# TE102/2

# RETROFIT TECHNOLOGIES DATABASE

## A REPORT PREPARED FOR BEACON PATHWAY LIMITED

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Creating homes and neighbourhoods
that work well into the future
and don't cost the Earth

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## CONTENTS

## TABLES

## FIGURES

# 1. EXECUTIVE SUMMARY

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.

The urgent need for retrofitting much of the New Zealand housing stock has been well documented (Beacon Report RF1). The results of Beacon Project TE102 will underpin the development of tools which help homeowners to evaluate the present standard of their homes and to select relevant technologies for retrofitting.

In the context of this report, the term retrofitting applies to all work undertaken to improve the sustainability performance of a house subsequent to its completion. This includes work on the existing house and its surroundings, as well as any proposed extensions and upgrades towards sustainability.

## 1.1 Database of retrofit technologies

The database contains information on 107 technologies which are relevant to the task of retrofitting New Zealand houses (Table 1). The intended audience for the database delivered from this project are Beacon partners, who can access the database and comment on it via the private section of the Beacon website. However, ultimately the database is aimed at home owners, builders and architects. Created using Microsoft Access, the database can be easily edited and kept up-to-date. The database has also been converted to an HTML format, enabling it to be made available for internal use within Beacon via the private section of the Beacon website. The HTML database can be searched by 1) keyword, 2) technology, and 3) category relating to the draft plan for the proposed Beacon THEN Home.

**Table 1: Categories and examples of technologies in the database**

| CATEGORY | SUBCATEGORIES | EXAMPLE |
|---|---|---|
| Accessories | Energy efficiency | Electronic socket timer controls |
| Appliances | Energy and water efficiency | Most efficient refrigerator |
| Decoration | Paint | Enviro-choice paints |
| Electricity generation | Solar and wind power conversion | Solar Panel photovoltaics |
| Fittings | Fastenings | Demountable fastenings |
| Insulation | Wall/under floor/roof insulation | Glasswool insulation |
| Lighting | Artificial and natural lighting | Light tube |
| Safety | Safety, security | Smoke detectors |
| Space heating | Insulation, provision of heat and/or cooling | Pellet burner |
| Structure | Internal and external walls, floor | Wide stud spacing |
| Ventilation | Extraction of used air, condensation | Extractor fan for bathroom |
| Waste | Solid waste | Home recycling station |
| Water | Water heating, saving, purification, plumbing | Solar water heater |
| Windows | Insulation | Vacuum glazing |

Recommendations:

- Ultimately the database is aimed at home owners, builders and architects. It is recommended that a publicly available online version of the database be developed. This should involve the development of a self-assessment tool that helps homeowners to evaluate the present standard of their home and to access relevant technologies from the database.
- That the database be maintained through periodic review (6 monthly recommended), by inviting end user feedback, and by saving keyword search enquiries.
- That the database be enhanced with case study information which includes up-to-date cost benefit information.

- That the database be used as a foundation for the retrofit programme within Beacon, and potentially be used as an input into external projects, such as the "your home" project.

### 1.2 Evaluation of technologies

The 107 technologies were short-listed to 65 and then ranked by a panel of experts against the Beacon sustainability footprint. According to these rankings, the options showing highest potential include: insulation materials, rainwater harvesting, permeable pavers, air-air heat exchangers, passive cooling systems, wood-pellet biomass boilers, energy-efficient home appliances, solar hot water heating, light tubes, and vacuum glazing. It general, it was found that "proven" technologies scored the highest.

However, it is important to note that in our statistical analysis, we found evidence that the experts may have differed in their individual interpretation of the nine Beacon objectives. Therefore, we urge caution in the use of the expert rankings. We also encourage a re-examination of the Beacon footprint to tighten up the definitions and to reduce the conceptual overlap.

### 1.3 Areas for innovation or adaptation of technologies

Further retrofitting technologies are presently under development or are not yet available in New Zealand. Technologies of this kind include:

- Evaporative panels on roofs for heat pumps
- Hand-basin water closets
- Solar panels as roofing systems
- Phase change materials
- Smart meters which give instant feedback on electricity and water consumption

### 1.4 Draft plan for the proposed Beacon THEN Home

Our plan for the proposed Beacon THEN Home involves three steps:

- Step 1: Essential measures for health, indoor comfort and intact structure.
- Step 2: Good practice in passive use of local renewable resources, long-term use of extracted materials, and minimal consumption of non-renewable materials and fossil fuels.
- Step 3: THEN Home, including community and environmental integration.

The benefit of this approach is that it recognises that the existing housing stock is made up of homes in various states of repair and at various stages along the pathway towards a sustainable home. The THEN Home is conceived as a goal which may not be able to be achieved all at once. What is important is that homeowners are assisted to identify where their home is situated on the pathway towards a sustainable home and that they are assisted in identifying the relevant retrofit technologies for their individual situation. The retrofit database facilitates this.

Recommendations:

- That Beacon develop a self-assessment tool to assist homeowners to calculate a retrofit budget which takes into account the market value of their home as well as other homes in their area.
- That Beacon tests the consumer response to the 3-step retrofitting pathway that has been proposed.
- That Beacon sponsors a student project at Canterbury University which documents and assesses a retrofit case study.

### 1.5 Summary of international retrofit programmes

The review of international retrofit programmes in Beacon Report RF1 was updated by examining recent international conference proceedings (SB02, SASBE03 and SB05). In summary:

- Most housing retrofit programmes are focussed on improving energy efficiency.

- The uptake of retrofitting technologies is to some extent driven by retrofitting programmes that are initiated by government.
- A key requirement in all programmes is the need to evaluate alternative technologies and systems.
- There is a general need for accessible information which helps homeowners to determine which products and systems apply to their individual situation.

# 2. INTRODUCTION

## 2.1 Background

Retrofitting of houses has been identified as a critical component of Beacon Pathway Ltd's programme to achieve its goal of an improvement in sustainability within 90 % of homes in New Zealand. The need for retrofitting older houses in New Zealand was documented in the report RF1 "Housing Retrofit" (Storey *et al*. 2004). Of the 1.6 million houses that exist today, one million were built prior to the introduction of thermal insulation standards in 1979. Although more than 60 % of the pre-1979 houses have been retrofitted with ceiling insulation, only about 120,000 houses are thought to comply with insulation standards from the year 2000. Storey *et al.* (2004) mentions hot water cylinder wraps and dual-flush toilet cisterns as the only two other technologies which have been retrofitted into houses in a noteworthy manner, though the numbers are not very significant. However, the number of smoke alarms has increased as well due to changes in the building code and campaigns by the fire service. The uptake of a wider range of retrofitting technologies is crucial to bring the existing housing stock up to modern standards of health, comfort and sustainability. The aim of this project is to initiate development of tools which can help the owners of older houses to identify the best solutions when retrofitting.

In a first step towards achieving this aim, a database of retrofitting technologies was developed. The database contains, as a subset, technologies from the previous study reported in TE101 (Bayne *et al*. 2005). It was decided that it was more relevant to focus on "technologies" rather than on specific products. An example of a technology is "a single-door refrigerator" — there are many brands available but they vary in quality, in electricity use and in size. Focusing on technologies rather than products dramatically reduced the number of items in the database (which makes updating it a much less onerous task), but this also meant foregoing the option of doing an economic or cost analysis (since within each technology there is variation in price between individual products).

The database consists of 107 technologies. The structure of the database will be described in detail in Chapter 4. In this chapter, we also describe how the 107 technologies were further short-listed to 65 and then evaluated by a panel of experts according to the nine Beacon sustainability objectives. This enabled a ranking of the technologies and an assessment of those that demonstrated the most promise for retrofitting, and which could contribute to sustainability. The results are presented in Chapter 6. Based on discussions within the research group it became apparent that the Beacon criteria were being interpreted in different ways by different individuals. To confirm this, we did an in-depth statistical study of the experts' evaluation of the technologies. This study is discussed in more detail in Chapter 5. We indeed found that interpretations varied widely amongst the group, suggesting that the Beacon criteria, or at least their definitions, need to be reassessed if they are to be a useful framework for ongoing decision making processes.

In preparing the database it became obvious that a listing of technologies with sustainability-related information was not sufficient for home owners to arrive at a decision about which technology to choose. With retrofitting, the present state of the house is all important in determining the appropriate technology: while solar panels might be the appropriate technology for the owner of a new, insulated house, they are not the most appropriate for a house with a leaky roof, for example. What is required is, in fact, a retrofitting strategy that could deal with houses in very different states, with the ultimate aim being Beacon's THEN home. The strategy we came up with is called "The retrofitting pathway" and is described in detail in Chapter 3. A brief summary is provided below.

Almost all the existing homes in New Zealand are below the sustainability targets of the THEN Home. The transition can be begun in various ways, from complete demolition of an existing structure to minor enhancements. There is a wide range of remodelling options over a wide cost range. For categorisation purposes, the transition to the THEN home has been organised into steps, reflecting the comprehensiveness of the retrofit. Whatever the state of the current home, it must meet basic health, well-being and integrity requirements in order to be considered on the path to the THEN home. Thus, the first step toward a sustainable home involves remodelling steps which are ESSENTIAL to ensure indoor comfort, health and a structural integrity. The second step represents the accepted GOOD PRACTICE that is required to provide for comfort and security using local renewable resources and minimising the use of fossil fuels or extracted resources. The ultimate third step, the THEN Home, can be achieved by having a fully integrated community and environmental design solution. The technologies in the retrofit database have been assigned to the appropriate steps in this path. A particular home owner needs to determine their current position on the pathway and therefore access the appropriate technologies which could take them to the next step.

Any retrofitting strategy must also consider the problem of how to convince home owners to take the pathway to the THEN Home. What would motivate owners to retrofit pre-1979 housing stock? It is well documented that cold, damp houses, in addition to reducing the comfort level of the occupants, actually have an adverse effect on the occupants' health, for example, by increasing the incidence of asthma. In addition, increasing energy prices tend to make older houses, which often lack insulation, more expensive to live in than similar-sized new houses. However, since many houses are either owned or seen from an investment perspective, any approach to increasing the level of retrofitting for sustainability will most likely need to consider the economic return to the owners.

Whether a house has wall or ceiling insulation or double-glazed windows is not directly visible to a buyer and therefore, at first sight, these technologies may not have a significant effect on the value of a property. For this reason, a property owner may not have sufficient incentive to take these retrofitting steps. However, a recent survey of real estate agents in Christchurch (Wallbank 2001) indicated that if the property has assets such as insulation, effective heating, low condensation (e.g., double-glazed windows), good solar exposure and no musty smell, then the property will have many more interested potential buyers than alternative properties. More interested buyers means a higher market value. Other surveys and research have indicated that home owners do desire good quality in their housing, particularly in the form of heating and comfort (Center for Advanced Engineering 2001, Krumdieck 2001). They also highly value community amenities such as clean air, clean water and reliable, renewable energy. Moreover, if retrofitting for sustainability is done in conjunction with remodelling of a house, the increase in property value could be significant. In Chapter 3 a remodelling strategy which utilises the existing economic drivers to achieve transitional steps toward the THEN Home target is described. Each home owner must follow an evaluation process and will develop a different remodelling plan depending on the particular details of their property, locality, budget, and desires. This is illustrated by a case study which follows a home-owning couple down the pathway to the THEN Home ending in a retrofitted sustainable home *and* financial security.

