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Building Sustainability and Fire-Safety Design Interactions:

Scoping Study

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Preface

This report summarises a review of available literature and developments related to building sustainability in consideration of the potential unintentional consequences on the fire-safety objectives of a building, if due consideration of all relevant building design objectives are not considered during the design process. The focus is on the New Zealand building industry and international results are included in cases where a broadening of depth or additional information may be of benefit to the education of the industry in general.

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Commercial products or services mentioned directly or indirectly are included only for demonstration of concept.

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Note

This report is intended for regulators, building officials, researchers, fire-safety engineers, sustainability engineers and designers.

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Abstract

The drive of government policies in conjunction with building-owner and -user positive perceptions toward sustainable buildings is influencing both the nature of the built environments and the design and construction systems for the delivery of the building.

Concerns regarding conflicts in building design resulting from sustainability and fire-safety objectives being considered in isolation have been raised. Sustainability-related changes to building design, materials, functionality and operation represent opportunities for improvements for multiple design objectives but may have unintended consequences if balanced building design objectives and fundamental understanding of the inter-relationships of building design, materials and operations between these different objectives is lacking or poorly communicated. Unintended fire-safety consequences may impact the safety of the building occupants and firefighters, and the extent of damage to the building, surrounding built environment and natural environment.

From another perspective, positive contributions of fire-safety design solutions to building sustainability objectives may include potential reductions in sustainability during a fire event and the subsequent firefighting operations, post-fire clean-up and recovery of building usage and functionality that could be used to further support the sustainability of the building.

This report summarises a review of the current situation of building sustainability design in relation to fire-safety in order to identify areas that need immediate attention and other opportunities to prevent unintentional consequences of design changes, as well as areas of potential collaboration that can be capitalised upon.

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Acronyms

ABCB	Australian Building Code Board
ACTP	Australian Capital Territory Parliament (Australia)
ANSI	American National Standards Institute
AS	Standards Australia
ASTM	American Society for Testing and Materials
BCA	Building Code of Australia
BEES	(US) Building for Environmental and Economic Sustainability
BEES	Building for Environmental and Economic Sustainability (developed at the National Institute of Science and Technology)
CCAEJ	Center for Community Action and Environmental Justice
CDF&FPOSFM	California Department of Forestry and Fire Protection Office of the State Fire Marshal
CFF	Common Fire Foundation
CGBC	Canada Green building Council
CIB	Conseil International du Batiment (International Council for Research and Innovation in Building and Construction)
CNYDDC	City of New York, Department of Design and Construction (US)
CPCPV	Chief Parliamentary Counsel, Parliament of Victoria (Australia)
DBH	Department of Building and Housing (New Zealand)
DBIS	Department of Business, Innovation and Skills (UK)
EH	English Heritage
EIE	Environmental Impact Estimator (developed at the ATHENA Sustainable Materials Institute)
FEMA	(US) Federal Emergency Management Agency
FEMP	Federal Energy Management Program
GBCA	Green Building Council Australia
GBI	Green Building Initiative
GGGC	Governor's Green Government Council (of Pennsylvania, US)
GWP	Global Warming Potential
ICC	International Code Council (US)
IGCC	International Green Construction Code
iiSBE	International Institute for a Sustainable Built Environment
IPCC	Intergovernmental Panel on Climate Change
JaGBC	Japan GreenBuild Council
JSBC	Japan Sustainable Building Consortium
LCA	Lifecycle Assessment

LCC	Lifecycle Costing
LEED	Leadership in Energy and Environmental Design
NC	North Carolina (US)
NCI	(US) National Charrette Institute
NIBS	(US) National Institute of Building Sciences
NIST	(US) National Institute of Science and Technology
NOAA	(US) National Oceanographic and Atmospheric Administration
NY	New York (US)
NZ	New Zealand
NZP	New Zealand Parliament
NZS	New Zealand Standards
ODP	Ozone Depletion Potential
OECD	Organization for Economic Cooperation and Development
OSB	oriented strand board
PA	Pennsylvania (US)
PCO	Parliamentary Council Office (New Zealand)
PUK	Parliament, United Kingdom
RILEM	(International Union for Experts in Construction Materials, Systems and Structures)
RMI	Rocky Mountain Institute (a US-based non-profit organisation specialising in energy and building issues)
SIPA	Structural Insulated Panel Association (US)
SIPs	structural insulated panels
SPUK	Scottish Parliament, United Kingdom
TJCGNC	Triangle J Council of Governments, North Carolina
UK	United Kingdom
UKG	UK Government (not representing the Scottish Parliament, the National Assembly for Wales nor the Northern Ireland Assembly)
UL	Underwriters Laboratories Inc
US	United States (of America)
USDOE	US Department of Energy
USGBC	US Green Building Council
WBCSD	World Business Council on Sustainable Development
WHO	World Health Organisation

1. INTRODUCTION

The drive of government policies in conjunction with building-owner and -user positive perceptions (associated with market value and credits for sustainable operations) toward sustainable buildings is influencing both the nature of the residential, commercial and industrial built environments and the design and construction systems for the delivery of the building. These drivers may be derived from implicit or explicit international agreements such as the climate change acts of several nations – e.g. Climate Change Response Act 2002, New Zealand (PCO, 2011), Climate Change Act 2010, Victoria, Australia (CPCPV, 2011), Climate Change and Reduced Greenhouse Gas Act 2010, Australian Capital Territory (ACTP, 2010), Climate Change Act 2008, United Kingdom (PUK, 2008), Climate Change (Scottish) Act 2009, Scotland (SPUK, 2009) – that have followed directly onto changes in building codes and regulations – e.g. New Zealand Building Code Clause H1, Energy Efficiency (DBH, 2011a), Section J, Energy Efficiency, of the Building Code of Australia (ABCB, 2010b) etc – or from shorter-term locally-focused commercial ventures such as increased rent/lease prices (Carter et al, 2011) or re-sale values etc.

Concerns regarding conflicts in building design resulting from sustainability objectives and fire-safety objectives being considered in isolation have been raised (Poh, 2010; Tidwell and Murphy, 2010; Chow and Fong, 1991; Chow, 2003; Hofmeister, 2010; Nichols and Stevenson, 2010).

Sustainability-related changes to building design, materials, functionality and operation represent opportunities for improvements for multiple design objectives but may have unintended consequences, if balanced building design objectives and fundamental understanding of the inter-relationships of building design, materials and operations between these different objectives is lacking or poorly communicated. Unintended consequences may impact the safety of the building occupants and firefighters, and the extent of damage to the building, surrounding built environment and natural environment.

Furthermore, positive contributions of fire-safety design solutions to building sustainability objectives may include potential reductions in sustainability impacts (such as carbon emissions) of fire-safety features, systems and procedures during a fire event within the life of the building and the subsequent firefighting operations, post-fire clean-up and recovery of building usage and functionality, as have been previously proposed (Robbins et al, 2008; Robbins et al, 2010; Moore et al, 2007; Gritzo et al, 2009; Wieczorek et al, 2010).

This report summarises a review of the current situation of building sustainability design in relation to fire-safety in order to identify areas that need immediate attention and other opportunities to prevent unintentional consequences of design changes, as well as areas of potential collaboration that can be capitalised upon.

1.1 Scope of Report

The scope of this report is to assess the current landscape of sustainable building design in relation to the potential various approaches for attempting to identify potential unintended impacts on fire-safety, areas of mutual benefit and the potential for development of methods to continue to identify such positive and negative issues.

1.2 Approach

Sustainability and green building design promotes embracing new ideas, technology, materials and approaches in order to improve practices and performance of the final products. Since this is a relatively new area of development, the changes of products and types of products used are dynamic. Therefore the approach taken for this scoping document was to review the influence of sustainable building design, construction and operation in terms of the fundamental intent, assess the general points of view from which this is approached and then examine examples of practice and products which demonstrate the implementation of these. However, the specific practices and products are included only as examples and are not expected to be representative of future inclusions in sustainable building designs. The fundamental intent and points of view are expected to be more consistent over the longer term and also help form a base of knowledge that may be useful when approaching sustainability engineers and designers so that unintended consequences of both aspects of design can be mitigated and opportunities to combine efforts to create more efficient solutions can be capitalised on.

2. CONTEXT OF SUSTAINABILITY DESIGN

The terms “green”, “high-performance” and “sustainability design” are often used interchangeably. However, sustainability design can be used to most comprehensively address the ecological, social and economic impact of a building on its community. Throughout this report the term “sustainability” and its concatenations have been used to refer generally to building design principles, concepts, solutions and assessment tools relating to the underlying philosophy of doing minimal damage and, potentially, positively contributing to the local community and global opportunity to enduringly provide food, energy, water, materials and shelter throughout the whole lifecycle from planning to disposal. Therefore sustainability building design has been used here in general discussion to implicitly include green building design and high-performance building design etc.

As defined by Task Group 16 of the International Council for Research and Innovation in Building and Construction (Conseil International du Batiment, CIB), the intent of sustainability design for buildings is “creating and operating a healthy built environment based on resource efficiency and ecological design” (CIB, 1994).

High-performance building has been used to describe a built environment that “uses whole-building design to achieve energy, economic and environmental performance that is substantially better than standard practice” (NIBS, 2011). This design philosophy requires that designers, engineers, architects, building occupants, owners and specialists for each aspect (e.g. indoor air quality, materials, energy and water efficiency etc) of the building fully collaborate from the inception of the project – a process referred to as “integrated design”. (Keeler and Burke, 2009, Yudelson, 2009, Kibert, 2008, Johnston and Gibson, 2008)

3. VIEWPOINTS OF FIRE-SAFETY AND SUSTAINABILITY INTERACTIONS

Fire-safety and sustainability can be considered from two primary points of view:

1. The sustainability impact of fire-safety systems and solutions:
    a. Environmental costs of development and testing, manufacturing, installing, maintaining, operation, decommissioning/disposing of all the components of the system.
    b. Environmental savings in reduced extent of a fire event.
2. When applying sustainability priorities to the design of a building, there may be unintended consequences that impact fire-safety solutions and performance.

These points of view will be referred to as “sustainability of fire-safety solutions” and “sustainable design impacts on fire-safety”, respectively. Both of these points of view are considered in this literature review and scoping study.

Attempts have been made to provide a definition of sustainability in the context of fire-safety building design. For example:

> “*Sustainability within the fire protection industry involves application of fire-safety systems and design measures that support and promote building characteristics that are environmentally friendly during the building’s daily use. These systems and designs must reduce the fire risk and impact that such characteristics and uses might contribute to throughout the full life expectancy of the building. Daily use characteristics include reducing harm to the environment by minimising energy consumption, water consumption, material consumption and fire risk*” (Carter et al, 2011).

A common definition of sustainability in the context of fire-safety building design would be central to aligning the focus and uniting the various efforts of all aspects of the building industry, incorporating building features, systems and procedures to benefit multiple building design objectives and to minimise unintended reductions in building safety, functionality or usage, or introduction of new hazards.

4. OVERVIEW

4.1 Principles, Applications and Assessment

This document is intended to be informative for the fire-safety related fields of building design, therefore similarities, parallels, differences, direct conflict and opportunities for combined solutions from sustainability and fire-safety building design perspectives are drawn into perspective at key points throughout.

A “sustainable” or “green” building refers to a built environment created using the principles of sustainable construction. The quality or extent of the sustainability can be inferred by the outcome of a “green” rating system. However, specific building features, systems or procedures relating to the sustainability are not indicated by the general descriptor or rating.

- The sustainability design principles are the fundamental concepts that underlie the applications of design methodologies and decision-making processes.

- The applications that result in a built environment are the results of the design methodologies that have been developed to focus on one or more aspects of the underlying fundamentals.
- The assessment of the building is the result of one or more “green” ranking systems, where each of the fundamental principles has a weighting and level of achievement associated with the specific ranking system.

Therefore the overall approach taken to discuss sustainability design impacts and interactions with fire-safety design within this document is to summarise firstly the fundamental sustainability design concepts, then the methods currently used and suggested to apply the fundamental principles, before finally discussing a selection of current ranking systems used in various countries. Examples of specific sustainability solutions are then included for discussion with specific interest in their potential unintended interaction with fire-safety solutions.

5. SUSTAINABILITY DESIGN PRINCIPLES AND CONCEPTS

5.1 General Sustainability Design Principles

Sustainability design principles can cover a wide variety of different aspects of a design from different points of view, depending on the underlying design objective or the intended aspect of sustainability that is to be achieved. For example, general sustainability design principles include (Kibert, 2008; Keeler and Burke, 2009):

- Precautionary principle (Foster et al, 2000):
    - Exercise caution when making decisions that may affect nature, natural ecosystems and global biogeochemical cycles.
    - One version of the tenets (CCAEJ) (Kibert, 2008):
        - People have a duty to take anticipatory action to prevent harm.
        - The burden of proof of harmlessness of a new technology process, activity or chemical lies with the proponents, not the general public.
        - Before use of a new technology, process or chemical, or starting a new activity, people have an obligation to examine a full range of alternatives including the alternative of not doing it.
        - Decisions applying this Principle must be open, informed and democratic and must include all the affected parties.
- Reversibility principle:
    - Making decisions that can be undone by future generations. (EH, 2008)
- Distributional equity:
    - The fair distribution of resources among present people, addressing the life prospect of all people. (Beder, 2000)
- Intergenerational justice:

    - Consideration of the impact of our choices today on the quality and quantity of resources remaining for future inhabitants of Earth and the quality of the environment. (Stavins et al, 2003)
- Polluter pays principle and produce responsibility (OECD, 1982):
    - With existing technologies that were not subject to the previous principles, such as the Precautionary Principle and the Reversibility Principle, then the onus for mitigating the damage and consequences is placed on the individuals causing the impacts.
- Protecting the vulnerable:
    - Those in power have an obligation to protect those dependent on them, whether they are people powerless due to governing or economic structures. Vulnerable populations include those of the animal world.
- Protecting the rights of the non-human world:
    - The non-human world refers to plants, animals, bacteria, viruses, mould and other living organisms. Protecting this world is an extension of the principle of Protecting the Vulnerable.
- Respect for nature and the land ethic:
    - This biocentric respect is based on four fundamental concepts:
        - Humans are members of the Earth's community of life.
        - All species are interconnected in a web of life.
        - Each species is a teleological centre of life pursuing good in its own way.
        - Human beings are not superior to other species.

The World Business Council on Sustainable Development (WBCSD) presented seven elements for use in calculating business efficiency that includes environmental impacts and costs (Verfaillie and Bidwell, 2000). The seven elements are:

1. Reduce the material requirements of goods and services.
2. Reduce the energy intensity of goods and services.
3. Reduce toxic dispersion.
4. Enhance materials recyclability.
5. Maximise sustainable use of renewable resources.
6. Extend product durability.
7. Increase the service intensity of goods and services.

5.1.1 General Sustainability Design Principles for the Built Environment

Considering a more direct application of sustainability design to the built environment, one philosophy as proposed by the CIB, combines seven sustainability principles with five types of resources for the consideration of eight phases of the lifecycle of a building. The principles of sustainable construction, applying to the whole lifecycle of a built environment, were proposed by the CIB as (CIB, 1994):

1. Reduce resource consumption.
2. Reuse resources.
3. Use recyclable resources.
4. Protect nature.
5. Eliminate toxics.
6. Apply life-cycling costing:
    a. Manufactured products are evaluated for their lifecycle impacts:
        i. Including energy consumption and emissions during resource extraction, transportation, product manufacturing, installation during construction, operational impacts and impacts at disposal.
7. Focus on quality.

