SM3570/3

Prioritisation of building systems

Final

A report prepared for Beacon Pathway Limited
December 2008

The work reported here was funded by Beacon Pathway Limited and the Foundation for Research, Science and Technology

About This Report

Title

Prioritisation of building systems

Authors

Barbara Nebel (team leader); Karen Bayne, Connie Crookshanks

Reviewer

Bob Shula, Scion

Abstract

This working paper is an interim report from the Systems Research Work Plan - “Criteria Development and Embedding Systems”. It sets out details of the steps that lead to the selection of two priority systems for further research: windows for retrofit projects; and walls for new build projects. These two systems were selected from a prioritised list of residential building systems obtained through a series of workshops and project team discussion meetings.

The definition of a ‘system’ in the context of the project is the smallest part of a building where a function (functional unit) can be appropriately prescribed. Within each system, a range of generic ‘solutions’ can be provided. For example retrofit window solutions include blinds and drapes; secondary glazing; and films, (Insulated Glass Units) IGU’s and draught-stopping devices.

The systems in the list were prioritised using a Hierarchy of Criteria which was also established as part of the project from key ‘sustainability’ criteria (essentially Beacon’s HSS High Standard of Sustainability® (HSS®)) and ‘uptake’ criteria (identified in the literature).

The two systems selected are key elements of the thermal envelope of a building. It is likely that a number of other systems that are also part of the thermal envelope will be investigated further. Learnings from further research on ‘new wall systems’ can be transferred to ‘existing wall systems’ and would therefore provide for an ‘existing wall system’ as a logical system to look at beyond this initial project. The same principle applies to ‘retrofit window systems’.

As part of this initial project, a generic list of systems was developed, and a prioritisation process undertaken to determine the initial systems to investigate. This list will need to be reviewed and re-prioritised at regular intervals. It was recommended by the project team to extend the stakeholder participation and to review the ranking of the priority of systems for new and for retrofit. The Hierarchy of Criteria should also be revised as Beacon’s HSS High Standard of Sustainability® (HSS®) evolves and further performance targets are derived.

The findings from this paper contribute to the project “Criteria Development and Embedding Systems” which is focused 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*”. According to the systems strategy the next steps of this research stream is the design and implementation of two new systems. However, during the project the team realised that it might not be necessary to develop a new solution, but to emphasise uptake issues of existing solutions.

Reference

Nebel, B., Bayne, K. and Crookshanks, C. December 2008. Prioritisation of building systems.Report SM3570/3 for Beacon Pathway Limited.

Rights

Disclaimer

The opinions provided in the Report have been provided in good faith and on the basis that every endeavour has been made to be accurate and not misleading and to exercise reasonable care, skill and judgment in providing such opinions. Neither Beacon Pathway Limited nor any of its employees, subcontractors, agents or other persons acting on its behalf or under its control accept any responsibility or liability in respect of any opinion provided in this Report.

Contents

Tables

1 Executive Summary

This working paper is part of the Systems Research Workplan "Criteria Development and Embedding Systems" ('the project'). The paper sets out the process for the selection of two building systems ('systems') for further research as part of the project "Criteria Development and Embedding Systems" which is focused 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 definition of a 'system' in the context of the project is the smallest part of a building where a 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 each system, a range of generic 'solutions' can be provided to aid in providing the required function(s). For example, retrofit window solutions include blinds and drapes; secondary glazing; and films, insulated glass units (IGU's) and draught-stopping devices.

This is an internal document which presents the approach taken by the project team[1], decisions made, any issues or problems encountered with the approach and any alternative approaches found to identifying two prioritised systems. This document is critical to ensuring that the assumptions used in the assessment are transparent and available.

The project focused on the development of systems that could be applied to both retrofit and new build situations to substantially improve their ability to perform to a high standard of sustainability. It is important to note that the scope of the current project might not lead to the development of a new solution of wall systems for new build or retrofit windows. Instead, a technological 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. In particular, issues such as: product availability (reality and perception); affordability and willingness to pay; skills and trades people (availability and knowledge and understanding in particular in retrofit situations); and regulatory barriers were all identified as potential barriers to change and to the achievement of Beacon's goal.

Specifically, this paper covers the delivery of the following components that contributed to the development of the prioritised list of systems for further research.

- Literature Review
- List of Systems
- Hierarchy of Criteria
- Evaluation of Systems
- Prioritised List of Systems

---

[1] ***The project team included Barbara Nebel, Karen Bayne, Daniel Kellenberger and James Turner (Scion), Kay Saville-Smith (CRESA), Ian Page (BRANZ) and Connie Crookshanks (East Harbour Management).***

Two key outcomes from the literature review were a general list of systems and a list of assessment criteria to be used in the evaluation of these systems. Table 1 presents a general list of criteria and Table 2 presents a list of systems which emerged from the literature survey.

Table 1: Overview table of the initial list of criteria for systems

Criteria	Description
Customisation	Allows ability to individualise or personalise system
Simple, easy to use	Easy to operate and maintain
Ability to upgrade in future	Able to retrofit system for future user needs – permits upgrades in future “Futureproof”
Resource Efficiency and Use - Energy	Reduce dependence on non-renewable energy supply, wherever possible
Resource Efficiency and Use - Water	Reduce dependence on treated water supply, wherever possible Reduce wastewater disposal going to sewer or untreated wastewater going into natural environment
Resource Efficiency and Use – Solid Waste	Reduce creation of waste
Air quality - outdoor	Minimise pollution to atmosphere
Air quality - indoor	Provide a healthy indoor environment
Health and Safety	Safe to operate, Or Facilitates safer living environment, Or Reduces risk of injury/ illness
Wellbeing	Maintains or revives spiritual wellbeing
Affordability	Cost to obtain, operate and maintain device, and to dispose of device at end (or house with device).
Socially responsible	
Prepared for climate change	Robustness of system and designed for extreme climate and weather events
Materials selection	Use sustainable and renewable materials that will best last the function intended for them
Quality	Meets higher performance than expectations

Table 2: Final list of systems used in the prioritisation process

No.	Final Systems List
1	Ceiling/roof
2	Ceiling/floor (e.g. between first and second story)
3	Doors (external)
4	Doors (internal)
5	Reticulated Energy Systems (Covering Electrical supply and Gas supply)
6	External walls
7	Groundfloor/foundations
8	Internal walls and partitions (including Finishing systems (mouldings, paint, wallpaper, etc.)
9	Lighting (natural and electrical)
10	Solid household waste
11	Space Conditioning (Covering Space cooling, Space heating and Ventilation) = HCV
12	Water heating
13	Integrated Water Systems
14	Windows
15	Access (Steps and Stairs)

These tables were the input information to two workshops.

The method of assessment identified for use in this project is the Analytical Hierarchy Process. The Analytical Hierarchy Process (AHP) is a quantitative method for ranking decision alternatives and based on multiple criteria. Essentially it is a process for developing a numerical score to rank each decision alternative based on how well each alternative meets the decision maker's criteria. In the most basic terms, the AHP process simply involves the development of a list of systems, the development of some robust ranking criteria and the scoring of the systems against those criteria.

The first workshop – a criteria workshop – was held with Beacon Research Team Leaders (RTLs) and some Research Guidance Committee (RGC) members. The workshop aimed to refine the list of criteria identified through the literature survey and ultimately to produce a Hierarchy of Criteria to be used to prioritise the systems. The outcome of the criteria workshop – including the refinement that took place after both workshops – was the Hierarchy of Criteria as presented in Table 3. The criteria are based on Beacon's HSS® and were extended to include uptake related criteria. The final list shows the two overarching criteria 'sustainability' and 'uptake'.

The second workshop – a scoring workshop – was held with members of the Beacon Research Guidance Committee (RGC) and a number of building practitioners. It aimed to identify priority built environment systems based on their contribution to the Hierarchy of Criteria (criteria such as energy, water, indoor environmental quality (IEQ), materials, future flexibility, affordability, buildability, desirability). The systems ranked by the participants in the scoring workshop are presented in Table 4.

The next steps of this research stream according to the systems strategy are the design and implementation of two new systems. However, during the project the team realised that it might not be necessary to develop a new solution, but to emphasise uptake issues of existing solutions.

Table 3: Hierarchy of Criteria

Criteria	Sub-criteria	Sub-criteria
Sustainability	Energy	Passive Solar Reticulated Energy Use Renewable Energy
	Water	Reticulated Water Use Integrated Water Mgmt
	Indoor Environment Quality	Temperature Humidity Ventilation Pollution Noise
		Injuries Crime
	Materials	Construction Waste Embodied Energy Carbon Footprint Renewable/Recyclable Manufacture Pollution
Uptake	Future Flexibility	Upgradeable Adaptable
	Buildability	Installation Operation

	Affordability	Purchase Cost Installation Cost Operating Cost Maintenance Cost Disposal Cost
	Desirability	Social Acceptability Character Low Maintenance Market size

Table 4: Prioritised systems ranked by workshop participants

System	Score
Design of new and retrofit systems to maximise solar, thermal mass, water capture, etc.	7.2
Exterior building envelope	6.9
Existing exterior walls and windows	6.6
Enhance existing window systems	6.6
Ventilation systems	6.6

Feedback from workshop participants indicated that the outcomes from the workshops were not entirely satisfactory. This was largely because participants did not appear to be entirely comfortable with the AHP methodology used in the workshops. They therefore doubted the robustness of the process to select the two 'priority' systems and it was clear that additional activities would have to be identified to ensure confidence in the system prioritisation process.

The project team resolved to extend the initial literature review to ensure that as many as possible previous studies that had identified building systems were considered. The team initiated an extended literature review and a review of relatively recent local residential new build and retrofit projects.

The project team considered all this information and undertook an exercise in which individual team members ranked the list of systems using the Hierarchy of Criteria. Two systems were identified as the two 'priority' systems to undergo further research in the next stage of the Systems work. Wall systems were identified as the priority system for new builds, and window systems were identified as the priority system for existing homes or retrofits.

Wall systems – Prioritised Systems for New Build

Current techniques for wall construction do not easily allow for increased amounts of insulation and a basic redesign could facilitate this increase and a reduction in thermal bridging.

Window systems – Prioritised Systems for Retrofit

Evidence from local projects indicate that retrofitting double glazing is proving problematic for a range of technical and uptake issues including availability, installation skills, buildability and cost-effectiveness. Further investigations will help to identify potential solutions to increase uptake.