## 2.2 Objective

This study provides a database for retrofitting technologies that can be used to improve the sustainability aspects of existing homes. Furthermore, a guideline for homeowners for retrofitting their homes — the pathway — has been developed and provides initial tools for greater uptake of retrofitting technologies in New Zealand.

The process of evaluating retrofitting technologies in terms relating to the Beacon objectives of sustainability provides an insight into the complexity of the occupant's decision-making process. The fact that retrofitting tends not to occur also highlights that the process is not simple.

## 2.3 Definition

The definition of the word "retrofitting" is critical to this report. In RF 1 the following definition was used: "Any work carried out on a house subsequent to its completion". It further suggests as a definition in the Beacon context: "Work undertaken to improve the sustainability performance of a house subsequent to its completion". Criteria for including technologies in the database are based on this latter definition. Accordingly, retrofitting a home:

- includes the house and its surroundings;
- includes extensions;
- involves any upgrade towards sustainability;
- excludes maintenance and replacement, where sustainability objectives are not specially considered.

## 2.4 Structure of the report

The retrofitting pathway provides a framework for the database and is therefore described in the following section (Chapter 3). The resulting structure and the process of developing the database are then described in Chapter 4. Chapter 5 deals with the evaluation of the technologies against the Beacon objectives. Retrofit options with the highest potential to assist in meeting Beacon's objectives are discussed in Chapters 6 and 7. The last chapter summarises international retrofit programmes.

## 2.5 Recommendation

A consistent definition of the word retrofitting should be used throughout the Beacon research program. The research team recommends the following definition:

Retrofitting a home includes all work undertaken to improve the sustainability performance of a house subsequent to its completion. It includes:

- the house and its surroundings;
- extensions;
- upgrades.

# 3. DRAFT PLAN FOR THE THEN HOME

To enable users to make informed decisions about a particular technology it is necessary to have in place a classification mechanism that determines the applicability of the technology to the particular home owner's house. Two obvious methods of doing this are:

1. By style of house (e.g., villas, Spanish California bungalows, Art Deco, cottages, state house, contemporary).
2. By material cladding type (weather board and corrugated roof, brick and tiled roof, fibre cement board and corrugated roof, etc.)

However, it was recognised early that for both such approaches there were not enough critical differences to assist home owners to identify criteria for retrofitting. In fact, there were no common 'themes' that could be established that could easily be seen as a way of assisting in the classification process. As a result, it was decided not to pursue analysis of the housing stock for the purpose of streamlining the technology selection process any further for this project. This approach may need to be revised subsequent to completing the market segmentation project. However, the research team decided it was important to provide the user with meaningful guidance in their choice of technologies for retrofitting. The current state of the house in relation to sustainability seemed to be the most appropriate principle for this guideline.

In this chapter we describe a categorisation scheme developed by the team, which divides the existing housing stock into three categories of houses depending on their level of sustainability. As well as enabling us to guide the users to the appropriate technology, these three categories also form steps on a pathway to increased sustainability. The three categories are labelled: "essential", "good-practice" and, ultimately, "the THEN Home". The basic idea behind this approach is that some retrofitting is essential for good health, safety and structural integrity and needs to be completed before considering reducing electricity consumption, for example. Retrofitting technologies can be assigned to an appropriate step on the pathway. For example, insulation will be part of the essential step. A homeowner can therefore first asses which step they are at and find the appropriate technology for the next step.

As discussed in the introduction, we must also consider the problem of how to convince New Zealanders to retrofit their homes towards sustainability. Since most New Zealanders rely on investment in residential property as their primary strategy for long-term financial security and as a source of retirement savings, the primary driver for New Zealand property owners will be the capital gain in their property. We believe retrofitting towards sustainability need not be at odds with this. By way of illustration, we have developed a remodelling strategy which a homeowner could follow to retrofit their house for sustainability utilising existing economic drivers.

An outline of this chapter is as follows: first we describe the three categories and how they form steps on the pathway to the THEN Home. An explanation of how the technologies naturally become associated with an appropriate step on the pathway is also included. Second, we describe a remodelling strategy which utilises economic drivers to achieve transitional steps toward the THEN Home target. Third, an example case study is presented describing two homeowners utilising the strategy to remodel their house. Finally, we give our recommendations that arise from this chapter, including a recommendation to develop a self-assessment tool for homeowners to determine their position on the pathway and an outline of an idea for a student project that arose from the current research project.

## 3.1 The retrofitting pathway

Many homes in New Zealand do not meet the sustainability targets of the THEN Home. The THEN Home is defined as sustainable home which relies to a large extent on renewable materials and energy.

Total demand for energy and fresh water is lower than in conventional houses, maintenance requirements are low, and durability is high. The house is fully integrated with the community and features environmental design solutions.

The transition can be achieved by any degree of remodelling of an existing home, from complete demolishing of an existing structure to minor enhancements. There is a wide range of remodelling options over a wide cost range.

For categorisation purposes, the transition to the THEN Home is broken down into three steps, reflecting the comprehensiveness of the approach. Whatever the state of the current home, it must meet basic health, well being, and integrity requirements in order to be considered on the path to the THEN Home. Thus, the first step toward a sustainable home involves remodelling steps which are ESSENTIAL to ensure indoor comfort, health and an intact structure. The second step represents the accepted GOOD PRACTICE that is required to provide comfort and security using local renewable resources and minimising the use of fossil or extracted resources. The third step, the THEN Home, can be achieved by having a fully realised community and environmentally integrated design solution. In summary, a retrofitting project can be categorised into:

Step 1) **ESSENTIAL** measures for health, wellbeing and structural integrity.

Step 2) **GOOD PRACTICE** in passive use of local renewable resources, long-term lifecycle of extracted materials, and minimal consumption of non-renewable materials and fossil fuels.

Step 3) **THEN Home**, including community and environmental integration.

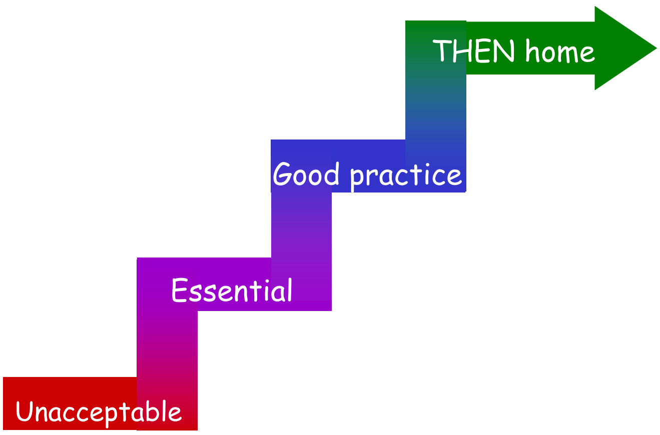


Figure 1: Retrofitting pathway

The details of the three retrofitting steps, including their definition, key performance characteristics and specific criteria, are identified in Table 2.

**Table 2: Three levels of retrofit**

| Step | Definition | Key Performances | Criteria | Technology Examples |
|---|---|---|---|---|
| Essential | Fulfils standard requirements regarding health, ventilation, structure and insulation | Warmth<br>No condensation<br>Non-polluting heat source<br>Secure | Has to be within the market range<br>Has to improve resale value of house | Glass wool insulation<br>Wood pellet burner |
| Good Practice | Minimised resource use to provide *essential* services<br>Passive use of local natural resources<br>Reduced waste | High energy efficiency<br>Minimum water use<br>Minimum waste<br>Intelligent application of passive solar heating | No structural changes to building | Most efficient refrigerator<br>Rainwater harvesting<br>Composting |
| THEN Home | Towards renewables, materials and energy<br>Away from fossils<br>Reduce total energy demand<br>Peak demand management<br>Low maintenance, long life | Minimum fossil fuels usage<br>High durability<br>Most sustainable options | Focus on renewables, low maintenance and long-life materials and products | Native plants – low water requirements<br>Fruit trees etc.<br>Photovoltaic |

The research team determined where each technology fitted in relation to the three steps. It was found that some technologies fitted into more than one step, depending on the specifics. Taking insulation as an example, it is used in all three steps, where the category determines the degree in thermal insulation provided. Thus, for:

**Step 1: ESSENTIAL**, the minimum insulation (thermal resistance) values for the roof/walls/floor is that dictated by NZS 4244 category 2a (improved windows). This translates to a reduced heat loss of about 25% compared to the New Zealand Building Code (NZBC).

**Step 2: GOOD PRACTICE**, the minimum insulation (thermal resistance) values for the roof/walls/floor is that dictated by NZS 4244 category 2c (improved windows and insulation). This translates to a reduced heat loss of about 35% compared to the NZBC.

**Step 3: THEN Home**, the minimum insulation (thermal resistance) values for the roof/walls/floor is that dictated by NZS 4244 category 3 (best windows and insulation). This translates to a reduced heat loss of about 60% compared to the NZBC.

The reason for the low ESSENTIAL insulation requirement is purely practical — providing higher insulation levels in a simple retrofit is technically difficult without considerable structural changes.

## 3.2 Implementation of retrofitting pathway: residential home owner

It may be possible to construct a vision of sustainable communities and buildings for New Zealand. Even if we have a sustainable urban form in mind, the investment in achieving that form will be done by individual property owners. For the next 10–20 years the primary driver for New Zealand property owners will be the realisation of capital gains in their property. For rental property owners, the income from properties is not highly dependent on the quality of the property, so they are less well motivated to remodel for sustainability unless regulations require it. The following chapter describes a remodelling strategy which utilises the existing economic drivers to achieve transitional steps toward the THEN Home target. Each homeowner must follow through the evaluation process and will develop a different remodelling plan depending on the particular details of their property, locality, budget, and desires.

### 3.2.1 Evaluation of present assets

Each residential property has a set of physical, natural, and community assets. An inventory of these assets will form the foundation for the retrofitting plan.

- **Economic Assets:** Present market value in the neighbourhood must be determined for:
  - the property in current condition;
  - the land as a vacant lot;
  - a property of the same size (floor area, number of bedrooms and lounges, and bathrooms) if it was a new, top-quality home;
  - the highest-value property in the area.
- **Physical Assets**: Structure and materials that are of value and will be preserved and carried into the future structure.
- **Location Assets**: Proximity to trade and production centres, accessibility to goods and services, employment and education.
- **Natural Assets**: Land, soil, rocks, native plants, garden areas.
- **Community Assets**: Urban form, streams, beaches, ponds, and parks.
- **Future Potential**: Identify factors for the community which may make it a more desirable place to live in the future.

### 3.2.2 Evaluation of present liabilities

Most residential properties have a mortgage liability. There may also be other liabilities such as repairs and maintenance that must be done, regardless of the decision to remodel. These repairs count against the value of the property, but would be avoided if the remodelling went forward. In other words, repairing keeps the property value from decreasing, but remodelling should actually increase the property value. If the areas that need repairing are included in the remodelling, then the repair liability is saved.

Evaluating the present liabilities of a residential property includes the following steps:

- Calculate the total debt encumbering the property.
- Make a list of the repairs and maintenance that should be done to maintain the property value and estimate the costs (e.g., painting, roofing, leaking bathroom fixtures, mould and rot repairs, decks, gardening…) .
- Make a list of the undesirable features of the property that limit the market appeal. (e.g., only one bathroom, bedrooms too small, kitchen too closed in…).
- Make a list of unhealthy features of the property (e.g. condensation and mould growth, low indoor temperatures).
- Assess energy and water use and quantity of household and garden waste generated.