The types of resources needed in the creation and operation of the built environment were listed as (CIB, 1994):

- Land:
    - The value of the intended site to be developed:
        - Greenfields – underdeveloped, natural or agricultural land:
            - To be left underdeveloped.
        - Brownfields – former industrial zones:
            - Ideal to convert back to productive use.
        - Greyfields – blighted urban areas
            - Ideal to convert back to productive use.
- Materials:
    - Closed-loop process:
        - Keeping materials in productive use either by reuse or recycling of the component or material.
    - Reuse materials and components from economical deconstruction of the previous built environment on the site:
        - Recycle, where the material is used for similar-value applications.
        - Downcycle, where the material is used for low-value applications such as fill or road sub-base.
    - Where new materials are used, selecting those that can be recycled into future applications after deconstruction.
- Water:
    - Protection of existing ground and surface supplies.
    - Conservation of potable supplies:

        - E.g. low-flow plumbing fixtures, water recycling, rainwater harvesting and use of drought-resistant plants.
    - Full scope of a building's hydrologic cycle includes wastewater processing and stormwater management.
- Energy:
    - Three general approaches are used in building design to achieve energy conservation:
        - Designing a building envelope that is highly resistant to heat transfer.
        - Employing renewable energy resources.
        - Implementing passive design:
            - Designing the building geometry, orientation and mass to condition (lighting, temperature and airflow) the structure using natural and climatological features:
                - E.g. site's incoming solar radiation, thermal chimney effects, prevailing winds, local topography, microclimate and landscaping.
- Ecosystems:
    - The role and interface of ecosystems in providing services in a synergistic fashion:
        - E.g. in relation to controlling external building loads, processing waste, absorbing stormwater, growing food and providing natural beauty (environmental amenity).

The phases of a built environment to be considered in the whole lifecycle were suggested as (CIB, 1994):

1. Planning.
2. Development.
3. Design.
4. Construction.
5. Use and operation.
6. Maintenance.
7. Modification.
8. Deconstruction:
    - It was noted that deconstruction was intentionally promoted over demolition so building materials and components would be recycled into the new construction or other related applications instead of being used for landfill etc.

When discussing the environmental impact of the built environment, examples of environmental issues that have been raised include (Kibert, 2008; Keeler and Burke, 2009):

- Climate change:
    - A relative metric is used Global Warming Potential (GWP), which is a relative measure of how much heat a gas traps in the atmosphere compared to carbon dioxide, where the GWP of carbon dioxide is 1 (IPCC, 2007).
- Ozone depletion:
    - A relative metric is used Ozone Depletion Potential (ODP), where the ODP of CFC-11 is defined as 1 (OECD, 1982).
- Soil erosion:
    - Destruction or degradation of natural vegetative cover leads to the loss of topsoil.
- Desertification:
    - Destruction or degradation of natural vegetative cover in semi-arid or arid regions leads to spread of desert areas.
- Deforestation:
    - Large-scale forest removal is linked to consequences such as biodiversity loss, loss of storage for carbon dioxide, global warming, soil erosion and desertification.
- Eutrophication:
    - Over-enrichment of water with nutrients from agricultural and landscape fertiliser, urban runoff, sewage discharge and eroded stream banks.
- Acidification:
    - The conversion of air pollution, such as ammonia, sulphur dioxide and nitrogen oxides are converted into acids. This is then deposited via acid rain onto forests etc and into lakes and waterways.
- Loss of biodiversity:
    - Biodiversity is the variety and variability of living organisms and the ecosystems in which they occur.
- Land, water and air pollution.
- Dispersion of toxic substances:
    - Toxic substances are chemicals that can cause death, disease, behavioural abnormalities, cancer, genetic mutations, physiological or reproductive malfunctions, physical deformities in any organism or its offspring, or can become poisonous after concentration in the food chain or in combination with other substances.
- Depletion of key resources:
    - Depletion of resources needed to support the energy and materials required to support today’s technological, developed world societies.

5.2 Comparing industry-wide multidisciplinary education Building Design Assessment from Fire-Safety and Sustainability Viewpoints

Using fire-safety design as a parallel example, there are the equivalents of prescriptive and performance-based approaches for sustainable building design, with a level of regulated building design performance or features and the potential for voluntary additional solution levels. Few of the sustainable design solutions are currently regulated, for example residential insulation requirements, and where they are regulated it is a piecemeal approach. Most sustainable design solutions are currently voluntary.

This is important in terms of the scope of this report in that, without regulatory requirements for whole building sustainable design, the assessment criteria of the suitability of a design solution is not defined and is therefore not consistent or necessarily similar, between designs or design approaches. The large voluntary component leads to the problem of wide variability, if taking a top-down approach, of assessment criteria and acceptance levels, design objectives and the design principles and assessment tools to achieve the aforementioned. The prevalence of one or a small number of “green” rating systems reduces this variability by explicitly or implicitly weighting the various aspects of sustainable design and required levels of achievement, which helps guide the selection of design principles and ultimately the design solution. However, the level of prevalence of any particular rating system depends on the application, which currently relies on the sustainability design market service providers and consumers, and therefore also marketing.

With such variability and non-homogeneity, sustainability-vocabulary is emerging with a number of complementary, overlapping and synonymous terms. In order to provide a context for sustainability language and concepts to be included in this report, the fundamental framework underlying sustainable design is discussed, continuing the use of fire-safety design as a parallel example. A framework for the assessment of a building design can be approached as a methodical quantitative statement of the design objectives followed by the analysis of the design and subsequently an assessment of the appropriateness of the design with respect to the stated objectives (Robbins et al, DRAFT). Using the proposed general building design assessment framework proposed for building fire-safety by Robbins, Gwynne and Kuligowski (DRAFT), a side-by-side description of this type of framework for fire-safety and sustainability design is presented in Table 1.

Table 1: General building design assessment framework for either a fire-safety design or sustainability design focus, adapted from the framework proposed by Robbins, Gwynne and Kuligowski (DRAFT)

<table>
<tr><td colspan="2">Define the Design Problem
Characterise the built environment and occupancy in terms of structure, environmental and population conditions as intended for use</td></tr>
<tr><td>Fire-safety design considerations may include:
• Fire-safety features, systems, strategies and procedures</td><td>Sustainability design considerations:
• Surrounding landscape
• Surrounding communities
• Ecology and culture into which the building will be embedded
• Sustainability features, systems, strategies and procedures</td></tr>
<tr><td colspan="2">Design Objectives and Acceptance Criteria</td></tr>
<tr><td>Fire-safety objectives may include one or more of:
• Life safety of occupants
• Life safety of Fire Service personnel
• Protection of other property
• Business continuity, etc
For an intended timeframe that may include one or several of:
• During the fire event
• During post-fire clean-up
• Until recommencement of building full occupancy, usage and functionality</td><td>Sustainability objectives may include one or more of:
• Doing minimal damage (“traditional” sustainable design and best representation of current practices) on aspects such as:
  ○ Water conservation
  ○ Energy conservation
  ○ Production of wastes
  ○ Use and release of toxins etc
• Restorative (assisting nature) design for specific aspects
• Reconciliatory (integral part of nature) design
• Regenerative (participating as nature) design
For an intended timeframe that may include one or several of:
• From the planning/design/construction/commissioning/ occupancy stage until …
• Under intended building operation and maintenance
• Under conditions outside normal operation, such as a fire event, failure of plumbing or an external natural disaster and recovery from the event
• To end of occupancy/ decommissioning/deconstruction/disposal of building</td></tr>
<tr><td colspan="2">Design Analysis Approaches</td></tr>
<tr><td>Fire-safety approaches:
• Human behaviour
• Structural
• Fire</td><td>Sustainability approaches:
• Ecological protection and contribution
• Water efficiency
• Energy efficiency
• Material and resources
• Limitations of emissions
• Indoor environmental quality</td></tr>
<tr><td colspan="2">Identify Key Real World Factors
… of the design problem that influence the stated Design Objectives</td></tr>
<tr><td colspan="2">Translate Key Real World Factors
… into estimates that can be analysed with current tools</td></tr>
<tr><td colspan="2">Select Analysis Tools
… that will best handle the estimates of the real world design problem when translated into a model, in relation to the stated Design Objectives</td></tr>
<tr><td>Fire-safety tools related to each approach, e.g.:
• Human behaviour
• ASET/RSET
• Structural
• Hand calculations of concrete thickness
• Fire
• Zone model of upper layer location etc</td><td>Sustainability tools related to each approach, e.g.:
• Incorporating combinations of various approaches and objectives:
  ○ Green building assessment, lifecycle assessment, lifecycle costing and high-performance building assessment etc
• “Green” rating systems</td></tr>
<tr><td colspan="2">Perform Assessment
… and consider the results in relation to stated Design Objectives and Acceptance Criteria</td></tr>
</table>

Timeframes of the different design types are a point of diversity. Sustainability design can be applied with the intention to consider the impact from the design stage to the end of the building's lifecycle. Fire-safety design is applied based on the influence of potential fire hazards given the intended usage and functionality of the building (minimising and mitigation of hazards) and then performance during a selected range of representations of relevant fire events – such an event that may occur a small number of times or not occur at all during a building's lifecycle. Therefore sustainability design is primarily concerned with high occurrence, low or higher consequences with high cumulative impact, where the features, systems, strategies and procedures are implemented on a daily ongoing basis. Conversely fire-safety design is focused on a low occurrence, high or higher consequence, with single event high impact, where the features, systems, strategies and procedures are passive or mostly remain dormant until triggered by the fire event. This difference in focus would be expected to influence the fundamental approach to the design solutions and leads to the obvious question as to whether there are gains to be achieved by collaboration between the fields and broadening points of view influencing our designs.

5.3 Marketplace Drivers

The three main drivers for sustainable design in the marketplace are (Kibert, 2008; Keeler and Burke, 2009; Yudelson, 2009; Johnston and Gibson, 2008):

1. Providing an ethical and practical response to issues of environmental impact and resource consumption.
2. Making lifecycle economic sense, although the initial capital or first-cost may be more expensive.
3. Including the influence of a built environment and operation on the health of the human occupants.

Fire-safety design for buildings can also positively contribute to each of these three drivers.

The three main drivers for sustainable buildings entail (Carter et al, 2011):

4. Regulations and legislation.
5. Economic incentives.
6. Social pressure.

In practice in New Zealand, the extent of influence of these drivers is determined predominantly by the building owner, with regulations incorporating sustainability through some prescriptive solutions in various aspects of compliance documents. With the majority of sustainability issues considered and incorporated into a built environment being determined by the building owner instead of a regulatory framework, the key drivers of the building owner are of importance in determining the aspects and extent that sustainability issues are to be incorporated into the building and what form these solutions may take. For example, a simplified key driver for a building owner to incorporate sustainability considerations into the design may be to achieve a particular "green" rating. Therefore the loadings of categories of the particular rating system selected (since different rating systems have different weightings of sustainability issues) would influence the aspects of sustainability and the potential solutions considered and incorporated into the design to achieve the desired outcome for the building owner. Consequently, general consideration of the range of “green” rating tools as well as information provided in guidelines will be incorporated into this summary document to help provide a context for the issues of unintended consequences and potential opportunities for the overlap between sustainability design and fire-safety design for a building. If the building is not going to be submitted for consideration for certification and there is no regulation regarding the aspects intended to be incorporated, then the sustainability-related criteria that would be applied to the design would be dictated solely by the customer.

A list of economic, environmental and social benefits from sustainable design was published by the Federal Energy Management Program of the US Department of Energy for federal facilities (USDOE, 2003). The benefits listed also apply to a wider range of applications of sustainable built environments. A summary of the list is included as Table 2.

Considering the US market, trends in sustainability design of buildings identified include (Kibert, 2008):

- Rapid penetration of the LEED rating system.
- Rapid growth of the US Green Building Council (USGBC) membership.
- Strong federal leadership.
- Public and private incentives.
- Expansion of state and local sustainability buildings programmes
- Sustainability industry professionals taking action to educate member and integrate best practices.
- Corporate America capitalising on green building benefits.
- Advances in sustainability building technology.

Considering the UK market, where reducing carbon (in the form of carbon dioxide emissions) and other greenhouse gas emissions (DBIS, 2010a) has been made a matter of legal obligation (DBIS, 2010c), the implementation of the UK Low Carbon Transition Plan (DBIS, 2010b) targets for residential buildings includes:

- Increasing energy efficiency in all homes to reduce heating-related carbon emissions by 29% by 2020 compared to 2008 levels.
  - All new homes to be zero carbon from 2016.
  - Smart displays to be fitted to existing meters in two to three million households and all new homes by 2020.
  - A retrofit programme to increase the energy efficiency of existing stock.

Table 2: Summary of economic, environmental and social benefits from long-term, widespread sustainable built environments (USDOE, 2003)

Part of the Built Environment	Economic	Societal	Environmental
Siting	Reduced costs for site preparation parking lots and roads	Improved aesthetics, more transport options for occupants	Land preservation, reduced resource use, protection of ecological resources, soil and water conservation, restoration of brownfields, reduced energy use, less air pollution
Water efficiency	Lower first costs, reduced annual water and wastewater costs	Preservation of water resources, fewer wastewater treatment plants	Less potable water use, reduced discharge to waterways, less strain on aquatic ecosystems in water-short areas, preservation of water resources
Energy efficiency	Lower first costs, lower fuel and electricity costs, reduced peak power demand, reduced demand for new energy infrastructure	Improved comfort conditions for occupants, fewer new power plants and transmission lines	Lower electricity and fossil fuel use, less air pollution, lowered impacts from fuel production and distribution
Materials and resources	Decreased first costs for reused and recycled materials, lower waste disposal costs, reduced replacement costs for durable materials, reduced need for new landfills	Fewer landfills, larger markets for environmentally-preferable products, decreased traffic due to use of local/regional materials	Reduced strain on landfills, reduced use of virgin resources, better-managed forests, lower transportation energy and pollution
Indoor environmental quality	Higher productivity, lower incidence of absenteeism, reduced staff turnover, lower insurance costs, reduced litigation	Reduced adverse health impacts, improved occupant comfort and satisfaction, better individual productivity	Reduced emissions of volatile organic compounds, carbon dioxide and carbon monoxide
Commissioning, operations and maintenance	Lower energy costs, reduced occupant/owner complaints, longer building and equipment lifetimes	Improved occupant productivity, satisfaction, health and safety	Lower energy consumption, reduced emissions

Key issues identified for successful implementation of the UK Low Carbon Transition Plan for new and existing for residential buildings included (DBIS, 2010e, DBIS, 2010c):

- A practical, workable definition of zero carbon, set on a nationwide basis.
- Affordability and the value attached (or not attached) by purchasers to energy efficiency and broader measures of sustainability.
- Addressing the technical constraints associated with smaller sites.
- A centralised and distributed energy policy, so that carbon is reduced in the most cost-effective way.
- Identifying appropriate retrofit approaches for different forms of construction, e.g.:
    - Room-by-room or whole-house treatments.
    - Development of an accredited supply chain.
    - Development of skills and practices.
    - The use of the social housing stock to kickstart large-scale retrofit of the nationwide housing stock.
    - A hub.
- A hub for a research, development, deployment and strategy group to collect and disseminate learning, and to provide leadership for the industry.

