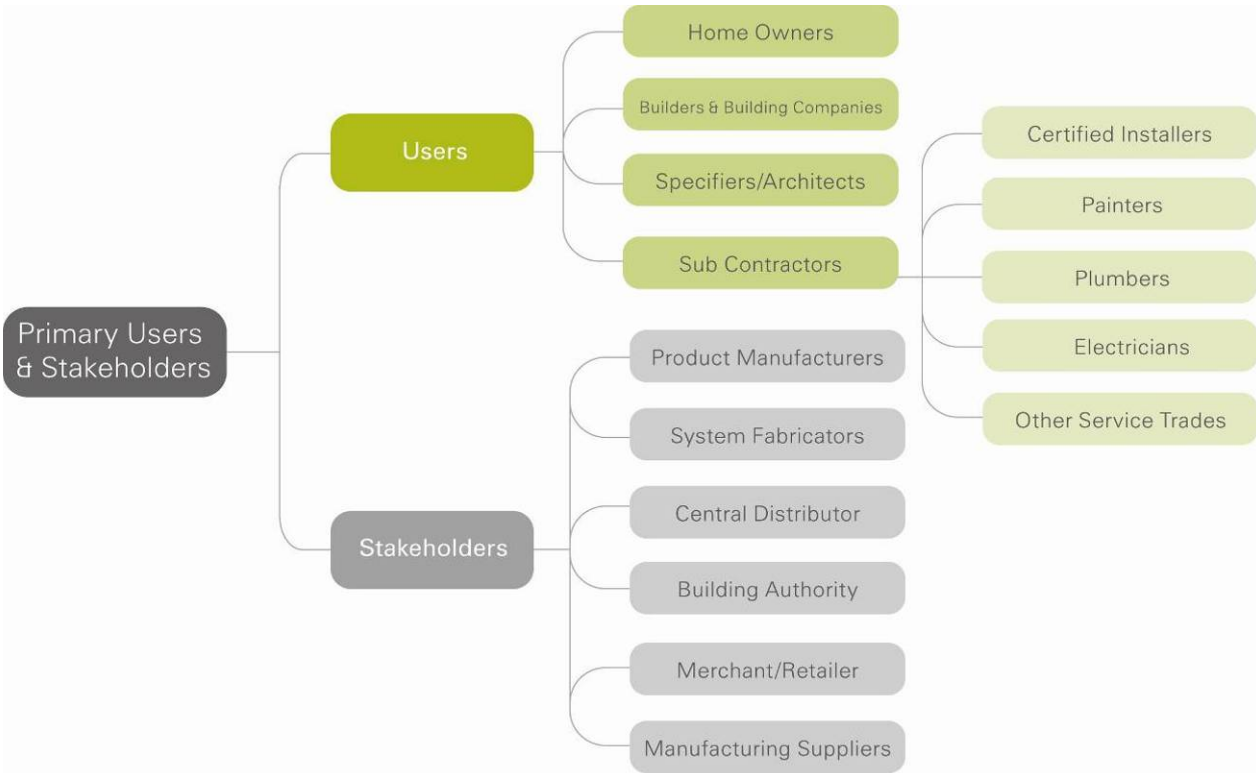
The system life cycle was developed to identify who the key users/actors are over the life of the system. Key life cycle stages and the stakeholders involved are shown in Table 21.

Table 21: *Product (Solution) Life Cycle*

Lifecycle Stages	Description	User/Actor	Notes
1. Manufacturing	Solution Components	Product Manufacturers (Timber, insulation, paint, indoor wall coverings etc)	
2. Fabrication/ assembly of sub-systems	Assembly and fabrication of sub-systems	System Fabricators	Possible step if a complete or partly pre-fabricated solution is used
3. Specification & Distribution	Specification, Code Compliance, Distribution and retail	Architect	Sold as a complete wall solution to new home builders through the Beacon housing scheme or direct from the manufacturer.
		Specifier	
		Building Authority	
		Builder	
		Merchant/Retailer	
4. Installation	Assembly on-site, Installation & Finishing of wall system, installation of services (integration of services functions)	Certified Installer	Installation of components or the complete wall system on site.
		Tradesman	
		Builder	
		Painter	
		Plumber	
		Electrician	
		Other services trades	
5. Product Lifespan	Intended Use	Home owner	Designed for optimal performance of the thermal envelope and maintenance of a healthy living environment. Upgrades to cladding (interior and exterior), surface refinishing, redecorating, etc. over the 50 year (structural) lifespan of the wall.
	Maintenance	Builder	
		Tradesman	
6. End of Life	Demolition of system	Home owner	Disposal of waste components to landfill. Use components of system in another context. Remanufacturing of salvaged materials
	Reuse	Builder	
	Recycle	Manufacturer	

The key users (or actors) and stakeholders that interact with the most important SLC steps (specification and distribution, installation, and use of the product over its lifespan) are outlined in Figure 17.

Figure 17: *Key Users & Stakeholders*



6.1.7 Codes and compliance

Fabrication of a new wall system for the New Zealand residential building market will require compliance with structural, durability, performance and environmental aspects of the New Zealand Building Code. A selection of relevant compliance documents on aspects such as energy efficiency, insulation and building construction is outlined in Table 22 for their potential relevance to the wall system context but cannot currently be analysed in detail since particular materials and methods of construction have not been defined for the wall system.

Table 22: Relevant compliance documents

Code	Name
NZBC	Schedule 1
NZS 3604:1999	Timber Framed Buildings
NZS 4246:2006	Energy efficiency: Installing insulation in residential buildings
SNZ/PAS 4244:2003	Insulation of lightweight-framed and solid-timber houses
NZS 3602:2003	Timber and wood-based products for use in building
NZS 4229:1999	Code of practice for concrete masonry buildings not requiring specific design
AS/NZS 4859.1:2002	Materials for the thermal insulation of buildings -General criteria and technical provisions
AS/NZS 2311-2000	Painting of Buildings
NZS 4218: 2004	Energy efficiency – housing and small building envelope
NZS 4214: 2006	Methods of determining the total thermal resistance of parts of buildings
AS/NZS4284-1995	Testing of Building Facades

In particular, those relating to the performance of the wall system in terms of thermal insulation and energy efficiency will be of interest to the Beacon development.

Adherence with any additional principles or rating schemes, such as the New Zealand Government-endorsed HERS, is not compulsory but may provide measurable targets for the environmental and functional performance of the system. Beacon's High Standard of Sustainability® will also provide a guideline for efficiency of the system.

New Zealand Building Code

The relevant elements of the New Zealand Building Code for consideration in the development of the new exterior wall system have been outlined in Appendix D.

H1 Energy Efficiency

The H1 Energy Efficiency clause of the NZBC defines the R-values that must be met for a range of construction types. The BRANZ House Insulation Guide (van Derff, 2007) has details and construction R-values for most generic construction products and systems used for wall construction in New Zealand. It is important to note that where a cladding is installed over a drained and vented cavity, the R-value of the cladding material must be down-rated by approximately 50% because of air movement (which is essential for drying) within the cavity. More information on R-Values and specific codes is provided in Appendix A.

6.2 Development of design criteria

6.2.1 Quality Function Deployment

The results of the workshop held on July 17, 2008 to complete a QFD 'House of Quality Matrix' for new exterior walls are outlined in this section. Firstly technical and customer requirements were identified and then relationships between these requirements established.

Requirements

Technical

Beacon's HSS High Standard of Sustainability® (HSS®) covers the main aspects of energy, indoor environment quality, water, materials, underpinned by future flexibility, buildability, and affordability. The following technical requirements (Table 23) were assessed against the end user requirements during the QFD workshop on July 17, 2008. In a similar manner to the windows assessment, the new exterior wall system criteria and subcriteria were developed prior to the workshop in order to qualitatively describe parameters. The criteria and subcriteria were discussed and modified during the workshop by the participants to be applicable to new wall systems.

Table 23: Technical Criteria – HSS® Grouped

Criteria	Sub-Criteria	Sub-Criteria
Sustainability	Energy	Heat Generation
		Low Energy Production
		Embodied Energy - Material Selection
	Indoor Environment Quality	Thermal Insulation
		Humidity
		Ventilation
		Internal Moisture Dispersal
		Noise/Acoustics
		Pollution
	Materials	Carbon Footprint
		% Content Recycled
		% Content Disposed
		% Content Reused
		Low Material Waste - Production
		Lifespan of product
		Impact Resistance of Glass
Uptake	Future Flexibility	Cleaning of Surface
		Low Maintenance Cost
		Upgrades
	Buildability	Consented
		Light Weight
		Ease of Installation
		Easy Finish (coating)
		Construction Waste
		Weathertight
		Operation/Use
	Affordability	Purchase Cost
		Incentive
		Return on investment

Customer

To account for end-user needs, in addition to the core functional performance needs from the PSA for new wall systems, the following list was developed and finalised at the QFD workshop in discussion with participants, as being representative of the "voice of the customer" (Table 24) for assessment of new exterior walls in the Quality Function Deployment (QFD) process:

Table 24 Voice of the Customer' end user needs

End User Needs	Sub Criteria
Structural functions	Resistance against loads
	Connection of roof to floor thus transferring loads
Separation functions	Weather resistance.
	Privacy
	Airtight against infiltration
Containment	Electrical wiring
Containment	Plumbing/gas
	Communication lines
Attachment of furniture and fittings	Screwholding of linings and cladding
	External bracing
Prefabrication of wall system components	Speed of erection
	Low specialist skill required to install
	Fit with existing infrastructure
	Limited off cuts and site waste
	Limited personnel needed onsite to install it
Low weight and low volume	Don't need a crane, and reduced transport costs
	Reduced storage
	Fits on truck
Wall straightness	Stiffness and support
	Bracing
	No distortion of studs
	Provision of surfaces which may be decorated
Insulation	Prevention of excessive heat gain or loss between the internal and external environment
	Containment and exclusion of noise
	Fire protection
	Moisture control
	Thermal Design
Installation	Improved education for specifications
Adaptability	Ability to change over time
Low maintenance	Long lasting and easy care coatings and replacement of elements
Architecture	Structural appropriateness and aesthetic for build type and neighbourhood
Economy	Affordability
Toxicity	Indoor air quality and exterior coatings
	Handling, creation of dust on installation or repair
Serviceability	Durability, toughness, maintenance needs and lifespan

Relationships
Assessment by participants at the QFD workshop, of the significance of relationships between the end user requirements and the technical requirements, resulted in the matrix provided in Appendix C. The scoring used was the same as that for the retrofit windows assessment.

The technical requirements as ranked by the QFD workshop are listed in Table 25. This indicates that the length of time the wall system is designed for, as well as the provision in the system for ease of upgrade and installation, are important considerations in meeting the end user requirements from the system.