Windows and wall systems are key elements of the thermal envelope and have the potential to make a significant impact on the performance of a building. It's likely that further systems to complete the thermal envelope will also undergo closer examination in subsequent work. For example, learnings from 'new walls' can be transferred to 'existing walls' and would therefore provide for 'existing walls' as a logical system to look at beyond this initial project. The same principle applies to retrofit window systems.

2 Introduction

This working paper is part of the Systems Research Work Plan- "Criteria Development and Embedding Systems" ('the project'). The paper sets out the process for the selection of two building systems ('systems') for further research.

This is an internal document which presents the approach taken, decisions made, any issues or problems encountered with the approach and any alternative approaches found to identifying two prioritised systems. This document is critical to ensuring that the assumptions used in the assessment are transparent and available.

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*"[2]. However, it is important to note the results of the project have shown that the scope of the current project might not necessarily lead to the development of a new solution of wall systems for new built – or retrofit windows. Instead, a technological 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.

The deliverables from this project are as follows:

- A prioritised list of about 20 systems for immediate and medium term research; and
- A prioritised list of critical new and retrofit building systems (based on quantified gains towards reaching Beacon's targets and the HSS High Standard of Sustainability® (HSS®)[3] and insights and experience from the Beacon RTL team). The list will be used to identify two systems for which specific designs are established in this project, at least one of which will be suitable for retrofit situations.

Further research on the two systems selected in this process is not presented in this report.

In order to achieve the selection of two prioritised systems the first step in the process was the preparation of a general list of residential building systems for consideration.

---

[2] ***Research Workplan, Systems Phase1: Criteria Development and Embedding Systems, February 2008 (6-3570).***

[3] ***Beacon High Standard of Sustainability™ (HSS) – The Beacon High Standard of Sustainability covers the main aspects of energy, indoor environment quality, water, and materials and is underpinned by future flexibility, buildability and affordability.***

The next step in the process was to develop a list of criteria that would be used to rank or prioritise these systems. The approach that was identified to prioritise the systems was the Analytical Hierarchy Process (AHP).

This paper is set out as follows:

Section 2 presents some background information that sets the context for this work. In particular, it notes the deliverable from this project according to the Systems Research Work Plan.

Section 3 sets out the project methodology. In particular, it sets out the phases beginning with a literature review to establish a general list of systems and a list of criteria used to evaluate these systems. Details of the findings from two workshops and subsequent additional research by the project team are also noted.

Section 4 presents the concluding research team discussion and final systems selection.

Section 5 presents conclusions from this study and anticipated next steps.

3 Background

The “Systems” workstream is an integral part of the Beacon delivery model and will be highly interlinked with other Beacon work programmes through close interaction with Research Team Leaders and other Beacon researchers.

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.

The research described in the Systems Research Work Plan - “*Systems Phase 1: Criteria Development and Embedding Systems*” - will apply the concept of Life Cycle Assessment into the design process of specific prioritised systems to design building systems that 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 process to develop the prioritised list of systems for further research.

Other aspects of the project (i.e., the LCA of the NOW Home® and two homes from the Papakowhai Renovation project, the development of design criteria for two systems, and the development of an LCA based systems calculator) are reported elsewhere.

Specifically, this paper covers the delivery of the following components that contributed to the development of the prioritised list of systems for further research:

- Literature Review
- List of Systems
- Hierarchy of Criteria
- Evaluation of Systems
- Prioritised List of Systems

3.1 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 into solutions that have similarity. For example, in the retrofit windows system case study, 'Additions' enabled grouping a range of solutions together such as blinds, drapes and external shades; whereas 'Complete Replacement' allowed 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; and films, IGU's and draughtstopping devices.

For every solution, specific **'Designs'** can be achieved, which comprise a particular packaging 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.

4 Project Methodology

This section of the report sets out the methodology used in each of the key phases of the project noting the aims of each phase and how the outcome from one phase feeds into the next.

The key phases are as follows:

1. Literature Review – research to collate details on building systems and ultimately produce a list of systems for evaluation; development of a list of criteria by which the identified building systems can be evaluated.
2. Two workshops – discussions to refine the list of systems and criteria. The workshops are the first step in the evaluation of the systems, the process to develop a high priority list of systems and ultimately to identify two priority building systems
3. Additional research activities – a number of additional activities were undertaken to ensure that a robust process had been applied to the identification of the two priority building systems.

As noted in Section 2, it was proposed in the Work Plan to use the Analytical Hierarchy Process (AHP) for the prioritisation of systems.

The method of assessment identified for use in this project is the Analytical Hierarchy Process. Analytical Hierarchy Process (AHP) is a quantitative method for ranking decision alternatives and selecting one given multiple criteria. Essentially it is a process for developing a numerical score to rank each decision alternative based on how well each alternative meets the decision maker's criteria. The process, and its outcomes, are often represented graphically.

AHP is most often used by teams of people who are working on complex problems. It has unique advantages where important elements of the decision are difficult to quantify or compare, or where communication among team members is impeded by their different specializations, terminologies, or perspectives.

AHP has been recommended to Beacon previously for assessing priority work streams and has been applied to inform building investment decisions.

In other words, in the most basic terms, the AHP process simply involves the development of a list of systems, the development of some robust ranking criteria and the scoring of the systems against those criteria.

From the outset, the Project Team identified the merits of consulting widely with building practitioners[4] to ensure that their insight was reflected in the final selection of the two prioritised building systems. The Project was limited in its ability to involve building practitioners directly, in for example workshops, not least because of the additional expense and availability of building practitioners but also because of the project timescale. It was therefore necessary to identify alternative approaches.

4.1 Literature Review

A literature review was undertaken in order to develop an initial list of systems as well as establish the criteria by which the systems could be evaluated.

A review of existing literature on sustainability criteria and housing design criteria was undertaken with the aim of uncovering explicit and strongly implied requirements for building systems. The review focused on criteria for the design of systems (both technical and end-user needs) and also the prioritisation of a list of common residential building systems.

The results of the review were intended to feed into subsequent stages of the programme, in particular two key workshops that were scheduled as part of the process. Details of the two workshops that were held (a criteria workshop and a scoring workshop) are presented in Sections 3.2.1 and 3.2.2.

4.1.1 List of Criteria

A preliminary list of criteria was developed with regard to Beacon's goal "*to bring the vast majority of New Zealand homes to a high standard of sustainability by 2012*". There are two crucial aspects that need to be taken into account in the development of this list:

- the vast majority of New Zealand homes, and
- a high standard of sustainability.

These two aspects were subsequently translated into 'uptake' related criteria (i.e., the vast majority of NZ homes) and 'sustainability' related criteria (i.e., to a high standard of sustainability). The sustainability related criteria were derived from Beacon's HSS High Standard of Sustainability® (HSS®). The uptake related criteria were based on the literature review and were further refined at the criteria workshop.

[4] ***Building practitioners are defined as those individuals or organisations involved in any part of the 'building value chain', from architects to plumbers, from builders to local Government planners and from building material retailers to manufacturers.***

The literature review of national and international research concerning sustainable housing criteria aimed to ensure that a "systematic, data-driven process" was used in the preparation of the list. The research was used to verify the HSS® as an appropriate indicator of the most important criteria, and also to extend the criteria to ensure adherence to international definitions. The consensus view from the international and national studies mainly agreed with the 7 elements present in the HSS®. Exceptions to this are that the HSS® IEQ[5] element is narrower in scope than the general consensus, which would usually include noise and pollutant sub-criteria, as well as safety elements.

The literature review focussed on studies based on residential buildings and identified lists and databases of systems and technologies. Reports in a total of 7 separate studies were reviewed as follows:

Study1	Criteria arising from Bates et al. 2001 "Room for View" scenario analysis;
Study 2	Criteria arising from Waitakere NOW Home® research project;
Study 3	Criteria arising from Bates and Kane 2005 "Future of Housing in NZ 2030" scenario analysis;
Study 4	Criteria arising from the HSS High Standard of Sustainability® (HSS®) research programmes 2006-2008;
Study 5	Criteria arising from other New Zealand sources;
Study 6	Criteria arising from the Queensland Smart Housing Programme;
Study 7	Criteria arising from other international sources.[6]

The main reports from these studies were analysed for any explicit or strongly implied criteria relating to sustainability and housing design. Criteria relating specifically to the house itself (e.g. indoor air quality, affordability, materials selection) were selected as these can be influenced by building systems.

Key criteria from each of the studies were collated and are presented in

[5] ***IEQ – Indoor Environmental Quality***

[6] ***A complete Bibliography and further details for each of the 7 main studies analysed are presented in Appendix 1.***

Table 5 below. This overview table interprets the various design criteria (many of which relate to the requirements for the entire house) into the criteria requirements for a housing system. For example ‘affordability’ can relate to the price of the entire house, and the operating costs, but can be reinterpreted as the price to purchase the system including installation, and the cost to operate and maintain that system. A ‘description’ column in the table aims to clarify this.

Table 5: Overview table of the initial list of criteria for systems - collated from all 7 studies

Criteria	Description
Customisation	Ability to individualise or personalise system
Simple, easy to use	Easy to operate and maintain
Ability to upgrade in future	Able to retrofit system for future user needs – permits upgrades in future "Futureproof"
Resource Efficiency and Use - Energy	Reduce dependence on non-renewable energy supply, wherever possible
Resource Efficiency and Use - Water	Reduce dependence on treated water supply, wherever possible Reduce wastewater disposal going to sewer or untreated wastewater going into natural environment
Resource Efficiency and Use – Solid Waste	Reduce creation of waste
Air quality - outdoor	Minimise pollution to atmosphere
Air quality - indoor	Provide a healthy indoor environment
Health and Safety	Safe to operate Or Facilitates safer living environment Or Reduces risk of injury/ illness
Wellbeing	Maintains or revives spiritual wellbeing
Affordability	Cost to obtain, operate and maintain device, and to dispose of device at end (or house with device).
Socially responsible	
Prepared for climate change	Robustness of system and designed for extreme climate and weather events
Materials selection	Use sustainable and renewable materials that will best last the function intended for them
Quality	Meets higher performance than expectations

4.1.2 List of Systems

An original list of systems was collated from past Beacon reports. The following lists emerged from the literature review [7]:

- List of generic functions of building systems.
- List of building systems.
- List of building technologies.