UK Low Carbon Transition Plan (DBIS, 2010b) targets for non-domestic buildings included:

- Increase energy efficiency to reduce carbon emissions by 13% by 2020 compared to 2008 levels:
    - All new public sector buildings to be zero carbon from 2018 and all private sector buildings from 2019.

Key issues identified for successful implementation of the UK Low Carbon Transition Plan for new and existing for non-residential buildings included (DBIS, 2010e, DBIS, 2010c):

- To stimulate market demand for products and works designed for carbon reduction.
- A means of financing the transition to low carbon.
- Appraisals, founded on a whole-life (embodied and operational carbon) approach (such as those operated by BSI and Lloyd's Register), that can enable project-level decision-making.
- To identify appropriate retrofit approaches for different forms of construction, with various values of properties from recent builds to older, lower-grade buildings, which is a similar problem to that for the existing domestic building stock.

In general, one of the main recommendations made by the UK Low Carbon Construction Innovation and Growth Team (DBIS, 2010c) and reiterated by the UK Government (UKG, 2011) was that a standard method of measuring embodied and operational carbon for use as a design tool and for the purposes of scheme appraisal needs to be agreed by both the industry and Government. An additional recommendation was that, in order to avoid the risk of a new generation of sick buildings, promotion of the health and well-being of occupiers should be placed on an equal footing with the current emphasis on carbon reduction (DBIS, 2010c; DBIS, 2010e; UKG, 2011). This recommendation recognises the use of carbon as a metric for sustainability of building design is not all-encompassing of the benefits that sustainable design can potentially achieve. To achieve long-term success recommendations were also made for (DBIS, 2010d):

- Industry-wide multi-disciplinary education, starting with undergraduate and apprentice programmes for a bottom-up approach to educating the industry and within organisations.
- Educating end-users who maintain, operate and live in completed construction projects.

Considering the US market, barriers to sustainability design of buildings identified include (Kibert, 2008; Keeler and Burke, 2009; Yudelson, 2009):

- Financial disincentives:
    - Lack of LCC analysis and use.
    - Real and perceived higher capital outlay.
    - Separate budgets for capital and operating costs.
    - Security and sustainability perceived as trade-offs.
    - Inadequate funding for public school facilities.
- Insufficient research:
    - Inadequate research funding.
    - Insufficient research on indoor environment, productivity and health.
    - Multiple research jurisdictions.
- Lack of awareness:
    - Prevalence of conventional thinking.
    - Aversion to perceived risk.

5.4 Design Processes to Facilitate Multi-Disciplinary Sustainable Design Solutions

The general approach to facilitating sustainable building design solutions is to take a multi-disciplinary tack and apply systems thinking or whole-systems thinking. This type of approach is used to consider the building structure and systems holistically, evaluating how they are interconnected, how they best work together to achieve a solution that addresses multiple problems or has multiple layers of benefits. An example is the advanced daylighting strategy: reducing the use of lighting fixtures during daylight, thereby reducing daytime peak cooling loads and justifying reduction in the size of the mechanical cooling system. In turn, capital outlay is reduced and energy costs over the lifecycle of the building are lowered.

Concurrent methods of encouraging collaboration of the multi-disciplinary, multi-objective design team (Kibert, 2008; Keeler and Burke, 2009; Yudelson, 2009):

- Performance-based fees:
    - Savings derived from highly efficient design increases the designers' compensation, therefore providing an effective and ethical incentive.
- Charrette:
    - A formal presentation of the problem and potential solutions, where immediate feedback is available to all participants.
    - The ideal participants of the Charrette would include the owner, design team, building, facility manager, local community representation, non-profit organisations, representing all the people affected by the building.
    - Principles intended to be applied to the planning of a community (as proposed by the NCI):
        - Involve everyone from the start.
        - Work concurrently and cross-functionally.
        - Work in short feedback loops.
        - Work in detail.
    - Principles intended to be applied to the planning of an individual building (as suggested by the NCI):
        - Startup – identify stakeholders and goals of the Charrette, scheduling the Charrette.
        - Research, education and concepts – to present and discuss at the Charrette.
        - The charrette – conducted by a facilitator.
        - Review, revise and finalise – report the results of the Charrette and incorporate into the design.
- Commissioning of the building:
    - The process of ensuring that building systems are designed, installed and functionally tested and capable of being operated and maintained to the building owner's requirements.

An integrated design is a collaborative solution produced from a multi-disciplinary team of specialists, designers, architects, engineers, building owners, intended users and regulatory authorities from the outset of the project.

In theory, this integrated approach is intended to incorporate fire-safety considerations, specialists and solutions into the final building design throughout the process. Therefore it is the responsibility of the fire-safety professional and industry to educate the sustainability professionals of the importance of fire-safety and to facilitate collaboration by providing information on appropriate lines of contact and a basis for asking the questions that are useful in establishing an holistic design team.

6. SUSTAINABILITY APPLICATION METHODS AND GUIDELINES

6.1 General Guidelines

Methods of application of sustainability principles to the built environment and assessment techniques for the degree of application of sustainability principles to a design include (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008; Johnston and Gibson, 2008):

- Biomimicry:
    - The fundamental idea is to utilise similar process and methods found in natural systems to then provide human-designed processes, services and products.
    - Ten lessons from nature for corporations (Benyus, 1997):
        - Use waste as a resource.
        - Fully utilise the habitat, by means of diversification and co-operation.
        - Gather and use energy efficiently.
        - Optimise rather than maximise.
        - Use materials sparingly.
        - Don’t foul the nest.
        - Don’t draw down resources.
        - Remain in balance with the biosphere,
        - Run on information (listen, observe and adapt).
        - Shop locally.
- Adaptive management:
    - The underlying principle is that ecological function can never be fully understood and is dynamic, responding to internal and external forces. Therefore adaptive management suggests that uncertainties and changes in the interaction between people and nature be persistently investigated, such that management adapts to the changing situation (Peterson, 2002). This leads to largely unknown and changing parameters, which may be an accurate depiction of our current human-nature interaction understanding. However, it is not practical in the application to design of a built environment.
- Industrial ecology:
    - The underlying principle is that all man-made systems should contribute to the survival of natural systems. The method focuses on the interface between man-made and natural systems, particularly where man-made systems can positively contribute to the survival of the natural system or where the efficiency of a man-made system can be improved by using systems similar to nature or utilising a natural sub-system to provide an otherwise man-made service or process (Kay, 2002).

- Ecodesign:
    - The five rules suggested for ecodesign are (Bringezu, 2002):
        - Environmental impact is considered on a cradle-to-cradle lifecycle basis.
        - Use of processes, product and services should be maximised.
        - Use of resources (materials, energy and land) should be minimised.
        - Hazardous substances (e.g. toxins, self-replicating nanomachines and genetically modified organisms) should be eliminated.
        - Renewable resources should be used.
- Natural capitalism:
    - Natural capitalism promotes the concept of maximising the productivity of resources, such that products are durable and, at the end of life, are efficiently and quickly dematerialised and recycled (Hawken et al, 2000).
    - Implementation of natural capitalism entails (Hawken et al, 2000):
        - Maximising productivity of natural resources.
        - Utilising biologically-inspired design.
        - Using solutions-based business models.
        - Reinvesting in natural capital.
- Cradle-to-cradle:
    - Cradle-to-cradle is the concept of an eco-effectiveness model applied to buildings that have a net positive contribution to the ecology (McDonough and Braungart, 2002).
    - Five principles for building cradle-to-cradle design (McDonough and Braungart, 2002) can be summarised as:
        - Produce more energy than consumed.
        - Purify own wastewater.
        - Effluents are potable water.
        - End of lifecycle is comprised of re-entry to natural or industrial cycles for reuse or recycling as biological nutrients or technical nutrients,.
        - Creation of wealth of resources.
- Ecological design:
    - Building design that facilitates and/or preserves the inter-relationship of nature and buildings. This concept comes from the perspective of a thorough understanding of ecology (Yeang, 1995).
    - Similar terms that are used interchangeably include “environmental design”, “green design”, “sustainable design” and “ecologically sustainable design”.

- Embodied energy:
    - An estimate of the total energy consumed in the extraction and processing of resources, manufacturing, transportation and final installation. The value may also be used per unit time the product or component is in use over its estimated lifetime.
- Carbon footprint:
    - A estimate of the amount of greenhouse gases (or a selection of these, e.g. carbon dioxide and methane etc) of the building and intended operations over the lifecycle of the building, including all sources, sinks and storage within the physical space and the lifetime of the building.
- Net-zero energy:
    - A building with zero net energy consumption and zero carbon emissions from annual operations.
- Lifecycle assessment (LCA):
    - A method for determining the resource limitations and environmental impact of a material, product or entire building. Energy, water and materials resources and emissions to the air, water and land are tabulated over the entity's lifecycle. The lifecycle must be specified and can span the extraction of resources, manufacturing process, installation in a building, disposal, and transportation between each of these.
    - ATHENA Environmental Impact Estimator (EIE) is an LCA tool that can be applied to assess whole building performance or building assembly (such as walls, floors or roof) performance. EIE was developed at the ATHENA Institute with the intended use in product selection in the early design stage of a building project. The tool is developed for North America and has a selection of 12 types of locations (Kibert, 2008).
    - Building for Environmental and Economic Sustainability (BEES) is another North American LCA tool. Its focus is the assessment of building materials and products, allowing side-by-side comparison of cost-effectiveness and environmental preference of various potential material or product options, utilising both LCA and lifecycle costing (LCC) data. The weighting of environmental versus economic performance is set by the user and the tool has four weighting schemes for assessing environmental performance. The database the tool refers to contains approximately 200 building products (for version 3.0), including a combination of brand name and generic products (Kibert, 2008).
- LCC:
    - A method to estimate a building's financial performance in terms of capital outlay and operational costs, savings and benefits, using a cost-benefit analysis including each year of the building's probable life.
- Factor 4 (or Factor 10):
    - Focus on the energy-related maximisation of processes, products and services and minimisation of resources.

- Factor 4 is a set of guidelines for comparing design options and evaluating building and component performance, based on the hypotheses that to live sustainably, energy consumption must be cut to one-quarter of today's usage (where conventional buildings' energy usage is approximately 292 kWh/m² in the US for commercial and institutional structures), or Factor 10 is suggested for long-term sustainability where energy consumption must be cut to one-tenth of today's usage (von Weizsacker, 1998). Eliminating over-designed elements and instead using precise design parameters for the actual usage in building systems, such as HVAC, has been adopted to achieve Factor 10 designs (RMI, 2011).
    - Suggested for applications regarding building water consumption (Kibert, 2008, Johnston and Gibson, 2008).
- Economic analysis:
    - An economic analysis can be used that includes sustainability impacts, if monetary values for the costs and benefits of the sustainability aspects are estimated.

6.1.1 Applications of Water Efficiency

Increasing water efficiency and potential benefits that follow on from the applications, includes considerations such as (RMI, 2011):

- Reducing the need to move, process and treat water will also lead to energy savings.
- Reducing building water consumption is suggested to reduce building wastewater production.
- Reducing the costs of water and wastewater infrastructure will also lower facilities services investments.
- Potential for new processes and new approaches may lead to improved industrial processes.
- Facilities that incorporate resource efficiency approaches are associated with more productive workforces.
- Implementation of a water efficiency improvement programme on an as-needed basis can be used to reduce costs and the associated risks for large facilities.
- Reducing the impact on natural systems provides environmental benefits.
- In general, increasing the sustainability of a building and its usage and operation, in such ways as increasing the water efficiency, is looked upon favourably by the general public and clients, increasing the public relations value.

6.1.2 Selection of Sustainable Building Materials

Selection of sustainable building materials can be a complex process, depending on the number of objectives to be considered and balanced. General guidance for selection of sustainable building materials includes (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008; Johnston and Gibson, 2008):

- Various approaches are used in selecting “green” solutions and the outcomes depend on the specific objectives at the time.
- Green building products (building components that have a wide range of sustainable attributes that contribute to the performance of the building compared to alternatives) may not contain green building materials (basic materials that have low environmental impacts compared to alternatives). Examples of green building products that are not made from inherently green materials include low-e windows (where the glass cannot be recycled because the films cannot be removed and would contaminate the recycling process), T-8 lighting fixtures (containing mercury etc) and energy recovery ventilators (because of the inclusion of desiccants, insulation, wiring electrical motor etc which contain components that cannot be readily recycled). (Kibert, 2008; Johnston and Gibson, 2008; Keeler and Burke, 2009; Yudelson, 2009).
- Rapidly renewable resources, as suggested for use by the USGBC’s LEED standard (USGBC, 2011):
    - Species with a growth and harvest cycle of ten years or less:
        - Does not include a measure of biodiversity, the level of environmental impact etc.
        - Materials may be selected based on the overall building environmental impact, rather than the impact of individual materials.
- Environmental Building News suggested five aspects of building products (BuildingGreen, 2012):
    - Environmentally attractive materials:
        - E.g. salvaged content, recycled content, rapidly renewable materials, minimally processed, made from waste materials etc.
    - Considering what is not present:
        - E.g. reduce material use, alternatives to components considered hazardous, such as ozone-depleting substance, PVC, polycarbonate, conventional preservative-treated wood etc.
    - Materials that reduce environmental impacts during construction, renovation or demolition.
    - Materials that reduce environmental impacts of the building during operation:
        - E.g. reduction of heating and cooling loads, equipment that conserves energy and/or water, equipment that enables use of renewable energy or fuel cells, exceptional durability or low maintenance requirements, prevention of pollution or reduction of waste, reduction or elimination of pesticide usage etc.
    - Materials that contribution to a safe, healthy indoor environment:
        - E.g. no release of significant pollutants into building, blocking of the introduction, development or spread of indoor contaminants, removal of indoor pollutants, warning occupants of health hazards in building, improvement of light quality etc.

6.1.3 Indoor Air Quality Best Practice

Increasing indoor air quality includes considerations such as (Kibert, 2008; Yudelson, 2009):

- Identification of how to evaluate the potential sources of contamination, including estimating the level and impact of hazard:
  - Identify relationships between indoor air pollution sources, ventilation and concentrations.
  - Use a dose-response basis for estimating health effects.
  - Estimate indoor air quality impact using a cradle to grave consideration.
- Identify specific aspects of the building design including:
  - Sources.
  - Applicable source control options and strategies.
  - Ventilation system design and operation.
- Design specifications:
  - Material selection and specification.
  - Construction procedures.
- Considered building operation impacts, opportunities and required design changes:
  - Maintenance and operation.
  - Change of use, renovation, adaptive reuse and demounting.