Table 25: Ranked Technical Requirements

Rank	Technical Requirement	Pts
1	Lifespan of product	103
2	Upgrades	102
3	Light Weight	99
4 =	Ease of Installation	88
4 =	Purchase Cost	84
5	Weathertight	71
6	Surface Options	71
7 =	Prefinished components	67
7 =	Consenting process	67
8	% Content Recycled	54
9	Resilience	50
10	Impact Resistance	47
11	Construction Waste	46
12	Return on Investment	44
13	Thermal insulation	42
14	Low Material Waste	39
15	Low energy production	37
16 =	Operation / Use	36
16 =	Running Cost	36
18	Cleaning of Surfaces	34
19	Flammability / Combustibility	31
20	Carbon Footprint	26
21	Embodied Energy	22
22	Moisture conductivity	18
23 =	Humidity	13
23 =	Noise /Acoustics	13
25	Pollution	10
26	Ventilation	6

The table showed that the priority end user needs that have the largest influence in terms of meeting Beacon's HSS® (as these were the basis for the technical requirements) are:

1. ***Insulation and Thermal design*** (impacts on cost and thermal performance including embodied energy considerations)
2. ***Affordability and building economics*** (buildability and trade-offs with performance)
3. ***Architecture*** (impacts on lifespan of the system, and waste)
4. ***Adaptability*** (Lifespan of the system and waste, as well as installation impacts)
5. ***Serviceability and durability*** (Carbon footprint and lifespan coupled with maintenance, resilience and consenting)

6.2.2 Product System Assessment

This section outlines results of the Product System Assessment (PSA) for exterior wall for new homes, including the core function, attributes, criteria and the key performance indicators.

Core System Function

The core function for new exterior walls has been defined as:

"A durable exterior structure providing protection, interior comfort and the containment of services"

This core function outlines the service being provided by the new exterior walls. It expresses the systems requirement for a structure that is protective and durable on the exterior, whilst providing and maintaining a comfortable interior environment for the occupants. The accommodation or containment of services such as electricity and plumbing is also a necessary function of the system.

It is important not to restrict the view of performance to one that embodies only energy usage as the wall performs a range of other functions.

Attributes of the core system function

The 'attributes' are more expansive and embody the essential factors that need to be considered for exterior walls. The defined attributes are listed in Table 26. To establish the exterior wall core function, a range of attributes were developed in a mind map within the development team as outlined in Figure 18.

Table 26: New Wall Attributes

Protection	Provision of a secure place to live in, protected from the elements and against fire damage.
Comfort	With specific reference to the living conditions of the indoor environment.
Structure	The ability of the system to both enclose a space and support the load of the building while also being able to withstand impact and movement.
Durability	Pertaining to the longevity of the system, including maintenance and the potential to upgrade elements over the life of the home.
Services	Containment of the necessary wiring, plumbing, etc., plus the provision of apertures for access and surfaces for decoration or furniture attachment.

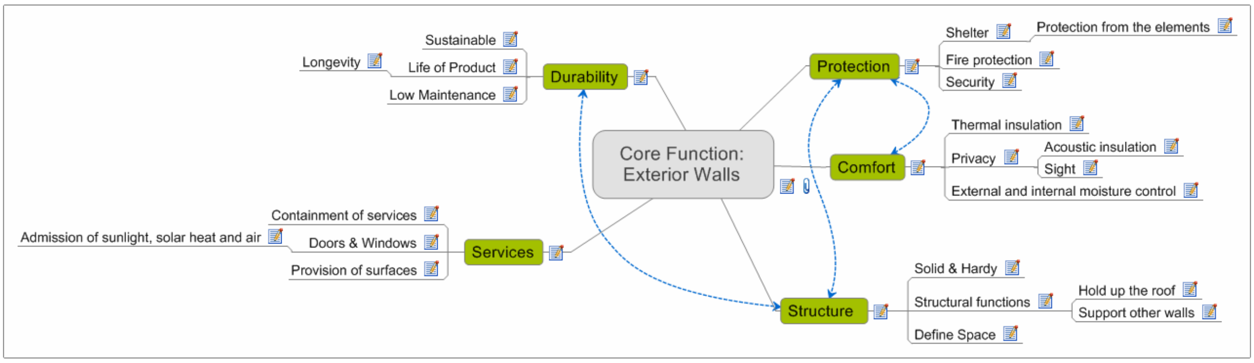


Figure 18: Core Function Mind Map

The functional attributes for new exterior walls are grouped and explained here in further detail to clarify their selection and relevance. These also explore some of the intangible, soft elements which are required from the system. The definitions have been developed by the research team to provide a qualitative basis for understanding the attributes. These definitions are not necessarily the same as those outlined in the NZBC or relevant standards, but are provided to give context to what the terms are understood to mean in the context of this report.

Design criteria

Specific design criteria were developed to describe the attributes in more detail (Table 27) These criteria were prioritised by the research team to form the key performance base indicators in the next step.

Table 27: Criteria grouped by attribute

Attribute	Criteria
Protection	Shelter
	Fire protection
	Security
Comfort	Thermal insulation
	Privacy

	External and internal moisture control
Structure	Solid & hardy
	Structural functions
	Define space
Durability	Sustainability
	Longevity/Life of product
	Low maintenance
Services	Containment of services
	Doors & windows
	Provision of surfaces

Key performance indicators

In a similar manner to the development of key performance indicators (KPI) for windows, the approach was used to develop KPIs for exterior wall systems.

KPIs were developed of the core function, key attributes and design criteria as described above, to provide the basis for an analytical comparison of the current solution categories available for exterior walls. The KPI's illustrate how the system solutions performed against each attribute (and criteria) and the HSS® criteria.

Firstly the performance of different solutions was ranked against design criteria (Table 28). Secondly categorised solutions were assessed against the HSS® and then multiplied by the 'performance indicator' to obtain the KPI (Table 31). The results for all considered solutions are shown in WHAT and where is able 30??.

Ranking of solutions against design criteria

In order to assist identifying the most relevant design focus, the solutions were scored against the attributes to develop performance indicators (Table 28).

Table 28: Design Criteria Ranking Matrix for Exterior Walls

		Protection			Comfort			Structure			Durabilty			Services		
		Shelter	Fire protection	Security	Thermal insulation	Privacy	Ext. & Int. moisture control	Solid & hardy	Structural functions	Define space	Sustainabilty	Longevity/Life of product	Low maintenance	Containment of services	Doors & windows	Provision of surfaces
Control	C+S+I+L	4	2	4	3	2	4	4	4	5	4	3	2	5	5	5
2-Part Int.	[C+S]+I+L	5	5	5	4	4	3	5	5	5	3	5	5	2	3	
	[C+I]+S+L	5	5	4	4	4	5	4			4	4	5		3	
	C+[S+I]+L	5	4	4	4	4	5	5	5	5	4	5		4	4	
	C+S+[I+L]		4		4	4		4			4	4	5	3	3	5
3-Part Int.	[C+S+I]+L	5	5	5	5	5	2	5	5	5	3	5	5	2	2	
Fully Int.	[C+S+I+L]	4	1	4	3	2	5	4	4	5	5	4	4	4	5	5
		28	26	26	27	25	24	31	23	25	27	30	26	20	25	15

Rating	Excellent	Very good	Good	Acceptable	Poor
Scale	5	4	3	2	1

The results of the design criteria ranking are two fold, including the ranking of the design criteria (bottom line of Table 28) for the system 'exterior walls for existing homes' and individual performance indicators for each category.
The ranking of the design criteria is summarised in Table 29. High scores indicate that these criteria can be addressed with current solutions. Low scores indicate areas which could be significantly improved through design intervention.

The performance indicators are used in the development of the KPIs which also take the HSS® into account.

In this instance, scoring was undertaken by the research team based on their understanding of the system criteria, and the importance of each of these to the core function.

Table 29: Ranked Criteria for Wall systems

Attribute	Criteria	Total
Structure	Solid & hardy	31
Durability	Longevity/Life of product	30
Protection	Shelter	28
Comfort	Thermal insulation	27
Durability	Sustainability	27
Protection	Fire protection	26
Protection	Security	26
Durability	Low maintenance	26

Comfort	Privacy	25
Structure	Define space	25
Services	Doors & windows	25
Comfort	Ext. & Int. moisture control	24
Structure	Structural functions	23
Services	Containment of services	20
Services	Provision of surfaces	15

Ranking design criteria against the HSS®

The ranking of attributes with regard to their contribution to the HSS High Standard of Sustainability® was done by the research team deciding whether a design criteria affects a certain HSS® criteria (Table 30). A qualitative scaling of 1 (it affects criteria) or 0 (is does not affect criteria) was applied. There fore a score of 1 is added to each square if the attribute affects the HSS® criteria column. This scoring can be then used across all categories within the system being assessed. For this project, the scoring was subjectively undertaken by research team members.

This was done for each solution. An example for 'systems that combine cladding and structure' ((C+S)IL) is shown in Table 30 (See Appendix E for rankings of other solutions). Note that the performance indicator column is based on the results for '((C+S)IL' of the criteria ranking in Table 28.

Table 30: Example of KPI/HSS® Criteria Matrix - Cladding and Structural Integration Exterior Walls

	[C+S]+I+L	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Protection	Shelter	5			1		1	1	1	1	5	25
	Fire protection	5						1		1	2	10
	Security	5			1			1	1	1	4	20
Comfort	Thermal insulation	4	1		1	1		1	1	1	6	24
	Privacy	4			1					1	2	8
	Ext. & Int. moisture control	3	1		1					1	3	9
Structure	Solid & hardy	5				1		1		1	3	15
	Structural functions	5				1	1	1			3	15
	Define space	5	1		1			1			3	15
Durabilty	Sustainabilty	3				1	1		1	1	4	12
	Longevity/Life of product	5				1	1		1	1	4	20
	Low maintenance	5				1				1	2	10
Services	Containment of services	2				1	1	1			3	6
	Doors & windows	3	1		1			1			3	9
	Provision of surfaces									1	1	0
								Total:			48	**198**

The key performance indicators for all categories of the system 'exterior walls for new homes', are shown in Table 31. The low scores indicate areas which could be significantly improved through design intervention.

Table 31: Exterior Walls KPI's

		Key Performance Indicator
Control	C+S+I+L	180
2-Part Int.	[C+S]+I+L	198
	[C+I]+S+L	161
	C+[S+I]+L	201
	C+S+[I+L]	117
3-Part Int.	[C+S+I]+L	200
Fully Int.	[C+S+I+L]	190

Table 31 shows the total HSS® weighted scores for the exterior wall results with the highest score containing the highest performing type of system. The highest scoring system categories are highlighted in a darker colour for ease of reference. The KPIs explain how the categories (in the case of wall systems) performed against each attribute (and criteria) and Beacon's HSS® criteria. This provides a balanced scorecard because it considers all performance attributes and all HSS® criteria.