These lists are presented in Appendix 2. A general list of building systems was then developed as input for the prioritisation process and the scoring workshop. This initial List of Systems (21 systems in total) is shown in Table 6.

Table 6: Initial list of systems derived from Beacon reports

No.	Initial List of Systems
1	Ceiling
2	Doors (external)
3	Doors (internal)
4	Electrical supply
5	External walls
6	Flooring
7	Foundations
8	Gas supply
9	Internal walls
10	Lighting
11	Paving systems
12	Roof
13	Security
14	Solid waste
15	Space cooling
16	Space heating

7 Additional references for the development of the lists were Batelle Corp. 1996. "Opportunities for Polymeric Materials in Construction". Confidential Multiclient Report. Jan 1996, Forest Research 2003 “Features and Benefits analysis from 'Value through Design' project) and Bayne, K and Walford, B. 2005. Beacon Pathway TE101 Technology Assessment Project- Handbook of Technologies.

17	Stormwater
18	Ventilation
19	Water heating
20	Water supply/waste water
21	Windows

In discussion, the project team subsequently revised and streamlined the list of systems according to the definition of systems used in the project. The final list of systems used in the prioritisation process is shown in Table 7. For simplicity, a number of systems were combined in this process, for example, 'Space Heating', 'Cooling' and 'Ventilation' were combined into one System – 'Space Conditioning', also referred to as HCV. The resulting final list has 15 systems in total.

Table 7: Final list of systems used in the prioritisation process

No.	Final Systems List
1	Ceiling/roof
2	Ceiling/floor (e.g. between first and second story)
3	Doors (external)
4	Doors (internal)
5	Reticulated Energy Systems (Covering Electrical supply and Gas supply)
6	External walls
7	Groundfloor/foundations
8	Internal walls and partitions (including Finishing systems (mouldings, paint, wallpaper, etc.)
9	Lighting (natural and electrical)
10	Solid household waste
11	Space Conditioning (covering space heating, space cooling and ventilation) = HCV
12	Water heating
13	Integrated Water Systems
14	Windows
15	Access (Steps and Stairs)

The project team identified the need to use terminology in use in the building industry in the development of the list of systems. The CBI List of Groups and Classes (Level 2) (as shown in Appendix 3) was considered in this process although it was noted that the CBI classification is strongly based on materials. For example, the subcategory “timber” in the category “structure” includes all structural elements such as wall framing and roof framing under one heading.

4.2 Evaluation of the Systems

Robust criteria are required for the evaluation and prioritisation of systems. For a classical AHP process a weighting of the criteria used in the process is required as well. The criteria that emerged from the literature review (as presented in

Table 5) were presented to a criteria workshop with Beacon Research Team Leaders (RTLs) and some Research Guidance Committee (RGC) members.[8] A further workshop was organised to score the systems.

4.2.1 Criteria Workshop

The aim of the criteria workshop was to refine the list of criteria identified through the literature survey and ultimately, to produce a Hierarchy of Criteria to be used in the AHP process.

As outlined in the work plan, the original intention was to use the AHP process to prioritise the systems. In the course of the workshop it became clear that the application of the AHP methodology *per se* to the prioritisation process wasn't working as well as was hoped. Despite this, it is important to note that the selection process still involved the development of a list of systems, the development of some robust ranking criteria and the scoring of the systems against those criteria. While it became clear that a more simple evaluation approach to the prioritisation of the identified systems was more appropriate, the principles are essentially the same as those of the AHP process.

Some progress was made at the criteria workshop in terms of identifying the high level criteria (sustainability and uptake) and sub-criteria. After the workshop, the project team finalised the sub-criteria. The refined criteria were finally agreed upon at the subsequent scoring workshop which focussed on using the criteria to score the list of building systems. It was decided that there should be equal weighting given to both the sustainability and uptake aspects of the goal. All sub criteria were also to be weighted equally.

The outcome of the criteria workshop – including the refinement that took place after both workshops – was a Hierarchy of Criteria that can be used to score systems. The criteria are based on Beacon's HSS® and were extended to include uptake related criteria. The final list is shown in Table 8. It includes the two overarching criteria 'sustainability' and 'uptake' and the respective criteria below.

Table 8: Hierarchy of Criteria

Criteria	Sub-criteria	Sub-criteria
Sustainability	Energy	Passive Solar Reticulated Energy Use Renewable Energy
	Water	Reticulated Water Use

[8] ***Attendees at the criteria workshop on 10th April 2008 were as follows: Nick Collins, Karen Bayne, Lois Easton, Verny Ryan, Bob Shula, Kay Saville-Smith, Maggie Lawton, Andries Popping, James Turner, Barbara Nebel, and Kevin Golding.***

		Integrated Water Mgmt
	Indoor Environment Quality	Temperature Humidity Ventilation Pollution Noise
		Injuries Crime
	Materials	Construction Waste Embodied Energy Carbon Footprint Renewable/ Recyclable Manufacture Pollution
Uptake	Future Flexibility	Upgradeable Adaptable
	Buildability	Installation Operation
	Affordability	Purchase Cost Installation Cost Operating Cost Maintenance Cost Disposal Cost
	Desirability	Social Acceptability Character Low Maintenance Market size

4.2.2 Scoring Workshop

A scoring workshop was held with members of the Research Guidance Committee (RGC) and a number of building practitioners. The invited RGC members were not the same as those present at the criteria workshop[9])

[9] ***For methodological reasons it was decided that the 'scoring' team needed to be different to the 'criteria development' team. Attendees at the scoring workshop on the 17th April 2008 were as follows: Nick Collins (Beacon), David Anderson (Scion), Karen Bayne (Scion), Alistair Fleming (Steel NZ), Terry Foster, Bob Greenbury, Roman Jacques (Branz), John Jamison (Fletcher Aluminium), Barbara Nebel (Scion), Wayne Sharman (BRE), Robert Tait (Unitec), James Turner (Scion).***

The aim of the scoring workshop was to identify priority built environment systems based on their contribution to the hierarchy of criteria (criteria such as Energy, Water, IEQ, Materials, Future Flexibility, Affordability, Buildability, Desirability) as presented in Table 8.

Two approaches to score the systems were applied in the workshop. Firstly, all participants were asked to identify their top two priority systems from the list of systems prepared as part of the literature review and shown in Table 6. As noted, the project team subsequently streamlined this list and the outcome – the final list of systems is presented in Table 7.

The priority systems that emerged from the discussions at the scoring workshop are presented in Table 9[10].

Table 9: Priority building systems identified by workshop participants in discussion

External walls (+ windows) of existing homes
Ventilation/moisture independent of people
Integrated water management (IWM)
Design of new and retrofit systems to maximise solar, thermal mass, capture water, passive ventilation
Existing windows
Solar capture
External envelope
Interior walls

In the next step the participants were asked to rank all the systems individually based on the Hierarchy of Criteria.

A matrix was drawn up and participants each completed the matrix with scores (1 – 10) reflecting their views and experience with the systems. Equal weighting applied and the scores were averaged. Appendix 4 shows the matrix and the scores allocated by participants to each of the systems and hence those systems that emerged as a priority for further investigation. The top five prioritised systems identified by participants in the scoring workshop are presented n Table 10.

Table 10: Prioritised systems ranked by workshop participants

System	Score
Design of new and retrofit systems to maximise solar, thermal mass, water capture, etc.	7.2
Exterior building envelope	6.9

[10] *Note – The system terms used in Table 9 are the record of workshop discussions.*

Existing external walls and windows	6.6
Enhance existing window systems	6.6
Ventilation systems	6.6

While not specifically the intention of this workshop, participants also discussed the Hierarchy of Criteria which emerged from the criteria workshop. Specifically, participants discussed the 'uptake' criteria that had been identified as part of the literature review.

The outcome of the scoring workshop was an initial scoring of building systems from which the three systems listed above emerged as the 'priority' systems and confirmation of the Hierarchy of Criteria that emerged from a combination of the criteria workshop and post workshop discussions (as shown in Table 8).

4.3 Additional Investigations of Building Systems and Evaluation Criteria

The literature review and the workshops produced two key inputs into the process to select two 'priority' building systems for further research.

The criteria workshop (and post workshop revisions) produced a Hierarchy of Criteria that could be used to score systems. The scoring workshop produced a prioritised List of Systems.

At this point, the project team reflected on the outcomes of the literature review and the workshops. It was felt that the outcomes of the workshops in particular were not satisfactory because participants did not appear to be comfortable with the AHP methodology. They therefore doubted the robustness of the process to select the two 'priority' systems.

A survey of building practitioners and/or an extended literature review were identified by the project team as suitable additional activities. However, due to the likely additional costs associated with a survey of practitioners and timescale delays that could not be accommodated within the current project, this activity had to be rejected. The team resolved then to extend the initial literature review to ensure that as many as possible previous studies that had identified building systems were considered.

For robustness therefore, and in addition to the literature review and the workshops, a number of additional activities were also undertaken by the project team and information identified was subsequently applied to the evaluation of the systems as follows:

- An extended literature review, covering other key residential building systems studies.
- Past learning's from the NOW Home® and Papakowhai projects – gap analyses.
- The Retrofit Database of Technologies (a previous Beacon project).

- Other research underway in New Zealand.
- Research team discussion and final selection process.

The aim of these additional activities was ultimately, in the light of all information available, to identify and agree upon two prioritised systems. Further, by examining additional studies covering both new builds and existing homes or retrofit projects, the project team would be better able to establish which of the prioritised systems should have a new build focus and which should have a retrofit focus.

4.3.1 Extended Literature Review

The project team listed a number of additional sources of information focussing on residential building systems from the literature. Specifically, the reports identified were 'whole of house' reports (i.e. not specific to one building system, for example a report on walls or a report on ceilings) as it was believed that these may provide information about systems within a house that would be of relevance to this work. The reports identified presented a balanced mix of new build and retrofit focussed projects. They are listed as follows:

- Recent work undertaken by Bob Lloyd of Otago University;
- Research undertaken by Robert and Brenda Vale, specifically in their publication "The New Autonomous House";
- *'Zaleh'* – The BRANZ Zero and Low Energy House Project Report;
- The Exemplar House (a previous Scion study); and
- The Retrofit Database of Technologies (a previous Beacon project).