6.2 Residential Building Regulations and Guidelines

6.2.1 New Zealand Regulations and Guidelines

Strategies implemented in New Zealand for the introduction of sustainability practices into the residential built environment include:

- Sustainability is recognised in the Building Act (NZP, 2004) in terms of energy, water and resource efficiency (Burgess, 2011), however there is little implementation of environmental sustainability within the New Zealand Building Code. Housing sustainability-related regulatory requirements (New Zealand Building Code Clause H1, Energy Efficiency (DBH, 2011a)) have been currently limited to energy efficiency, specifically:
  - Insulation of the thermal envelope (NZS4218, 2004; AS/NZS4859:Part1, 2002) that is primarily driven by the intent to increase indoor environmental quality.
  - Energy efficiency of hot water systems (NZS4305, 1996).
- Non-mandatory guidance for owners and occupants seeking sustainability design in the New Zealand housing stock has been provided:
  - At a national level, through the Department of Building and Housing, Ministry of the Environment, Beacon and BRANZ:

        - Smarter Homes (http://www.smarterhomes.org.nz).
  - At the regional level, through local councils, e.g.:
    - Wellington City Council's Sustainable Building Guidelines (http://www.wellington.govt.nz/services/environment/sustain/sustainable.html).
    - Auckland City Council's Sustainable Home Guidelines (http://www.waitakere.govt.nz/abtcit/ec/bldsus/shsummary.asp).
  - As well as organisations providing guidance either directly or indirectly via assessment schemes, e.g.:
    - Organisation guidelines:
      - BRANZ, Level (http://level.org.nz/)
      - BRANZ industry publications, such as Bulletins, Guideline, and Builder's Mate.
      - New Zealand Green Building Council (http://www.nzgbc.org.nz/main/).
      - Sustainability Council of New Zealand (http://www.sustainabilitynz.org/).
      - New Zealand Business Council for Sustainable Development (http://www.nzbcsd.org.nz/).
      - Construction (http://www.constructionnews.co.nz/articles/july10/Sustainable-construction.php).
    - For assessment of homes:
      - BRANZ's Green Homes Scheme (Jaques, 2004, Camilleri, 2000).
  - News and magazine articles, e.g.:
    - Construction (http://www.constructionnews.co.nz/articles/july10/Sustainable-construction.php).

6.2.2 International Regulations and Guidelines

Strategies implemented in other countries for the introduction of sustainability practices into the residential built environment include:

- Mandatory regulations:
  - International Code Council (ICC) 700 National Green Building Standard™ (ICC-700, 2008) "is the first and only residential green building rating system to undergo the full consensus process and receive approval from the American National Standards Institute (ANSI)" (http://www.nahbgreen.org/).
  - Boulder, Colorado, US, took an aggressive stance in 1998 with respect to green building by passing an ordinance requiring specific measures.

- Non-mandatory guidance:
    - From regulatory authorities:
        - UK Government (http://cdn.hm-treasury.gov.uk/2011budget_growth.pdf).
        - Pennsylvania, US, established the Governor's Green Government Council (GGGC) in part to address the implementation of green building principles in the state.
        - Austin, Texas, was a recipient of an award at the first UN conference on sustainable development in 1992, in Rio de Janeiro.
        - Other US cities and areas that have actively implemented sustainability within the built environment include Denver, Colorado, Kitsap County, Washington and Clark County, Washington.
    - From organisations:
        - Model Green Home Guidelines by the National Association of Home Buildings in co-operation with the Green Building Initiative (http://www.thegbi.org/residential/featured-projects/newmexico/CNM_MODEL_GHB_GUIDELINES.pdf).
        - Whole building design (http://www.wbdg.org/).
        - High performance, resilient buildings guidelines by the National Institute of Building Sciences (http://www.nibs.org/client/assets/files/nibs/Desiging_for_a_Resilient_America.pdf) (NIBS, 2010).
        - Natural hazards and sustainability for residential buildings, FEMA (http://www.fema.gov/library/viewRecord.do?id=4347) (Gromala et al, 2010)
        - Standard guide for general principles of sustainability relative to buildings, ASTM E 2432 (http://enterprise.astm.org/filtrexx40.cgi?+REDLINE_PAGES/E2432.htm) (ASTM-E-2432, 2011)
        - Suburban Builders Association in Baltimore, Maryland, US.
        - EarthCraft Houses Program in Atlanta, Georgia, US.

This by no means represents an exhaustive listing of the guidance published nationally and internationally. Commercially-derived guidelines, including commercial building products, have only been included as to provide a general overview of the direction of building sustainability design approaches and processes. Mention or not of any commercial product represents neither an endorsement nor invalidation, respectively. This is for general information purposes only.

6.3 Non-Residential Building Regulations and Guidelines

6.3.1 New Zealand Regulations and Guidelines

Strategies implemented in New Zealand for the introduction of sustainability practices into the non-residential built environment include:

- Regulated requirements:
    - Sustainability is recognised in the Building Act (NZP, 2004) in terms of energy, water and resource efficiency and reduction of wastage (Burgess, 2011), however, as with residential buildings, implementation of environmental sustainability within the New Zealand Building Code has been limited so far. Non-residential sustainability-related regulatory requirements (New Zealand Building Code Clause H1, Energy Efficiency (DBH, 2011a)) are also currently limited to energy efficiency, specifically:
        - Insulation of the thermal envelope (NZS4218, 2004, NZS4243:Part1, 2007) for net lettable areas of greater than 300 m².
        - Control of solar gain (NZS4218, 2004, NZS4243:Part1&4, 2007).
        - Artificial lighting (NZS4218, 2004, NZS4243:Part2&3, 2007).
- Non-mandatory guidance for owners and tenants seeking sustainability design in the non-residential stock has been provided:
    - At a national level through the Department of Building and Housing, and Ministry of the Environment, e.g. (Fullbrook et al, 2006).
    - As well as organisations providing guidance either directly or indirectly via assessment schemes.

6.3.2 International Regulations and Guidelines

Strategies implemented in other countries for the introduction of sustainability practices into the non-residential built environment include:

- Standards and building codes:
    - California Green Building Standards Code – Non-Residential (CALGreen).
- Non-mandatory guidance:
    - From regulatory authorities:
        - New York City Council, US (CNYDDC, 1999) (http://www.nyc.gov/html/ddc/downloads/pdf/guidelines.pdf).
        - Pennsylvania Department of Environmental Protection, US (Kobert et al, 1999) (http://www.portal.state.pa.us/portal/server.pt?open=514&objID=588208&mode=2).
        - Triangle Region, North Carolina, US (http://www.tjcog.org/docs/regplan/susenerg/grbuild.pdf).

- From organisations:
  - Guiding Principles of Sustainable Design from the National Park Service (www.nps.gov/dsc/d_publications/d_1_gpsd.htm).
  - Whole building design (http://www.wbdg.org/).
  - Sustainable Building Technical Manual from the US Department of Energy (www.Sustainable.doe.goc/freshstart/articles/ptipub.htm).
  - GreenSpec Directory published by BuildingGreen, Inc, (www.buildinggreen.com).
  - Green Globes Design and Green Globes for Continual Improvement of Existing Buildings.
  - Building database from the US Department of Energy (http://buildingdata.energy.gov/) and (http://apps1.eere.energy.gov/buildings/commercial_initiative/resource_database/).
  - High-Performance Building Data Collection Initiative, National Institute of Building Sciences (http://www.nibs.org/index.php/newsevents/HPBData/).
  - Low carbon construction from the Department for Business Innovation and Skills, UK (http://www.bis.gov.uk/constructionigt).
- News and magazine articles, e.g.:
  - Environmental Building News published by BuildingGreen, Inc, (www.buildinggreen.com).

Similarly, this by no means represents an exhaustive listing of the guidance published nationally and internationally. Commercially-derived guidelines, including commercial building products, have only been included as to provide a general overview of the direction of building sustainability design approaches and processes. Mention or not of any commercial product is neither an implicit endorsement nor invalidation, respectively. This is for general information purposes only.

7. SUSTAINABILITY ASSESSMENT METHODS – GREEN RATING SYSTEMS

There are a number of sustainability-related rating systems in use in communities nationally and internationally. Each rating system is tuned to the weather conditions and the environment sensitivities of each area to which it is intended to be applied. Such concerns are reflected in the weighting (e.g. relative number of credits etc) of each aspect (e.g. site use, water efficiency, energy etc) considered in the ranking system. A summary of selected ranking systems is presented in Table 3.

Table 3: A summary of selected green building ranking systems currently in use

Rating System	Implemented by	Country of Application	Applicability Aspect Considered (Maximum Points/Weighting/Credits)	Reference
LEED (Leadership in Energy and Environmental Design)	US Green Building Council (USGBC)	USA	LEED-NC, New Construction (used for all types of buildings, except single-family homes), version 2009: • Sustainable site (26) • Water efficiency (10) • Energy and atmosphere (25) • Materials and resources (14) • Indoor environment quality (15) • Innovation and design process (6) • Regional priority credits (4) Other specific applications of LEED developed for: LEED-EB for existing buildings, operations and maintenance LEED-CS for core and shell LEED-CI for commercial Interiors LEED for schools LEED-H for homes LEED for retail LEED-ND for neighbourhood development LEED for healthcare	(USGBC, 2011), (Gromala et al, 2010), (FMLink, 2011), (Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
LEEDS-Canada (Leadership in Energy and Environmental Design – Canada)	Canada Green Building Council (CGBC)	Canada	Construction: • Sustainable site (14) • Water efficiency (5) • Energy and atmosphere (17) • Materials and resources (14) • Indoor environment quality (15) • Innovation and design process (5)	(CGBC, 2011)
Green Globe	Green Building Initiative (GBI)	Canada, USA	Version 1: • Project management – policies and practices (50) • Site (115) • Energy (300) • Water (100) • Resources, building materials and solid waste (100) • Emissions and effluents (75) • Indoor environment (200)	(GBI, 2011), (FMLink, 2011), (Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)

Table 3 (continued): A summary of selected green building ranking systems currently in use

Rating System	Implemented by	Country of Application	Applicability Aspect Considered (Maximum Points/Weighting/Credits)	Reference
Green Star	Green Building Council Australia (GBCA)	Australia	Office New/Existing Building, version 1.0: • Management (7) • Indoor environment quality (16) • Energy (7) • Transport (4) • Water (5) • Materials (8) • Land use and ecology (5) • Emission (9) • Innovation (3) Office Interior, version 1.0: • Management (6) • Indoor environment quality (15) • Energy (4) • Transport (3) • Water (1) • Materials (11) • Land use and ecology (6) • Emission (2) • Innovations (3)	(GBCA, 2011), (FMLink, 2011), (Kibert, 2008)
Building Research Environment Assessment Method Consultancy (BREEAM)	BRE Global	United Kingdom	Applicable to various occupancies Design stage: Management (4) Health and wellbeing (13) Energy (4) Transport (4) Water (4) Materials (7) Land use (6) Pollution (8) Management and operation: Management (4) Health and wellbeing (15) Energy (8) Transport (5) Water (6) Materials (3) Pollution (7)	(BRE, 2011), (FMLink, 2011)

Table 3 (continued): A summary of selected green building ranking systems currently in use

Rating System	Implemented by	Country of Application	Applicability Aspect Considered (Maximum Points/Weighting/Credits)	Reference
Comprehensive Assessment System for Built Environment Efficiency (CASBEE)	Japan Sustainable Building Consortium (JSBC) and Japan GreenBuild Council (JaGBC)	Japan	Applicable to various occupancies Phases of the building assessed: • Planning • Design • Completion • Operation • Renovation • For each phase, the Building Environmental Quality and Performance is evaluated in terms of: • Indoor environment • Quality of service • Outdoor environment on-site And related to each category of Building Environmental loadings: • Energy • Resource and materials • Off-site environment	(JSBC, 2011), (Kibert, 2008), (FMLink, 2011)
Green Building Tool (GBTool)	International Initiative for a Sustainable Built Environment (iiSBE), used for the Green Building Challenge	A tool used to compare competition entries from various countries	Provides a comparison with a building that represents the norm, allowing for benchmarking and comparison between countries. Categories assessed: • Resource consumption • Environmental loadings • Indoor environmental quality • Service quality • Economics • Management • Commuting transport	(iiSBE, 2009), (Kibert, 2008)

This by no means is a complete listing of the green ranking systems. This list is included to provide a general indication only of the range and focus of some of the green ranking systems currently in use. This list is also expected to change as the influence and use in the marketplace of the different ranking systems change and development of current and new systems continue. Mention or not of any ranking system is neither an implicit endorsement nor invalidation, respectively. The intent of this report is for general information purposes only.

When applying a voluntary rating system, generally the designer and owner want the building to be green. However, there may be a lack of communication of the intended use of the building to the facility manager, the systems maintenance staff or the tenants' interior designers. Therefore a building that has a particular sustainable rating does not mean that it is actually operated in a way consistent with the intended use.

No green rating system yet includes credit for fire-safety building features, systems or procedures. It has been suggested that fire-safety be included in green rating systems to reflect the extension of building lifetime that fire-safety design provides (Carter et al, 2011).

8. SUSTAINABILITY DESIGN STRATEGIES AND PRACTICES

8.1 General Aspects of Building Sustainability Design Considered

General aspects of buildings considered in sustainability design and how these aspects are considered in a sustainability context can be summarised as:

- Siting and landscaping:
  - Passive design.
  - Integration with local ecology.
  - Reduction in transport costs of occupants and goods.
  - Transport of people and goods during construction.
  - Transport of people and goods during operation.
- Materials and resources:
  - Materials selection to reduce resource use.
  - Material selection to reduce indoor air contamination.
  - Material storage and handling during construction to reduce wastage and inadvertent contamination of the final building.
  - Wastage during construction.
  - Wastage during operation.
  - Materials, building design and construction practices to enable deconstruction and/or high-value recycling of materials at the end of the building lifetime to reduce low-value recycling and to eliminate landfill.
- Energy efficiency:
  - Passive design to achieve higher energy efficiency.
  - Renewable energy:
    - Energy storage and integration.
  - Refrigeration.
  - Identification and reduction of miscellaneous electric loads.
  - Energy management systems.
  - Indoor environment:
    - Heating, ventilation and air conditioning.
    - Lighting and daylighting.
  - Building envelope construction and materials.
  - Insulation materials.
  - Glazing.
  - Reduction in internal plug thermal load.
  - Reduction in internal plug electrical load.

- Water efficiency:
    - Rainwater collection and use.
    - Greywater collection and use.
    - Passive design to achieve higher water efficiency.
    - Use of active systems to achieve higher water efficiency.
- Indoor environmental quality:
    - Indoor air quality (direct and indirect links with energy efficiency and materials and resources):
        - Heating, ventilation and air conditioning.
        - Material selection for limitation of released volatiles and particulate contaminants.
        - Building envelope.
        - Monitoring of air quality.
        - Passive design to achieve higher indoor air quality.
        - Control of construction practices and materials that may contaminate the final building.
        - Control of operation practices that may contaminate the building.
    - Indoor lighting quality (direct and indirect links with energy efficiency):
        - Individual occupant lighting control for spaces.
        - Sensors-controlled lighting.
        - Passive design to achieve higher daylighting quality:
            - Advanced daylighting strategy, which reduces the use of lighting fixtures during daylight, thereby reducing daytime peak cooling loads and justifying reduction in the size of the mechanical cooling system. In turn, capital outlay is reduced and energy costs over the lifecycle of the building are lowered.
    - Indoor thermal comfort (direct and indirect links with energy efficiency):
        - Monitoring of thermal environment.
        - Heating and cooling systems to work with the local environment.
        - Passive design to achieve higher thermal comfort.
    - Acoustic quality:
        - Materials used.
        - Passive design to achieve higher acoustic quality.
- Social and behavioural impacts:
    - Homeowner education (residential).
    - Building owner education (non-residential).
    - Building occupant education (non-residential).

- Building analysis, performance and monitoring:
    - Sensors and controls.
    - Operations and maintenance.
    - Waste:
        - Solid waste from operations, handling and storage.
    - Emissions and effluents:
        - Air emissions.
        - Water pollution and sewerage handling.
        - Pest management.
        - Hazardous materials handling and storage.