It should be noted that the categories are not ranked against each other, but each category is ranked against design criteria and the HSS®. This provides a balanced scorecard because it considers all performance attributes and all HSS® criteria. The highest scoring system categories are highlighted in a darker colour for ease of reference.

This method provides an analytical basis for understanding how solutions perform comparatively against others within the same system. However, it should be noted that these results do not constitute 'consumer preferences'. These were determined during the QFD analysis in the previous section.

6.2.3 Conclusions

For new wall systems, important design criteria are the length of time the wall system is designed for, the provision in the system for easy of upgrade and installation, and key performance indicators are shelter, security, longevity and thermal insulation.

The key requirements for new wall systems solutions would need to include:

- Optimising thermal mass, glazing and insulation elements. This may require a new modelling tool for better systems design of the full thermal envelope.
- Designing in adaptability using pre-finished componentry and easy connections for addressing future upgrades and ease of installation.

The comparative assessment of KPIs across various categories of solutions indicate that solutions where the structure and insulation are combined, and lining is separate, appear to offer the most significant opportunities (refer Table 31 for scores).

7. Summary with Recommendations

This report outlines the approach used for establishing Design Criteria by which various systems can be assessed. Assessment is in order to determine key performance parameters with which to develop solutions to improve the system towards better meeting the Beacon High Standard of Sustainability® (HSS®). The study reports on the testing of the approach and provides specific results from the approach's application to windows for existing houses, and walls for new houses.

The purpose of this report is therefore twofold:

- Firstly to introduce the method by which any system can be reviewed and assessed
- Secondly to show how this method can be used, via case studies of two systems. These two case studies assess retrofit window systems and new wall systems. The case studies test the methodology and also provide guidance for the second stage of the Systems work stream.

7.1.1 Methodology

There were two approaches used — Quality Function Deployment (QFD) and Product System Assessment (PSA). The results of both methodologies, though providing differing insights, met with very similar conclusions in terms of the important attributes and key design parameters of each system.

QFD is usually used for component development and product design, not at a whole system level. The QFD process applied during the case studies was a robust process using a proven and established methodology. The research was undertaken in consultation with practitioners via structured phone interviews, and experts undertook the assessment and completion of the final matrix via a workshop approach. The research process undertaken to develop the initial systems design criteria has proven that the QFD process is useful to Beacon in determining key technical parameters. The project has shown that the core principles behind the method still apply in a systems context, so long as the results of the analysis are interpreted in conjunction with broader signals from the market and expert knowledge. By incorporating Beacon's HSS® as the basis for the technical criteria, this established the aspects that are the most important to the end user and that have the most impact on achievement of the HSS®. This can aid Beacon in determining key technical parameters, as well as demonstrating how solutions development for systems may impact on research requirements in the various work streams comprising Beacon's Research Programme. This will be very beneficial in the design of novel systems and will allow the research team to determine the design tradeoffs that can occur.

The PSA approach offers a more life cycle oriented approach that embeds the service the product delivers into the development process. This process demonstrates the usefulness of life cycle thinking in assessing the impacts of components of a system, particularly in the ability to categorise and quantitatively compare and assess various system solutions against technical criteria. This approach is well suited to a 'system' level investigation which Beacon operates in, allowing it to provide useful research driven results. Further robustness could be added to the approach simply by building experts and consumers into the scoring process.

The use of both methods in conjunction has been found to be of considerable use in the assessment of systems and in aiding in establishing the critical design parameters for a solution, in the system under study. The application of those results might be two-fold, one a specific system development aid for partners, and two a generic guide that provides a means of selecting solutions for designing a house using the HSS® criteria as the basis. This would embed the HSS® in both new solutions and specification of products that are retrofit or new construction. It is envisaged that this could be extended to other systems over a period of time, eventually providing broad coverage of all the key systems within residential construction.

7.1.2 Retrofit Window System

The significant parameters to consider appear to be regulation; ease of installation ease and environment. The assessment highlights that while double glazing provides the best benefits for window retrofitting in terms of heat regulation while retaining visibility and light, payback and the wide variety of housing typologies mean that optimum retrofit solutions will need to be assessed on a case by case basis. However, ensuring that the issues surrounding weathertightness are addressed and ensuring a minimum convective air flow behind curtains and drapes are essential to ensure sustainable window performance in any home environment. There are further opportunities for Beacon in providing an affordable secondary glazing system to fit aluminium window frames of less than 11 mm and advocating for a NZ Standard around IGU installation guidelines for retrofit projects. There may also be an opportunity solution in aiding householders to determine the most effective package of solutions to take for their given situation, and provides information on where the various components of the solutions ‘package’ can be obtained.

In summary, the key requirements for retrofit window systems solutions appear to be four-fold:

- Address the issues surrounding weathertightness and moisture/air infiltration by better sealing of the units, and sealing of the frames on closure.
- Provide all exterior windows in inactive locations where people use their rooms most (e.g. lounge/living; bedrooms; kitchens) with a system which seals the convective air flow behind curtains and drapes. This in reality would entail a programme of uptake of heavy drapes and pelmets, where the drapes are close fitting.
- Provide an affordable secondary glazing system which can be retrofitted to a majority of aluminium windows where there is often less than a 1cm space in which to fit these.
- Provision of installation guidelines or a revised New Zealand Standard for installation procedures during replacement of single glazing units with IGUs.

7.1.3 New Wall System

The length of time the wall system is designed for, the provision in the system for ease of upgrade and installation, and key performance indicators are shelter, security, longevity and thermal insulation are the important design criteria. Key performance requirements for a new wall system include optimising thermal mass, glazing and insulation elements, and designing in adaptability using prefinished componentry and easy connections. The comparative assessment indicates that

solutions where structure and insulation are combined, with lining separate, appear to offer the most significant opportunities.
Two examples of promising new systems that might be explored in future projects include combining the benefits of Structurally Insulated Panels (in terms of reduced thermal bridging, and thicker walls for more energy efficiency) with biofoams or adhesives; and utilising thermal mass and moisture buffering capacities of timber surfaces.

The key requirements for new wall systems solutions can be summarised as follows:

- Optimising thermal mass, glazing and insulation elements. This may require a new modelling tool for better systems design of the full thermal envelope.
- Designing in adaptability using prefinished componentry and easy connections for addressing future upgrades and ease of installation.

7.1.4 Next steps

As part of the Beacon systems project *"Criteria development and embedding systems",* this project also aimed to establish priority areas for the development and uptake of the initial phase systems choice of innovative window retrofits and novel wall systems.

While the goal of the systems strategy initially was to develop novel solutions, the results of the research, especially for windows for existing homes, has shown that the development of a new solution may not always be essential, and in particularly in the case of window systems and wall systems, it was clear that their high ranking was influenced in many respects by 'uptake' related issues, i.e., not necessarily technological issues. It is therefore recommended to use the criteria developed in this study for an extensive review of existing solutions for retrofit solutions of windows and wall systems for new buildings. Once existing solutions are identified the barriers for their uptake need to be identified and addressed.

In undertaking consultations with industry, the team is aware that Fletcher Building are currently working on the issue of new wall and window systems, particularly high mass walls, taking a whole thermal envelope approach (i.e. including window and cladding systems). The company has held joint technology forums with various divisions (Tasman Insulation; Fletcher Aluminium; Winstone Wallboards; Diamond; Firth etc.) and as significant work is already underway with one of the major market players, it is highly recommended that Beacon consult with their partner shareholder in taking this project forward, and look for collaborative opportunities.

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9. Appendix A New Zealand Building Codes and Compliance

Retrofitting Window Systems

NZBC

The requirements for the relevant Building Code clauses are described in the table below. The requirements shown with (AS) are deemed Alternative Solutions that comply with the Code.

		ref: Level Sustainability Series - Windows*
Clause	**Clause Title**	**Requirements**
B1	Structure	The building elements must withstand the combination of loads that they are likely to experience during construction or alteration and throughout their lives. They must not rupture, become unstable, lose equilibrium, or collapse during construction or alteration and throughout their lives.
B2	Durability	Building elements are not required to satisfy a durability performance which exceeds the specified intended life of the building. Intended life of not less than 50 years, if the building element provides structural stability to the building or are difficult to access or replace. Intended life of 15 years if the building elements are moderately difficult to access or replace. Individual building elements which are components of a building system and are difficult to access or replace must either all have the same durability, or be installed in a manner that permits the replacement of building elements of lesser durability without removing building elements that have greater durability and are not specifically designed for removal and replacement.
C	Fire Safety	Must allow an adequate means of escape from fire. Collapse of elements having lesser fire resistance shall not cause the consequential collapse of elements required to have a higher fire resistance.
E2	External Moisture	Buildings must be constructed to provide adequate resistance to penetration by, and the accumulation of, moisture from the outside. Building elements must be constructed in a way that makes due allowance for variation in the properties of materials and in the characteristics of the site.

		Weathertightness: Provide air barriers and air seals to ensure there is no airflow from outside to inside. Provide a water handling system to return any water that penetrates to the outside of the building. Provide flashings and ventilation.
E3	Internal Moisture	Safeguard against illness or property damage from internal moisture build up. An adequate combination of thermal resistance, ventilation, and space temperature must be provided to all spaces where moisture may be generated or may accumulate.
F2	Hazardous Building Materials	Building materials which are potentially hazardous, shall be used in ways that avoid undue risk to people.
F4	Safety from falling	A barrier shall be provided where people could fall 1 metre or more from an opening.
G4	Ventilation	Spaces within buildings shall have means of ventilation with outdoor air that will provide an adequate number of air changes to maintain air purity.
		(AS) Natural ventilation from net openable area of the windows to be 5% of the floor area.
G6	Airborne and impact sound	Covers only sound transmission between dwelling units
G7	Natural light	Natural light shall provide an illuminance of no less than 30 lux at floor level for 75 percent of the standard year. Openings to give awareness of the outside shall be transparent and provided in suitable locations.
		(AS) Windows in external walls to be no less than 10% of floor area. Window head height of at least half the width of the room (window on one wall only) or 1/4 of the width of the room (windows on opp. walls) Glazing light transmittance of no less than 0.7.

H1	Energy Efficiency	Buildings must be constructed to achieve an adequate degree of energy efficiency when that energy is used for modifying temperature or humidity. Buildings must be constructed to ensure that: (a) if they are buildings in climate zone 2 or climate zone 3, their building performance index does not exceed 1.55; and (b) if they are buildings in climate zone 1 and are in a warm location, their old measure building performance index does not exceed 0.13; (c) if they are buildings in climate zone 1 and are in a cool location, their old measure building performance index does not exceed 0.12. Account must be taken of physical conditions likely to affect energy performance of buildings, including the thermal mass of building elements; the airtightness of the building envelope; and heat gains from solar radiation.

* BRANZ Level Sustainable Building Series: Windows

WANZ WIS

The WANZ Window Installation System is certified alternative solution under the NZBC for the installation of Windows & Doors.