Using the final list of systems (as shown in Table 7) and the Hierarchy of Criteria (as shown in Table 8), the prioritised list of systems (Table 9) and the three priority systems identified by the participants at the scoring workshop, the project team reviewed the reports listed above. The key findings of each report are noted below (see Appendix 4 for more detail of the literature review):

4.3.1.1 Recent work undertaken by Bob Lloyd of Otago University[11]; [Retrofit Focus]

The study states that upgrading existing New Zealand State Housing stock will provide benefits at different levels:

- Social cost and benefits by improving the quality of life through reducing health risks and seasonal mortality.

---

[11] ***Report Reference: Title: Retrofit alternatives for State Houses in Cold Regions of New Zealand, Report No. 2, Authors: Bob Lloyd, Tim Bishop, Maria Callau, A research project by the Energy Management Group, Physics Department - University of Otago - Dunedin - New Zealand, September 2007.***

- Private cost and benefits by providing a healthier environment to achieve thermal comfort at home will have an impact in the way people live and use their homes.

The study has an energy and cost focus and is not driven by the wider concepts of sustainability. Its aim was to establish what upgrades could achieve by way of improving the energy efficiency (and specifically reducing heat loss) of the property and at what cost.

The report confirms that the energy efficiency and indoor comfort of existing housing can be raised by: improving the building fabric performance, improving the heating system efficiency (including the control system), increasing the amount of solar gains into the house, (openings and configuration improvements), using high efficiency appliances and educating occupants on optimal behaviour.

The research consisted of monitoring the efficacy of Housing New Zealand Corporation's (HNZC) energy efficiency retrofit programme implemented in state houses across New Zealand. The Otago Research Team identified upgrades that would reduce heat loss, in order of efficacy. These are listed and ranked below in Table 11, along with their corresponding systems from the Revised List of Systems.

Table 11: Upgrades identified by the Otago Team matched with Building Systems

Rank	Upgrade identified by the Otago Team	Building System
1	Insulate the ceiling	Ceiling/Roof
2	Insulate the floor	Groundfloor/foundations
3	Install a low emissions wood burner or pellet fire	HVC
4	Install a heat pump if it will replace electric heaters used elsewhere in the house.	HVC
5	Improve air-tightness	Exterior Walls Exterior Doors Groundfloor/foundations
6	Insulate walls	Exterior Walls
7	Install double glazing and/or drapes	Windows

While these results are generally what would be expected (and consistent with where most heat is lost in a building) of additional interest to the systems work are the difficulties experienced by the Otago Team during the retrofitting processes. Specifically, difficulties were experienced with skills and experience, retrofitting windows (experience and materials availability) and retrofitting the walls (accessibility issues).

4.3.1.2 Research undertaken by Robert and Brenda Vale, specifically in their publication – "The New Autonomous House"[12,13] [New Build Focus]

The Vale's project is new build focussed and while many of the concepts are generic it should be noted that the study is UK-based and therefore not all experiences are applicable to New Zealand. The project looks broadly at a range of sustainability concepts beyond energy use.

Chapter 5 covers the following issues: saving energy, structure (external walls, the cellar, windows doors and glazing, the roof, the conservatory); building enclosure (thermal bridging, air-tightness and ventilation); and services (sewerage, water supply, space heating, electricity). Under 'saving energy' the authors note their focus in terms of insulating the house was driven by the availability of the materials rather than their performance per se. Through this project they wanted to demonstrate that the materials were readily available, that any contractor/builder could install them and that costs would be minimised.

The design for the house aimed to eliminate thermal bridging where possible and minimise it in other places. This required continuous insulation around the house and in situations where joints were unavoidable, specific construction details at each situation were designed. This was particularly the case with windows and doors and with cavity wall construction.

The project team noted in particular the actions to increase the amount of insulation in the wall units and to eliminate thermal bridging and the resulting need for the Vales to design a specific solution to frame the wall / window junctures.

4.3.1.3 'Zaleh' – The BRANZ Zero and Low Energy House Project Report[14]; [Retrofit Focus].

The ZALEH project attempted to quantify a wide range of non-energy benefits for home occupants. These include outcomes such as improvements in comfort, health, noise, maintenance and the environment.

---

[12] ***Note – the Systems Team had originally specified that the Robert Vale work to be reviewed would be a report called "the house with no bills". It was subsequently identified that while the Vales had made presentations to this effect, there is no such report to review. The closest source of information is "The New Autonomous House".***

[13] ***Report Reference: The New Autonomous House – Design and Planning for Sustainability, Authors: Brenda and Robert Vale, Thames & Hudson, ISBN 0-500-28287-0, 2000.***

[14] ***Report Reference: The Value of Low Energy Technologies for Occupant and Landlord, Authors: Albrecht Stoecklein, Yuan Zhao, Lauren Christie, Lisa Skumatz, published at a conference NZCEE, Ecological Economics in Action, December 11-13, 2005 at Massey University, Palmerston North, New Zealand.***

The review for this current work focuses on the low energy houses in the ZALEH survey work. Several measures in the project were ranked according to their "cannot see" positive and negative non-energy benefits. The measures in the project are matched with systems from the final list of systems (Table 7) and are shown in Table 12 following.

Table 12: Ranking of the "cannot see" positive and negative non-energy benefits from the Zaleh Project matched with systems from the final List of Systems

Rank	Upgrade	System
1	Insulation significantly better than NZ Building Code requirements.	Ceiling/roof
1	Insulation significantly better than NZ Building Code requirements, trombe walls, etc.	External walls
1	Insulation significantly better than NZ Building Code requirements.	Groundfloor/ foundations
2	Double-glazing, sun-termpering technology	Windows
3	Solar, heat pump, wetback or wood fired hot water heater.	Water heating
4	Renewable energy technologies.	Space Conditioning or Heating, Cooling, Ventilation (HCV)

Again, it is of interest to the project team in the selection of priority systems from this current work to understand the difficulties that may have been experienced in the Zaleh Project. Interestingly, the report notes that interviews conducted as part of the other similar overseas projects indicate that participants were concerned that the maintenance for what have been termed "*advanced measures*" (for example solar water heating, latest technology space heating and cooling) might be more complex, that it might be hard to find contractors to repair some technologies, and parts might be difficult to find. Although these issues were not probed in the New Zealand work, concerns might be similar.

The project team noted in particular the high ranking insulation (ceiling, wall and floors) measures and windows identified as key positive "cannot see" non-energy benefits. The perception of the wider benefits associated with these measures is likely to influence uptake.

4.3.1.4 The Exemplar House [15], [New Build Focus].

The "exemplar house study" is a Life Cycle Assessment study of a typical New Zealand residential building (Szalay 2006). Six combinations of floor, wall cladding and roofing were compared, including concrete or timber piled floor; timber weatherboard, brick or fibre cement cladding as well as concrete tiled and steel roofing. The energy use calculations were based on the assumption that the house was insulated to code requirements.

The base scenario (Wellington, evening heating only) has shown that for all material combinations, operational energy had the largest contribution with about 60 %.
Due to the nature of the study, the materials with the greatest contribution to the life cycle impacts were identified: metals (aluminium and steel), fibre cement and carpet.
The following building components contributed most significantly to the embodied GHG emissions (with no. 1 the greatest contributor):

1) foundation/floor
2) wall
3) roofing
4) windows

The difference between roofing (incl. structure) and windows was negligible.

The following ranking was determined from the heat loss calculation (with no. 1 the greatest contributor):
1) heating up of thermal mass (concrete floor)
2) windows
3) walls
4) floors
5) ventilation losses
6) roof

The project team noted in particular the ranking of the floor, window and wall systems as having the highest contributions to heat lost in the home. It was also noted that the material contributions to GHG emissions were greatest for foundation (floor), wall, windows and roofing. This is a clear indication that improvements to systems that contribute to the building envelope will have the greatest gains with respect to the Beacon High Standard of Sustainability®.

[15] ***Szalay, Z. (2006): The Exemplar House. Life Cycle Assessment of a New Zealand house. Scion internal report. 2006.***

4.3.1.5 The Retrofit Database of Technologies[16], [Retrofit Focus].

Beacon's project TE102 has developed a database of retrofit technologies, an evaluation of these technologies with respect to the Beacon sustainability footprint, and a draft plan for the proposed Beacon THEN Home.

The 102 technologies listed initially were short-listed to 65 and then ranked by a panel of experts against the Beacon sustainability footprint[17]. According to these rankings, the technology options showing the highest potential to increase sustainability include:

1) insulation materials,
2) rainwater harvesting,
3) permeable pavers,
4) air-air heat exchangers,
5) passive cooling systems,
6) wood-pellet biomass boilers,
7) energy-efficient home appliances,
8) solar hot water heating,
9) light tubes,
10) vacuum glazing.

In general, it was found that "proven" technologies scored the highest. However, it is important to note that there is evidence to suggest that a statistical analysis indicates that the experts may have differed in their individual interpretation of the nine Beacon objectives. The report authors therefore urged caution in the use of the expert rankings.

The project team noted the emergence of 'insulation materials' as the highest ranking technology implies the need to improve the building envelope in order to increase sustainability.

4.3.2 The NOW Homes Project – Gap Analysis [New Build Focus]

A high level gap analysis of the NOW Home® projects was undertaken in order to identify the need for systems for newly built homes. Available reports and working papers[18] were reviewed

***

[16] ***Nebel, B.; Krumdiek, S.; Jaques, R.; Nielsen, P. (2006): Retrofit Technologies Database. Beacon Project TE102. A report prepared for Beacon Pathway Limited.***

[17] ***Beacon's nine sustainability objectives were at the time of the study "Affordability", "Community", "Desirability", "Future proof", "Investment potential", "Landscape", "Performance", "Personal health", and "Resource use". The list of experts included researchers from within the team as well as a selection external participants.***

[18] ***Reviewed reports included: Kane, C.D, Allison, R, Jaques, R.A, and Pollard, A.R. (November 2005) NOW 101 Olympic Place NOW Home Monitoring Report 1. A report prepared for Beacon Pathway Limited.***

and discussions with the Existing Homes Research Team Leader and a key researcher were also held.

The following systems (and the resulting performance of the house) were highly rated by the occupants of the Waitakere NOW Home®:

- layout and open plan areas
- natural light
- warmth and temperature
- concrete floor
- solar water heating, and
- reduced energy costs.