8.2 Residential Building Features, Systems, Strategies and Procedures

Examples of a selection of residential building features, systems, strategies and procedures used in some design approaches for sustainability objectives are provided in Table 4. This list is not intended to be exhaustive; instead it is intended as a sample demonstration of the complex nature of sustainability design, where a single sustainability-related building feature, system, strategy or procedure may have various impacts associated with multiple sustainability design aspects. Examples of the potential interaction with other building design objectives, specifically related to fire-safety design, are discussed in the following section (Section 9).

Table 4: Examples of residential building features, systems, strategies and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for References)
All	Size the building appropriately	Providing a base for all other sustainability design aspects to improve from	(CFF, 2011b), (Johnston and Gibson, 2008)
Landscaping	Reduced built-environment area (e.g. narrower streets)	Reduction in stormwater infrastructure	(Kibert, 2008), (Johnston and Gibson, 2008), (Keeler and Burke, 2009), (Yudelson, 2009) e.g. Village Homes
Siting and landscaping	Infiltration swales (e.g. grassed swales with check dams)	Reduction in stormwater infrastructure	(Kibert, 2008), (Johnston and Gibson, 2008) e.g. Village Homes
Siting and landscaping	On-site stormwater detention basins (e.g. basement tank)	Reduction in stormwater infrastructure Use of greywater	(Kibert, 2008), (Johnston and Gibson, 2008) e.g. Village Homes, Solaire

Table 4 (continued): Examples of residential building features, systems, strategies and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for references)
Siting and landscaping	Constructed wetlands	Reduction in stormwater infrastructure	(Kibert, 2008)
Siting and landscaping	Drought-tolerant plants, trees and turf for landscaping	Increase water efficiency	(Kibert, 2008), (Johnston and Gibson, 2008)
Siting and landscaping Energy efficiency Indoor air quality	Fully using the sun, prevailing winds and foliage in the passive solar design	Increase energy efficiency Increase indoor air quality	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009), (Johnston and Gibson, 2008), (CFF, 2011b), (Gromala et al, 2010)
Siting and landscaping	Pervious concrete and asphalt for paved surfaces	Reduction in stormwater infrastructure	(Kibert, 2008), (Johnston and Gibson, 2008)
Siting and landscaping	Bioretention	Reduction in stormwater infrastructure	(Kibert, 2008)
Siting and landscaping	Rainwater gardens	Reduction in stormwater infrastructure	(Kibert, 2008)
Landscaping Energy efficiency Social impacts	Rooftop gardens, green roof or eco-roof	Reduction in stormwater infrastructure Increased energy efficiency (e.g. providing insulation to reduce cooling and heating loads) Reduction in stormwater infrastructure Natural beautification	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009), (Johnston and Gibson, 2008), e.g. Solaire
Landscaping Energy efficiency Social impacts	Vertical landscaping (gardens at different levels of a high-rise building)	Increased energy efficiency (e.g. providing shade to reduce cooling and heating loads) Increase in indoor air quality (e.g. providing wind breaks) Reduction in stormwater infrastructure Natural beautification	(Kibert, 2008), (Yeang, 1995, Yeang, 2000, Hart, 2011)
Energy efficiency Behavioural impacts	Façade containing photovoltaic cells Use energy efficient lights (e.g. compact florescent bulbs instead of incandescent bulbs etc)	Production of electricity Reduce energy usage	(Johnston and Gibson, 2008), (CFF, 2011a), (CFF, 2011b), (Kibert, 2008), (Gromala et al, 2010) e.g. Solaire, Net Metre approaches etc

Table 4 (continued): Examples of residential building features, systems, strategies and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for References)
Energy efficiency Behavioural impacts	Reduce water heater temperature setting	Reduce energy usage	(CFF, 2011a)
Energy efficiency Behavioural impacts	Reduce house thermostat setting during the winter (to no greater than 20ºC) and reduce it further at night	Reduce energy usage	(CFF, 2011a)
Energy efficiency Behavioural impacts	Reduce house thermostat setting during the summer (to no less than 25ºC)	Reduce energy usage	(CFF, 2011a)
Energy efficiency Behavioural impacts	Use energy efficient appliances	Reduce energy usage	(CFF, 2011a)
Energy efficiency	Geothermal heating and cooling	Increase energy efficiency	(CFF, 2011a), (CFF, 2011b)
Water efficiency	Use of water efficient appliances (e.g. dual flush toilets etc)	Water usage reduction	(CFF, 2011a)
Water efficiency	Use of rainwater (e.g. watering gardens etc)	Potable water usage reduction	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009) e.g. Solaire
Water efficiency	Use of greywater (e.g. use in cooling towers of the air-conditioning system, flushing toilets etc)	Potable water usage reduction	(Kibert, 2008), (CFF, 2011a), (Keeler and Burke, 2009), (Yudelson, 2009), (Johnston and Gibson, 2008), (CFF, 2011a), e.g. Solaire
Indoor lighting quality Energy efficiency	Low-e window glazing	Increased natural lighting, reduced use of electrical lighting	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009), (Johnston and Gibson, 2008)
Indoor lighting quality Energy efficiency	Skylights	Increased natural lighting, reduced use of electrical lighting	(Kibert, 2008), (Johnston and Gibson, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)

Table 4 (continued): Examples of residential building features, systems, strategies and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for references)
Indoor lighting quality Energy efficiency	Light shelves	Increased natural lighting, reduced use of electrical lighting	(Kibert, 2008)
Indoor lighting quality Energy efficiency	Controls to adjust electric lighting intensity according to the natural available daylight	Increased natural lighting, reduced use of electrical lighting	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009), (Kibert, 2008)
Indoor lighting quality Energy efficiency	Occupancy sensors to control electrical lighting	Increased natural lighting, reduced use of electrical lighting	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009), (Kibert, 2008)
Indoor environmental quality	Use of no-VOC and low-VOC primers, paints, sealants and floor coverings	Increased indoor air quality	(Johnston and Gibson, 2008), (CFF, 2011b)
Materials and resources Energy efficiency	Metal roof	Increase of recycled and recyclable materials Reduced maintenance Increase energy efficiency by reducing thermal load because of reflected thermal energy	(CFF, 2011a)
Materials and resources	Use local materials	Reduce transport costs	(Johnston and Gibson, 2008), (CFF, 2011b)
Materials and resources	Minimise (through correct sizing) and recycle construction waste	Reduce amount of waste to landfill Reduce transport costs (of excess initial materials to site)	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009), (CFF, 2011b)
Materials and resources	Compressed wheatboard	Substitute for plywood	(Kibert, 2008)
Materials and resources	Low maintenance claddings	Reduction in resources to maintain and/or replace (in terms of time) cladding	
Siting and landscaping Indoor lighting quality Energy efficiency	Optimise the passive solar design (e.g. increase ratio of window area to internal space, light wells and atria, facing of building and shading of walls, shapes of internal spaces)	Increased energy efficiency Increased natural lighting quality	(Kibert, 2008), (Johnston and Gibson, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)

Table 4 (continued): Examples of residential building features, systems, strategies and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Procedure	Intended Sustainability-Impact	Example for Reference (See Table Notes for references)
Energy efficiency Indoor thermal comfort	Maximise thermal performance of the building envelope (e.g. increasing wall insulation, decrease in thermal conductance, reducing the thermal mass of the exterior surface, increasing the thermal mass of the interior surface)	Increased energy efficiency Reduce need for active heating and cooling	(Kibert, 2008), (Johnston and Gibson, 2008), (Keeler and Burke, 2009), (Yudelson, 2009), (CFF, 2011a), (CFF, 2011b)
Energy efficiency	Building-integrated photovoltaic technologies (Photovoltaic cells are built directly into building materials, e.g. semitransparent insulated glass windows, skylights, spandrel panels, flexible shingles, raised-seam metal roofing, façade containing photovoltaic cells etc)	Generate the building's electricity	(Kibert, 2008), (Johnston and Gibson, 2008), (Keeler and Burke, 2009), (Yudelson, 2009), (CFF, 2011b) e.g. Solaire, Net Metre approaches etc
Energy efficiency Indoor environmental quality	Double-skin glass façade (inner glass curtain-walls and an outer glass façade, with a ventilated cavity between)	Reduce the cooling load of the building (because the ventilated cavity allows air heated by the solar gain to naturally rise through the cavity as a chimney effect) while still allowing maximum amount of light to enter the full height windows	(Ding et al, 2005)
Indoor environmental quality	Positioning of areas within the building design (e.g. conference rooms remote from elevator machine rooms, chiller rooms etc) or iInsulation or dampening	Control of sound and noise transmission	

Table 4 (continued): Examples of residential building features, systems, strategies and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Procedure	Intended Sustainability-Impact	Example for Reference (See Table Notes for references)
Indoor environmental quality (after a natural disaster) Materials and resources (after a natural disaster) Societal impacts (after a natural disaster)	Passive survivability may include the following building design features, systems and procedures: Storm resilient buildings Limit building height High-performance envelope Minimize cooling loads Provide natural ventilation Incorporate passive solar heating Natural day-lighting Solar water heating Photovoltaic power Configure heating equipment to operate on PV power Store water onsite Install composting toilets and waterless urinals Provide for food production in the site plan Etc.	Occupant survivability in the wake of natural disasters Allowing for faster recovery after a disruption or disaster	(Wilson, 2006) (Gromala et al, 2010)

Table 4 Notes for examples of existing buildings:

- Solaire, a 27-storey residential tower in Battery Park, New York City (Kibert, 2008).
- Village Homes, a 240-unit residential subdivision in Davis, California (Kibert, 2008).

8.3 Non-Residential Building Features, Systems, Strategies and Procedures

Examples of a selection of non-residential building features, systems, strategies and procedures used in some designs for sustainability objectives are provided in Table 5. Again, this list is not intended to be exhaustive. This list is provided to serve as a sample demonstration of the fundamental nature of sustainability design, where a single sustainability-related building feature, system, strategy or procedure may have various impacts associated with multiple sustainability design aspects. Examples of the potential interaction with fire-safety building design objectives are discussed in the following section (Section 9).

Table 5: Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for References)
Siting	Sound levels below 65dB at property line	Increased acoustic quality of the surrounding area by reducing the level of noise pollution to surrounds	(Kibert, 2008)
Siting (after a fire event) Materials and resources	Halon replacements as sustainability-induced fire-safety change	Reduction in use of greenhouse gases and emissions Use of sustainable materials	(Kibert, 2008)
Siting and landscaping	Stormwater retained and released	Assist groundwater recharge	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009) e.g. Audubon Center
Siting and landscaping Water efficiency Social and behavioural impacts	Native and adapted species of plant that are drought-tolerant and fire-resistant	Increased water efficiency Attract wildlife	(Kibert, 2008) e.g. Audubon Center
Siting and landscaping	Pervious concrete and asphalt for paved surfaces	Reduction in stormwater infrastructure	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for References)
Siting and landscaping (during construction) Materials and resources (during construction) Societal impact	Construction site location and design: Site access plan, including temporary roads, storage areas, staging areas, waste and recyclable areas and scheduling delivery of goods, removal of wastes and adaptation of construction site Protect or "rescue" trees and vegetation Wastewater runoff and erosion control Salvage existing clean topsoil for reuse Mitigate dust, smoke, odours and other impacts Noise control and scheduling Reduced footprint of construction operations that may include: Specify locations for trailers and equipment Specify locations that are to be kept free of traffic Prohibit clearing of vegetation beyond 12.2m from the building perimeter Educate the workers of the goals and procedures for protecting vegetation Use low impact methods for clearing and grading the site Control runoff from the site to reduce erosion of surrounding area	Reduce impact on site and surrounds Increase indoor environmental quality of building Increase sustainability-related awareness of workers	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Landscaping Energy efficiency Social and behavioural impacts	Rooftop gardens, green roof or eco-roof	Reduction in stormwater infrastructure Increased insulation of roof Beautification of area	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009), e.g. city halls and courthouses in Chicago, Toronto, and Seattle
Landscaping Energy efficiency Indoor environmental quality Social and behavioural impacts	Vertical landscaping (gardens at different levels of a high-rise building)	Increased energy efficiency (e.g. providing shade) Increase in indoor air quality (e.g. providing wind breaks) Beautification of area	(Kibert, 2008), (Yeang, 1995, Yeang, 2000, Hart, 2011)

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for References)
Water efficiency	Low-flow shower heads	Reduce water usage	(Kibert, 2008) e.g. Audubon Center
Water efficiency	Dual-flush toilets	Reduce water usage	(Kibert, 2008) e.g. Audubon Center
Water efficiency	Greywater/blackwater recycling system	Reduce potable water usage	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009), e.g. Audubon Center
Energy efficiency	Three- to five-day battery backup system	Off-grid building Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009), e.g. Audubon Center
Energy efficiency	Photovoltaic array	Generate the building's electricity Increased energy efficiency	(Kibert, 2008) e.g. Audubon Center
Energy efficiency	Building-integrated photovoltaic technologies (Photovoltaic cells are built directly into building materials, e.g. semitransparent insulated glass windows, skylights, spandrel panels, flexible shingles, raised-seam metal roofing etc)	Generate the building's electricity Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	Glass vacuum tube solar collectors	Provide high-temperature hot water to air-conditioner chillers Increased energy efficiency Increased indoor thermal comfort	(Kibert, 2008) e.g. Audubon Center
Energy efficiency	Solar hot water system	Provide domestic use hot water Increased energy efficiency	(Kibert, 2008) e.g. Audubon Center

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for references)
Energy efficiency	Automated load-shedding system	Supply to priority electrical loads, and shutdown of others, when batteries are low for an off-grid building Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009) e.g. Audubon Center
Energy efficiency Indoor environmental quality	Low to high cross-ventilation for passive cooling	Increased energy efficiency Increased indoor air quality Increased indoor thermal comfort	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009) e.g. Audubon Center, San Francisco Federal Building
Energy efficiency Indoor environmental quality	Exposed interior concrete floors and concrete block walls	Passive thermal control to provide thermal mass for storing the cooling effect Increased energy efficiency Increased indoor thermal comfort	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009) e.g. Audubon Center
Energy efficiency Materials and resources Indoor environmental quality	Formaldehyde-free batt insulation with recycled content	Increase energy efficiency Use of recycled materials Reduction of toxins	(Kibert, 2008) e.g. Audubon Center
Energy efficiency	Reduced light pollution (e.g. exterior building and sign lighting reduced or turned off when not in use)	Increased energy efficiency	(Kibert, 2008)
Energy efficiency	Optimise the passive solar design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency	Efficient HVAC system (i.e. precisely designing to the requirements)	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for references)
Energy efficiency	Combined heat and power system (i.e. to harvest waste energy)	Increased energy efficiency	(Kibert, 2008)
Energy efficiency	Ventilation/exhaust air energy recovery systems (i.e. to harvest waste energy)	Increased energy efficiency	(Kibert, 2008)
Energy efficiency Indoor environmental quality	Internal and external louvers as part of a passive solar design	Increased energy efficiency Increase indoor light quality	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	Building aspect ratio (close to 1.0 in colder climates) as part of a passive solar design	Increased energy efficiency Increased indoor natural lighting	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	Long building axis oriented east-west in warmer climates as part of a passive solar design	Increased energy efficiency Increased indoor natural lighting	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	Appropriate use of thermal mass as part of a passive solar design	Increased energy efficiency Indoor air quality	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	Photo-sensor controlled lighting as part of an advanced daylighting design	Increased energy efficiency Increased indoor lighting quality	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	Slanted and shaped ceilings in rooms as part of an advanced daylighting design	Increased energy efficiency Increased indoor natural lighting	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009) e.g. Rinker Hall, Forensic Science Center