### 3.2.3 Evaluation of property development potential

Most New Zealanders rely on investment in residential property as their primary strategy for long-term financial security and as a source of retirement savings. The value of their investment *at the time of re-sale* depends on the market value of the assets minus the cost of the liabilities. When the owner sells the home, they realise the purchase price minus the debt owed on the mortgage and the real estate commissions. Most people understand this aspect. However, other aspects such as the cost of living in the home in terms of health, energy, water, and waste may not be considered. Even less consideration is given to long-term maintenance costs and structural integrity (as demonstrated in the leaky building episode).

A survey of 45 real estate agents in Christchurch in 2001 indicated that location and land area are the primary indicators of the market value of a home, but that in fact a wide range of price can be expected depending on the assets and liabilities (Wallbank 2001). The survey focused on heating, warmth, and mustiness/condensation. The results indicated that if the property has assets such as insulation, effective heating, low condensation (e.g., double-glazed windows), good solar exposure and no musty smell, then the property will have many more interested potential buyers than the standard property. More interested buyers means a higher market value. The indication is that properties with comfort and health liabilities can try to decorate their way into a higher market value, but that a warm, comfortable property is a hot property. Other assets that increase market value such as open plan architecture, number of bathrooms, etc., are well known and universal.

Other surveys and research have indicated that New Zealanders do desire good quality in their housing, particularly in the form of heating and comfort (Center for Advanced Engineering 2001, Krumdieck 2001). They also highly value community amenities such as clean air, clean water and reliable, renewable energy. This has been born out by the recent HEEP report by BRANZ, which showed that half of homes use a log fire to heat the home. This indicates that people really do want to be warm, and that most people are correct in their analysis that the only way to get warm in an under-insulated home is to put in a large heat source. Access to fire wood is considered to be reliable and sustainable, whereas fear of an electrical power outage is widespread.

All property owners, even those that plan to pay off their homes and live there for the long term, must take the asset-liability balance into consideration when planning a remodel project. However, long-term residents have even more at stake in improving the assets and reducing liabilities for their properties. Developing a retrofitting budget and a retrofitting plan are the first steps that a homeowner needs to take:

- Retrofitting Budget: The amount of funds that can be invested in a property remodel while maintaining the asset-liability balance can be determined by looking at the market value of the remodelled property and subtracting the mortgage debt. Consideration should also be given for avoided repair and maintenance in the plan, and for recycling of existing materials into the remodel.

- Retrofitting Plan: The objective of the THEN Home remodelling plan is to increase the quality and asset value of the property while balancing household income with mortgage payments and living expenses. There are many ways that this process can be achieved. The best way to portray the THEN Home transformation is to provide examples — this is more effective than lists of technologies.

### 3.3 Case study of retrofitting a 1940s bungalow

To see how this stepped system may work in practice, an example scenario[1] is given.

**Example: 1940s bungalow**

**Asset Inventory:**

Joe and Angela have two teenaged children. They bought their 1940's bungalow which is on a 650 $m^2$ section 12 years ago. The home has three bedrooms, one bathroom, a small, separate kitchen, one lounge and one dining room. The home is presently worth $195,000, and the lot would be worth $130,000 without a home. A brand new home of the same size would be worth $280,000. A new home with one more bedroom and one more bathroom would be worth $400,000. The home is in a desirable neighbourhood with good schools and walking access to public transport. Shopping centres and work centres are within 5–10 minutes by car. The home is walking distance to a park and has a stream boundary. The bungalow has rimu framing and floors and weatherboard cladding. There are several mature native trees and a large vegetable garden plot on the section. The architectural aspect of the house is appealing from the street view.

**Liability Inventory:**

Joe and Angela owe $35,000 on the mortgage. They spend $350 per month on electric heating in the winter. The home is not comfortable, and even with the night store heaters, column heaters and fan heaters they cannot keep the home above 16°C. Their home is not desirable, with a definite musty smell, particularly in the bathroom. The wood sills on the windows are damaged by condensation and in need of repairs. The walls of the bathroom are constantly mouldy, and one of the children suffers from asthma with visits to the doctor and medications costing about $600 each winter. The house exterior and interior need painting and the roof needs treatment (estimated maintenance costs $10,000).

**Sustainable Housing:**

Joe and Angela would like to find a nice, comfortable, healthy home. If they sell their current home and buy another, they would realise $160,000 minus the real estate commission ($13,650). Given that they would then purchase a home worth around $350,000 and re-invest their earnings, their new mortgage would be $203,650, which they feel they can afford. If they could find a new home with passive solar heating, good insulation, and wood pellet heating, the winter electricity

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[1] Note that this scenario is fictitious.

bill would be around $100 a month and the medical bills should be reduced. However, they have not been successful in finding a suitable home in the area.

They used the remodel planning guide on the Beacon website and a local architect. They decided to develop a THEN Home remodel plan. The asset-liability balance on their present property indicates that it has many desirable features, including a good section size and community attributes. The undesirability of the home stems from decisions made by the original builder and the architectural style. However, the foundation and much of the framing are still sound.

The amount of money that Joe and Angela have to invest is $165,000 to reach the same quality of housing they would have if they sold the existing home and bought a new home. Using the THEN Home plan, they have remodelled their old home into a new THEN Home on a budget of $90,000. Discounting this figure by the $10,000 which they needed to spend on maintenance in any case, they have achieved a new home for an $80,000 investment. They have a new mortgage of $115,000 on a sustainable home worth $350,000 – $400,000.

**THEN Home retrofit:**

All of the plasterboard board and windows of the bungalow were removed. The bathroom and kitchen were completely removed. The windows and reusable items from bathroom and kitchen, e.g. the sink, were salvaged by a demolition trader. The bungalow was enlarged in an area of the section that allowed for increased passive solar gain, the addition of a bathroom, enlargement of the kitchen/dining area, and the addition of a large bedroom/study. The framing and cladding was found to be sound and so was preserved. The home was fully insulated above standard in floor, walls and ceiling. New double-glazed windows were installed throughout and electrical outlets and wiring were up-dated. Interior walls were moved to add a second bathroom and to enlarge and open up the kitchen/dining area, and to open up a dark hallway. Window openings were enlarged on the north-facing side, and a solar tube light was added to a dark area of a back hallway, along with an art nook.

Joe carefully pulled the mouldings in the bungalow. They were found to be high-quality rimu. Joe sanded them down and they were recycled into the living/dining area. A pellet-fuelled boiler was installed to provide the hot water and to feed a radiator system to heat the home. The rimu floor boards were polished and not carpeted. Extraction fans were added to bathrooms and kitchen to reduce indoor moisture and smells.

Replacement of the plasterboard board with fresh plasterboard and plaster, as well as the new windows and new internal architecture transformed the home into a "new" home with attractive architectural features. The all-new interior walls provided an ideal situation for interior design and decoration. The "all new" feel together with the new kitchen and bathrooms brought the value of the home up to the top of the market value. They have also upgraded their internet connection to broadband and Angela can now use the extra bedroom as a study and work from home three days a week.

Low-flow water fixtures and the most highly energy-efficient appliances were purchased. New guttering and refurbishment of the roof included long life, low-toxicity paint and rainwater collection for gardening. The full remodel provided a good opportunity for earthquake strapping and addition of fire alarms and security window fixtures.

## 3.4 Recommendations

In the following section we discuss three recommendations that have arisen out of the work described in this chapter. The first is for a self-assessment tool for homeowners to determine their position on the sustainability pathway, the second suggests further research around the retrofitting pathway and the third is for a student project on a case study of the above remodelling strategy.

### 3.4.1 Database self-assessment tool

In order to guide homeowners on their individual pathway to a more sustainable home, the homeowners need to know where their current home sits on the pathway. Every individual home has different features, and some homes have already had sustainability features added, e.g., by installing ceiling insulation. Therefore, an individual assessment of each home has to be made. Since the homeowners usually know most about their homes we recommend a self assessment tool. The tool should be part of the website and should be programmed in a way that the retrofit technologies database can only be accessed after the user has gone through the self assessment tool. The home owner could then be presented with technologies that are appropriate to them.

The questions in the self-assessment tool would need to be easily understandable and must not require any expert knowledge. A questionnaire of this type has been successfully trialled as part of a recent project carried out at Scion on the housing of a small Māori community in Rotorua (Delrieu 2005). Relevant questions from the questionnaire used in this project could form the basis of the self-assessment tool described here. Examples of the type of questions that might be asked are: "Is your hot water cylinder warm to the touch?" (to determine if cylinder is insulated); "Do any of the rooms in the house have a musty smell?"(indicating ventilation problems); "Can you heat your home to a comfortable level in winter?" (implies lack of insulation); "When do you receive the most light through the windows?"; "Is there anything that blocks the sunlight into your house?"(both relevant to passive solar heating of the house). All these questions are easily answered without the need for expert knowledge, and yet can be quite informative in assessing the state of the house.

### 3.4.2 Consumer research

The retrofitting pathway is built on the understanding that economic issues are a key consideration for a home owner (Krehl 2005). The research team recommends that the consumer response to the proposed retrofitting pathway be tested. Case studies and detailed consumer surveys would provide an insight to the buy-in from home owners in the proposed concept.

### 3.4.3 Case study

Conducting a case study for the implementation of the retrofitting pathway is recommended by the research team. This case study could be used to illustrate some of the technologies in the retrofit database. The first stage for the realisation of this case study is an engineering optimisation analysis of an existing home which is currently at the 'unacceptable level'. This study will show the necessary steps to bring it to essential, good practice and THEN home level. The research team suggests that this could be done in cooperation with the University of Canterbury. A detailed project plan should be developed in discussion with Dr Susan Krumdieck at University of Canterbury. A proposal for a possible student project has already been submitted to Beacon (see Appendix 1). The suggested outputs of the student project are:

- Design a renewal for a particular home in Christchurch from an unacceptable level to an essential standard and ultimately to the THEN Home standard as defined in TE102;
- Conduct a standard engineering optimisation analysis to determine the optimal design elements for comfort, energy efficiency, renewable energy, and sustainability in Christchurch housing;
- Develop a life-cycle cost and sustainability analysis for re-modelling and re-building projects;

- Produce an action plan for local government and business which would bring about the urban renewal.

Examples of successful student projects are listed at the following website:

http://www.mech.canterbury.ac.nz/MEFinalYear/pastprojects.shtml

# 4. DATABASE

The database provides information on 107 technologies, which are predominantly retrofitting technologies. Although a focus is on currently available technologies, some technologies which are still under development are included. The structure of the database accommodates for a range of different search scenarios and allows regular updating of the information. The information contained in the database provides a brief description of each technology on function and key features as well as relevant information regarding sustainability aspects.

The intended audience for the database are at this stage Beacon partners, who can access the database and comment on it via the private section of the Beacon website. Ultimately the database is aimed at home owners, builders and architects.

An outline of this chapter is as follows: In Chapter 4.1 we describe the process used to select technologies and the criteria for including technologies in the database. Chapter 4.2 describes the structure of the database and, with examples, what kind of information is provided for each technology. In Chapter 4.3 the various search options of the database are explained. Finally, in Chapter 4.4 recommendations are provided, which include a recommendation on how to keep the database up to date and further additions to the database.