The Rotorua NOW Home® highlighted the importance of choosing systems that are reliable, perform well and that are easy to use, for example for solar hot water heating and rainwater tanks. Other learnings from the Rotorua NOW Home® include that complex roofing systems should not be used and that concrete flooring is not necessarily the best choice for thermal mass. The conclusion from the project was that thermal walls should be a solution considered in future work.

The following system solutions were identified by the Retrofits Research Team Leader as good candidates for prioritisation in terms of solutions that future studies should focus on:

- thermally broken window frames;
- lower cost, better performing windows; and
- insulated concrete floors.

Although solutions, for example, for thermally broken window frames or insulated concrete floors were available in New Zealand, the uptake was recognised as an issue. Whereas consumers in colder parts of the country would be ready to pay for insulated concrete floors or thermally broken window frames, this was not the case in warmer regions.

The review of the NOW Homes Projects clearly indicated to the project team that issues of desirability, affordability and availability can be key when considering the factors that influence householders as they make decisions about the type of home that they would like to live in.

Pollard, A, French, L, Heinrich, M, Jaques, R, Zhao, J, (April 2008) Waitakere NOW Home: Second Year of Performance Monitoring. A report prepared for Beacon Pathway Limited.
Trotman, Rachael, May 2008, Waitakere NOW Home: Occupants Experience of the Home and Implications for Future NOW Homes, for Beacon Pathway Limited.

4.3.3 Papakowhai Renovations work – a Gap Analysis [Retrofit Focus]

A high level gap analysis of the Papakowhai Renovation projects was undertaken in order to identify the need for systems for existing homes. Available reports and working papers[19] were reviewed and a discussion with the Existing Homes Research Team Leader was also held.

The Papakowhai project is still underway and final monitoring reports were therefore not available. From the current state of knowledge the following systems were highly rated by the participants as having made a significant difference to the performance of the house:

- underfloor insulation;
- ceiling insulation;
- efficient wood/pellet burner; and
- solar hot water heater.

The project has shown that simpler or more straightforward and therefore accessible options are required for the following:

- secondary glazing;
- passive venting systems;
- solar tube ventilation systems; and
- heat pump hot water systems.

Other key learnings are that no acceptable solutions for weather tightness were available, that the availability and skill level of some trained trades people can be a problem and that the consent process can be difficult and time consuming. Anecdotal evidence has shown in particular that the installation of double glazing units can be problematic.

The ‘wish list’ from the Existing Homes Research Team Leader for retrofitting solutions, based on the experience of the Papakowhai project was:

- a wall retrofit solution, also addressing condensations issues (vapour barrier);
- improved ventilation;
- availability and installation of secondary glazing;
- effective and easy to install draft stopping products (current foam products wear out hinges of window frames);
- rain water collection systems;
- an underfloor insulation solution for less than 600mm underfloor space; and
- an insulation solution for uninsulated concrete slabs.

[19] ***Burgess, J.C. Buckett, N. and French, L. (2008), Interim Monitoring Results from the Papakowhai Renovation Project. Report TE106-2 for Beacon Pathway Limited.***

The gap analysis of the Papakowhai Renovation project clearly indicated to the project team that there were a number of solutions for retrofit situations that were still difficult to source. The team noted in particular that a need for more insulation solutions was identified; solutions for improved glazing (double and secondary glazing) and improvements to ventilation were also highlighted.

5 Research team discussion and final systems selection

The project team met to consider all of the information as presented in the preceding sections, including results from the criteria and scoring workshops, the extended literature review, and the NOW Home® and Papakowhai gap analyses. The team discussed the findings from each of the various activities.

The project team noted how uptake issues in particular were emerging from the reports in the extended literature review. Specifically, difficulties were experienced with skills and experience of trades people and in particular the retrofitting of windows (experience and materials availability). Problems with walls were also identified from both a retrofit and new build perspective. Retrofitting walls proved difficult and was time consuming while unique solutions to accommodate thicker walls in new builds was essential since current construction materials and techniques did not suit non-standard building dimensions.

The NOW Homes and the Papakowhai Renovation project in particular gave valuable insight into the difficulties faced in upgrading homes to the HSS®. Particular difficulties again focussed on insulation and glazing for technical reasons, and issues relating to cost.

Based on the research findings and team discussions, the project team then undertook their own ranking of the list of building systems for both new built and existing homes according to the criteria described in Table 3. Individual team members scored each system independently and justified their score and supporting views, to the others in the team. A matrix of systems and criteria emerged and the ranking exercise resulted in the identification of two prioritisation lists as shown in Table 13 (new builds) and Table 14 (existing homes or retrofit projects) below.

Table 13: Prioritised list of systems for new buildings from the project team discussions

= 1	Windows
= 1	External walls
2	Groundfloor/foundations
3	Ceiling and Roof System
4	Space Conditioning (covering space heating, space cooling 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 andstairs)
7	Doors (external)
7	Doors (internal)
7	Solid household waste

Table 14: Prioritised list for existing homes from the project team discussions

1	Windows
2	External walls
2	Space Conditioning (covering space heating, space cooling and ventilation) = HCV
3	Ceiling and Roof System
3	Integrated Water Systems
4	Groundfloor/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

The ranking exercise undertaken by the project team identified two systems for prioritisation (one for new builds and one for existing homes or retrofit projects).
The new build system was agreed as walls and the retrofit system was agreed as windows.

In discussion, the project team noted that standard construction techniques restricted the amount of insulation that can be accommodated in wall panels. This restriction manifests itself across a number of the processes involved in house construction from the standard size of the wall studs (and therefore the thickness of the walls), to the framing required for wall stability (which increase thermal bridging) right down to the perception at the point of sale of a much smaller living space with thicker walls.

With respect to windows, the project team also noted that there were conflicting views about the availability of double glazing systems (complete window units and double glazing glass for retrofit to original frames) that need to be addressed. Information about availability, reliability and cost-benefit will be essential if customer interest is to be secured and uptake increased. New requirements under the Building Act highlight double glazing as a requirement in new homes. However, as the majority of New Zealand homes do not currently have double glazing, identifying ways of increasing uptake is essential if achieving the HSS High Standard of Sustainability® is to be realised. Anecdotal evidence has also emerged in relation to the ability of trades people to install double glazing in retrofit situations. Planning issues have also been identified as an issue that could be hampering the installation of double glazed units.

These two systems prioritised by the project team also appeared in a prioritised list of systems developed by the participants in the scoring workshop (Table 9). Table 9 is the outcome of a discussion at the scoring workshop.

The two systems identified by the project team also scored highly in the ranking exercise undertaken at the scoring workshop (Table 10). While they are not in the same order, the findings from the literature review influenced the views of the project team (in particular a number of uptake issues) and so the final prioritisation.

Water capture and ventilation systems were also identified in Table 10 but it was also noted by the project team that there were plans within the Beacon 'water strategy' as well as in the 'IEQ' strategies to develop systems that were specific to those research streams and so they would be addressed elsewhere.

6 Conclusion

This working paper sets out the process for the identification of the two priority systems to be examined in more detail in the Systems Research Work Plan.

This paper has set out how initial lists of residential building systems and criteria used to evaluate systems were established in the early stages of the project through a literature review.

The paper then notes how these initial lists were refined through discussions at two workshops. A Hierarchy of Criteria made up of sustainability and uptake criteria was applied to the final list of systems and a list of 'priority' systems emerged for application to both new build and retrofit situations. Participants in the scoring workshop also identified the three systems that, in their view, should be prioritised for further research.

Following a stock take of progress made in the project up to the point of the workshops, the project team felt that the outcomes of the workshops in particular were not satisfactory. Participants did not appear to be comfortable with the AHP methodology employed and therefore doubted the robustness of the process to select the two 'priority' systems.

A survey of building practitioners and/or an extended literature review were identified by the project team as suitable additional activities in an effort to ensure confidence in the system prioritisation process. However, due to the likely additional costs associated with a survey of practitioners and timescale delays that could not be accommodated within the current project, this activity had to be rejected. The team resolved then to extend the initial literature review to ensure that as many as possible previous studies that had identified building systems were considered.

For robustness therefore, and in addition to the literature review and the workshops, a number of additional activities were also undertaken by the project team and information identified was subsequently applied to the evaluation of the systems. National and international research was also considered alongside the findings emerging from two key Beacon initiatives – the NOW Homes® and the Papakowhai Renovation projects. The project team noted in particular how issues relating to uptake criteria were identified on several occasions in the extended literature review and in the gap analysis of the NOW Homes ®and the Papakowhai Renovation projects.

Having considered all of the information available to them the project team finally identified two 'priority' systems through a further ranking exercise.

The systems emerging for further work are as follows:

Wall systems – Prioritised Systems for New Build

Current techniques for wall construction do not easily allow for increased amounts of insulation and a basic redesign could facilitate this increase and a reduction in thermal bridging.

Windows – Prioritised System for Retrofit

Evidence from local projects indicate that retrofitting double glazing is proving problematic for a range of technical and uptake issues including availability, installation skills, buildability and cost-effectiveness. Further investigations will help to identify potential solutions to increase uptake.

Windows and wall systems are key elements of the thermal envelope and have the potential to make a significant impact on the performance of a building. It's likely that further systems to complete the thermal envelope will also undergo closer examination in subsequent work. For example, learnings from 'new walls' can be transferred to 'existing walls' and would therefore make 'existing walls' a logical system to look at as part of the systems research beyond this initial project. The same principle applies to retrofit window systems.

As part of this initial project, a generic list of systems was developed, and a prioritisation process undertaken to determine the initial systems to investigate. This list will need to be reviewed and re-prioritised at regular intervals. It was recommended by the research team to extend the stakeholder participation and to review the ranking of the priority of systems for new and for retrofit. The Hierarchy of Criteria should also be revised as the HSS® evolves and further performance targets are derived.

The next steps of this research stream according to the systems strategy are the design and implementation of two new systems. However, during the project, the team realised that it might not be necessary to develop new solutions, but to emphasise uptake issues of existing solutions. It is therefore important to note that the scope of the current project might not lead to the development of a new solution of wall systems for new built – or retrofit windows. A technological solution is not always going to be essential and in particular in the case of window systems and wall systems in this work, it was clear that their high ranking was influenced in many respects by 'uptake' related issues. In particular, issues such as – product availability (reality and perception); affordability and willingness to pay; skills and trades people – availability, knowledge and understanding in particular in retrofit situations, and finally, regulatory barriers were all identified as potential barriers to change and to the achievement of Beacon's goal.