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for references)
Energy efficiency Indoor environmental quality	Core daylighting (e.g. using a central well or atrium) as part of an advanced daylighting design	Increased energy efficiency Increased indoor natural lighting	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	Reflective roofing on sawtooth clerestories as part of an advanced daylighting design	Increased energy efficiency Increased indoor natural lighting	(Kibert, 2008)
Energy efficiency Indoor environmental quality	Extended windows as part of an advanced daylighting design	Increased energy efficiency Increased indoor natural lighting	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	Glass internal walls as part of an advanced daylighting design	Increased energy efficiency Increased indoor natural lighting	(Kibert, 2008) e.g. San Francisco Federal Building
Energy efficiency Indoor environmental quality	Skylights (with or without trackers) as part of an advanced daylighting design	Increased energy efficiency Increased indoor natural lighting	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	Thermal chimney as part of a passive ventilation design	Increased energy efficiency Indoor air quality	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	Venturi as part of a passive ventilation design	Increased energy efficiency Indoor air quality	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for references)
Energy efficiency Indoor environmental quality	Windcatchers as part of a passive ventilation design	Increased energy efficiency Indoor air quality	(Kibert, 2008) e.g. Jubilee Campus
Energy efficiency	Thermal wheels	Increased energy efficiency	(Kibert, 2008) e.g. Jubilee Campus
Energy efficiency	Location of buildings to locally increase prevailing wind speeds to be used at air intakes to the buildings	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency	Earth-to-air heat exchangers as part of a passive cooling design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency	Slab cooling (groundwater is pumped through slab cavities) as part of a passive cooling design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	ASHRAE 55-2004 ASHRAE 62.1-2004	Increased energy efficiency Increased indoor environment quality	(Kibert, 2008)
Energy efficiency	Increasing wall insulation as part of a building thermal envelope design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009) e.g. super-insulated building envelope of the Philadelphia Forensic Science Center
Energy efficiency	Decrease in thermal conductance as part of a building thermal envelope design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009) e.g. Philadelphia Forensic Science Center

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (See Table Notes for references)
Energy efficiency	Reducing the thermal mass of the exterior surface as part of a building thermal envelope design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency	Increasing the thermal mass of the interior surface as part of a building thermal envelope design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency	Ventilating facades to carry away energy absorbed from the sun by the exterior surface as part of a Building thermal envelope design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency	Shading facades from the sun as part of a Building thermal envelope design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency	Decrease in thermal conductance as part of a building thermal envelope design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009), e.g. Philadelphia Forensic Science Center
Energy efficiency	Low-emissivity and reflective coatings for windows as part of a Building thermal envelope design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency	Light-coloured, reflective (high albedo, or a high Solar Reflectance Index) roof as part of a building thermal envelope design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency	Thermal insulation of roof as part of a building thermal envelope design	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	Reduction in internal plug thermal load (i.e. replacement of electrical items with versions that produce less heat during use, upsizing of wiring gauge)	Increased energy efficiency Increased indoor thermal quality	(Kibert, 2008)

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for references)
Energy efficiency	Reduction in internal plug electrical load (i.e. reduction in number of electrical items and use of low-electrical consumption devices where possible, integrated on/off-control of office-hour use electrical circuits and arming of the security system)	Increased energy efficiency	(Kibert, 2008)
Energy efficiency	Economiser (an energy recovery system using exhausted building air to cool intake air)	Increased energy efficiency	(Kibert, 2008)
Energy efficiency	Energy recovery ventilator (an energy and humidity exchanger system using exhausted building air to cool intake air)	Increased energy efficiency	(Kibert, 2008)
Energy efficiency	Solar water heating	Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency	Tankless water heating	Increased energy efficiency	(Kibert, 2008)
Energy efficiency Indoor environmental quality	Low energy lighting systems (e.g. fluorescent, fibre-optic or LED methods)	Increased energy efficiency Increased lighting quality	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009) e.g. Hard Rock Hotel & Casino
Energy efficiency Indoor environmental quality	Radiant cooling (circulation of cooled water in floor, wall and/or ceiling elements or panels to cool the building spaces, instead of moving cooled air) using concrete core (plastic tubes in floor and ceiling slabs), metal panels (metal tubes connected to aluminium panels) or cooling grids (plastic tubes embedded in plaster or gypsum)	Increased energy efficiency Increased indoor thermal quality	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency Indoor environmental quality	Ground coupling (thermally connecting to the ground for cooling and heating) Direct system (using groundwater in radiant cooling systems) Indirect system (using heat pumps)	Increased energy efficiency Increased indoor thermal quality	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Energy efficiency	Small wind turbines (<100 kW output) intended for incorporation into a building design	Generate the building's electricity	(Kibert, 2008)

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for References)
Energy efficiency	Fuel cells specifically design for building use: Reformer (for extraction of hydrogen from a source, e.g. natural gas or LPG) Storage (source for hydrogen, hydrogen, oxygen) Fuel cell (for combination of hydrogen and oxygen) Power conditioner (for converting fuel cell's output to the type and quality required for the building)	Generate the building's electricity	(Kibert, 2008) e.g. GenSys® fuel cell
Energy efficiency Societal and behavioural impacts	Energy Management Systems (an older approach to Smart Buildings) may include: Controls energy-consuming equipment to maintain building power efficiency and effectiveness Options so that sustainability-intended building systems can be integrated with fire protection and security systems	Increased energy efficiency Induces changes in energy usage by occupants Integrates or enables integration of sustainability-focused systems with other building systems	(Kibert, 2008)
Energy efficiency Indoor environmental quality Societal and behavioural impacts	Smart Buildings may include: Building divided into zones, where each zone is monitored and controlled by a building automation system Building aspects integrated into this system include: Telecommunication Heating, ventilation, air conditioning and refrigeration components Fire, life and safety systems Lighting Emergency and redundant power Security systems Smart Building concept is recommended for consideration in green buildings to achieve flexible layout and responsiveness Direct Digital Controls: Controls and devices added to the heating, ventilation, air conditioning and refrigeration systems Can be used to monitor: Temperature Humidity Air quality Carbon dioxide levels	Increased energy efficiency Increased indoor air quality Increased indoor lighting quality Induces changes in energy usage by occupants Integrates or enables integration of sustainability-focused systems with other building systems	(Kibert, 2008)

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for References)
Materials and resources	Synthetic gypsum board	Using recycled content	(Kibert, 2008) e.g. Audubon Center
Materials and resources	Wood-based products (plywood, redwood, Douglas fir etc)	Increased use of sustainable products Recycled material from previous building	(Kibert, 2008) e.g. Audubon Center
Materials and resources	Cast-in-place concrete with 25% fly ash	Displacing concrete to use less materials	(Kibert, 2008) e.g. Audubon Center
Materials and resources	Steel reinforcing bars with 97% recycled content	Using recycled content	(Kibert, 2008) e.g. Audubon Center
Materials and resources	Wheat and sunflower medium-density fibreboard	Use of sustainable materials Reduction of toxins	(Kibert, 2008) e.g. Audubon Center
Materials and resources	Sisal fibre carpet	Use of sustainable materials	(Kibert, 2008) e.g. Audubon Center
Materials and resources	Design for deconstruction and disassembly (e.g. exposed frame joints for ease of access, bolts used for fastening etc)	Increased capability and ease of reuse, repurpose and recycling of building products and materials at the end of life of the building	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009) e.g. Rinker Hall

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for References)
Materials and resources	Building commissioning that may include: A commissioning plan, including repeatable testing methods and required performance, must be produced before the commissioning begins For new construction systems to be commissioned should be reviewed throughout construction An evaluation report must be produced to summarise the commissioning procedure and results A review of operation and maintenance documentation is also included in the commissioning Systems to be commissioned may include: HVAC system Non-mechanical systems, e.g. all electrical components, telecommunications, security systems, plumbing, rainwater harvesting systems, greywater systems, electronic water controls, finished construction (finishes, doors, door hardware, windows, millwork, ceiling times etc) in accordance with the building's Etc	Ensuring operation of building systems Reducing likelihood for redesign, replacement and repair of non-operational building systems	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Materials and resources (during construction)	Construction waste management, including: Keep building materials dry Seal unnecessary openings in the partially constructed building Ventilate activity sites and building when needed Require VOC-safe masks for workers installing VOC-emitting products for either the interior or exterior Reduce construction dust Use wet sanding for gypsum board assemblies Avoid combustion equipment indoors Sort waste for reclaim and reuse by the manufacturer, recycling and landfill Hazardous wastes to be kept separated from general waste Reuse salvaged material at the site, where available Educate the workers on waste prevention goals and handling and storage of materials Co-ordinate delivery of materials between contractors to ensure correct amount of each material is ordered, supplied and arrives at the optimum time and place	Reduced impact on site Increased indoor environmental quality of building	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Indoor environmental quality	Ceiling fans	Enhanced cooling effect to increase indoor thermal comfort	(Kibert, 2008) e.g. Audubon Center

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for references)
Indoor environmental quality Energy efficiency	Carbon dioxide sensors used as an indicator of how many people are in the building for control of fresh air intake	Increased indoor air quality Increased energy efficiency	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Indoor environmental quality	Reduction in the use of building materials with volatile organic compounds (VOCs)	Increased indoor air quality	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Indoor environmental quality	HVAC system design	Control indoor air quality by limiting contaminant circulation Control thermal conditions	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Indoor environmental quality	Selection of adhesives, sealants and finishes with low volatile organic compounds (VOCs)	Control indoor air quality by limiting contaminant introduction	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)
Indoor environmental quality	Control of building materials and contents to limit or eliminate off gassing and the production or release of solid particles	Control indoor air quality via control of contaminant generation	(Kibert, 2008)
Indoor environmental quality	Positioning of areas within the building design (e.g. conference rooms remote from elevator machine rooms, chiller rooms etc) or Insulation between spaces or dampening applied to space surfaces	Control of sound and noise transmission	(Kibert, 2008)
Indoor environmental quality	Choice of lighting systems	Lighting quality	
Indoor environmental quality	Sound transmission class levels for the building envelope	Increase occupant acoustic comfort	(Kibert, 2008)
Indoor environmental quality	Noise attenuation in the structure and insulation of primary spaces from impact noise	Increase occupant acoustic comfort	(Kibert, 2008)

Table 5 (continued): Examples of non-residential building features, systems and procedures designed for a sustainability-related intended impact

General Sustainability Design Aspect	Sustainability Feature, System, Strategy or Procedure	Intended Sustainability-Impact	Example for Reference (see Table Notes for references)
Indoor environmental quality	Interior design for appropriate ambient noise levels	Increase occupant acoustic comfort	(Kibert, 2008)
Indoor environmental quality	Design to mitigate mechanical and plumbing system noise	Increase occupant acoustic comfort	(Kibert, 2008)
Indoor environmental quality (after a natural disaster) Materials and resources (after a natural disaster) Societal impacts (after a natural disaster)	Passive survivability may include the following building design features, systems and procedures: Storm resilient buildings Limit building height High-performance envelope Minimize cooling loads Provide natural ventilation Incorporate passive solar heating Natural day-lighting Solar water heating Photovoltaic power Configure heating equipment to operate on PV power Store water onsite Install composting toilets and waterless urinals Provide for food production in the site plan Etc.	Occupant survivability in the wake of natural disasters Allowing for faster recovery after a disruption or disaster	(Kibert, 2008), (NIBS, 2010)
Societal impacts (during construction) Siting and landscaping (during construction) Indoor environmental quality (at commissioning)	Construction health and safety plan including: Separation and protection of occupied areas from construction areas Protection of ducts from dust, moisture, particulates, volatile organic compounds and microbes associated with construction and demolition activities Increased ventilation or exhaust at the construction site Scheduling activities that will produce volatile organic compounds in order to eliminate exposure of absorbent materials A flush-out period (using outside air for a minimum of 20 days) of the new building before furniture, fittings and equipment are installed	Increased awareness and education of workers in relation to changes in practices Reduced impact on site Increased indoor environmental quality of building Bring about change in behaviour and practices through education	(Kibert, 2008), (Keeler and Burke, 2009), (Yudelson, 2009)

Table 5 Notes for examples of existing buildings:

- Audubon Center, a children's educational building in Debs Park, near Los Angeles (Kibert, 2008)
- Audubon House, renovated in 1992, New York City (Kibert, 2008)
- Rinker Hall at the University of Florida (Kibert, 2008)
- Jubilee Campus, University of Nottingham, England built in 1999 (Kibert, 2008)
- Hard Rock Hotel & Casino, Las Vegas, Nevada (Kibert, 2008)
- San Francisco Federal Building, San Francisco, California (Kibert, 2008)
- Forensic Science Center, Philadelphia, Pennsylvania (Kibert, 2008)

9. SELECTED EXAMPLES OF BUILDING SUSTAINABILITY DESIGN SOLUTIONS

Following are a selection of examples of sustainability design building features, systems and procedures, listed in terms of sustainability design aspects and presented with a brief discussion of potential unintended fire-safety consequences or potentially beneficial fire-safety impacts.

9.1 Reduced Impact on Surrounding Environment

9.1.1 Site Selection

Location of the building, the landscaping and the sizing of the infrastructure to access the building based on sustainability objectives may have unintended consequences that include:

- Fire Service access to the building that may include (Tidwell and Murphy, 2010):
    - Load-carrying capacity of non-traditional road surface (e.g. permeable concrete etc).
    - Ease of identification of special access-ways intended for emergency access by both the community (to avoid obstructions) and Fire Service personnel.
    - Long hose stretches over open spaces or hard-to-reach spaces (e.g. that may be present in walkable communities, urban villages etc).
    - External access via ladders to a building with shading structures (awnings, external louvers, shading ledges over windows and walls, use of vegetation close to or climbing on the walls etc).
- An increased external vegetation and wildland-urban interface concern due to the proximity and amount of vegetation relative to a building of some landscaping and building-shading approaches – e.g. trees located close to a building, mulch in gardens adjacent to a building (Ailworth, 2008), climbing vegetation located on external walls etc (Tidwell and Murphy, 2010).

9.1.2 Onsite Blackwater/Sewerage Treatment Systems

When blackwater systems are present on a site, unintentional consequences may include:

- Overloading the system with runoff from firewater, either forwards through the system or backwards could potentially cause an unintentional biological hazard.
- Mechanical breakage of the system during Fire Service operations (e.g. location of a Fire Service vehicle over the top of a submerged treatment system or pipes etc) may release biologically-hazardous materials.
- Mechanical breakage of the system during a partial collapse of the building that allowed the release of materials used could pose a biological hazard.

9.1.3 Greywater Systems

Greywater systems may pose similar unintentional fire-safety-related consequences as blackwater systems, with a potentially lessened biological hazard level (Section 9.1.2). However, the greywater systems require integrated cisterns, pipes and carry non-potable water from where it is waste to where the greywater is used, or treated and then used, elsewhere within the building and therefore there may be more locations for potential mechanical breakage of the system (Tidwell and Murphy, 2010). There is also the possibility of the practical use of greywater in firefighting operations, which would need to be determined before a fire event, constantly monitored to determine appropriateness with greywater outlets clearly marked to indicate that they are appropriate for use in firefighting operations.