## 4.1 Technologies included in the database

It was decided to focus on "technologies" rather than on specific products in the current database. An example of a technology is "a single door refrigerator". There are many brands available but they vary in quality, in electricity use and size. By focusing on technologies rather than products we dramatically reduced the number of items in the database, but gave up the ability to do an economic or costs analysis - as the variation in price of each product in one group of technologies was so large.

In principle, building technologies rather than materials are listed in the database. However, the line between technologies and materials is often difficult to determine. Insulation materials for example are listed in the database, because they are a key element of retrofitting a house to a more sustainable standard, although they are strictly speaking building materials. However, building materials which are usually used in houses before they are retrofitted to a more sustainable standard, and need to be replaced during the retrofitting are not listed in the database; plasterboard is an example for this.

The database developed in the Beacon project TE101 was used as the basis for the retrofitting technologies database. Technologies for new build were not excluded from the current database, but a search criteria was included in the database which enables the user of the database to search for retrofitting technologies only, or for technologies for new build only or for both.

The first additions to the database were appliances, such as a most energy efficient fridge. Although these are strictly speaking not retrofitting technologies, they were included, because the energy/water consumption of appliances contributes significantly to the overall energy consumption in a home.

Having made these additions, the database then contained more than 170 technologies. At first sight there seemed to be many which were only useful for commercial buildings (e.g., solar walls) or not useful in terms of sustainability for homes (e.g., ocean thermal energy conversion). The research team decided to reduce the number of technologies in order to reach a manageable number which can be regularly updated. The key researchers of the team were asked to individually shortlist the 60 most important technologies out of the full list of 170. Each technology that was chosen by at least one team member remained in the database. The brief was to chose technologies that are either currently available or are considered to have a huge potential in the near future to contribute to a sustainable retrofit of a home in New Zealand.

This process cut the list down to 65 technologies and did not include some of the most common and well known technologies. For example, glass wool for insulation was not included, whereas sheep wool insulation was included in the first version of the database. This shortlist was used for the evaluation in relation to the Beacon objectives as described in Chapter 5.

The research team has then added technologies such as glass wool insulation or polystyrene panels for underfloor insulation, extractor fans for bathrooms or hot water cylinder wraps which were not included in the original TE101 database.

## 4.2 Structure of database

The database contains the following information for each technology:

- classification of technology;
- general information;
- sustainability related information.

### 4.2.1 Classification of technologies

All technologies are classified according to their suitability for new build and/or retrofit, their category, and their relationship to the 3 steps in the retrofitting pathway. This classification allows for a range of search options for the database (see Chapter 4.3).

**New Built and/or retrofit**

Each technology is classified according to its suitability for retrofit and/or new built. Many of the technologies can be used for either new or retrofit situations.

Technologies identified exclusively as retrofit options were:

- Hot water cylinder wraps. New houses require higher performing cylinders.
- Flush saver devices for toilets.

**Categories**

All technologies are therefore allocated to one of a total of 14 main categories, e.g. appliances, decoration, electricity generation.

Each category is further divided into several subcategories (Table 3).

**Table 3: Technology categories and sub categories**

| Category | Sub categories | Example |
|---|---|---|
| Accessories | Energy efficiency | Electronic socket timer controls |
| Appliances | Energy efficiency<br>Water efficiency | Most efficient refrigerator |
| Decoration | Paint | Enviro-choice paints |
| Electricity generation | Wind power conversion<br>Solar power conversion | Solar panel photovoltaics |
| Fittings | Plumbing | Fusiotherm plumbing |
| Insulation | Wall insulation<br>Underslab insulation<br>Underfloor insulation<br>Ceiling or loft insulation | Glasswool insulation |
| Lighting | Artificial lighting | Light tube |

| | | |
|---|---|---|
| | Natural lighting | |
| Safety | Safety<br>Security | Smoke detector |
| Space heating | Provision of heat<br>Provision of cooling or heat<br>Condensation | Pellet burner |
| Structure | Internal walls<br>External walls<br>Floor | Wide stud spacing |
| Ventilation | Extraction of used air<br>Supply of fresh air | Extractor fan for bathroom |
| Waste | Solid waste | Home recycling station |
| Water | Water heating<br>Water purification<br>Water saving | Heat pump water heaters |
| Window | Insulation | Vacuum glazing |

**Retrofitting pathway**

Each technology was allocated to one or more steps of the retrofitting pathway. Insulation materials for example were allocated to all three steps, because the degree of insulation varies with each step. Whereas all insulation materials are given as an option for the essential step, only renewable materials were an option of step three. Examples for the allocation of technologies to the pathway are given in Table 2.

A self assessment tool as described in Chapter 3.4.1 will guide the user of the database to the relevant step on the "retrofitting pathway".

### 4.2.2 General information

General information for each technology includes a short description, general comments, sources for further information, advice on the installation and building consent requirements.

**Description of the technology**

A short description of each technology is given, which describes the function and key features of each technology. Examples are:

| Solar water heater |
|---|
| A solar water heater typically uses glazed collectors that are roof-mounted and connected to a preheat storage tank. Fluid is pumped to the collectors where it is warmed by the sun and returned to a heat exchanger where it heats water in a preheat storage tank. |

| Pelmets |
|---|
| Pelmets are an essential addition to thermal drapes for windows. Thermal drapes should seal at the top against a pelmet. Otherwise the cold surface of the window will trigger a continuous sheet of cold air sliding down and out across the floor. |

### General comments

General comments include cautionary notes, advise on maintenance or ideas for longterm planning. Examples are:

| |
|---|
| Solar panel photovoltaics |
| A PV system can be installed in stages and developed as energy use or financial resources grow. It requires very little maintenance over its lifespan. |

| |
|---|
| Smoke detectors |
| Smoke detectors should be cleaned with the vacuum cleaner once a month and the alarm should be tested once a month by pushing the test button in. |

### Further information

The database contains generic information about technologies, but no specific product related details. The choice of a specific product depends very much on the individual situation of the home owner. In order to choose a specific product, a home owner therefore needs more detailed information. The database guides the homeowner towards sources of further information. In most cases this will be a specialist, for example a heat and gas specialist for a heatpump, or a retailer for appliances. In some cases the database also refers to more detailed websites. For some technologies, e.g. sheep wool insulation, further information is only available from manufacturers. If possible, in these cases the websites of at least two manufactures are listed.

### Installation

Do-It-Yourself (DIY) plays a very important role in the retrofitting sector, but as a general rule, the database recommends professional contractors in cases where advanced DIY skills are required. Only a few retrofitting technologies can be installed with very basic DIY skills and without expert knowledge; examples are draught-stopper tape for windows or the installation of smoke detectors. In other cases more advanced DIY skills are required, for example, for the installation of underfloor insulation. In this case the database lists both options.

For technologies which could be installed by home owners with advanced DIY skills, the database recommends a professional contractor. In any case, where building consent is required and for technologies, e.g. an extractor fan for a bathroom, where no building consent is required, but some councils require the provision of a certificate from a professional contractor, the database states "professional contractor required".

### Building consent

The requirements for building consents are very clear for a number of retrofit technologies, for example, for the installation of any solid fuel heater. For other technologies the regulations are not that clear. If for example a window is replaced with another window at exactly the same location and of exactly the same frame size, it is unlikely that a building consent is required. The database would in this case say "building consent may be required".

### 4.2.3 Sustainability-related information

Information related to desirability, investment potential, personal health and resource use is contained in the database. Examples of the type of information provided are given below.

Information on Affordability[2], Community, Future proof, Performance and was only available for very few technologies and is included under general notes. Should more information become available in the future then the database can be updated.

Desirability

Information with regard to Desirability is covered under the heading "quality of life". Issues such as security and safety are also covered here. Examples are:

| |
|---|
| Security stays for windows: Increases safety, protection from theft<br>Light tubes or skylights: Natural lighting |

Personal Health

Personal Health covers issues like warmth, ventilation, noise and air quality and is covered under several headings in the database.

Examples are:

| |
|---|
| Heat pump:<br>Keeps house warmer in winter and cooler in summer<br>Reduces condensation |

| |
|---|
| Vacuum glazing:<br>Keeps house warmer in winter and cooler in summer<br>Reduces condensation<br>Improves sound insulation |

Resource use covers not only the consumption of resources such as energy and water, but also the use of storm water and the reduction of materials going to landfills.

Examples are:

| |
|---|
| Energy<br>Most energy efficient fridge: Reduces electricity consumption<br>Most water efficient washing machine: Reduces electricity consumption by using less hot water<br>Solar panel photovoltaics: Reduces demand for mains electricity. |

| |
|---|
| Waste<br>Demountable fastenings: Waste reduced as can be used several times.<br>Home recycling station - kitset of containers and labels: Waste reduced by recycling |

[2] Affordability is regarded as a key objective. However, due to the focus on technologies rather than products it was difficult to determine specific costs. Also, without reliable information on the payback period the information on cost is difficult to interpret. See below for further discussion on this issue.

Investment potential covers features such as proven technology, reliable utilities or conservative design.

A technology was classified as having an investment potential if it increases the asset value of a house (see Chapter 3.2). Examples are: insulation, heating, low condensation (e.g. double paned windows), good solar exposure and no musty smell.

Affordability includes financial aspects such as first cost, installation cost and operating cost, but also payback.

This is a key issue for every homeowner who wishes to retrofit their house. Capital cost and payback time were identified as the two criteria which a homeowner would be interested in. However, since the database does not list specific products, it was not possible to provide exact information on these. The payback period is especially difficult to quantify because it is very dependent on the personal circumstances of the respective homeowner. For a solar hot water heater, for example, the number of people living in the household has a great influence on the payback period. Other issues are that commonly assumed paybacks may not be accurate due to recent technological developments and may not reflect the total cost of installation and/or ownership.

### 4.3 Database search options

The following search scenarios are programmed for the HTML version of the database:

1. Search step by step in retrofitting pathway
2. Search by specific category
3. Search by keyword

**Search scenario 1:**

1. Choose the level of retrofitting applicable for their house, e.g. essential
2. A list of technologies for the essential stage is presented
    - insulation
    - space heating
    - ventilation
3. Choose one group, and a list with relevant technologies is provided

**Search scenario 2:**

1. User searches specifically within a certain category of technologies (e.g. space heating)
2. All technologies for space heating are displayed, but also insulation technologies

**Search scenario 3:**

Key word search for technology name and technology category over complete database

## 4.4 Recommendations

### 4.4.1 Publication of the database

The translation of the Access database into HTML allows Beacon shareholders and researchers to access the database via the restricted area on the Beacon website. However, it is recommended to develop a program for making the database publicly available for home owners, builders and architects. Any publicly available online version of the database should also include the self-assessment tool as described in Chapter 3.4.1.

A disclaimer with regard to the information on consent requirements should be part of any publicly available information, especially with the dynamic nature of the NZBC, which is being revised currently, and the slight variations in interpretation of it. The disclaimer should advise the user that ALL technologies should be checked with the local council - its easy to do and can be usually done at the counter.

### 4.4.2 Maintenance of the database

The usefulness of the database is strongly dependent on a regular update of the information provided and on adding additional technologies as they become available in New Zealand. Several approaches for maintaining the database are recommended.

- A feedback option should be included in the final website. Users should be proactively invited to provide feedback on the database and suggest further technologies to be included.
- Keywords inserted for the "keyword search" should be saved to identify technologies which are not included. An analysis of keywords can also give an indication on which technologies are most popular.
- A review of the database by experts should be done at least every six months. The date of the latest review should be noted on the website.