Weathertightness Testing

To determine the weathertightness of the system against external moisture (NZBC Clause E2 External Moisture) the following testing methods have been outlined by the Window Association of NZ (WANZ):

- *E2/VM1* The Verification Method E2/VM1 (NZBC: Schedule1) is only applicable for testing the weathertightness of windows in a Cavity Construction.
- *AS/NZS 4284:1995* A modified version of the testing procedure from AS/NZS 4284:1995 could be used for testing weathertightness of the window in a Direct Fix Cladding system

NZS 4223

All glazing must comply with NZS 4223 Part 3 *Human Impact Safety* and all possible provisions of NZS 4223.

New Wall Systems

The relevant elements of the New Zealand building code for consideration in the development of the new exterior wall system have been outlined as the following:

- B1 Structure
- B2 Durability
- E2 External Moisture
- E3 Internal Moisture
- G4 Ventilation
- G5 Interior Environment
- G7 Natural Light
- G9 Electricity
- H1 Energy Efficiency

The requirements for the relevant clauses have been described in the NZBC Schedule 1 as follows:

Clause	Title	Requirements
B1	Structure	Buildings, building elements and sitework shall have a low probability of rupturing, becoming unstable, losing equilibrium, undue deformation, vibratory response, degradation, other physical characteristics or collapsing during construction or alteration and throughout their lives.
B2	Durability	B2.3.1 Building elements must, with only normal maintenance, continue to satisfy the performance requirements of this code for the lesser of the specified intended life of the building (50 years).
E2	External Moisture	E2.2 Buildings must be constructed to provide adequate resistance to penetration by, and the accumulation of, moisture from the outside.
E3	Internal Moisture	E3.2 Buildings must be constructed to avoid the likelihood of fungal growth or the accumulation of contaminants on linings and other building elements; free water overflow penetrating to an adjoining household unit; and damage to building elements caused by the presence of moisture. E3.3.1 An adequate combination of thermal resistance, ventilation, and space temperature must be provided to all habitable spaces, bathrooms, laundries, and other spaces where moisture may be generated or may accumulate.
G4	Ventilation	G4.3.1 Spaces within buildings shall have means of ventilation with outdoor air that will provide an adequate number of air changes to maintain air purity.

G5	Interior Environment	G5.3.1 Habitable spaces, bathrooms and recreation rooms shall have provision for maintaining the internal temperature at no less than 16°C measured at 750mm above floor level, while the space is adequately ventilated.
G7	Natural Light	G7.3.1 Natural light shall provide an illuminance of no less than 30 lux at floor level for 75 percent of the standard year. G7.3.2 Openings to give awareness of the outside shall be transparent and provided in suitable locations.
G9	Electricity	G9.2 Where provided in a building, electrical installations shall be safe for their intended use.
H1	Energy Efficiency	H1.2 Buildings must be constructed to achieve an adequate degree of energy efficiency when that energy is used for modifying temperature or humidity; providing hot water to sanitary fixtures or sanitary appliances; or providing artificial lighting. H1.3.1 The building envelope enclosing spaces where the temperature or humidity (or both) are modified must be constructed to provide adequate thermal resistance and limit uncontrollable airflow. H1.3.2C Buildings must be constructed to ensure that if they are buildings in climate zone 2 or climate zone 3, their building performance index does not exceed 1.55; if they are buildings in climate zone 1 and are in a warm location, their old measure building performance index does not exceed 0.13; and if they are buildings in climate zone 1 and are in a cool location, their old measure building performance index does not exceed 0.12. H1.3.3 Account must be taken of physical conditions likely to affect energy performance of buildings, including the thermal mass of building elements; the building orientation and shape; the airtightness of the build- envelope; the heat gains from services, processes and occupants; the local climate; and heat gains from solar radiation.

H1 Energy Efficiency

The H1 Energy Efficiency clause of the NZBC defines the R-values that must be met for a range of construction types. Some of the updated values are outlined below:

Changes to minimum R-values for walls

	Minimum R-values ($m^2\ {}^oC/W$)					
	Climate Zone 1		Climate Zone 2		Climate Zone 3	
Non-solid construction – minimum R-values for schedule method	R 1.9		R 1.9		R 2.0	
Solid timber construction – alternative minimum R-values for schedule method	1a	1b	1a	1b	1a	1b
75mm external + timber framed internal	R 1.3	R 1.0	R 1.4	R 1.1	R 1.6	R 1.2
60mm external + solid timber 45mm internal	R 1.0	R 0.8	R 1.3	R 1.0	R 1.6	R 1.2
90mm external + solid timber 45mm internal	R 1.0	R 0.8	R 1.2	R 0.9	R 1.4	R 1.1
60mm external + solid timber 60mm internal	R 1.0	R 0.8	R 1.2	R 0.9	R 1.4	R 1.1
Solid construction (excluding timber) – alt. minimum R-values for schedule method	1a	1b	1a	1b	1a	1b
	R 0.8	R 0.8	R 1.0	R 0.9	R 1.2	R 1.0

The BRANZ House Insulation Guide Third edition has details and construction R-values for a generic direct-fixed sheet cladding and for fibre-cement planks. Pages 62, 63, 68 and 69 should be reduced by approximately R0.015 when the fibre-cement cladding is installed over a cavity.[20]

It is important to note that where a cladding is installed over a drained and vented cavity the R-value of the cladding material must be down-rated by approximately 50% because of air movement (which is essential for drying) within the cavity.

Standards

Because of the generic nature of the project at this juncture, particular materials or methods of construction have not been defined for the wall system and any relevant Standards for these cannot be analysed in detail. The Standards that have been outlined through the initial research relate to various construction and finishing methods which can be referenced as the project develops further. In particular, the Standards relating to the performance of the wall system in terms of thermal insulation and energy efficiency will be of interest to the Beacon development. These are outlined below.

Energy Efficiency

20 http://www.branz.co.nz/branzltd/pdfs/GLJanuary2008.pdf

- NZS 4246:2006 - Energy efficiency: Installing insulation in residential buildings
- NZS 4218: 2004 Energy efficiency – housing and small building envelope
- NZS 4214: 2006 Methods of determining the total thermal resistance of parts of buildings

Insulation

- AS/NZS 4859.1:2002 Materials for the thermal insulation of buildings -General criteria and technical provisions
- SNZ/PAS 4244:2003 - Insulation of lightweight-framed and solid-timber houses

NZS 4246 in particular provides guidance to help incorporate thermal performance and thermal durability of building elements into the design of the home. Of interest also is another Standard, AS/NZS 4284: 1995, which sets out a testing method for determining the performance of building facades under loading, in relation to water penetration and ultimate load capacity.

The following Standards have been sourced as potential references for the development of the wall system and will be purchased if they are found to be relevant to the chosen system. The table below provides a general scope for each of the Standards.

Potential NZ Standards for Wall Systems

NZS 4246:2006 - Energy efficiency: Installing insulation in residential buildings[21]
Provides guidance to insulation installers in order to help achieve the design thermal performance and thermal durability of building elements, as well as minimizing the risk to installers.
NZS 4218: 2004 Energy efficiency – housing and small building envelope[22]
Provides details and guidance to meet adequate energy efficiency performance requirements for the building envelope of housing and small buildings. Incorporates glazing into the schedule and calculation methods of compliance with the required performance and focuses on excessive heat-loss through the area of glazing. It also brings the window R-values into line with Window Efficiency Rating Scheme (WERS) and adds an Appendix on glazing performance. It focuses on areas of glazing above 30 % of the total wall area as these significantly affect thermal efficiency of the envelope.
NZS 4214: 2006 Methods of determining the total thermal resistance of parts of buildings[23]
This Standard gives methods of determining the thermal resistance of building components and elements consisting of thermally homogeneous layers which may include air layers. The methods may be applied to individual elements and components, or to complete assemblies such as walls, roofs and floors.
AS/NZS 4859.1:2002 Materials for the thermal insulation of buildings - General criteria and technical provisions

21 http://www.standards.co.nz/web-shop/?action=viewSearchProduct&mod=catalog&pid=4246:2006(NZS)
22 http://www.standards.co.nz/web-shop/?action=viewSearchProduct&mod=catalog&pid=4218:2004(NZS)
23 http://shop.standards.co.nz/scope/NZS4214-2006.scope.scope.pdf

This Standard specifies requirements and methods of test for materials that are added to, or incorporated in, opaque envelopes of buildings designed for human occupancy, to provide thermal insulation by moderating the flow of heat through these envelopes.
SNZ/PAS 4244:2003 - Insulation of lightweight-framed and solid-timber houses[24]
Provides guidance on the selection of insulation levels and window options to improve the energy efficiency of houses beyond the minimum required by the New Zealand Building Code. The PAS also identifies the insulation levels required by NZS 4218 to meet the minimum requirements of the New Zealand Building Code.
NZS 3604:1999 - Timber Framed Buildings[25]
Provides suitable methods and details for the design and construction of timber framed buildings up to three storeys high. This standard is intended to apply to domestic dwellings, most residential and some commercial and other buildings, without the need for specific engineering design. This standard provides an acceptable solution for clauses B1 (Structure), B2 (Durability) and E2 (External Moisture) of the NZBC.
AS/NZS 2311-2000 Painting of Buildings[26]
This Standard provides a guide to products and procedures for the painting of buildings for general domestic, commercial and industrial use. It does not include specific recommendations for the long-term protection of iron or steel exposed directly to the atmosphere or to internal climates likely to have aggressive environments which are dealt with in AS/NZS 2312. In providing guidance on the preparation of painting and repainting specifications for surfaces forming parts of buildings, the Standard necessarily gives choices of paint types for use in different areas. For each contract, the architect, or owners, should draw up a complementary painting schedule to detail the options that are to be used together with a colour schedule. This Standard can then be referred to when specifying the necessary preparation, the coating system and the methods and conditions of application. [List of content: Design for painting, Preparation of surfaces, General description of paints, related materials and treatments, Systems for painting, Paint application, Maintenance of painted surfaces and painting systems, Preparation of painting specifications.]
NZS 3602:2003 Timber and wood-based products for use in building.[27]
States how timber and wood-based products are to be specified for particular end uses in building to ensure that they give acceptable performance during the life of the building. Covers the materials themselves and also certain aspects of design and construction that are relevant to their performance and use for compliance with NZS 3604 and NZS 3631. Cited in BIA Approved Document B2.
NZS 4229:1999 Code of practice for concrete masonry buildings not requiring specific design.[28]
Sets down the structural requirements for buildings not requiring specific design where the foundations and some or all of the walls in any storey are constructed of masonry, and the

24 http://www.standards.co.nz/web-shop/?action=viewSearchProduct&mod=catalog&pid=4244:2003(SNZ|PAS)
25 http://www.standards.co.nz/web-shop/?action=viewSearchProduct&mod=catalog&pid=3604:1999(NZS)
26 http://www.saiglobal.com/shop/script/Details.asp?docn=AS659699569532
27 http://www.ccc.govt.nz/Building/infosources.asp
28 http://www.ccc.govt.nz/Building/infosources.asp

floors, ceiling and roof are constructed of light timber frame, with the exception that the ground floor can be a concrete slab – on – ground. (The superseded Standard NZS 4229:1986 is cited in BIA Approved Documents B1, E1 and G13.)
AS/NZS4284-1995 Testing of Building Facades[29]
This Standard sets out a method for determining the performance of a representative building facade under loading. Tests include displacement of the facade or prototype, water penetration and ultimate load capacity as well as optional tests, including BMU restraint, seismic loading and seal degradation. This test method is applicable to prototype testing in a laboratory as well as on-site testing.