7 Appendix One: Main studies reviewed in order to establish an initial list of criteria

Study 1: Criteria arising from Bates et al. 2001 "Room for View" scenario analysis.
This study, undertaken during 1999-2001, sought to identify key drivers of change in the Australasian built environment, and created three plausible scenarios for the urban environment of 2015. Actor-testing of the scenarios identified implications on building requirements from the scenarios, and identified criteria for future buildings, including residential. Source documents used:

- Bayne, K M; Barnard, T D; Gaunt, D J; McIntosh, C D; Turner, J C P. 2001. 'Building needs for the next decade' and Bayne et al. 2002: 'Building systems for future scenarios'
- FRST Contract C04X0013 'Consumer Solutions for the Built Environment' – background materials and draft reports around Forest Research's 'Concept House'.

Study 2: Criteria arising from Waitakere NOW Home® Research Project
The Waitakere NOW Home® research project, undertaken during 2002-2005, sought to design a residential stand-alone three bedroom home that met the previously identified future needs of the 'post-Kyoto' vision. This was "the environmentally friendly home that people want to, and can afford to, live in". Through this process, a range of design criteria and performance specifications were identified, and the Beacon Sustainability Footprint (refer Figure 2) was developed. Source documents used:

- NOW Home® Design Brief and Monitoring Measures;
- Beacon Sustainability Footprint;
- Jaques, R et al. 2004. Sustainability framework benchmarking report SF1.2 Now vs ROM;
- Sustainability framework benchmarking report SF1.1 Now vs ROM.

Study 3: Criteria arising from Bates and Kane 2005 "Future of Housing in NZ 2030" Scenario analysis.
The Centre for Housing Research Aotearoa New Zealand (CHRANZ) commissioned Scion to undertake a scenario planning exercise for the New Zealand housing situation in 2030. The resultant scenarios provided the basis for Scion's analysis of the future building requirements. A set of criteria were identified through more detailed examination of the key drivers of change. Source documents used:

- Walford et. al 2005 "QFD Matrix for Biomaterial Housing";
- Bayne et al. 2006. Biohousing and the new bungalow: modern timber housing forms for New Zealand. 2nd Smart and Sustainable Built Environments (SASBE) Conference, Shanghai, People's Republic of China, 15-17 November 2006;
- Bates et al. 2006 " New Housing Solutions for future New Zealanders';
- Bayne K et al. 2006 " Modern Timber Housing Guide".

Study 4: Criteria arising from the HSS High Standard of Sustainability® (HSS®) research programmes 2006-2008.

To gain the largest degree of change in the residential sector from research, the Beacon Research Pathway programme has reduced its focus from the original 9 Beacon Sustainability Footprint criteria to 7 elements of Water, Waste, Energy, Indoor Environment Quality (IEQ), Materials, Affordability and Future flexibility. Recent research reports have considered the requirements from each of these criteria, and set targets against them. Source documents used:

- Beacon Report PR205;
- Beacon High Standard of Sustainability 6-2372– overview table with performance targets;
- Beacon Reports MT 101 -105 ;
- Beacon "NHPR What is a NOW Home®?" document.

Study 5: Criteria arising from other NZ sources

The New Zealand Building Code outlines a number of areas or criterion that are used to legislate for minimum building standards. The Department of Building and Housing are currently reviewing the Code documentation and have included additional elements relating to sustainability, energy efficiency and use, wellbeing, design and materials performance. Storey and Pederson (2006) outline wellbeing factors for healthy living environments. Source documents used:

- Storey, J. and Pederson, M. "Factor x, well-being as a key component of next generation green buildings". Conference Proceedings 12th International Rinker Conference "Rethinking Sustainable Construction". 19-22 Sept 2006, Florida, USA.
- DBH New Zealand Building Code Review Documents 2004-2007.

Study 6: Criteria arising from the Queensland Smart Housing Programme

The Queensland Government Smart Housing programme has been developed in response to the demand for housing that better meets people's needs and responds to the Queensland climate while saving money. The four major elements that design criteria were established from included: cost efficient over time; resource efficient; safe and secure; and universally designed. Source documents used:

- Queensland Smart Housing Fact Sheets http://www.build.qld.gov.au/smart_housing/

Study 7: Criteria arising from other international sources

Other source documents were identified from a number of international studies. Source documents used:

- Government of South Australia Housing Design Guidelines. Part 2.3 Design Criteria for Adaptable Housing;
- NY City Governers Island Sustainable Development Framework – Sustainability Criteria;
- CABE Building for life programme www.buildingforlife.org;
- Bristol City Council Sustainable Development Criteria: Appendix 7, 2004;
- Daniel Hellström, Ulf Jeppsson, Erik Kärrman. "A framework for systems analysis of sustainable urban water management" Environmental Impact Assessment Review 20 (2000) 311– 321;
- Sahelly et al, 2005. "Developing sustainability criteria for urban infrastructure systems". Canadian Journal of Civil Engineering Vol32 . pp 72-85.

8 Appendix Two: Lists of functions of buildings systems, systems and technologies emerging from the initial literature review

Generic functions of building systems
Support mechanism (structural, load-bearing, bracing etc)
Containment function
Aesthetic function
Augmentation/ decoration (sometimes functional)
Insulation function
Barrier (to weather, noise, heat, light, air filtration/ leakage, wind, water, visual)
Opening (for light, heat, airflow, exitways)
Protects (surface coatings etc.)
Ventilates
Accessway (path, passageway, door, transportation lift)
Distributes or controls (water, air, waste, gas, electricity, communications)
Facilitates use (water, waste, heat, light etc.) eg. Faucet or switch or handle
Resists (seismic, wind, UV, human intrusion, pest intrusion)
Retards (dirt, glare, fire spread etc)
Detects and facilitates automated control (sensors etc)

List of building systems	
Roofing structure	Door systems (external)
Roofing external cladding	Vanities cupboards
Roofing internal linings	Security systems
Roofing flashings and weathertightness	Door hardware systems (hinges, rollers, locks, handles)
Guttering and downpipes	Plumbing
Roofing insulating	Tapware
Roofing external coatings	Fenestration (windows and blinds)
Roofing internal lining coating	Glazing
Skylighting	Storage

Ventilation systems	Waste solid storage
Heating systems	Waste solid removal
Wall structural	Waste water removal
Wall external cladding	Water storage
Wall exterior coatings	Water supply
Wall insulation	Appliances
Wall weatherproofing (membranes and cavities)	AudioVisual systems
Wall internal linings	Home Automation
Wall interior coatings	Sheds / garages
Lighting systems	Automated garage doors
Telecommunications	Paving systems
Air ducting systems / humidity control	Access internal (Steps, stairs hallways)
Electrical supply	Access external (Steps, stairs, pathways)
Gas supply	Landscaping
Flooring structural	Fencing and gates
Flooring insulation	Outdoor lighting
Floor coverings	Light fittings
Floor coatings	Switches and sockets
Trims and mouldings exterior	Foundations
Trims and mouldings interior	
Door systems (internal)	

List of building technologies	
Ecopaints/ 'natural coatings'	Resilient mountings for seismic and acoustic dampening
Phase change materials	Automated timers
UV resistant films/ coatings	Automated sensors
Coatings that improve performance (better adherance to surface, repel dirt, antifungal, repel heat etc)	High energy efficiency appliances
Natural fibre materials (plant and animal)	Solar panels for PV electricity supply

Solar chimneys	Solar panels for water heating
Heat pumps	Mini wind turbines
Tankless water heaters	Methane digestors
Mulcher or chipper	Combined heat and power generation systems (CHP)
Low-flush toilets	District heating
Low flow devices (retrofit for shower rose)	Distributed energy
Low conductivity window frame	Thermosiphoning
Passive window vents/ securitivents	Improved timber products (better screwholding, hardening etc)
Composting and worm farms	Wood Plastic composites and bioplastics
Modular or prefabricated wall/ floor/ roof components	Demountable fasteners (Camlocks, click profiles etc) including adhesives
Security devices	Composting toilet
Night store heater	Raintank water quality improvements
Underfloor insulation	Daylight harvesting
Passive heat loss measures (thermal backed curtains, pelmets, draught stopper tape, draught 'snakes for doors, etc)	Low energy lightbulbs
Access flooring	Fibre-optics
Control systems	Smart cabling
Cooling systems	Domotics (Home automation (also called smart homes))
Massive timber structures (STIC etc)	Fuel cells
Improvements to timber framing systems (wider studs)	Pellet burner
Double+ glazing and vacuum glazing	Biomass boiler
Trombe walls	Ground source heat pumps
Solar powered devices (fans, pumps, battery chargers etc)	Greywater reuse

9 Appendix Three: CBI Groups and Classes (level 2)

1 General

11 Contract conditions
12 Preliminaries and general

2 Site

21 Demolition
22 Preparation and groundwork
23 Foundations
24 Minor demolition and alterations

3 Structure

31 Concrete
32 Earth
33 Masonry
34 Steel
35 Stainless steel
36 Aluminium
37 Other metals
38 Timber
39 Plastics

4 Enclosure

41 Tanking, damp-proofing, wraps and underlays
42 Cladding
43 Roofing
44 Membrane roofing and waterproofing
45 Windows, doors and roof lights
46 Glazing
47 Insulation
48 Sealants, flashings and adhesives
49 Metalwork

5 Interior

51 Linings
52 Partitions and doors
53 Ceilings
54 Access floors
55 Joinery fixtures and hardware
56 Specialist equipment and assemblies
57 Furniture and appliances
58 Signs and features

6 Finish

61 Trowelled, liquid applied and sprayed coatings
62 Tiling
63 Timber flooring, sheet, slab and panel surfacing
64 Resilient surfacing
65 Carpeting
66 Flooring ancillaries
67 Painting and paperhanging

7 Services

71 Liquid
72 Gas
73 Fire
74 Drainage
75 Heating and cooling
76 Ventilation and air-conditioning
77 Electrical
78 Communications and controls
79 Transport

8 External

81 Retaining walls
82 Roads and pavings
83 Landscaping
84 Pools
85 Engineering works
86 Specialist structures

10 Appendix Four: Average Score from Workshop Participants – Scoring Workshop

The table below shows the minimum, maximum and average scores for each building system, by criteria. The final column calculates the average score across all criteria, assuming an equal weighting for each criteria. The Systems highlighted indicate those chosen as 'Priority Systems' from the Workshop.