### 4.4.3 Additions to the database

Case studies which demonstrate the use of technologies listed in the database will help homeowners to see the implementation of the technologies.

More research on economic cost-benefit analysis of technologies is required if useful information on affordability should be provided.

Landscaping technologies should be included. For the ESSENTIAL stage of the retrofitting pathway, in particularly these are important features. An extension of the database which includes landscaping technologies should be considered.

### 4.4.4 Analysis of data from self assessment tool for payback information

The calculation of payback periods could be facilitated through the self assessment tool. For example, information on the number of people in a household is crucial for a good estimation of the payback period for a solar hot water heater.

### 4.4.5 Linking the database to other projects

The database should be a foundation for the retrofit programme within Beacon, but could also be used as an input into other projects, such as the "your home" project or the proposed "Green Building Products, Systems and Services Resource" project.

## 5. EVALUATION OF TECHNOLOGIES

The 65 short-listed technologies were evaluated by a small panel of experts[3] according to Beacon's nine sustainability objectives: "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. Each of the nine objectives was described in detail, based on the footprint diagram, in order to provide the experts with a good understanding of the basis on which the technology should be assessed. Since a number of indicators are mentioned in several categories of the Beacon footprint diagram, slightly stricter definitions of the objectives were given to the experts. Another problem, which makes it difficult to provide clear and distinct definitions of the objectives, is the fact that there is an overlap between some of the categories. Aesthetics, for example, is listed under "Landscape" and "Community"; operating cost comes under "Affordability" as well as under "Performance"; and privacy is part of "Personal Health" and "Landscape". The footprint diagram also includes specific technologies or categories of technologies for some of the objectives. For example, appliances and lighting are both included under "Performance". In order to avoid a high score for all appliances in "Performance", for example, technologies were left out of the definitions.

The following definitions were given to the experts to be used for the ranking:

**Affordability** includes not only financial aspects such as first cost, operating cost etc. but also the general availability of a technology, i.e. whether it is mainstream, location specific etc.

**Community** relates to the direct impact on neighbors in terms of emissions and aesthetics.

**Desirability** relates to issues around the general quality of life. Issues such as security, privacy, but also prestige are covered here.

**Future proof** covers long term as well as short term future needs of home owners.

**Investment potential** covers features such as proven technology, reliable utilities or conservative design.

**Landscape** relates to the loss of land, impermeability and general disturbance of ecology.

**Performance** covers issues related to the building envelope, including improved sound insulation and durability.

**Personal Health** covers issues like warmth, ventilation, noise and air quality.

**Resource use** covers not only the consumption of resources in the form of energy and water, but also the use of storm water and the reduction of materials going to landfills.

The experts were asked to give each technology a score in each of the nine objectives according to a 7 point system – ranging from -3 (strongly negative impact) through to +3 (strongly positive impact). See Appendix 2 for a layout of the ranking sheet, including the average results. The scores enabled us to rank the technologies and pinpoint those with high potential. This is described in the next chapter. However, the scores that the experts assigned were found to contain more information than this simple ranking of the technologies and in the rest of this chapter we will discuss some of the findings from our in-depth statistical analysis.

[3] Albrecht Stoecklein (BRANZ), Jane Henley (Sustainable Business Network), Hugh Tennent (Architect), Charles Wilkie (Energy Options Whakatane), Robin Allison (Architect), Roman Jaques (BRANZ), Per Nielsen (Scion), Susan Krumdieck (University of Canterbury), Barbara Nebel (Scion)

## 5.1 Statistical analysis of expert scores

For some technologies, the experts assigned very different scores; however, the variance averaged over the scores for each expert and objective was only 0.3 out of the -3 to +3 range. What our statistical analysis uncovered, however, was a difference of a more subtle and yet more profound nature: the *interpretation* of the objectives differed fundamentally from expert to expert. We were able to determine this because the experts' interpretations of the objectives tended to manifest themselves in correlations between the objectives in their assigned scores. This can be illustrated by the following example: one of the experts that scored technologies high on "Investment potential" also tended to score them high on "Future proof". This correlation between the scores assigned to the two objectives means that this particular expert was essentially equating "Investment potential" with "Future proof".

Some examples of differences between the correlations for different experts and, therefore, the differences between their interpretation of the objectives are illustrated in the two graphs presented below.

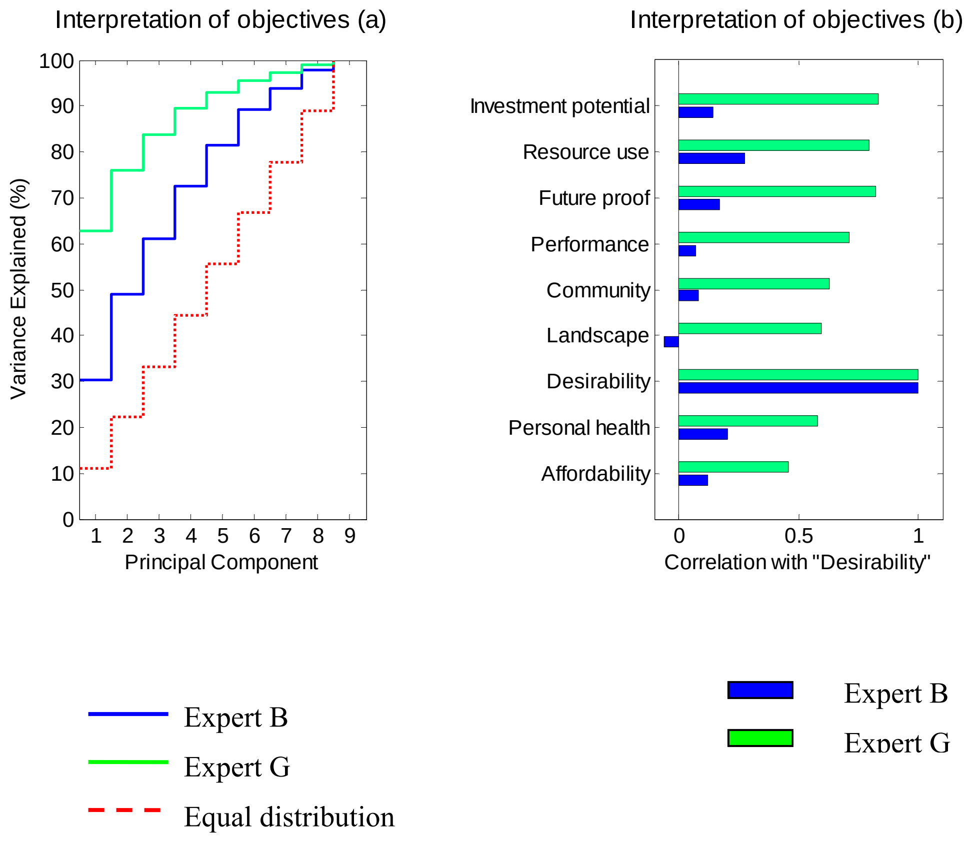


**Figure 2: Results of statistical analysis**

Figure 2 (a) shows the results of a principle components analysis (PCA) (Manly 1994), which is a statistical technique for dealing with multivariate data. PCA tries to find new independent coordinates such that as much of the variance as possible is contained in the first principle component and the next most in the second and so on. PCA can be illustrated by the following example: Suppose we have recorded the heights and weights of a group of people, then height and weight are our two coordinates and the results can be plotted as points on a graph. Due to the strong correlation between height and weight the first principle component will be a new coordinate that is a combination of height and weight which we could just call "size". This quantity captures most of the variation in the data. The second principle component will be a quantity which shows the variation in the group about the mean height/weight ratio. However, since most of the variation is captured in our variable “size” we can to a good approximation estimate a person’s weight from their size.

Similarly, in the present case, the nine objectives can be regarded as coordinates in a nine-dimensional space with the scores being points in this space. The aim is to find new coordinates that are combinations of the objectives that are the principle components.

Figure 2 (a) shows the amount of variance in the scores that is explained by each of the principle components for two different experts. As you can see for one of the experts, G (for green), more than 60% of the variance is explained by the first principle component. This suggests that to a good approximation G scored the technologies according to a *single* criteria despite the fact that there are actually nine objectives. Whereas, the other expert, B (for blue), demonstrates a more “multi-dimensional” scoring methodology, where the variance is distributed more evenly over the nine principle components. Note that the analysis of the scores showed that none of the experts considered the nine objectives to be completely independent of each other, as this would lead to principle components that explained equal proportions of the total variance. This hypothetical situation is shown by the dotted red line in figure (a) above.

Figure 2 (b) shows the same two experts’ correlations between the objective “Desirability” and the other objectives, where 1 signifies perfect correlation. We chose “Desirability” because in discussions it was raised as a particularly ambiguous objective. From this bar graph we can see that expert G’s results show that “Desirability” is strongly correlated with most of the other objectives. This means that G is essentially interpreting “Desirability” to mean something that scores highly in any of the other objectives. Expert B’s results on the other hand, show only a weak correlation between “Desirability” and the other objectives, suggesting that expert B is using a more complex definition of “Desirability”.

The conclusion from the above results is that the objectives were quite open to interpretation in the above study. In addition, the results show that there was quite a large overlap between the conceptual space of each of the objectives. While these results are specific to our study, we believe that they represent a more general concern with the use of the objectives as an assessment tool. Three approaches which might improve this situation are described in the recommendations for the footprint diagram.

## 5.2 Recommendations

### 5.2.1 Use of evaluation information

The evaluation of the technologies against the Beacon objectives has provided valuable insight for the project and for testing the Beacon objectives. However, the results are to be considered as preliminary results and should not be used externally.

### 5.2.2 Footprint diagram

Three options for further work on the footprint diagram include tightening up the definitions of the objectives, reducing the conceptual overlap between the objectives so that they are more independent of each other, or thirdly, to potentially reduce the number of objectives while still keeping enough to cover the essentials.

The definitions used for the ranking process were one attempt to reduce the overlap between the objectives and to provide more consistency in the definitions, i.e. exclude quantified targets or specific technologies.

## 6. RETROFIT OPTIONS WITH HIGH POTENTIAL

In order to identify technologies with high potential for improving sustainability of retro-fitted houses, the 65 short-listed technologies were ranked with respect to their overall score averaged over the experts. The overall score was simply an equally waited sum over the scores for all the objectives. The variance in this score was 1.7 from a range of -27 to 27[4] and therefore it was deemed that although the objectives were being interpreted in different ways by the experts, as discussed above, the ranking that arises from this overall score was still meaningful. This can perhaps be understood by the fact that no matter how the objectives are being interpreted a particular expert would still want the technology they considered to be superior to be reflected in it's score. In contrast, the scores themselves were deemed to be not as useful as first thought due to the problems discussed in the previous chapter and, while suggestive, should be used with a measure of caution.

The overall scores for the technologies are given in Appendix 2. Proven technologies tended to score more highly than the more radical ones, such as mini wind turbines and eco-waste water treatment systems. Several common-place technologies such as composting, dual-flush toilets, rainwater collecting and home recycling kits also ranked quite highly.

It is notable that six of the top twelve technologies are from the space-heating/insulation category, suggesting that this area as a whole is worth further investigation. The results also suggest that some of the technologies might benefit from a drop in price. For example, in the case of vacuum glazing, the large negative score for affordability lowers the overall score, which would otherwise be quite high.

[4] A technology achieving a perfect score of 3 in each objective would get an overall score of 27.