9.1.4 Stormwater Retention Systems

When stormwater is retained on site for either use within the building or for landscaping purposes, unintentional fire-safety-related issues may include:

- Difficulties containing contaminated fire-water at the site to reduce the unintentional release of fire products into the local waterways or groundwater.
- Underground cisterns that may pose a collapse threat (e.g. if a vehicle was accidently located on top of it etc) (Tidwell and Murphy, 2010).
- Rooftop water tanks may change expected reaction of the building to fire because of high loads, increasing demands on structural design (Tidwell and Murphy, 2010).

9.1.5 Pervious Concrete and Asphalt for Paved Surfaces

Concrete or asphalt can be designed to be pervious or can be cast into open-web pavers to allow water to infiltrate into the ground underneath. This is applied for reduction in stormwater infrastructure and minimising the impact on local ecology and hydro-period of the site. (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008; Johnston and Gibson, 2008) Subsequent unintended fire-related changes may include:

- Behaviour of pool fires on the pervious surface.
- Release of fire-water to the surrounding environment before it can be dammed.
- Vehicle accessways that are not rated for Fire Service vehicle weights or clearly identifiable (by both Fire Service personnel and the community, to reduce the likelihood of obstructions) (Tidwell and Murphy, 2010).

9.1.6 Rooftop Garden/Green Roof/Eco-Roof

Rooftop garden systems use multiple layers, from the bottom (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008; Johnston and Gibson, 2008):

- Insulation layer (optional).
- Waterproof membrane.
- Root barrier.

- Drainage layer.
- Water retention layer.
- Filter fabric.
- Soil mix.
- Plants.

Extensive rooftop gardens are low-maintenance, drought-tolerant, self-seeding vegetated roof covers. The garden typically consists of vegetation that is native to semi-dry grassy conditions or rocky surfaces, such as alpine environments. They can be placed on pitched roofs with up to a 40% slope (Kibert, 2008; Johnston and Gibson, 2008).

Intensive rooftop gardens require a higher load-bearing capacity than extensive rooftop gardens. Intensive rooftop gardens may include lawns, bushes, trees ponds and terraced surfaces (Kibert, 2008; Johnston and Gibson, 2008).

Unintended fire-safety related impacts may include:

- Reaction of structure due to increased roof insulation during fire, changes in potential ventilation routes under the roof, potential change in expected timing and geometry of collapse due to higher mass on the top of the structure and a higher centre mass of structure compared to traditional construction (Tidwell and Murphy, 2010).
- Unexpected reaction to fire from the underside (therefore testing of the system would be required).
- Reduced thermal indication from rooftop of potential for collapse for firefighters.
- If buildings are at or below ground level, then building design must include vehicle loads and access paths/roads need to be clearly identified (Tidwell and Murphy, 2010).
- Reduction in traditional roof access for firefighters and access hatches/openings may be required to be included in the design (Tidwell and Murphy, 2010).
- Potential loss of growth media, e.g. when saturated with water, may require parapets to protect the areas below the green roof (Tidwell and Murphy, 2010).

9.1.7 Refrigerant Selection

Ammonia gas and newer refrigerants used in HVAC and refrigeration systems may have unintentional fire-safety consequences that include (Tidwell and Murphy, 2010):

- A need for changes in strategies in emergency response to a fire event in the building for different types of refrigerants.
- Different needs for personal safety protection for responders, depending on the type of refrigerants present.

9.2 Increased Energy Efficiency – Reducing Heating/Cooling Load

9.2.1 Earth-to-Air Heat Exchangers as Part of a Passive Cooling Design

Cool air brought into the building through underground metal ducts (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008) may have the following unintended effect concerning fire-safety:

- Mechanical breakage of the air ducts that may provide additional paths for transport of:
    - Smoke through the building.
    - Oxygen to the fire.

9.2.2 Passive Cooling Design

One disadvantage of a passive cooling strategy is that the mechanical plant will be unable to cope with extreme weather conditions (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008). An effect concerning fire-safety may include:

- Unexpected usage of the building systems and appliances by the occupants that may overload those systems or change ventilation paths within the building that will subsequently impact either fire start hazards or fire and effluent spread during a fire event.

9.2.3 Radiant Cooling

Radiant cooling is the circulation of cooled water in floor, wall and/or ceiling elements or panels to cool the building spaces, instead of moving cooled air. Direct ground coupling uses groundwater for radiant cooling of the building. There are three applications of this concept in use (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008; Johnston and Gibson, 2008):

- Concrete core (plastic tubes in floor and ceiling slabs).
- Metal panels (metal tubes connected to aluminium panels).
- Cooling grids (plastic tubes embedded in plaster or gypsum).

These applications may have an unintended positive effect on the fire-safety aspects of a building, however implications that would need to be assessed include:

- Actual application of the changes to the building components.
- Influence of design guidelines for buildings with this installation (e.g. the building to be well sealed, how large surface areas to aid heat transfer are implemented etc).
- Potential impacts of a dry system (i.e. if the system was decommissioned etc).
- Potential impacts of a broken system (e.g. due to non-fire-related causes before a fire, because of the fire, during firefighting operations etc).

9.2.4 Geothermal Heating

Geothermal heating of the building or use within building operations may entail piped geothermally-heated water. The temperature of this water may be approximately 80°C (Stothart, 2011). Unintended fire-safety consequences may include:

- Accidental mechanical metal damage of the pipes may lead to thermal burns of occupants or Fire Service personnel.
- Depending on the chemicals present, heated water could have a negative effect in some fire events.

However, positive fire-safety related issues could include an additional water source that may need to be assessed for the appropriateness of Fire Service use in the context of the specific building and intended usage of the spaces, and then monitored and clearly marked.

9.2.5 Building Thermal Envelope Design

Building thermal envelope design includes such applications as (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008; Johnston and Gibson, 2008):

- Increasing wall insulation.
- Decreasing thermal conductance.
- Reducing the thermal mass of the exterior surface.
- Increasing the thermal mass of the interior surface.
- Ventilating facades to carry away energy absorbed from the sun (in warmer climates).
- Increasing the reflectivity of the roof:
    - E.g. a "self-washing" white shingle, which leads to the question of how the traction changes in terms of standing on these new roofing materials during firefighting operations. (It is to be noted that manual roof venting strategies that require firefighters to be located on a roof are more common in US firefighting operations than NZ.)
- Increasing the thermal resistance of the roof.

Unintended effects concerning fire-safety aspects of a building design may include:

- The potential effect of the increased thermal insulation on the fire, such as delayed window breakage and/or fallout, increased thermal mass of interior surfaces and re-radiation etc.
- Decrease or concealment of the thermal notification of a fire through the building envelope systems.
- Changes in construction response when exposed to a fire because of the materials used and the way they are used in the building envelope systems.
- Changes in expected smoke and flame spread within the building envelope systems (i.e. cavities, voids and venting of the façade).

- Potential changes to firefighting equipment needed to cut through construction to access the internal cavities, voids and venting paths within the building envelope systems.
- Potential changes to roof surface, e.g. use of metal layer to increase reflectivity.

9.2.6 Laminated Glass

Laminated glass may be incorporated into a building with the intent of capitalising on the natural light and sound damping properties. Laminated glass may be used within the building for floors, stair treads, internal walls etc. Unintended effects on building fire-safety may include:

- The potential impact of increased thermal insulation on the fire, such as delayed window breakage and/or fallout, increased thermal mass of interior surfaces and re-radiation etc.
- Potential changes to firefighting equipment needed to create building access through the system and appropriate identification of the system to notify emergency workers (Tidwell and Murphy, 2010).

A benefit from delayed window breakage may include reducing potential fire spread to other buildings.

9.2.7 Multi-Pane Glazing

Multi-pane glass may be incorporated into a building with the intent of capitalising on the natural light and insulation properties as part of the building envelope. Unintended fire-safety-related consequences may include:

- The potential effect of the increased thermal insulation on the fire, such as delayed window breakage and/or fallout, increased thermal mass of interior surfaces and re-radiation etc (Shields et al, 1997).
- Potential changes to firefighting equipment needed to create building access through the system and an appropriate identification method to notify emergency workers of the presence of the system (Tidwell and Murphy, 2010).

A fire-safety benefit from delayed window breakage may include reducing potential fire spread to other buildings.

A series of small and large-scale tests have been completed on the transmission of radiant energy and window breakage characteristics of seven types of multi-plane glazing samples, with the focus of assessing the potential impact of life safety associated with radiant transmission (Klassen et al, 2006). The samples included double-pane and triple-pane systems with a laminate interlayer and tempered glass. In general, the total transmittance, back-side temperature and back-side heat flux were lower for the triple-pane samples than for the double-pane samples (Klassen et al, 2006). Single-pane samples were not included in this study for comparison. The general indications were consistent with other investigations of single and multi-pane float glass and more recent investigations of multi-pane tempered systems with a laminated interlayer (Shields et al, 1997; Klassen et al, 2010). Therefore such systems may be used in the context of a fire-safety design to reduce thermal exposures of the occupants and contents of spaces. On the other hand, time to compartment ventilating by way of glass breakage may be significantly extended depending on the specific glazing system.

9.2.8 Rooftop Garden/Green Roof/Eco-Roof

(See Section 9.1.6)

9.2.9 Cavity Walls

Cavity walls are being promoted as one possible solution to achieving thermal insulation (limiting thermal bridging (Butcher, 2011)) and air-tightness (limiting thermal bypass (Butcher, 2011) and increasing weathertightness (Bassett and McNeil, 2005)) targets. This type of construction has been used prior to sustainability applications. However, it is important to note if there are any changes when achieving thermal insulation and air-tightness that would potentially have unintentional consequences for the fire-safety design of the building, such as changes in potential smoke travel paths, thermal notification of the extent of fire spread (for the Fire Service personnel) from the exterior of the building, and types of fires, spread of fire and the best suppression techniques for fires in these concealed spaces.

9.2.10 Double-Skin Glass Façade

Double-skin glass facades refer to construction consisting of the first layer of cladding being full-height glass curtain-walls and an outer glass façade, with a ventilated cavity between the inner and outer glass layers. The sustainability-related intention of the ventilated cavity is to reduce the solar gain of the building. The cavity is either naturally or mechanically-assisted. Air in the cavity is heated and removed via venting of the space, to reduce the solar thermal load received through the full-height windows (Ding et al, 2005).

Concerns about the fire-safety of this type of construction have been previously raised, e.g. (Chow and Hung, 2006). Unintended fire-safety consequences may include:

- Potential vertical fire spread between the floors with full-height windows for the inner layer of the façade.
- The depth of the cavity may be influential on the time to glass breakage of the window panes located above the fire room, as indicated by preliminary testing and modelling (Chow and Hung, 2006; Stec and van Paassen, 2002).
- The applications of materials, such as tempered glass, for use as spandrels.

9.2.11 Solar and Thermal Insulation for Windows

Low-emissivity and reflective coatings for windows as part of a building thermal envelope design may be associated with such unintended fire-safety related consequences as:

- Coatings may change glass breakage by holding broken glass together for longer.
- Retrofitted coatings may interfere with firefighter use of windows for search, whereby the tinting obstructs view into room and venting, holding broken glass for longer during breakage.

- Low emissivity glass coatings may interfere with firefighter wireless communication devices.

9.2.12 Insulation

Insulation, either retrofitted or installed in new construction, must be tested and appropriate for the application, since it is known that different types of insulation exhibit different behaviour, e.g. for the same timber-frame wall system exposed to a standard fire test (EN1995-1-2), a glass wool insulation was reported to melt at approximately 430 to 450ºC and was completely lost by 650ºC, whereas a mineral wool was reported to start to shrink at approximately 700ºC and be about 60% of the original volume by 800ºC (Takeda and Kahsay, 2006, Just, 2010). Similar observations have also been reported for sandwich elements (Fontana and Frangi, 2005). Furthermore, ceiling assembly experiment results have been reported that indicate mineral wool batts and cellulose fibre insulation may provide an increase in fire resistance, but glass wool batts may lead to reduced fire resistance (Sultan and Lougheed, 2002). Heat resistant glass wool has also been investigated (Coray and Hug, 2008).

Unintended consequences from the installation of untested systems (including framing, cladding, geometry and orientation) with the intended insulation used for an inappropriate application may include:

- Unexpected performance of wall, ceiling or floor systems during a fire event.
- Inadvertent introduction of combustible materials into concealed spaces.
- Changes in ventilation paths through cavity walls and concealed spaces.
- Changes in irritant and toxic properties of fire effluent (Tidwell and Murphy, 2010).
- Foam facades may not be structurally sound (Tidwell and Murphy, 2010) and may provide paths for external fire spread (e.g. fire incidents including the 2009 Monte Carlo fire in Las Vegas, 2007 Borgata Water Club fire in Atlantic City and 2009 Mandarin Oriental Hotel fire in Beijing).
- Buildings under construction may not have all of the fire-protection in place for the foam insulation (Tidwell and Murphy, 2010) and uncovered insulation may contribute to different fire scenarios than considered for the finished design.

9.3 Increased Energy Efficiency – Onsite Energy Production

9.3.1 Fuel Cells and Associated Equipment

Fuel cells are being specifically design for building use. The associated equipment required for use of fuel cells to generate a building’s electricity includes (Kibert, 2008):

- Reformer:
  - For extraction of hydrogen from a source, e.g. natural gas or LPG.
- Storage:
  - For the source of hydrogen and oxygen.
- Fuel cell:
  - For combination of hydrogen and oxygen.

- Power conditioner:
    - For converting fuel cells' output to the type and quality required for the building.

Unintended fire-safety related consequences may include:

- Additional fuel load to the building from the flammable gases (Tidwell and Murphy, 2010).

9.3.2 Building-Integrated Photovoltaic Cells

A photovoltaic system has many points at which the power may be considered to be shut-off, yet components of the system may remain powered. The safest point of power shutdown would be internal to the photovoltaic panel, however currently available panels do not have this feature. The next best point for power shut-off is at the invert and the building power system should be designed to automatically shut down upon loss of power to the inverter. (Tidwell and Murphy, 2010; Matthews, 2011) Unintended fire-safety-related consequences may include:

- Electrical impact on firefighters and firefighting equipment caused by breakage of cells or by the fire event or firefighting operations.
- Electrical impact on firefighters and firefighting equipment caused by breakage of a still-live system.
- System not being fully powered at night may not become evident until automatic powering of the system when exposed to sunlight or when cell coverage changes (e.g. if the fire event had started the night before and then sunlight conditions changed at dawn etc).
- Photovoltaic cells built into glass openings may change glass breakage during the fire by holding broken glass for longer.
- Photovoltaic cells built into glass openings may also change the difficulty of firefighters breaking glass to intentionally form openings during search and rescue or firefighting operations.
- Photovoltaic cells built into building materials may interfere with firefighter wireless communication devices.
- Depending on how the photovoltaic cells are integrated into the systems (i.e. roof and wall etc) there may be the need to have the fire rating tested for the systems with the photovoltaic cells mounted within the other building components (Tidwell and Murphy, 2010) or be proven to be nonprejudical to the fire rating performance of the building component they are mounted to, in combination with appropriate tested flame spread ratings.
- For large coverage areas on a roof, access may need to be designed for Fire Service and ventilation operations (Tidwell and Murphy, 2010; CDF&FPOSFM, 2008).
- Retrofitted systems need to be considered in terms of structural loads during fire exposure and potential collapse (Tidwell and Murphy, 2010).