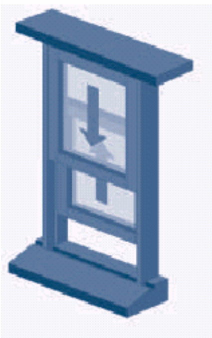
29 http://www.saiglobal.com/PDFTemp/Previews/OSH/As/as4000/4200/4284.pdf

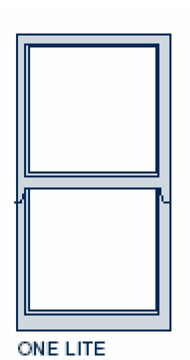
10. Appendix B Windows Historical Context

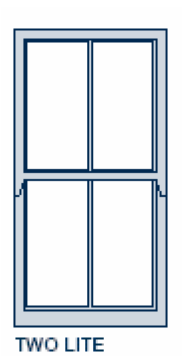
Pre-1920s Dbl/Sgl Hung Sash

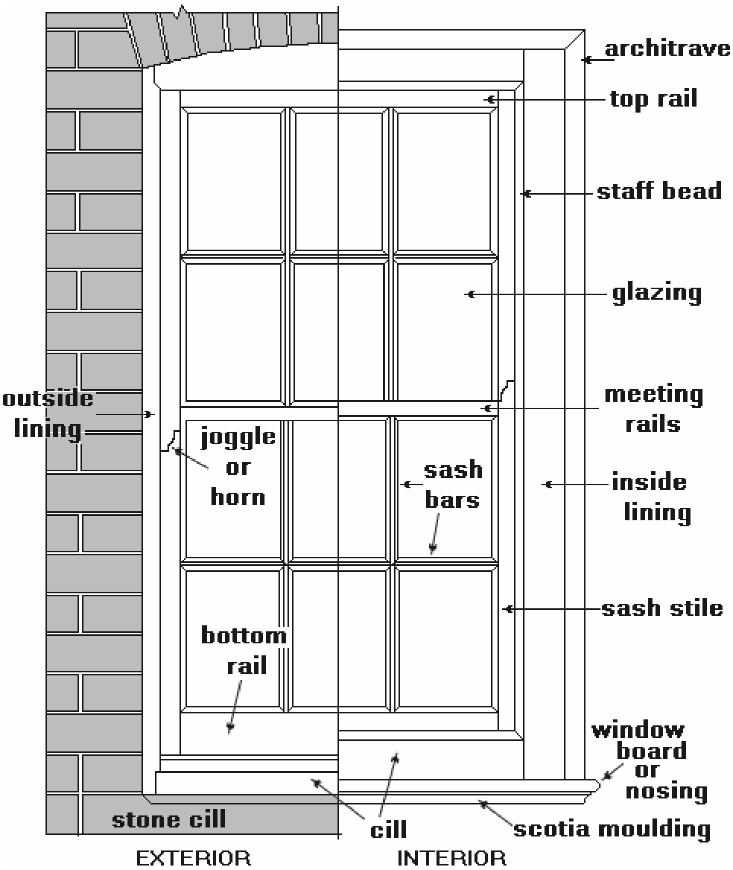
Early housing and Villa Typology

A traditional vertical sliding design that can open at the top and bottom. A double hung sash allows greater ventilation in a room through its two openings - cool air is let in through the bottom opening and hot air can escape out the top opening.









http://www.sashwindows.com.au/

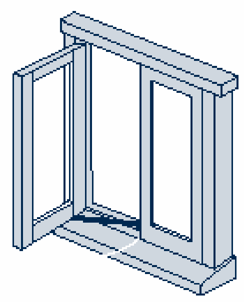
http://www.bungalowandvilla.co.nz/stockjoinery/windows.htm

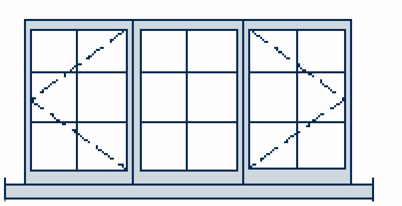
http://www.sash-style.co.uk/parts.php

1920-35 Casement

Bungalow and Art Deco Typology

Windows that open like a door and can be hinged at the side, top or bottom. Sometimes incorporate fixed panels on one or more sides of the sash. Able to direct a breeze into the home through the large directional opening.





http://en.wikipedia.org/wiki/Window#Double-hung_sash_window

http://www.buffaloah.com/a/DCTNRY/c/casement.html

http://www.bungalowandvilla.co.nz/stockjoinery/windows.htm

http://www.stegbar.com.au/products/windows_and_doors/at2000/casement_windows/

1935-40 Fixed Pane & Transoms

Bungalow and Art Deco Typology

Fixed or picture windows were a feature of Art Deco homes and were often situated between casement windows.

These are defined by larger panes in more modern homes to maximise the view.

A transom is a small window situated above a door that is often fixed but can open either by hinges at top or bottom, or can rotate about hinges at the middle of its sides. It provided ventilation before forced air heating and cooling was introduced.

http://www.loewen.com/home.nsf/windows

http://en.wikipedia.org/wiki/Window#Double-hung_sash_window

http://www.buffaloah.com/a/DCTNRY/t/transom.html

1940-60 Top Hinged Large Pane

State Housing and Mass Housing Typology

Top hinged, or awning, windows open out from the bottom, to shield the home from rain while letting air circulate freely.

http://www.stegbar.com.au/services/resource_centre/photo_library/main/

http://www.loewen.com/home.nsf/windows/awning

1970 Early Aluminium Joinery

70's House Typology

Aluminium joinery was introduced in the late 60's, early 70's. Much of this is now requiring replacement because the aluminium used was not a high grade.

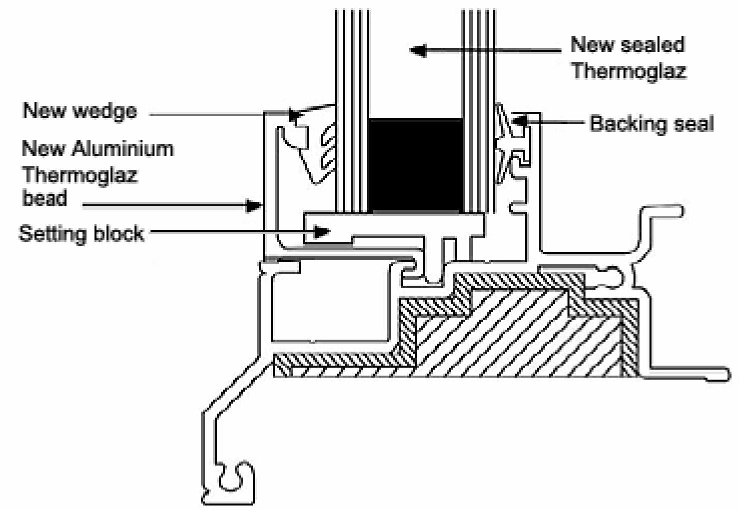
QFD meeting - Scion 17/07/08

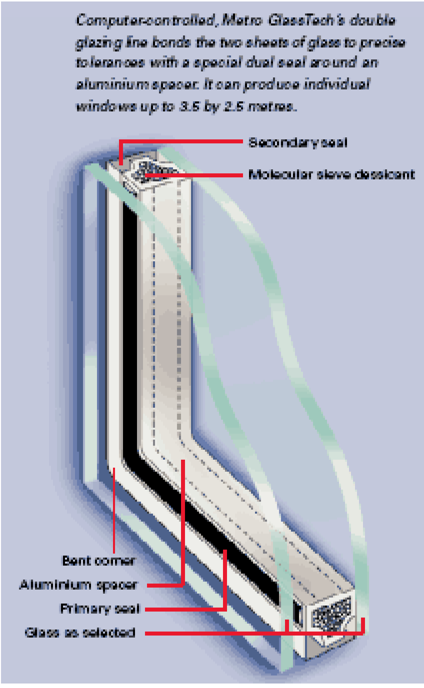
1970-2000 Al. Joinery & Dbl Glazing

70's House, 80's house; Early 90's House and Last Decade Typology

Joinery has advanced with the creation of better installation and sealing methods and drainage now incorporated to minimise water damage in homes.

Glazing developments have also provided larger windows and include innovations like double glazing with advanced coatings for homes in later years.