# 7. AREAS FOR INNOVATION OR ADAPTATION OF TECHNOLOGIES

A proportion of the technologies that the experts were requested to rank are presently in development or are not yet available in NZ. In addition, the experts were asked to highlight any areas for innovation or adaptation of existing technologies that they considered would provide significant benefit to existing homes in NZ. A selection of technologies of this nature are listed below together with a brief description or justification for their choice:

- Evaporative panels on roofs for heat pumps—much better performance than condensers located on the ground.
- Hand basin water-closet—widely used in Japan, the hand basin is mounted over the cistern so that the water used for hand washing is reused for the next flush.
- Solar panels as a roofing system—aesthetic properties in addition to other favorable properties, scored 6.2 overall, but -2 for affordability in the expert ratings.
- Phase change materials—lightweight nature and high-efficiency make them comparatively easy to install and useful where a house has little existing thermal mass. Note: this technology was also identified as a high-priority in TE101.
- Smart meters that provide instant feedback (and records for longer periods) on electricity and water use and also electricity going back into the grid—raises awareness, encourages lower consumption, allows households to know how well they are doing.

As these technologies are still under development or are not yet available in New Zealand, they would benefit from further research into their suitability for the NZ environment and market.

Current research that is undertaken internationally on retrofitting technologies was reviewed in the following chapter.

# 8. INTERNATIONAL RETROFITTING RESEARCH

The uptake of retrofitting technologies is to some extent driven by retrofitting programmes that are initiated by government. A review of international retrofitting programmes was carried out in order to provide some ideas on possible adaptations of such programmes for New Zealand. The findings of this research are given in Chapter 8.1.

Recent international conference proceedings relating to sustainable building were also reviewed to identify retrofitting technologies which are still under development or not yet available in New Zealand. These findings are described in Chapter 8.2.

Recommendations based on these international reviews are given in Chapter 8.3.

## 8.1 International retrofit programmes

A good overview of international retrofit programmes is given in Beacon report RF1 (Storey et al. 2004). Some of the key programs included in this report are outlined briefly below. More detailed information is available within the RF1 report. The review of recent conference proceedings has not identified any new retrofitting programmes; however, an internet search has identified some additional retrofitting programmes which are described in this chapter.

Storey et al.'s report for RF1 outlines the following 5 retrofitting programs which promote and encourage sustainable retrofitting by homeowners. Four of the five that Storey et al. outline are energy-efficiency based. Only the Green Home Remodel from Seattle relates to resource use in general.

- **Building America**, which supports the development of energy-based solutions through R&D activities.
- Weblink: www.eere.energy.gov/buildings/building_america/

- **DEFRA, UK**, which supports electricity and gas suppliers in meeting new energy efficiency targets in the domestic sector.
- Weblink: www.defra.gov.uk/environment/energy/betterbuildings.htm

- **Energy Star**, helping individuals to have more energy efficient homes, and outlining in their website suggestions for home improvements to increase energy efficiency.
- Weblink: www.energystar.gov/

- Canadian Office of Energy Efficiency's **EnerGuide for Houses**, which gives professional advice and encouragement on how to improve housing energy performance.
- Weblink: http://oee.nrcan.gc.ca/residential/personal/index.cfm?text=N&printview=N

- **Green Home Remodel**, from the City of Seattle, which provides tips and incentives for residents to conserve resources.
- Weblink: www.ci.seattle.wa.us/sustainablebuilding/greenhome.htm

Further investigation of these programmes reveals that they go further than only having an energy focus, incorporating other aspects of sustainability such as seismic retrofitting, affordability, and water efficientcy.

- **US: Seattle Government Project Impact: Home Retrofit.** This programme aims to improve the seismic performance of homes in Seattle by providing classes for the public on assessing their own home's performance, and principles of seismic retrofitting. Seismic retrofitting of 125,000 older wooden dwellings through structural strengthening is planned. A home earthquake retrofit handbook is also published and available online. The home retrofit objectives are to:
    - Develop the ongoing capability among local builders, contractors and homeowners to seismically retrofit homes
    - Implement consistent, effective mitigation measures
    - Simplify and accelerate the permit process for home retrofit projects
    - Foster community support and involvement
    - Encourage other Washington communities to learn from Seattle's successes
    - Provide financial incentives and other resources to assist homeowners who retrofit
    - Retrofit all vulnerable homes.
- Weblink: www.ci.seattle.wa.us/projectimpact/pages/pioverview/homeretrofit/homeretrofit.htm

- **Canada: EnerGuide for Low Income Households.** The Government provides between $C3,500-$C5,000 to assist low-income families with the cost of retrofitting, such as, draft-proofing and heating upgrades, including window replacement. A similar programme for people who are not on a 'low-income' is the **EnerGuide for Houses Retrofit Incentive Program**, which aims to retrofit 750,000 homes by 2010 through providing incentives for best-in-class devices and home heating practices.
- Weblink: http://oee.nrcan.gc.ca/residential/personal/index.cfm?text=N&printview=N

- **UK: DEFRA Market Transformation Programme** supports the development and implementation of the UK Government policy on sustainable products by collecting information, building evidence / quantifying the impacts and working with industry and stakeholders to reduce the environmental impact of products across the product life cycle. Policy scenarios, targets and action plans are given for various building product sectors, as well as the identification of issues that might arise due to the action plan being implemented. For example, the domestic shower sector has 5 targets to transform the market and reduce water consumption:
    - 50% of showers sold to have user selectable water efficient settings by 2006
    - Reduce the sale of high-flow rate showers by reducing the threshold by which the local water supplier must be notified from 12 litres per minute to 10 litres per minute.
    - Reduce shower water consumption by 3% by promoting regular maintenance
    - 10% of shower stock to have retrofitted low-flow shower head or flow restrictors by 2006
    - 1% of showers sold to be recycling showers by 2012
- Weblink: www.mtprog.com/Index.aspx

Our research has also revealed a further two international retrofitprogrammes:

- **EU: SHINE THERMIE** (**Solar Housing through Innovation for the Natural Environment**). This is an EU initiative with 6 refurbishment housing projects across Europe using solar technologies to upgrade multi-housing complexes and produce energy savings and healthier living spaces. The programme has 3 aims:
    - Demonstrating new and innovative solutions to energy conservation and efficiency
    - Achieving average energy savings of 60%
    - Improving the quality of life and health for occupiers of social housing across Europe.
- Weblink: www.learn.londonmet.ac.uk/portfolio/1996-1998/shine.shtml

- **Australia: Water for Life Program** and **Public Housing Retrofit Program.** The NSW Government aims to retrofit Department of Housing properties in Sydney with water-saving devices and energy and water-saving appliances, by providing these free to tenants. By 2010, an estimated 520 million litres of water will be saved per annum.
- Weblink: www.waterforlife.nsw.gov.au/

## 8.2 Retrofit technologies

A review of international conference proceedings relating to sustainable building practices (SB02;SASBE 2003; SB05) reveals that the research into sustainable retrofitting of existing buildings is, as yet, only an emerging field of research, and there are very few papers outlining specific technologies to deal with the retrofit process. Awareness and interest in this issue, has, however, grown over the past three years since SB02. This is exemplified by the appearance of double the number of papers regarding retrofit for sustainability or sustainable retrofitting technologies in the SB05 proceedings (11), compared to the combined numbers in the SB02 (4) and SASBE 2003 (2) conferences.

The papers largely dealt with addressing environmental impacts of renovation (Hansen 2002; Almgren 2002; Palmer 2002), and improving energy efficiency (Viriden 2002; Tywoniak 2002; Hama 2005; Borgstrom 2005; Boelmen 2005; Yamaguchi 2005; Skopek 2005), ventilation or indoor air quality (Viriden 2002; Tywoniak 2002; Kristensson 2003; Borgstrom; Lemaire 2005) and thermal comfort (Gilbert 2003; Boelmen 2005). Waste issues and deconstruction were discussed in earlier papers (Hansen 2002; Almgren 2002; Schultmann 2003), whereas the latest research addressed the need for adaptable design and described case studies on adaptable buildings (Palmer 2005; Schueblin 2005; Omi 2005). At SB05 an individual unit was dedicated to this latter subject. Another feature of the 2005 conference proceedings was 2 papers which used software tools to evaluate environmental impacts. This research is similar to the aims of the present technology database, i.e.:

- Boelmen's (2005) paper outlines a dynamic simulation tool developed to quantify the influence of window size, glass type, wall insulation and sun shading on annual energy use and thermal comfort – aimed to be applied to renovation projects for energy optimising.
- Lemaire's (2005) work produced a decision aid tool to choose building products on environmental and health characteristics.

## 8.3 Recommendations

### 8.3.1 Non-energy related retrofitting programmes

Internationally, there are many benchmark programs available regarding energy efficiency, and NZ already has a good program run by EECA. Beacon should explore whether programmes that look at retrofitting for non-energy benefits are suitable and could be developed in NZ, and if there is already an appropriate group/ body to implement such a programme, or whether a new body will need to be formed (perhaps with support from Beacon).

### 8.3.2 Experience from international programmes

It is suggested that any proposed retrofitting programme for New Zealand would benefit from the example of the UK DEFRA programme of targets, action plans and issues for sectoral-based policies. This programme appears to be well structured and very well thought through regarding 'how' to implement the targets and the implications of doing so.

The SHINE programme may have some key lessons for HNZC, and may provide Beacon with some pointers for engagement with the social housing sector. EnerGuide may also provide lessons, although this appears to be more of a financial incentive programme only.

Many of these programmes still require basic knowledge and assessment of alternative techniques and building systems in terms of 'best-in-class' in order to offer incentives. There is a definite need for some kind of decision support system for home-owners and government agencies, as well as a national impact assessment tool to determine expected costs and benefits from schemes that offer incentives.

### 8.3.3 Retrofitting technologies

It will be worthwhile for Beacon to keep a watch on international developments, especially with regard to the Sustainable Building Information System database from iiSBE (available via subscription). www.sbis.info

As this is an emerging field, it is recommended that Beacon researches link with others working in this field via CIB and other international groups.

Finally, there may be opportunities to develop best practise tools and decision support systems to aid home retrofit programs.

# 9. SUMMARY AND CONCLUSIONS

Retrofitting houses is an essential part of improving sustainability of New Zealand's homes. The uptake of a wider range of retrofitting technologies is crucial to bring the existing housing stock up to modern standards of health, comfort, and sustainability. The development of tools which can help the owners of houses to identify the best solutions when retrofitting was therefore the key objective of this project. As such, a retrofitting strategy (the so-called "retrofitting pathway") and a database of retrofitting technologies were developed.

The retrofitting pathway defines a sustainable home (the "THEN Home") as the ultimate goal of retrofitting. However, the first priority should be to bring the existing housing stock to an ESSENTIAL level, which provides indoor comfort, health and an intact structure. The second step represents the GOOD PRACTICE that is known in order to provide for comfort and security using local renewable resources and minimising use of fossil or extracted resources. The third step, the THEN Home, can be achieved by having a fully realised community and environmental integrated design solution.

Since every individual house is at a different stage, what is needed is a self-assessment tool which guides a homeowner in developing an individual retrofitting plan for their home. The database provided in this report lists 107 technologies for retrofitting, with only some exceptions which are more useful for new built houses. The database describes these technologies and provides information which relates to the nine sustainability criteria as described in the Beacon footprint diagram.