	Criteria								
Systems/Participants	**Energy**	**Water**	**IEQ**	**Materials**	**Future**	**Afford**	**Build**	**Desire**	**Avg**
1. Existing ext walls and windows									
Min	7	0	7	6	2	2	2	2	
Max	10	7	10	9	9	9	10	10	
Avg	9.5	2.4	8.4	7.8	5.5	5.8	6.3	7.0	**6.6**
2. Ventilation									
Min	1.0	1.0	8.0	2.0	3.0	3.0	5.0	5.0	
Max	10.0	8.0	10.0	8.0	8.0	9.0	9.0	10.0	
Avg	7.0	2.8	9.3	5.4	6.0	6.9	7.2	8.1	**6.6**
3. IWM									
Min	1.0	5.0	1.0	1.0	3.0	2.0	2.0	2.0	
Max	8.0	10.0	9.0	10.0	10.0	10.0	8.0	10.0	
Avg	4.1	9.4	4.5	4.5	6.3	5.8	5.5	6.2	5.8
4. Max solar, thermal mass, etc									
Min	8.0	0.0	1.0	3.0	3.0	3.0	4.0	3.0	
Max	10.0	10.0	10.0	10.0	10.0	10.0	9.0	10.0	
Avg	9.6	4.7	7.5	6.9	7.1	7.3	7.1	7.5	**7.2**
5. Enhance existing window systems									
Min	4.0	0.0	5.0	3.0	2.0	4.0	6.0	5.0	
Max	10.0	7.0	10.0	10.0	9.0	10.0	10.0	10.0	
Avg	7.5	2.1	7.5	7.0	6.1	7.2	7.9	7.2	**6.6**
6. Solar capture systems									
Min	7.0	0.0	1.0	3.0	1.0	1.0	1.0	5.0	
Max	10.0	10.0	8.0	8.0	10.0	9.0	10.0	10.0	
Avg	8.6	2.9	6.9	6.1	5.5	5.6	6.0	7.6	6.2
7. Exterior building envelope									
Min	8.0	0.0	7.0	3.0	2.0	1.0	2.0	2.0	
Max	10.0	10.0	10.0	10.0	9.0	10.0	10.0	10.0	
Avg	9.5	3.8	8.4	7.7	5.8	5.8	6.5	7.3	**6.9**
8. Interior walls									
Min	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	
Max	9.0	3.0	10.0	10.0	10.0	8.0	10.0	9.0	
Avg	3.5	0.8	5.3	6.1	6.5	5.2	5.5	5.2	4.8

11 Appendix Five: Extended Literature Review

The project team established a list of a number of additional sources of information focussing on residential building systems from the Literature. Specifically, the reports identified were 'whole of house' reports (i.e. not specific to one building system, for example a report on walls or a report on ceilings) as it was believed that these may provide information about systems within a house that would be of relevance to this work. The reports identified presented a balanced mix of new build and retrofit focussed projects. They are listed as follows:

- Recent work undertaken by Bob Lloyd of Otago University;
- Research undertaken by Robert and Brenda Vale, specifically in their publication "The New Autonomous House";
- *'Zaleh'* – The BRANZ Zero and Low Energy House Project Report;
- The Exemplar House (a previous Scion study); and
- The Retrofit Database of Technologies (a previous Beacon project).

Recent work undertaken by Bob Lloyd of Otago University[20]; [Retrofit Focus]

The study states that upgrading existing New Zealand State Housing stock will provide benefits at different levels:

- Social cost and benefits by improving the quality of life through reducing health risks and seasonal mortality.
- Private cost and benefits by providing a healthier environment to achieve thermal comfort at home will have an impact in the way people live and use their homes.

The study has an energy and cost focus and is not driven by the wider concepts of sustainability. Its aim was to establish what upgrades could achieve by way of improving the energy efficiency (and specifically reducing heat loss) of the property and at what cost.

The report confirms that the energy efficiency and indoor comfort of existing housing can be raised by: improving the building fabric performance, improving the heating system efficiency (including the control system), increasing the amount of solar gains into the house, (openings and configuration improvements), using high efficiency appliances and educating occupants on optimal behaviour.

---

[20] ***Report Reference: Title: Retrofit alternatives for State Houses in Cold Regions of New Zealand, Report No. 2, Authors: Bob Lloyd, Tim Bishop, Maria Callau, A research project by the Energy Management Group, Physics Department - University of Otago - Dunedin - New Zealand, September 2007.***

The research consisted of monitoring the efficacy of Housing New Zealand Corporation's (HNZC) energy efficiency retrofit programme implemented in state houses across New Zealand. The efficacy of upgrade programmes has been found to be somewhat controversial as they can be expensive and can often produce ambiguous outcomes. This has been particularly true in terms of levels of energy reduction, where for instance, Milne and Boardman found in the UK that "*in most cases of domestic energy efficiency retrofits, there are varying degrees of differences between the predicted energy savings, based on the calculated heat loss reduction, and the actual energy savings achieved in practice*". This finding is often referred to as 'comfort factor'. Savings of up to 20% were possible with the improvements to the property. Leaving the concept of 'comfort factor' to one side, the Otago Research Team identified upgrades that would reduce heat loss, in order of efficacy. These are listed and ranked below in Table 15, along with their corresponding Systems from the Revised List of Systems.

Table 15: Upgrades identified by the Otago Team matched with Building Systems

Rank	Upgrade identified by the Otago Team	Building System
1	Insulate the ceiling	Ceiling/Roof
2	Insulate the floor	Groundfloor/foundations
3	Install a low emissions wood burner or pellet fire	HVC
4	Install a heat pump if it will replace electric heaters used elsewhere in the house.	HVC
5	Improve air-tightness	Exterior Walls Exterior Doors Groundfloor/foundations
6	Insulate walls	Exterior Walls
7	Install double glazing and/or drapes	Windows

While these results are generally what would be expected (and consistent with where most heat is lost in a building) of additional interest to the Systems work are the difficulties experienced by the Otago Team during the retrofitting processes. Table 16 notes a number of specific difficulties experienced in the Otago study which are of interest and are matched with the Beacon HSS®/Hierarchy of Criteria. Specifically, the experiences are matched largely with the 'Uptake' component of the Criteria. The difficulties experienced are issues that could impact on the selection of two 'priority' systems from this current work. Specifically, difficulties were experienced with skills and experience, retrofitting windows (experience and materials availability) and retrofitting the walls (accessibility issues).

Table 16: Difficulties experienced in the Dunedin Retrofits and links to the Beacon HSS® /Hierarchy of Criteria

Otago Project Retrofitting Experiences	**Difficulty in Achieving the Beacon HSS®/ Hierarchy of Criteria**	**System of Interest**
Difficulty getting contractors – "*Some comments from the builders included that the cost of retrofitting was not easy to estimate and that they preferred to work in new construction*."	Future Flexibility – Upgradeable Buildability – Installation Affordability – Installation Cost	General
Retrofitting existing windows – "*The first intention was to retrofit existing windows by installing double glass panes into existing wooden frames. Unfortunately this was not cost effective as the market was not prepared to provide this service at a cost much lower than a new installation. It was finally found that it was more cost effective to purchase new aluminium framed double glazed windows. Even though the frames of these windows provided very poor performance in terms of heat losses, as they were not thermally broken, it was thought that some benefit was going to be achieved by improvement in air tightness. This decision was made on a cost basis only.*"	Future Flexibility – Upgradeable Buildability – Installation Affordability – Purchase Cost, Installation Cost, Disposal Cost Materials – Recyclable	Window
Retrofitting the walls – "*Insulating the walls by installing the product Formaliner was not found to be easy by the contractor. Cutting this material to fit each area required more time than anticipated. It was suggested by the contractor that in most cases it would have been easier to install bulk insulation in the cavity and re- GIB the walls, (as was done in the wet areas). The advantages of using the Formaliner were that an extra layer was provided on top of the existing wall giving added extra surface resistance layers and with the additional advantage of avoiding thermal bridging due to the studs and dwangs. Another complication of this system, however, was having to match the in-situ angles of an old established house. These angles were not always 90º and required more time and skill*."	Buildability – Installation	Wall

Research undertaken by Robert and Brenda Vale, specifically in their publication – "The New Autonomous House"[21,22] [New Build Focus]

The Vale's project is new build focussed and while many of the concepts are generic it should be noted that the study is UK based and therefore not all experiences are applicable to New Zealand. The project looks broadly at a range of sustainability concepts beyond energy use.

Chapter 5 covers the following issues: saving energy, structure (external walls, the cellar, windows doors and glazing, the roof, the conservatory); building enclosure (thermal bridging, air-tightness and ventilation); and services (sewerage, water supply, space heating, electricity). Under 'saving energy' the authors note their focus in terms of insulating the house was driven by the availability of the materials rather than their performance per se. Through this project they wanted to demonstrate that the materials were readily available and that any contractor/builder therefore could install them and further that costs would be minimised. Wall construction was the now conventional UK approach which includes cavity walls but a wider than normal cavity was allowed for to ensure as much insulation as possible could be accommodated while minimising costs. The choice was in some part influenced by a recognised lack of skilled plasterers in the UK. The total area of windows in the property was 21% for each of the ground and first floor of the property. The best available triple glazed windows (with two low-emissivity coatings and krypton gas filling) were sourced with similar specs for external doors.

The design for the house aimed to eliminate thermal bridging where possible and minimise it in other places. This required continuous insulation around the house and in situations where joints were unavoidable, specific construction details at each situation were designed. This was particularly the case with windows and doors and with cavity wall construction. UK manufacturers are trying to solve this by offering insulated cavity closers (an extrusion of PVC-U with a polyurethane foam) but for this house as the walls were thicker than normal, an alternative solution had to be devised. A plywood box was designed that spans the cavity between the inner and outer leaves of the wall and is fixed to them with plugs and screws.

In terms of air tightness and ventilation particular attention was applied to ensure the creation of an air tight shell in particular the use of precast concrete floor beams. The block infill to the floor beams was screeded to tie the blocks together, but the screed also acted like the plaster on a wall to create an airtight barrier. The windows and doors have in-built seals round the opening components to ensure reduced draughts. Specific design features were utilised to

---

[21] ***Note – the Systems Team had originally specified that the Robert Vale work to be reviewed would be a report called "the house with no bills". It was subsequently identified that while the Vales had made presentations to this effect, there is no such report to review. The closest source of information is "The New Autonomous House".***

22 Report Reference: The New Autonomous House – Design and Planning for Sustainability, Authors: Brenda and Robert Vale, Thames & Hudson, ISBN 0-500-28287-0, 2000.

control ventilation. For example, the house exterior doors opened into a draught-lobby and not directly to the outside. The lobby acted as an airlock. The house included three specific ventilation measures – windows that open, windows with trickle ventilation and both the kitchen and the bathrooms had individual ADM Indux through-the wall-heat recovery units.