http://www.stegbar.com.au/products/windows_and_doors/at2000/awning_windows/

http://www.tasmanglass.co.nz/products/metro_doubleglazing.html

http://www.thermoglaz.co.nz/aluminium.html

11. Appendix C QFD Matrix for Retrofitted Window Solutions

Retrofit Windows / Technical requirements

Customer, Regulatory, Builder		End user needs	1 Heat Generation	2 Low Energy Production	3 Embodied Energy - Material Selection	4 Thermal conductivity / Heat Loss	5 Humidity	6 Ventilation	7 Internal Moisture Dispersal	8 Noise/Acoustics	9 Pollution	10 Carbon Footprint	11 % Content Recycled; disposed; and reused	12 Low Material Waste - Production	13 Lifespan of product	14 Impact Resistance of glass	15 Cleaning of Surface	16 Low Maintenance Cost	17 Upgrades	18 Consented	19 Light Weight	20 Ease of Installation	21 Pre-finished components.	22 Construction Waste	23 Weathertight	24 Operation/Use	25 Purchase Cost	26 Incentive	27 Return on investment	
C , R	1	Ventilation	9	0	0	9	9	9	9	9	9	9	0	0	9	0	0	3	3	9	3	3	3	0	9	9	9	9	3	144
C	2	Opening to outside	9	9	0	9	3	9	0	9	0	3	0	0	9	9	1	3	3	9	3	0	0	0	9	9	3	3	3	115
C	3	Cost effective	9	9	0	3	0	0	0	0	0	0	3	3	9	1	0	0	9	0	3	9	9	3	9	9	9	9	3	109
C	4	Architecture	3	3	3	9	3	3	0	3	0	1	9	0	9	0	0	3	9	0	9	3	3	0	9	9	3	3	9	106
C	5	Sufficiently sealed air gap	0	9	0	9	9	9	0	9	0	9	0	0	9	0	0	0	3	9	3	3	3	0	9	3	3	3	3	105
C, B, R	6	Weatherproof	0	0	0	1	3	3	3	0	0	0	0	0	9	0	0	1	3	9	9	9	9	0	9	9	9	9	9	104
C, R, B	7	Easy cleaning	0	0	0	0	0	0	3	0	9	3	0	0	9	0	9	0	0	3	9	3	9	0	9	9	9	9	3	96
C	8	Installation Ease / Handling	0	0	0	0	0	3	0	3	0	0	3	3	9	3	0	0	9	1	9	9	9	0	9	9	9	0	0	88
C	9	Reduces Condensation	0	3	0	9	9	9	9	0	0	0	0	0	3	0	0	3	3	9	0	0	3	0	3	9	3	3	3	81
C	10	Views	3	0	0	3	0	0	0	9	0	0	1	0	3	0	9	0	3	9	3	0	0	0	9	3	3	9	9	76
C, B	11	Security	0	0	0	0	0	9	0	0	0	0	3	0	3	3	0	0	3	0	9	3	3	0	9	9	9	9	3	75
C	12	Shade provision	9	3	0	0	0	1	0	0	0	0	0	0	1	0	3	0	3	0	9	3	0	0	9	3	9	3	3	59
C, R, B	13	Quiet	0	0	0	0	0	3	0	9	0	0	0	0	1	1	0	0	3	3	1	0	1	0	3	9	3	3	9	49
C, B	14	Internal window sills	0	0	0	9	0	1	3	0	0	0	0	0	3	0	9	9	3	0	0	0	0	0	3	0	0	3	3	46
			42	36	3	61	36	59	27	51	18	25	19	6	86	17	31	22	57	61	70	45	52	3	108	99	81	75	63	

Beacon

QFD Matrix for New Wall Solutions

New Construction Exterior Walls			Technical requirements																												
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Customer, Regulatory, Builder			Low Energy Production	Embodied Energy - Material Selection	Thermal Insulation	Moisture Conductivity	Humidity	Ventilation	Noise/Acoustics	Pollution	Carbon Footprint	% Content Recycled; disposed; and reused	Low Material Waste - Production	Lifespan of product	Impact Resistance	Flammability/ Combustability	Cleaning of Surfaces	Upgrades	Consenting process	Light Weight	Ease of Installation	Surface Options	Pre-finished components	Construction Waste	Weathertight	Operation/Use	Resilience	Purchase Cost	Running cost	Return on investment	
End user needs																															
R, B	1	Insulation, thermal design	9	9	9	3	3	3	1	0	0	9	3	9	0	1	0	9	9	9	3	9	3	0	3	0	0	9	9	9	131
R, B	2	Economy, affordability	9	1	9	0	0	0	0	0	1	3	9	9	1	0	0	9	0	9	9	9	3	9	3	3	9	9	3	9	126
R, B	3	Architecture, style, street appeal	0	0	0	0	0	0	0	0	0	9	9	9	9	3	3	9	9	3	9	9	0	9	9	1	3	3	3	1	110
C, B, R	4	Adaptability	0	0	0	0	0	0	0	0	3	9	3	9	0	9	0	9	0	9	9	9	9	3	0	9	1	3	9	3	106
B,	5	Serviceability, durability	1	3	0	0	0	0	0	0	9	0	0	9	9	3	9	9	9	3	0	9	1	0	9	3	9	3	3	3	104
B, R	6	Low maintenance	9	3	0	0	0	0	0	0	9	0	0	9	9	0	9	3	1	3	0	9	0	0	1	9	1	9	9	9	102
B, C	7	Separation functions	3	0	9	3	1	0	3	1	0	0	0	9	0	3	3	9	9	9	9	0	0	0	9	0	9	9	0	0	98
C, R	8	Prefabrication of wall system components	3	3	3	0	0	0	0	0	3	0	9	9	3	0	0	9	9	9	9	1	9	9	3	0	3	0	0	1	95
R, B	9	Structural functions	0	0	0	0	0	0	3	0	0	9	3	9	3	0	0	9	9	9	9	0	9	0	3	0	9	3	0	3	90
C	10	Toxicity, indoor air quality	0	0	9	9	9	3	0	9	0	0	3	1	0	3	9	3	0	3	0	3	3	9	9	3	0	0	0	0	88
C	11	Containment	0	0	0	0	0	0	3	0	0	0	0	9	0	0	0	9	9	9	9	0	9	3	9	3	0	9	0	0	81
C, B, R	12	Installation	0	0	0	0	0	0	0	0	0	9	0	0	1	9	1	9	3	9	3	1	9	3	9	1	0	9	0	0	76
C	13	Low weight and low volume	3	3	3	0	0	0	3	0	1	0	0	0	3	0	0	0	0	9	9	0	9	0	0	0	0	9	0	0	52
C	14	Attachment of internal furniture and fittings	0	0	0	0	0	0	0	0	0	3	0	9	9	0	0	3	0	3	9	3	0	0	3	3	3	0	0	3	51
C	15	Wall straightness	0	0	0	3	0	0	0	0	0	3	0	3	0	0	0	3	0	3	1	9	3	1	1	1	3	9	0	3	46
			37	22	42	18	13	6	13	10	26	54	39	103	47	31	34	102	67	99	88	71	67	46	71	36	50	84	36	44	

12. Appendix D Details of functional attributes for window systems for existing homes

Light
See also: A view to outside, Reduce energy use, Heat/Insulation, Health

The window provides natural light and allows the sun to heat the room. The presence of light reveals space and creates visibility within the home.

- Visibility
- Windows allow light into the interior of the home.
- Protection (from UV)
- UV rays can damage furnishings if the window does not have any inbuilt resistance.
- Natural heat source
- Passive solar energy warms the room but proper window coverings/furnishings must be used to stop heat from escaping through the window at the end of the day.

Environment
Windows maintain a healthy living environment for the home's occupants.

- Health See also: Air Quality, Light. Keeping the home fresh, dry and light. Optimum environment for healthy living - keeping the family safe from toxins (materials - internal and external) and the elements.

Regulation of environment – By opening the windows they can regulate moisture levels, heat build up, and the amount of light in a room to keep the home environment warm and dry. Windows let in the elements when necessary and provide the opportunity to reduce humidity and condensation by opening the window.
Aerated - Fresh air circulating through the home.
Dry - An aperture that can allow moisture that accumulates in the home to escape. Depending ont the R-value of the window and frame as well as the temperature difference between inside and outside windows can collect condensation, removing it from the room and other furnishings, but this must be dealt with to remove the moisture from inside the home.

- Acoustics
- The potential to shut out sound or let it in; reducing exterior noise and limiting the amount of interior noise that escapes, or allowing preferable noises from the outside in.
- Privacy
- Windows have the ability to both enhance and negate visual and acoustic privacy through the use of films, reflection, lamination etc.

Regulation
The environment of the home can be regulated or controlled by the strategic use of windows.

- Heat/Insulation See also: Reduce energy use, Air Quality, Light. Windows are a method for regulating heat in the home, particularly in summer when hot air is dispelled through an open window.

Retention in Winter - Utilising passive solar gain through proven methods to retain the heat in the home during winter months which include curtains with pelmets to trap the air and create insulation in conjunction with a single glazed window.
A number of options, including double glazing, low-e glass, thermally broken frames can be used to retain heat in the home. However, in some cases the curtain/pelmet combination proves to be more efficient than double glazing (Tasmanian Environment Centre, 2008; Sustainability Victoria, 2008; University of Texas, 2008) – refer Table 5 and Figure 5.
Protection in Summer - External protection or shading is used to stop heat gain during summer. These are visual or decorative elements on the exterior that can ideally be removed to allow maximum heat gain during winter, while still providing summer protection to window systems. Tinted glazing or films on the window surface reflect some of the light intensity but external elements are recommended to shade the window during periods of high heat gain.

- Reduce energy use See also: Heat/Insulation, Light. Correct installation of the new window system could improve the performance of the home's insulation but may cause a weaker link in the thermal performance of the home.

Thermal Envelope - The thermal envelope extends beyond the window frame. The entire envelope is necessary to provide insulation and retention of heat across the expanse of the living area. Higher levels of heat retention allow lower use of heating appliances and therefore lower space heating energy usage.
Natural Light - The addition of natural light to an internal space reduces the necessity for artificial light fixtures during the day, bringing space heating energy consumption down, however, as lighting is also a source of heat, this will only reduce when sunlight brings additional warmth to a room also (i.e. this does not always reduce energy on cloudy but bright days).

- Air Quality See also: Heat/Insulation, Health. The ability to open and close the window at will provides proper ventilation which maintains a healthy environment within the home.

Regulation of heat - Windows can be opened to create an atmosphere that is cooler in summer and closed to retain heat and keep the interior warmer in winter.
Fresh Air - An opening aperture for increased circulation of fresh air to maintain a healthy living environment.
Moisture Regulation - Circulation of air aids in the reduction and dispersion of moisture to the exterior of the home.

Aperture
The window either as a wall or as a structural component of the wall. It can also be seen as semi-invisible boundary.

- Aperture. A variable opening or gap for admitting light into the home.
- *A view to outside* (See also: Light) - Generating a safe environment without excluding wider external space. Extension of the living area. An important element of streetscape or frontage. Maximising the site of the home - particularly in picturesque areas (i.e. coastal or alpine).

Looking out, not looking in - Coverings or components that provide privacy. Tinted glass for privacy during the daytime.
Expanded perception of space - Visual element that seems to increase the size of the interior space.

Installation
The window is only a part of the thermal envelope. Increasing the thermal performance of the window may not increase another part of the envelope and the thermal envelope may not have adequate insulation and R-value even if the window R-value is substantially improved. The thermal envelope extends beyond the window and installation requirements must ensure the integrity of the building envelope with regard to thermal and moisture protection is not compromised.
Easy to install

The system needs to provide a simple method for improving the performance of the home.

- Compatibility with existing systems

  The retrofit window system must fit with the style of the home and function well as a part of the wall and house system.

- Cost Effective

  Costs need to be relative to other alterations cost/benefit ratios and to the actual value of the home and the value of any improvements made.
  For example a consumer is unlikely to invest in completely new windows if the house value and location is unsuitable and unlikely to yield the necessary performance returns to make it worthwhile.

Details of functional attributes for exterior walls for new homes

Protection
See also: Comfort, Structure
Exterior walls provide protection and privacy from a variety of sources including intruders, the elements (weather), and neighbours.

- Shelter

  The walls form the primary aspect of protection from the elements, and other factors such as noise.
  The concept of shelter contributes to the comfort of the living space.
  Protection from the elements - A weathertight barrier against wind, rain and cold (or extreme) temperatures.

- Fire protection

  External walls can provide some protection of occupants and internal structures from external ignition sources.