The report makes a number of recommendations around the retrofitting pathway, the database and further research on retrofitting technologies.

Key recommendations from the report are:

- The development of a self-assessment tool
- Case studies for testing the retrofitting pathway
- Maintenance and extension of the database
- Clarification of the sustainability criteria
- Further investigation into technologies related to space heating and insulation
- Explore whether international programmes that look at retrofitting for non-energy benefits are suitable and could be developed in NZ

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## APPENDIX 1

**Student project at Canterbury University:**

THEN Home: planning and modelling a THEN Home

| | |
|---|---|
| Field of study: | Technologies for sustainable retrofitting |
| Situation assessment | In 28 % of New Zealand homes the average indoor air temperature is below the healthy minimum (16°C) recommended by the World Health Organisation.<br><br>Over 380,000 of New Zealand's 1.5 million homes have no, or inadequate, ceiling insulation.<br><br>Mildew and dampness occurs in 37% of New Zealand homes.<br><br>The housing stock has to be brought to an essential level (i.e. standard requirements) and can then brought further to good practice and a high sustainability level (as detailed in TE102, forthcoming).<br><br>A number of technologies are available to improve the existing building stock up to an essential level (e.g. insulation materials). Other technologies provide opportunities to upgrade a home to a sustainable standard, where renewable materials (e.g. sheepwool for insulation) and renewable energy (e.g. mini wind turbines) are key features. |
| Relevance to Beacon: | Technologies identified in TE102<br><br>Retrofitting is considered as key objective to reach 90 % goal. |
| Desired result: | Conduct a standard engineering optimization analysis to determine the optimal design elements for comfort, energy efficiency, renewable energy, and sustainability in Christchurch housing.<br><br>Develop a life-cycle cost and sustainability analysis for re-modelling and re-building projects.<br><br>Design a renewal for a particular home in Christchurch to an essential standard and ultimately to the THEN Home standard as defined in TE102.<br><br>Produce an action plan for local government and business which would bring about the urban renewal. |
| Project idea: | Barbara Nebel, Scion and Susan Krumdieck, University of Canterbury |
| Project start: | February 2006 |
| Project team: | 4 final year students |
| Cost involved: | 8000 NZD funding to University of Canterbury<br><br>Supervision by industrial supervisor (time and travel) |
| IP: | All developed IP will belong to BEACON |

## APPENDIX 2

**Evaluation of technologies:**

## Evaluation of technologies

**Ranking system**

| -3 | -2 | -1 | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|
| strong negative impact | negative impact | light negative impact | no impact | light positive impact | positive impact | strong positive impact |

| Category | Technology | Description | Affordability | Personal health | Desirability | Landscape | Community | Performance | Future proof | Resource use | Investment potential | Overall Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Sustainability objectives** | | | | | | | | | |
| *Example* | *Example* | *Example* | *-2* | *2* | *2* | *0* | *0* | *1* | *1* | *2* | *1* | |
| Appliances | one kWh/day refrigerator | Highly efficient fridge-freezer which is about double the existing efficiency of the standard off-the shelf unit available today. | -0.56 | 0.11 | 1.33 | 0.00 | 0.22 | 0.11 | 1.67 | 2.44 | 2.22 | **7.56** |
| Appliances | Most water efficient washing machine | 7.0kg front loader | -0.33 | 0.00 | 0.67 | 0.44 | 0.22 | 0.33 | 1.44 | 2.33 | 1.56 | **6.67** |
| Appliances | Most water efficient dishwasher | 14 place settings | -0.11 | 0.11 | 1.00 | 0.44 | 0.11 | 0.11 | 1.22 | 2.00 | 1.56 | **6.44** |
| Appliances | Most energy efficient Washing machine | 6.5kg front loader | -0.11 | 0.00 | 0.78 | 0.33 | 0.11 | 0.11 | 1.22 | 2.22 | 1.56 | **6.22** |
| Appliances | 1 watt stand-by power for home appliances | Incorporated technology in (especially) lower value consumer electronics and appliances so that standby power reduces by at least 65% of current levels. | -0.33 | 0.11 | 0.78 | 0.22 | 0.33 | 0.11 | 1.78 | 2.33 | 1.78 | **7.11** |
| Appliances | Solar chargers | Mobile phone and rechargeable battery chargers using solar Photo Voltaik. | -0.78 | 0.00 | 0.78 | 0.33 | 0.11 | -0.33 | 0.89 | 2.00 | 1.11 | **4.11** |
| Decoration | High tech mineral silicate paints | Biopaint that doesn't form a surrface film that can flake off, providing excellent durability/life-expectancy. | -1.00 | 1.00 | 1.00 | 0.56 | 0.11 | 1.22 | 1.33 | 1.11 | 0.78 | **6.11** |
| Electricity generation | Mini wind turbine on roof | Small turbine for providing electricity supply to power a dedicated device. | -1.67 | -0.33 | 0.22 | -0.33 | -1.00 | -0.44 | 1.44 | 2.11 | 0.44 | **0.44** |
| Electricity generation | Solar Panels as a Roofing System | Solar panels which are incorporated into the roof structure, rather than attached onto the roof, above an an already existing conventional skin to protect against the weather. | -2.00 | -0.11 | 1.22 | 0.33 | 0.33 | 0.56 | 2.00 | 2.44 | 1.44 | **6.22** |
| Electricity generation | Micro Hydropower | A system that extracts excess pressure in water pipes and converts it into power. | -1.11 | -0.11 | 0.33 | -0.11 | -0.11 | 0.11 | 1.22 | 1.67 | 0.56 | **2.44** |
| Electricity generation | Biogas pits and methane digestors | Harvesting methane energy from a septic tank or biodegradation | -1.78 | -0.33 | -0.33 | 0.11 | -0.56 | -0.22 | 0.89 | 1.56 | 0.33 | **-0.33** |
| Fenestration | Vacuum Glazing | Two sheets of glass are sealed around the edges, and a vacuum is created in the narrow gap between them, eliminating heat flow through gases between the sheets. An array of tiny support pillars maintains the 0.2 mm separation of the | -1.78 | 1.56 | 1.00 | 0.22 | 0.11 | 1.78 | 1.22 | 1.78 | 0.89 | **6.78** |
| Fenestration | Solar Control Film | Thin film coating that reduces heat gain without reducing daylight transmittance proportionally. | -0.56 | 0.67 | 0.44 | 0.11 | 0.00 | 0.89 | 0.78 | 0.89 | 0.33 | **3.56** |
| Fenestration | Integrated window systems | Integrated Window Systems are a form of panelised construction where the wall panel includes an operable or fixed window sash, recessed night insulation, integral solar shading, and in order to minimize thermal short circuits and | -1.67 | 0.89 | 0.78 | 0.00 | 0.00 | 1.00 | 0.78 | 0.67 | 0.22 | **2.67** |
| Fenestration | Inert gas window fills | The use of a low-conductivity inert gas instead of air in double glasing cavities in order to reduce heat transmission through the window. | -1.89 | 1.11 | 0.78 | 0.00 | 0.11 | 1.11 | 0.89 | 1.56 | 0.67 | **4.33** |
| Lighting | Compact Fluorescent portable plug-in fixtures | Ensuring lamps etc. are compatible with CFL technologies, making it easier for consumer change. | -0.33 | 0.00 | 0.44 | 0.11 | 0.00 | 0.11 | 0.78 | 1.33 | 1.00 | **3.44** |
| Lighting | Light tubes or skylights | Filtering of natural light into central and darker areas. | 0.11 | 0.56 | 1.56 | 0.11 | 0.00 | 0.89 | 1.22 | 1.22 | 1.44 | **7.11** |
| Lighting | Fibre-optic lighting | Fibre optic lighting utilises light-transmitting cable fed from a light source in a remote location. | -1.56 | 0.33 | 0.63 | -0.13 | 0.13 | 0.50 | 0.38 | 0.88 | 0.25 | **1.40** |

## Evaluation of technologies

**Ranking system**

| -3 | -2 | -1 | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|
| strong negative impact | negative impact | light negative impact | no impact | light positive impact | positive impact | strong positive impact |

| Category | Technology | Description | Affordability | Personal health | Desirability | Landscape | Community | Performance | Future proof | Resource use | Investment potential | Overall Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Sustainability objectives** | | | | | | | | | |
| *Example* | *Example* | *Example* | *-2* | *2* | *2* | *0* | *0* | *1* | *1* | *2* | *1* | |
| Lighting | Electroluminescent | Stores daylight energy and requires no electrical connections. Safety lamps, but also normal lighting available. | -0.14 | 0.25 | 1.00 | 0.11 | 0.11 | 0.00 | 1.00 | 1.33 | 0.56 | **4.22** |
| Lighting | Daylight harvesting | Light-level sensors detect available daylight and then modulate the output of electric lights to compensate for light coming into an architectural space from the outside | -1.00 | 0.25 | 0.67 | 0.22 | 0.22 | 0.33 | 1.22 | 1.56 | 0.67 | **4.14** |
| Lighting | LED Lighting | As drop-in replacements for standard lighting in certain applications, using superb right types, getting better lumen/Watt efficiencies than CFL's | -0.50 | 0.00 | 0.56 | 0.11 | 0.11 | 0.33 | 0.67 | 1.44 | 0.44 | **3.17** |
| Lighting | Airtight recessed downlights | Airtight downlights with modified ballasts which can handle increased temperature build-up. | -0.57 | 0.29 | 0.38 | -0.13 | 0.00 | 0.25 | 0.63 | 1.00 | 0.50 | **2.34** |
| Sanitation | Thermosiphoning solar storage tanks | Thermosiphoning systems consist of a solar collector panel to absorb solar heat, and a separate storage tank to hold solar-heated water. The solar collector must be mounted at least a foot below the storage tank to permit thermosiphoning (upward movement of water by natural convection). When the water in the | -1.13 | 0.00 | 0.78 | -0.11 | -0.33 | 0.56 | 1.33 | 2.22 | 1.33 | **4.65** |
| Sanitation | Solar water heating | A solar water heater typically uses glazed collectors that are roof-mounted and connected to a preheat storage tank. Fluid is pumped to the collectors where it is warmed by the sun and returned to a heat exchanger where heat from the fluid is used to heat the water in a preheat storage tank. | -0.50 | 0.00 | 1.33 | 0.00 | -0.11 | 0.67 | 2.00 | 2.33 | 1.78 | **7.50** |
| Sanitation | Heat pump water heaters | Uses the vapour compression refrigeration cycle, like an air-conditioner, getting efficiencies between 2-3x what an standard electrical resistance HWC would. | -0.75 | 0.00 | 0.44 | -0.11 | -0.33 | 0.44 | 1.33 | 1.56 | 0.89 | **3.47** |
| Sanitation | Residential condensing water heaters (addendum to CHP above) | Are able to capture almost all (90%) of the heat value of the condensing flue gases water vapour to liquid, rather than the usual 60%. | -1.00 | 0.00 | 0.13 | 0.00 | 0.00 | 0.38 | 0.88 | 1.38 | 0.63 | **2.38** |
| Sanitation | Gravity fed cisterns | Small capacity exterior wallmounted rainwater tank above toilet which fills or tops up cistern automatically after flush. Can be used for toilets, landscaping, laundry. | 0.00 | -0.13 | 0.44 | 0.89 | 0.00 | 0.11 | 1.44 | 2.00 | 0.89 | **5.65** |
| Sanitation | Ecowaste water treatment | Sewage treatment based on biological plant processes. | -1.38 | -0.38 | -0.33 | 0.78 | -0.44 | -0.11 | 0.67 | 0.67 | 0.56 | **0.03** |
| Sanitation | Tankless Water Heaters | Tankless water heaters have an electric or gas heating device that is activated by the flow of water. The heater provides a constant supply of hot water. Large units intended for whole house water heating are located centrally while, in point-of-use applications, the water heater usually sits in a closet or under a sink. | -0.63 | 0.13 | 0.56 | -0.33 | -0.22 | 0.44 | 0.44 | 0.44 | 0.33 | **1.17** |
| Sanitation | Rainwater harvesting | Rainwater tanks to collect roof run-off for garden use | 0.00 | 0.25 | 1.22 | 1.56 | 0.22 | 0.89 | 1.89 | 2.33 | 1.78 | **10.14** |
| Sanitation | Low-flush toilets | Low-flush toilets are designed to use six litres of water per flush | 1.25 | 0.25 | 1.33 | 0.78 | 0.11 | 0.44 | 2.11 | 2.33 | 1.89 | **10.50** |
| Sanitation | Ground Water Circulation Wells | An new energy efficient method of small scale single well extraction that does not rely on a pump. | -0.29 | 0.13 | 0.22 | 0.67 | 0.00 | 0.22 | 1.11 | 1.11 | 0.89 | **4.06** |
| Sanitation | Drainwater heat recovery (DHR) | DHR devices fit into existing waste drain lines from showers and bathtubs to capture heat from the drainwater to preheat cold water going to other showers or a water heater. | -1.13 | 0.00 | 0.33 | 0.56 | 0.00 | 0.44 | 1.00 | 1.22 | 0.78 | **3.21** |