Due to the high levels of insulation and the body heat of the inhabitants in the house, a central heating was not required, although a single wood burner was installed. .
Electricity was used in the house for domestic hot water and cooking, heat recovery ventilation and lighting, appliances and television, water pumps etc. The Vales connected to the grid for back-up power whilst using PV for main electricity generation.

The Vales construction illustrates, as they intended, what can be achieved with readily available products and materials while using design solutions and amendments to achieve as high a performance as possible.

The project team noted in particular the actions to increase the amount of insulation in the wall units and to eliminate thermal bridging and the resulting need for the Vales to design a specific solution to frame the wall / window junctures.

'Zaleh' – The BRANZ Zero and Low Energy House Project Report[23]; [Retrofit Focus].

The ZALEH project is the first New Zealand research project attempting to quantify a wide range of non-energy benefits for home occupants. These include outcomes such as improvements in comfort, bill control, health, noise, maintenance and the environment.

The ZALEH project aims at quantifying the value perception of these benefits to the consumer rather than the saved cost. Other New Zealand based studies have conducted extensive studies on the health benefits of insulating homes (Howden-Chapman et al 2004). The ZALEH study, in contrast, takes a value-based approach independent of the actual health cost, but based on the value perception of the home occupants. It is therefore more applicable for marketing planning rather than public health policy development.

The review for this current work focuses on the low energy houses in the ZALEH survey work. Several measures in the project were ranked according to their "cannot see" positive and negative non-energy benefits. The measures in the project are matched with systems from the final list of systems and are shown in Table 17 following.

[23] ***Report Reference: The Value of Low Energy Technologies for Occupant and Landlord, Authors: Albrecht Stoecklein, Yuan Zhao, Lauren Christie, Lisa Skumatz, published at a conference NZCEE, Ecological Economics in Action, December 11-13, 2005 at Massey University, Palmerston North, New Zealand.***

Table 17: Ranking of the "cannot see" positive and negative non-energy benefits from the Zaleh Project matched with systems from the final List of Systems

Rank	Upgrade	System
1	Insulation significantly better than NZ Building Code requirements.	Ceiling/roof
1	Insulation significantly better than NZ Building Code requirements, trombe walls, etc.	External walls
1	Insulation significantly better than NZ Building Code requirements.	Groundfloor/ foundations
2	Double-glazing, sun-termpering technology	Windows
3	Solar, heat pump, wetback or wood fired hot water heater.	Water heating
4	Renewable energy technologies.	Space Conditioning or Heating, Cooling, Ventilation (HCV)

Again, it is of interest to the project team in the selection of priority systems from this current work to understand the difficulties that may have been experienced in the Zaleh Project. Interestingly, the report notes that interviews conducted as part of the other similar overseas projects indicate that participants were concerned that the maintenance for what have been termed "*advanced measures*" (for example solar water heating, latest technology space heating and cooling) might be more complex, that it might be hard to find contractors to repair some technologies, and parts might be difficult to find. Although these issues were not probed in the New Zealand work, concerns might be similar.

The project team noted in particular the high ranking insulation (ceiling, wall and floors) measures and windows identified as key positive "cannot see" non-energy benefits. The perception of the wider benefits associated with these measures is likely to influence uptake.

The Exemplar House [24], [New Build Focus].

The "exemplar house study" is a Life Cycle Assessment study of a typical New Zealand residential building. The house is a basic two storey design with three bedrooms and a garage with a total floor area of 195 m^2. Six combinations of floor, wall cladding and roofing were compared, including concrete or timber piled floor; timber weatherboard, brick or fibre cement cladding as well as concrete tiled and steel roofing. The energy use calculations were based on the assumption that the house was insulated to code requirements.

[24] ***Report Reference - Szalay 2006***

Embodied energy, embodied GHG emissions as well as the operational energy over 50 years was taken into account in three different locations in New Zealand (Auckland, Wellington and Queenstown). Different heating systems (wood burner, natural gas and electric heating) and different heating regimes (24 hr heating and evening heating only) were also compared. The heating energy demand was calculated with ALF (v 3, BRANZ). Energy requirements for hot water were not taken into account.

The base scenario (Wellington, evening heating only) has shown that for all material combinations, operational energy had the largest contribution with about 60 %.
Due to the nature of the study, the materials with the greatest contribution to the life cycle impacts were identified: metals (aluminium and steel), fibre cement and carpet.
The following building components contributed most significantly to the embodied GHG emissions (with no. 1 the greatest contributor):

1) foundation/floor
2) wall
3) roofing
4) windows

The difference between roofing (incl. structure) and windows was negligible.

The following ranking was determined from the heat loss calculation (with no. 1 the greatest contributor):

1) heating up of thermal mass (concrete floor)
2) windows
3) walls
4) floors
5) ventilation losses
6) roof

The project team noted in particular the ranking of the floor, window and wall systems as having the highest contributions to heat lost in the home. It was also noted that the material contributions to GHG emissions were greatest for foundation (floor), wall, windows and roofing. This is a clear indication that improvements to systems that contribute to the building envelope will have the greatest gains with respect to the Beacon High Standard of Sustainability®.

The Retrofit Database of Technologies[25], [Retrofit Focus].

The Beacon Project TE102 has developed a database of retrofit technologies, an evaluation of these technologies with respect to the Beacon sustainability footprint, and a draft plan for the proposed Beacon THEN Home.

[25] *Beacon Project TE102*

The 102 technologies listed initially were short-listed to 65 and then ranked by a panel of experts against the Beacon sustainability footprint[26]. According to these rankings, the technology options showing the highest potential to increase sustainability include:

1) insulation materials,
2) rainwater harvesting,
3) permeable pavers,
4) air-air heat exchangers,
5) passive cooling systems,
6) wood-pellet biomass boilers,
7) energy-efficient home appliances,
8) solar hot water heating,
9) light tubes,
10) vacuum glazing.

In general, it was found that "proven" technologies scored the highest. However, it is important to note that there is evidence to suggest that a statistical analysis indicates that the experts may have differed in their individual interpretation of the nine Beacon objectives. The Report authors therefore urged caution in the use of the expert rankings.

The project team noted the emergence of 'insulation materials' as the highest ranking technology implies the need to improve the building envelope in order to increase sustainability.

11.1.2 The NOW Homes Project – Gap Analysis [New Build Focus]

A high level gap analysis of the NOW Home® projects was undertaken in order to identify the need for systems for newly built homes. Available reports and working papers were reviewed and discussions with the Existing Homes Research Team Leader and a key researcher were also held.

The following systems (and the resulting performance of the house) were highly rated by the occupants of the Waitakere NOW Home®:

- layout and open plan areas
- natural light
- warmth and temperature
- concrete floor
- solar water heating, and
-

[26] ***Beacon's nine sustainability objectives were at the time of the study "Affordability", "Community", "Desirability", "Future proof", "Investment potential", "Landscape", "Performance", "Personal health", and "Resource use". The list of experts included researchers from within the team as well as a selection external participants.***

- reduced energy costs.

There were several issues identified as problematic by the occupants, such as lack of privacy or condensation. However, some of those were due to the specific neighbourhood of the NOW Home® and possibly user behaviour (for example, drying clothes indoors).

The Rotorua NOW Home® highlighted the importance of choosing systems that are reliable, perform well and that are easy to use, for example for solar hot water heating and rainwater tanks. Other learnings from the Rotorua NOW Home® include that complex roofing systems should not be used and that concrete flooring is not necessarily the best choice for thermal mass. The conclusion from the project was that thermal walls should be a solution considered in future work.

The following system solutions were identified by the Existing Homes Research Team Leader as good candidates for prioritisation in terms of solutions that future studies should focus on:

- thermally broken window frames;
- lower cost, better performing windows; and
- insulated concrete floors.

Although solutions, for example for thermally broken window frames or insulated concrete floors were available in New Zealand, the uptake was recognised as an issue. Whereas consumers in colder parts of the country would be ready to pay for insulated concrete floors or thermally broken window frames, this was not the case in warmer regions.

The review of the NOW Homes Projects clearly indicated to the project team that issues of desirability, affordability and availability can be key when considering the factors that influence householders as they make decisions about the type of home that they would like to live in.

11.1.3 Papakowhai Renovations work – a Gap Analysis [Retrofit Focus]

A high level gap analysis of the Papakowhai Renovation project was undertaken in order to identify the need for systems for existing homes. Available reports and working papers were reviewed and a discussion with the Existing Homes Research Team Leader was also held.

The Papakowhai project is still underway and final monitoring reports were therefore not available. From the current state of knowledge the following systems were highly rated by the participants as having made a significant difference to the performance of the house:

- underfloor insulation;
- ceiling insulation;
- efficient wood/pellet burner; and
- solar hot water heater.

The project has shown that simpler or more straightforward and therefore accessible options are required for the following:

- secondary glazing;
- passive venting systems;
- solar tube ventilation systems; and
- heat pump hot water systems.

Other key learnings are that no acceptable solutions for weather tightness were available, that the availability and skill level of some trained trades people can be a problem and that the consenting process can be difficult and time consuming. Anecdotal evidence has shown in particular that the installation of double glazing units can be problematic.

The 'wish list' from the Existing Homes Research Team Leader for retrofitting solutions, based on the experience of the Papakowhai project was:

- a wall retrofit solution, also addressing condensations issues (vapour barrier);
- improved ventilation;
- availability and installation of secondary glazing;
- effective and easy to install draft stopping products (current foam products wear out hinges of window frames);
- rain water collection systems;
- an underfloor insulation solution for less than 600mm underfloor space; and
- an insulation solution for uninsulated concrete slabs.

The gap analysis of the Papakowhai Renovation project clearly indicated to the project team that there were a number of solutions for retrofit situations that were still difficult to source. The team noted in particular that a need for more insulation solutions was identified; solutions for improved glazing (double and secondary glazing) and improvements to ventilation were also highlighted.