- Security

Security in an enclosed space, creating a safe place for a family to live and relax in. Affording the ability to shut out the external world or to lock and secure personal belongings.

Comfort

See also: Protection

Thermal comfort and visual privacy in the form of warmth and protection is provided by the walls.

- Thermal insulation

  Minimise heat gain or loss between the internal and external environment, and between rooms within the house.

- Privacy

  Maintaining personal space or privacy for occupants of the home.

  Sight - A physical barrier to the outside world and the public domain. Visual privacy/ protection with contained apertures for viewing.

  Acoustic insulation - Sound dampening creates a quiet environment for the occupants, providing privacy for noises from inside and a sound barrier for noises from outside. Containment and exclusion of noise between occupancies (neighbours), the internal and external environment, and between rooms within the house.

- External and internal moisture control

  Other than resistance to direct wetting from external sources, there is the requirement for condensation control within the interior of the home through adequate insulation, and restricting moisture ingress within any wall cavities.

Structure

See also: Durability, Protection

External walls form a rigid and durable structure that provides a skeleton (or external shell) for the layout of the home, and protects the home's inhabitants.

- Solid & Hardy

  The walls are to be durable and long lasting, enduring wear and tear on both the interior and exterior of the home.

- Structural functions

  Resistance against vertical, normal, and racking loads imposed by wind, earthquake and occupancy.

  Hold up the roof - A necessary element in building that forms the connection of roof to floor, transferring loads imposed on upper parts of the building, and on the wall itself, to the floor and foundation. This combined structure forms an integral part of the weatherproofing of the house.

  Support other walls - A sound structure is created by multiple wall components that form a contained environment or what is known as the thermal envelope of the living area.

- Define Space

Delineate an area for living. Provide privacy or separation from the exterior while providing easy interaction for the home dwellers. E.g. indoor/outdoor flow, windows, doorways, etc.

Durability

See also: Structure

The ability of the home to withstand the elements, geological movement, wear and tear, etc.

- Sustainable

  Sustainable in an environmental sense but the wall system must also be sustainable over the lifetime of the home. The ability to upgrade or maintain the integrity of the home would be essential.
- Longevity

  Exterior walls are an integral part of the structure and must therefore maintain integrity throughout the expected life of the home.

  Life of Product - Maintaining performance of the wall system over the life of the home, including retention of the thermal envelope and weathertightness of the exterior.
- Low Maintenance

  Interior surfaces can be resurfaced for decorative purposes but exterior surfaces may need resurfacing or upgrading over the life of the home in order to retain their integrity. The required maintenance should be minimal to reduce impact on both overall cost and the environment.

Services

The external wall needs to accommodate and deliver services throughout the home.

- Containment of services

  Containing and delivering electrical and communication (audio/visual)wiring, plumbing, and other services throughout the home as required, increasingly communications and audio visual cabling is also required.
- Doors & Windows

  The investigation and analysis of the system does not consider these but they sit within the exterior wall to provide pedestrian access and environmental regulation.

  Admission of sunlight, solar heat and air - Through elements designed for these purposes, including mechanical devices.
- Provision of surfaces

  A clear surface provided for interior decoration and individual adaptation of the space or a surface for attachment of internal furniture (shelves etc.), furnishings, and pictures.

Surfaces for installation of devices that are incorporated into and supported by the exterior wall such as air conditioning units, etc.

13. Appendix E Key Performance Indicators for Window Systems for Existing Homes

Results

		Performance Indicator
Addition	External Shades	82
	Films	48
	Blinds, drapes, and pelmets	100
	Draughtstopping	70
	Secondary glazing	116
Complete Replacement	Single Glazing	110
	Double Glazing - Standard	131
	Double Glazing - Argon	131
	Double Glazing - Std + Low E	166
	Double Glazing - Argon + Low E	166
Partial Repl.	Resetting of current windows	88
	Retrofit frame to install IGU	124
	Single Glazing Upgrade	123

Master

	Window MASTER	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility		1		1					1	3	0
	Protection				1		1			1	3	0
	Heat		1		1						2	0
Environment	Health		1		1					1	3	0
	Acoustic				1					1	2	0
	Privacy					1	1	1		1	4	0
Regulation	Heat/Insulation		1		1	1		1		1	5	0
	Air Quality				1			1		1	3	0
Aperture	Frame									1	1	0
	Structure					1		1			2	0
	Security				1					1	2	0
	Mechanical				1			1			2	0
Installation	Easy to Install						1	1		1	3	0
	Cost-effective								1	1	2	0
	Compatibility						1	1		1	3	0
								Total:			40	**0**

Single Glazing Replacement

	Single Glazing Replacement	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility	5	1		1					1	3	15
	Protection				1		1			1	3	0
	Heat	5	1		1						2	10
Environment	Health	3	1		1					1	3	9
	Acoustic	2			1					1	2	4
	Privacy					1	1	1		1	4	0
Regulation	Heat/Insulation	2	1		1	1		1		1	5	10
	Air Quality	2			1			1		1	3	6
Aperture	Frame	4								1	1	4
	Structure	5				1		1			2	10
	Security	2			1					1	2	4
	Mechanical	5			1			1			2	10
Installation	Easy to Install	2					1	1		1	3	6
	Cost-effective	5							1	1	2	10
	Compatibility	4					1	1		1	3	12
									Total:		40	**110**

Double Glazing [Argon + Low E]

	Double Glazing [Argon + Low E]	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility	5	1		1					1	3	15
	Protection	5			1		1			1	3	15
	Heat	5	1		1						2	10
Environment	Health	5	1		1					1	3	15
	Acoustic	4			1					1	2	8
	Privacy	3				1	1	1		1	4	12
Regulation	Heat/Insulation	5	1		1	1		1		1	5	25
	Air Quality	4			1			1		1	3	12
Aperture	Frame	4								1	1	4
	Structure	5				1		1			2	10
	Security	3			1					1	2	6
	Mechanical	5			1			1			2	10
Installation	Easy to Install	2					1	1		1	3	6
	Cost-effective	3							1	1	2	6
	Compatibility	4					1	1		1	3	12
									Total:		40	**166**

Single Glazing Upgrade

	Single Glazing Upgrade	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility	5	1		1					1	3	15
	Protection	5			1		1			1	3	15
	Heat	5	1		1						2	10
Environment	Health	3	1		1					1	3	9
	Acoustic	2			1					1	2	4
	Privacy	3				1	1	1		1	4	12
Regulation	Heat/Insulation	3	1		1	1		1		1	5	15
	Air Quality	2			1			1		1	3	6
Aperture	Frame	3								1	1	3
	Structure					1		1			2	0
	Security	2			1					1	2	4
	Mechanical				1			1			2	0
Installation	Easy to Install	3					1	1		1	3	9
	Cost-effective	3							1	1	2	6
	Compatibility	5					1	1		1	3	15
								Total:			40	**123**

Blinds, drapes and pelmets

	Blinds, drapes & pelmets	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility	4	1		1					1	3	12
	Protection	4			1		1			1	3	12
	Heat	2	1		1						2	4
Environment	Health	2	1		1					1	3	6
	Acoustic	5			1					1	2	10
	Privacy	1				1	1	1		1	4	4
Regulation	Heat/Insulation	4	1		1	1		1		1	5	20
	Air Quality	2			1			1		1	3	6
Aperture	Frame	3								1	1	3
	Structure					1		1			2	0
	Security				1					1	2	0
	Mechanical	3			1			1			2	6
Installation	Easy to Install	4					1	1		1	3	12
	Cost-effective	1							1	1	2	2
	Compatibility	1					1	1		1	3	3
								Total:			40	**100**

Films

	Films	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility	1	1		1					1	3	3
	Protection	1			1		1			1	3	3
	Heat	3	1		1						2	6
Environment	Health		1		1					1	3	0
	Acoustic				1					1	2	0
	Privacy	3				1	1	1		1	4	12
Regulation	Heat/Insulation	2	1		1	1		1		1	5	10
	Air Quality				1			1		1	3	0
Aperture	Frame	4								1	1	4
	Structure					1		1			2	0
	Security				1					1	2	0
	Mechanical				1			1			2	0
Installation	Easy to Install	1					1	1		1	3	3
	Cost-effective	2							1	1	2	4
	Compatibility	1					1	1		1	3	3
									Total:		40	**48**

External Shades

	External Shades	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility	4	1		1					1	3	12
	Protection	4			1		1			1	3	12
	Heat	2	1		1						2	4
Environment	Health	4	1		1					1	3	12
	Acoustic				1					1	2	0
	Privacy	1				1	1	1		1	4	4
Regulation	Heat/Insulation	3	1		1	1		1		1	5	15
	Air Quality				1			1		1	3	0
Aperture	Frame	2								1	1	2
	Structure					1		1			2	0
	Security				1					1	2	0
	Mechanical				1			1			2	0
Installation	Easy to Install	4					1	1		1	3	12
	Cost-effective	3							1	1	2	6
	Compatibility	1					1	1		1	3	3
								Total:			40	**82**

Draughtstopping

	Draughtstopping	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility		1		1					1	3	0
	Protection				1		1			1	3	0
	Heat		1		1						2	0
Environment	Health	3	1		1					1	3	9
	Acoustic	1			1					1	2	2
	Privacy					1	1	1		1	4	0
Regulation	Heat/Insulation	3	1		1	1		1		1	5	15
	Air Quality	2			1			1		1	3	6
Aperture	Frame									1	1	0
	Structure					1		1			2	0
	Security				1					1	2	0
	Mechanical				1			1			2	0
Installation	Easy to Install	5					1	1		1	3	15
	Cost-effective	4							1	1	2	8
	Compatibility	5					1	1		1	3	15
									Total:		40	**70**

Secondary Glazing

	Secondary Glazing	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility	5	1		1					1	3	15
	Protection	1			1		1			1	3	3
	Heat	5	1		1						2	10
Environment	Health	3	1		1					1	3	9
	Acoustic	3			1					1	2	6
	Privacy					1	1	1		1	4	0
Regulation	Heat/Insulation	3	1		1	1		1		1	5	15
	Air Quality	3			1			1		1	3	9
Aperture	Frame	4								1	1	4
	Structure	3				1		1			2	6
	Security	2			1					1	2	4
	Mechanical	3			1			1			2	6
Installation	Easy to Install	3					1	1		1	3	9
	Cost-effective	4							1	1	2	8
	Compatibility	4					1	1		1	3	12
									Total:		40	**116**

Double Glazing – Standard

	Double Glazing - Standard	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility	5	1		1					1	3	15
	Protection				1		1			1	3	0
	Heat	5	1		1						2	10
Environment	Health	4	1		1					1	3	12
	Acoustic	4			1					1	2	8
	Privacy					1	1	1		1	4	0
Regulation	Heat/Insulation	4	1		1	1		1		1	5	20
	Air Quality	4			1			1		1	3	12
Aperture	Frame	4								1	1	4
	Structure	5				1		1			2	10
	Security	3			1					1	2	6
	Mechanical	5			1			1			2	10
Installation	Easy to Install	2					1	1		1	3	6
	Cost-effective	3							1	1	2	6
	Compatibility	4					1	1		1	3	12
								Total:			40	**131**