## Evaluation of technologies

**Ranking system**

-3 strong negative impact | -2 negative impact | -1 light negative impact | 0 no impact | 1 light positive impact | 2 positive impact | 3 strong positive impact

**Sustainability objectives**

| Category | Technology | Description | Affordability | Personal health | Desirability | Landscape | Community | Performance | Future proof | Resource use | Investment potential | Overall Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Example* | *Example* | *Example* | *-2* | *2* | *2* | *0* | *0* | *1* | *1* | *2* | *1* | |
| Space heating | Phase Change Materials (PCMs) | PCMs are solid at room temperature. When the temperature becomes warmer, PCMs liquefy and absorb and store heat, thus cooling the house. Conversely, when the temperature drops, the material will solidify and give off heat, warming the house. | -1.78 | 0.78 | 0.56 | -0.11 | 0.00 | 1.11 | 1.22 | 1.22 | 0.56 | **3.56** |
| Space heating | Air-Air heat exchanger | Warm air heats (or cools) incoming cool air on exiting house | -0.11 | 1.33 | 1.00 | 0.00 | 0.11 | 1.00 | 1.56 | 1.78 | 1.33 | **8.00** |
| Space heating | District heating system | Waste hot water and/or steam from nearby industrial plants is supplied to suburbs, for use in residential heating pipes | -1.22 | 1.00 | 0.78 | -0.22 | 0.78 | 0.33 | 1.22 | 2.00 | 1.11 | **5.78** |
| Space heating | Solarwall | Perforated metal external wall which heats air which is then drawn into the inside. In the winter when sunlight hits the metal panels it heats an air-space behind the panels and the air convects to the top of the wall where it is collected by a low | -0.78 | 1.11 | 0.44 | 0.00 | -0.22 | 1.11 | 1.22 | 1.56 | 1.22 | **5.67** |
| Space heating | Sheeps Wool Batts | Wool bound using polyester fibres and treated with inert mineral. Location: Lofts, suspended floors, ceilings, walls. The wool is bound into batts using polyester fibres for reinforcement and treated with an inert, naturally occurring mineral, to | 0.11 | 2.00 | 1.44 | 0.11 | 0.00 | 1.89 | 1.67 | 2.56 | 2.22 | **12.00** |
| Space heating | Blown fibre/foam insulation | Cellulose, fiberglass, or mineral wool (rock wool and slag wool) is sprayed in a moist state into an open stud cavity. Moist cellulose creates its own glue, but some manufacturers add adhesive. Both mineral wool and fiberglass need added adhesive. Properly installed, it completely fills the cavity, suppressing air leakage. | -0.11 | 0.67 | 0.33 | -0.11 | -0.11 | 1.44 | 1.56 | 1.44 | 0.44 | **5.56** |
| Space heating | Passive cooling systems | A system to heat and cool buildings that relies primarily on radiation heat transfer. Typically, heated or chilled water is circulated though floor or ceiling panels to condition the space. | -1.11 | 1.44 | 1.22 | 0.11 | 0.00 | 1.44 | 1.78 | 1.67 | 1.44 | **8.00** |
| Space heating | Icynene | Open-cell, soft foam insulation that expands into cracks, corners and crevices forming an air-tight seal. | -0.25 | 0.63 | 0.38 | 0.00 | 0.00 | 1.13 | 0.75 | 1.13 | 0.88 | **4.63** |
| Space heating | Wood fibre insulation | Softboards of batts based on wood fibres. Softwood chippings are pulped and soaked in water, then mechanically pressed into boards, dried, and cut to shape. | -0.56 | 0.78 | 0.11 | -0.67 | -0.44 | 0.89 | 0.67 | 1.11 | 0.56 | **2.44** |
| Space heating | Trombe Walls | A north-facing masonry wall covered with glass spaced a few inches away. Sunlight passes through the glass and is absorbed and stored by the wall. The glass and airspace keep the heat from radiating back to the outside. Heat is transferred by conduction as the masonry surface warms up, and is slowly | -1.11 | 1.22 | 0.78 | 0.00 | -0.11 | 1.00 | 1.11 | 1.22 | 1.22 | **5.33** |
| Space heating | Wood Pellet Biomass Boiler | A biomass boiler with built-in heat storage unit to subsequently store heat produced from boiler to heat the building and provide hot water. | -0.22 | 1.67 | 1.33 | -0.11 | -0.22 | 0.78 | 1.44 | 1.67 | 1.44 | **7.78** |
| Space heating | Solar slates | A small solar powered fan sucks the solar heated warm, dry, fresh from directly beneath the slates or tiles and to blow it through a flexible duct to a grille, normally mounted in the ceiling of the hallway of the house and from there to other rooms in the house. The Solar Slate system is entirely automatic and consumes no mains | -0.44 | 1.00 | 0.44 | 0.00 | 0.00 | 0.67 | 1.33 | 1.67 | 1.22 | **5.89** |
| Space heating | Advanced cold climate heat pump | Heating systems and controls which are optimised for cold climates | -1.11 | 1.33 | 1.22 | 0.00 | -0.22 | 1.00 | 1.00 | 1.11 | 1.22 | **5.56** |

## Evaluation of technologies

**Ranking system**

| -3 | -2 | -1 | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|
| strong negative impact | negative impact | light negative impact | no impact | light positive impact | positive impact | strong positive impact |

| Category | Technology | Description | Sustainability objectives | | | | | | | | | Overall Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Affordability | Personal health | Desirability | Landscape | Community | Performance | Future proof | Resource use | Investment potential | |
| *Example* | *Example* | *Example* | *-2* | *2* | *2* | *0* | *0* | *1* | *1* | *2* | *1* | |
| Structure | Permeable pavers for driveways, paths etc. | Interlocking concrete grid porous pavers for use as a replacement for convential concrete pavers | 0.75 | 0.00 | 0.88 | 1.89 | 0.89 | 0.89 | 1.22 | 1.44 | 1.78 | **9.74** |
| Structure | Green roof | Sedum is planted to filter rainwater, and cool rooftops | -1.56 | 0.56 | 0.56 | 1.67 | 0.89 | 0.56 | 0.67 | 0.78 | 0.78 | **4.89** |
| Structure | Deconstructable house frames | Use small frames of 450mm width between each full frame with coach screws for gibboard. Disconnect cables and pipes at the panels. | -1.14 | 0.13 | 0.63 | 0.13 | 0.00 | 0.63 | 1.63 | 1.25 | 1.13 | **4.36** |
| Structure | Fibre Reinforced Polymers (FRPs) | A high strength fibrous material which can be used for both new and strengthening of existing buildings. | -0.50 | -0.22 | 0.22 | 0.00 | 0.00 | 1.00 | 0.67 | 0.00 | 0.44 | **1.61** |
| Supporting technology | UV proof films | Polarising films that blocks incoming UV rays | -0.33 | 0.56 | 0.56 | -0.11 | 0.00 | 0.67 | 1.00 | 0.22 | 0.89 | **3.44** |
| Sanitation | Self powered sensor activated | Selfcharging hydro-powered faucet coupled to lithium battery doesn't require mains | -1.25 | 0.13 | 0.38 | 0.38 | 0.00 | 0.38 | 0.88 | 0.63 | 0.63 | **2.13** |
| Supporting technology | Hotel/motel key card system | Card to control lighting and HVAC energy usage, where occupancy status is assessed and energy consumption is adjusted accordingly. | -1.56 | -0.11 | 0.78 | 0.00 | 0.11 | 0.44 | 0.89 | 1.00 | 0.78 | **2.33** |
| Supporting technology | Fusiotherm plumbing | This piping system consists of green polypropylene pipes and fittings that are fused together with heat. This process yields a seamless piping system with no joints to crack or break under fatigue. | -0.33 | 0.22 | 0.33 | 0.11 | 0.00 | 0.67 | 1.11 | 0.67 | 1.00 | **3.78** |
| Supporting technology | Electronic socket timer controls | Allow electrical appliances to switch on at certain times only | 0.78 | 0.00 | 0.89 | 0.00 | 0.00 | 0.44 | 1.00 | 1.44 | 1.89 | **6.44** |
| Ventilation | Robust Air conditioners and heat pumps | Air conditioners that conpensate for charge losses and low air flow, by very good high temperature perfomance, an adaptive refrigerant metering device, and a fan assembly that adapts to the house's duct system. | -1.33 | 0.33 | 0.56 | 0.00 | 0.00 | 0.44 | 0.33 | 0.22 | 0.11 | **0.67** |
| Ventilation | Breathing Window | Fine-wire heat exchange ventilation system. can be installed next to windows or in the skin of buildings. In contrast to traditional centrally controlled ventilation systems each room is individually monitored. CO2- and humidity sensors check the air and activate the device when concetration levels surpass 500 parts per | -1.57 | 1.71 | 0.43 | 0.00 | 0.00 | 0.71 | 0.71 | 0.14 | 0.57 | **2.71** |
| Waste | Composter for home biodegradeables | Deals with vegetative waste products on-site, and provides fertilizer. | 1.22 | 0.33 | 1.56 | 1.44 | 0.22 | 0.56 | 1.78 | 1.89 | 1.38 | **10.38** |
| Waste | Home recycling station - kitset of containers and labels | Recycling deposits (kitset of containers and station) for household separation at source. Also community-based recycling deposit containers and stations for apartment buildings/ student accommodation. | 1.22 | 0.22 | 1.44 | 1.11 | 1.11 | 0.33 | 1.44 | 1.89 | 1.56 | **10.33** |
| Waste | Demountable fastenings | Clips, screws, camlocks etc. which enable structural and non-structural elements | -0.25 | 0.00 | 0.63 | 0.00 | 0.00 | 0.75 | 2.13 | 1.50 | 1.50 | **6.25** |