Double Glazing – Argon

	Double Glazing - Argon	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility	5	1		1					1	3	15
	Protection				1		1			1	3	0
	Heat	5	1		1						2	10
Environment	Health	4	1		1					1	3	12
	Acoustic	4			1					1	2	8
	Privacy					1	1	1		1	4	0
Regulation	Heat/Insulation	4	1		1	1		1		1	5	20
	Air Quality	4			1			1		1	3	12
Aperture	Frame	4								1	1	4
	Structure	5				1		1			2	10
	Security	3			1					1	2	6
	Mechanical	5			1			1			2	10
Installation	Easy to Install	2					1	1		1	3	6
	Cost-effective	3							1	1	2	6
	Compatibility	4					1	1		1	3	12
								Total:			40	**131**

Double Glazing – Standard + Low E

	Double Glazing - Standard + Low E	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility	5	1		1					1	3	15
	Protection	5			1		1			1	3	15
	Heat	5	1		1						2	10
Environment	Health	5	1		1					1	3	15
	Acoustic	4			1					1	2	8
	Privacy	3				1	1	1		1	4	12
Regulation	Heat/Insulation	5	1		1	1		1		1	5	25
	Air Quality	4			1			1		1	3	12
Aperture	Frame	4								1	1	4
	Structure	5				1		1			2	10
	Security	3			1					1	2	6
	Mechanical	5			1			1			2	10
Installation	Easy to Install	2					1	1		1	3	6
	Cost-effective	3							1	1	2	6
	Compatibility	4					1	1		1	3	12
								Total:			40	**166**

Resetting current windows

	Resetting current windows	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility	5	1		1					1	3	15
	Protection				1		1			1	3	0
	Heat	5	1		1						2	10
Environment	Health	2	1		1					1	3	6
	Acoustic	2			1					1	2	4
	Privacy					1	1	1		1	4	0
Regulation	Heat/Insulation	1	1		1	1		1		1	5	5
	Air Quality	2			1			1		1	3	6
Aperture	Frame	4								1	1	4
	Structure	3				1		1			2	6
	Security	1			1					1	2	2
	Mechanical	5			1			1			2	10
Installation	Easy to Install	1					1	1		1	3	3
	Cost-effective	1							1	1	2	2
	Compatibility	5					1	1		1	3	15
								Total:			40	**88**

Retrofit IGU

	Retrofit IGU	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Light	Visibility	5	1		1					1	3	15
	Protection				1		1			1	3	0
	Heat	5	1		1						2	10
Environment	Health	4	1		1					1	3	12
	Acoustic	4			1					1	2	8
	Privacy					1	1	1		1	4	0
Regulation	Heat/Insulation	4	1		1	1		1		1	5	20
	Air Quality	4			1			1		1	3	12
Aperture	Frame	3								1	1	3
	Structure	2				1		1			2	4
	Security	3			1					1	2	6
	Mechanical	4			1			1			2	8
Installation	Easy to Install	2					1	1		1	3	6
	Cost-effective	4							1	1	2	8
	Compatibility	4					1	1		1	3	12
								Total:			40	**124**

14. Appendix F - Key Performance Indicators for Walls Systems of New Homes

Results summary

		Weighted Performance Ranking
Control	C+S+I+L	180
2-Part Int.	[C+S]+I+L	198
	[C+I]+S+L	161
	C+[S+I]+L	201
	C+S+[I+L]	117
3-Part Int.	[C+S+I]+L	200
Fully Int.	[C+S+I+L]	190

Master

	MASTER	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Protection	Shelter				1		1	1	1	1	5	0
	Fire protection							1		1	2	0
	Security				1			1	1	1	4	0
Comfort	Thermal insulation		1		1	1		1	1	1	6	0
	Privacy				1					1	2	0
	Ext. & Int. moisture control		1		1					1	3	0
Structure	Solid & hardy					1		1		1	3	0
	Structural functions					1	1	1			3	0
	Define space		1		1			1			3	0
Durabilty	Sustainabilty					1	1		1	1	4	0
	Longevity/Life of product					1	1		1	1	4	0
	Low maintenance					1				1	2	0
Services	Containment of services					1	1	1			3	0
	Doors & windows		1		1			1			3	0
	Provision of surfaces									1	1	0
									Total:		48	**0**

C+S+I+L

	C+S+I+L	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Protection	Shelter	4			1		1	1	1	1	5	20
	Fire protection	2						1		1	2	4
	Security	4			1			1	1	1	4	16
Comfort	Thermal insulation	3	1		1	1		1	1	1	6	18
	Privacy	2			1					1	2	4
	Ext. & Int. moisture control	4	1		1					1	3	12
Structure	Solid & hardy	4				1		1		1	3	12
	Structural functions	4				1	1	1			3	12
	Define space	5	1		1			1			3	15
Durabilty	Sustainabilty	4				1	1		1	1	4	16
	Longevity/Life of product	3				1	1		1	1	4	12
	Low maintenance	2				1				1	2	4
Services	Containment of services	5				1	1	1			3	15
	Doors & windows	5	1		1			1			3	15
	Provision of surfaces	5								1	1	5
									Total:		48	**180**

[C+S]+I+L

	[C+S]+I+L	**Performance Indicator**	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	**HSS Total**	**Performance Weighted**
Protection	Shelter	5			1		1	1	1	1	5	25
	Fire protection	5						1		1	2	10
	Security	5			1			1	1	1	4	20
Comfort	Thermal insulation	4	1		1	1		1	1	1	6	24
	Privacy	4			1					1	2	8
	Ext. & Int. moisture control	3	1		1					1	3	9
Structure	Solid & hardy	5				1		1		1	3	15
	Structural functions	5				1	1	1			3	15
	Define space	5	1		1			1			3	15
Durabilty	Sustainabilty	3				1	1		1	1	4	12
	Longevity/Life of product	5				1	1		1	1	4	20
	Low maintenance	5				1				1	2	10
Services	Containment of services	2				1	1	1			3	6
	Doors & windows	3	1		1			1			3	9
	Provision of surfaces									1	1	0
								Total:			48	**198**

[C+I]+S+L

	[C+I]+S+L	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Protection	Shelter	5			1		1	1	1	1	5	25
	Fire protection	5						1		1	2	10
	Security	4			1			1	1	1	4	16
Comfort	Thermal insulation	4	1		1	1		1	1	1	6	24
	Privacy	4			1					1	2	8
	Ext. & Int. moisture control	5	1		1					1	3	15
Structure	Solid & hardy	4				1		1		1	3	12
	Structural functions					1	1	1			3	0
	Define space		1		1			1			3	0
Durabilty	Sustainabilty	4				1	1		1	1	4	16
	Longevity/Life of product	4				1	1		1	1	4	16
	Low maintenance	5				1				1	2	10
Services	Containment of services					1	1	1			3	0
	Doors & windows	3	1		1			1			3	9
	Provision of surfaces									1	1	0
								Total:			48	**161**

C+[S+I]+L

	C+[S+I]+L	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Protection	Shelter	5			1		1	1	1	1	5	25
	Fire protection	4						1		1	2	8
	Security	4			1			1	1	1	4	16
Comfort	Thermal insulation	4	1		1	1		1	1	1	6	24
	Privacy	4			1					1	2	8
	Ext. & Int. moisture control	5	1		1					1	3	15
Structure	Solid & hardy	5				1		1		1	3	15
	Structural functions	5				1	1	1			3	15
	Define space	5	1		1			1			3	15
Durabilty	Sustainabilty	4				1	1		1	1	4	16
	Longevity/Life of product	5				1	1		1	1	4	20
	Low maintenance					1				1	2	0
Services	Containment of services	4				1	1	1			3	12
	Doors & windows	4	1		1			1			3	12
	Provision of surfaces									1	1	0
								Total:			48	**201**

C+S+[I+L]

	C+S+[I+L]	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Protection	Shelter				1		1	1	1	1	5	0
	Fire protection	4						1		1	2	8
	Security				1			1	1	1	4	0
Comfort	Thermal insulation	4	1		1	1		1	1	1	6	24
	Privacy	4			1					1	2	8
	Ext. & Int. moisture control		1		1					1	3	0
Structure	Solid & hardy	4				1		1		1	3	12
	Structural functions					1	1	1			3	0
	Define space		1		1			1			3	0
Durabilty	Sustainabilty	4				1	1		1	1	4	16
	Longevity/Life of product	4				1	1		1	1	4	16
	Low maintenance	5				1				1	2	10
Services	Containment of services	3				1	1	1			3	9
	Doors & windows	3	1		1			1			3	9
	Provision of surfaces	5								1	1	5
									Total:		48	**117**

[C+S+I]+L

	[C+S+I]+L	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Protection	Shelter	5			1		1	1	1	1	5	25
	Fire protection	5						1		1	2	10
	Security	5			1			1	1	1	4	20
Comfort	Thermal insulation	5	1		1	1		1	1	1	6	30
	Privacy	5			1					1	2	10
	Ext. & Int. moisture control	2	1		1					1	3	6
Structure	Solid & hardy	5				1		1		1	3	15
	Structural functions	5				1	1	1			3	15
	Define space	5	1		1			1			3	15
Durabilty	Sustainabilty	3				1	1		1	1	4	12
	Longevity/Life of product	5				1	1		1	1	4	20
	Low maintenance	5				1				1	2	10
Services	Containment of services	2				1	1	1			3	6
	Doors & windows	2	1		1			1			3	6
	Provision of surfaces									1	1	0
									Total:		48	**200**

[C+S+I+L]

	[C+S+I+L]	Performance Indicator	Energy	Water	Indoor Env. Quality	Materials	Future Flexibility	Buildability	Affordability	Desirability	HSS Total	Performance Weighted
Protection	Shelter	4			1		1	1	1	1	5	20
	Fire protection	1						1		1	2	2
	Security	4			1			1	1	1	4	16
Comfort	Thermal insulation	3	1		1	1		1	1	1	6	18
	Privacy	2			1					1	2	4
	Ext. & Int. moisture control	5	1		1					1	3	15
Structure	Solid & hardy	4				1		1		1	3	12
	Structural functions	4				1	1	1			3	12
	Define space	5	1		1			1			3	15
Durabilty	Sustainabilty	5				1	1		1	1	4	20
	Longevity/Life of product	4				1	1		1	1	4	16
	Low maintenance	4				1				1	2	8
Services	Containment of services	4				1	1	1			3	12
	Doors & windows	5	1		1			1			3	15
	Provision of surfaces	5								1	1	5
								Total:			48	**190**