9.3.3 Wind Turbines

A wind turbine power generation system may include unintended fire-safety-related consequences such as:

- The system needs to be equipped with automatic and manual power shutdown at the inverter and a breaking system for the blades (Tidwell and Murphy, 2010).
- Retrofitted systems need to be considered in terms of structural loads during fire exposure and potential or partial collapse of the supporting structure (Tidwell and Murphy, 2010).

9.3.4 Battery Storage

Battery storage systems may include unintended fire-safety-related consequences such as (Tidwell and Murphy, 2010):

- Normally-generated gases during charging cycles (e.g. hydrogen generation in lead acid batteries) may be flammable and normal ventilation design may not take into account a building fire event.
- Mechanical or fire damage of the batteries may release acid that is corrosive and toxic:
    - Exposure to these materials may be a contact and/or inhalation hazard.
    - Application of water to these materials may cause a rapid chemical reaction.
- A large installation storage capacity may be sufficient to create shock hazards for personnel or equipment.

9.4 Increased Energy Efficiency – Using Other Systems

9.4.1 Photo-Sensor Controlled Lighting

Photo-sensor controlled lighting, as part of an advanced daylighting design, that throttles and dims lighting to compensate for levels of natural light and turning lights on and off in response to the presence of occupants (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008) may have unintended fire-safety related effects concerning:

- The reaction of the photo-sensors to viewing a fire:
    - In terms of control of lighting for occupants who are evacuating.
- The reaction of the control system:
    - In terms of, for example, external louvers being forced open or removed for firefighter visibility into the building and access for operations.

9.4.2 Solar Water Heater

Solar water heating systems may have similar potential issues to roof-mounted photovoltaic cells (Section 9.3.2) and unintended fire-safety-related effects may include:

- For large coverage areas on a roof, design for Fire Service access and ventilation operations may be required.
- The systems may need to have the same tested fire rating as the building components they are integrated within (Tidwell and Murphy, 2010) or to be proven to be nonprejudical to the fire rating performance of the building component they are mounted to, in combination with appropriate tested flame spread ratings.
- Retrofitted systems need to be considered in terms of structural loads during fire exposure and potential collapse.

9.4.3 Tankless Water-Heating Systems

Tankless water-heating systems may introduce unintended fire-safety-related effects concerning:

- For gas tankless water heating systems, a standing pilot light is needed, which introduces additional potential ignition sources to the building.
- For electric tankless water heating systems, a high energy input is required at the heating element. Units may need a three-phase power supply. This may introduce additional potential ignition sources to the building and potential additional hazards during firefighting operations, if the power cannot be shut off.

9.5 Energy Efficiency – Reduced Embodied Energy in Initial Materials/Products, Construction Practices and Maintenance Requirements

9.5.1 Bio-Based Polymers

Bio-based plastic products are manufactured from renewable resources (such as agricultural products, e.g. sugar beets, cassava and wood (Bowyer, 2010)) instead of petroleum. For example (Kibert, 2008):

- BIOBALANCE polymers, from Dow Chemical, that are advanced polyurethane polymers designed to be used as commercial carpet backing.
- WOODSTALK™ (also from Dow Chemical) is an alternative for medium-density fibreboard (for millwork, cabinetry and shelving) made from formaldehyde-free polyurethane resin and harvested wheat straw fibre.
- BioBase 501 is a low-density, open-cell polyurethane foam insulation made in part from soybeans.
- Hemicellulose-based hydrogels, developed by the Royal Institute of Technology in Stockholm, Sweden, are made from wood.

Subsequent unintended fire-safety related changes may include:

- Fuel load of structure.
- Fire growth characteristics.
- Reaction to fire exposure fire when incorporated into building systems.

9.5.2 Plastic and Recycled Plastic Building Products

Postconsumer plastics (particularly high-density polyethylene, HDPE and polyethylene terephthalate, PET) are being recycled into a range of building products, including plastic lumber (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008; Johnston and Gibson, 2008). Unintentional fire-safety related consequences may include changes to the:

- Fuel load of structure.
- Fire growth characteristics.
- Reaction to fire exposure fire when incorporated in building systems.
- Yields of irritant and toxic fire effluent and visible smoke.

9.5.2.1 Plastic Lumber

Plastic lumber can be manufactured from a range of plastics, including high-density polyethylene (HDPE), low-density polyethylene (LDPE), polystyrene (PS) or polyvinyl chloride (PVC). However, the plastic recommended from a sustainability perspective is postconsumer HDPE (Platt et al, 2005). This product can have a very high durability, resistance to rot, insects and saltwater damage, and a lifetime of hundreds of years (Kibert, 2008; Platt et al, 2005). Non-load-bearing applications for plastic lumber include decking and fencing. High-load-bearing plastic lumber products, such as fibreglass-reinforced plastic and polystyrene-polyethylene blends, are also available and have been used as railroad ties and bridge supports (Platt et al, 2005). Unintentional fire-safety related consequences may include changes to the:

- Fuel load of structure.
- Fire growth characteristics.
- Reaction to fire exposure when incorporated in building systems.
- Yields of irritant and toxic fire effluent and visible smoke.

9.5.2.2 Interior Panels from Recycled Copolyester

Interior panels for workstation, trim or toilet partitions made with 40% preconsumer recycled copolyester, e.g. Varia™ (Kibert, 2008), may have subsequent unintended fire-safety related changes that include:

- Fuel load of structure.
- Fire growth characteristics.
- Reaction to fire exposure.
- Yields of irritant and toxic fire effluent and visible smoke.

9.5.2.3 Interior Mouldings from Recycled Polystyrene

Interior moulding profiles made with at least 90% recycled polystyrene, e.g. Timbron (Kibert, 2008), may have unintentional fire-safety related consequences that include changes to the:

- Fuel load of structure.
- Fire growth characteristics.
- Reaction to fire exposure.
- Yields of irritant and toxic fire effluent and visible smoke.

9.5.3 Wood and Wood Products

Wood and wood products are important construction materials that are also attractive from a renewable resource perspective. (Bowyer, 2010) Although wood and wood products are not new to the building industry, increased use and novel uses of these materials may cause unintended changes in:

- Fuel load of structure.
- Fire growth characteristics.
- Flame spread characteristics.
- Reaction to exposure to fire when incorporated in building systems.
- Yields of irritant and toxic fire effluent (especially associated with adhesives etc in wood products) and visible smoke.

9.5.3.1 Bamboo as a Structural Material

Bamboo may be used as a framing material for sustainability objectives related to the use of renewable materials. Bamboo can be used as trusses in walls, floors and roofs or as individual studs (Killough, 2008; Keverling Buisman, 2005). Unintended changes to resulting fire-safety objectives may include:

- Reaction of systems incorporating this material when exposed to fire.
- Fuel load of structure.
- Fire growth characteristics.
- Fire spread characteristics.

9.5.3.2 Engineered Timber/Lumber

Engineered lumber uses tree products and wood by-products (which may include chipboard, oriented strand board and particleboard etc). The size and shape can be engineered to the desired geometry, reducing waste compared to sawn lumber.

Structural Insulated Panels (SIPs) are a type of engineered lumber. SIPs are prefabricated insulated structural elements intended for use in walls, ceilings, floors, and roofs. Advantages of SIPs include high R-values that are more uniform than traditional framed walls with insulation and high strength-to-weight ratios. SIPs consist of a block of foam insulation board, that may be fire-retardant-treated and is commonly made from expanded polystyrene or polyisocyanurate, but can consist of compressed straw, recycled cellulosic waste foam, willow-based polyurethane foam, corn-based foam, soy-based foam etc, that is glued between two sheets of oriented strand board (OSB) using a waterproof construction adhesive (USDOE, 2011, SIPA, 2011, McIntosh and Harrington, 2007). SIPs have been used in construction of houses, apartments and commercial buildings, and may be incorporated as exterior, load-bearing walls and roofs (Harvel, 2010).

The issue of preventing insects and rodents tunnelling through SIPs has also been raised as a large concern. Solutions such as applying insecticides to the panels are suggested and boric-acid treated insulation panels are already available (USDOE, 2011).

Unintended fire-safety changes may include:

- Fuel load of structure.
- Reaction to fire exposure (Tidwell and Murphy, 2010; Blaich, 2009).
- Fire growth characteristics.
- Changes to expected local indicators of danger for firefighters during the fire event (Backstrom and Tabaddor, 2009; Izydorek et al, 2008; Izydorek et al, 2009).
- Yields of irritant and toxic fire effluent (especially associated with adhesives etc in wood products) and visible smoke.
- Influence of insecticide treatments on the combustibility and fire effluent.
- Potential changes in air-tightness of structures (Blaich, 2009).

As an example of the potential hazard posed by engineered lumber, research was conducted at Underwriters Laboratories (UL) (Backstrom and Tabaddor, 2009; Izydorek et al, 2008; Izydorek et al, 2009) specifically to investigate the hazards to firefighters posed by the use of lightweight wood trusses and engineered lumber in roof and floor designs that are increasingly replacing conventional solid joist construction in residential structures in the US, for sustainability objectives among other reasons. UL has released a video demonstration (as part of the education package titled "Structural Stability of Engineered Lumber in Fire Conditions", http://content.learnshare.com/courses/73/187716/player.html) of a test fire in a basement configuration where a representation of first responder was located on the floor above the fire. Thermal imaging equipment located at the representation of first responder indicated the presence of the fire below just before collapse of the floor occurred.

It is noted that fire is a common concern and that some fire-safety solution approaches have included protecting the face of SIPs with a fire-resistant material (USDOE, 2011).

9.5.3.3 Natural Wood Interior Panelling

Wood floors and use of exposed wood panelling, e.g. hospitals in the Seattle, WA region (Gryc, 2011b), may contribute to unintended fire-safety related changes in:

- The building fuel load.
- Fire growth characteristics.
- Flame spread characteristics.
- Yields of irritant and toxic fire effluent (especially associated with adhesives etc) and visible smoke

Fire retardant chemicals may be used to improve fire properties, however these would be expected to be balanced with other sustainability related objectives such as VOC emission influence on indoor air quality etc. Therefore the impact of the selection of fire retardants would also need to be considered in terms of the fire-safety design.

9.5.3.4 Compressed Wheatboard Internal Cladding

Use of renewable materials to replace gypsum board (Kibert, 2008; Johnston and Gibson, 2008), such as compressed wheatboard, may result in unintended changes related to the:

- Fuel load of structure.
- Fire growth characteristics.
- Flame spread characteristics.
- Reaction of systems to fire exposure fire.

9.5.3.5 Recycled Paper Composite Interior Panels

Use of recycled paper in building materials, for example, a solid composite water-resistant material made from postconsumer paper PaperStone™ (Kibert, 2008), may contribute to unintended fire-safety-related changes concerning:

- Fuel load of structure.
- Fire growth characteristics.
- Flame spread characteristics.
- Reaction of systems to fire exposure fire.

9.5.4 Concrete Content

Concrete is a commonly-used building material that also has attributes related to sustainability such as high strength, thermal mass, durability and high reflectance, is generally locally available, can be used without either interior or exterior finishes, does not off gas or affect indoor air quality, is readily cleanable and is resistant to insect damage and fire. However, cement production is associated with high carbon dioxide emissions. Therefore cement is replaced, at least partially, with other cementitious materials such as fly ash (replacing more than 30%) or blast furnace slag (replacing more than 35%) (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008).

Similarly, recycled concrete aggregate can be substituted for up to one-third of the virgin aggregate in concrete mixes in the Netherlands (Kibert, 2008; Johnston and Gibson, 2008).

The use of such partial replacement materials has been associated with increases in various aspects of concrete performance. However, there may be unintended changes in such fire-safety-related aspects as:

- Reaction of systems with exposure to fire.
- Cement thicknesses required to provide standard fire ratings.

9.5.5 Lightweight Construction

Intentionally reducing the amount of materials used in construction in order to reduce the sustainability impact of the building, for example by re-sizing steel or concrete components, may have unintentional consequences related to the:

- Reaction of systems with exposure to fire (Tidwell and Murphy, 2010) such as:
    - Potential early collapse of building elements.
    - Unexpected movement of building elements.

9.6 Increased Energy Efficiency – Reduced Embodied Energy through Construction Practices

9.6.1 Construction Procedures

Construction procedures may change, for example to protect intended building components from being contaminated with particles, water or emissions that would then be inadvertently introduced into the building to adversely affect the indoor air quality (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008; Johnston and Gibson, 2008). Such procedures may change how building materials and components are stored, e.g. keeping materials stored in dry, covered spaces near to the construction. This may lead to unintended fire-safety related effects concerning:

- Changes in fire hazard potential during the construction phase, such as:
    - How additional temporary space for pre-construction storage of materials and components is handled and adapted throughout the expectedly dynamic and sometimes unexpectedly changeable stages of construction, and how aware the occupants of this temporary and changeable space are of their surroundings, emergency detection and notification, and potential escape opportunities.

9.6.2 Design for Deconstruction and Disassembly

In order to maximise the reuse, repurposing and recycling of building materials and products at the end of the building's useful life, intentional design of deconstruction and disassembly into components is recommended. Examples of this type of design include bolted steel frame connections that are exposed and easily accessible (Rinker Hall, University of Florida) and a "zippering" separation system between the backing and face of Solenium™ textile flooring for ease of dismantling (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008). However this may introduce unintended fire-safety changes in such aspects as:

- Exposure of beams and joints to fire, where shielding coatings and elements are removed or not included in the design.
- Reaction of systems exposed to fire.

9.7 Increased Energy Efficiency – Reduced Embodied Energy through Building Operation/Maintenance

9.7.1 Low-Maintenance External Cladding

Low-maintenance external cladding may have unintended fire-safety related effects concerning:

- Potential differences in terms of Fire Service access to concealed spaces for suppression, such as:
    - Possibility of specialised cutting tools for accessing concealed spaces through the cladding.

9.8 Increased Water Efficiency

9.8.1 Blackwater, Greywater and Reclaimed Water

The capture, processing and use of reclaimed water for non-potable purposes may pose a risk of unintended exposure of firefighters or building occupants to non-potable water during an event that results in damage or failure of the reclaimed water infrastructure (e.g. piping, storage or treatment plants) or use of the reclaimed water in firefighting operations, as discussed previously in Sections 9.1.2, 9.1.3 and 9.1.4. Therefore in summary, unintentional fire-safety consequences may include:

- Potential overloading of the system with runoff from firewater, either forwards through the system or backwards, could cause an unintentional biological hazard.
- Underground cisterns that may pose a collapsing threat (e.g. if a vehicle was accidently located on top of it etc) (Tidwell and Murphy, 2010).
- Rooftop water tanks may change expected reaction of the building to fire because of high loads (Tidwell and Murphy, 2010).
- Mechanical breakage of the system during Fire Service operations (e.g. location of a Fire Service vehicle over the top of a submerged treatment system or pipes etc) may release biologically hazardous materials.
- Mechanical breakage of the system during partial collapse of the building that allows the release of materials used in the system which could pose a biological hazard.

However, where the potential exposure of people to pathogens has been identified before the intended application and therefore can be appropriately managed during the event and operations, grey (non-potable) water might be useful in firefighting operations. This would need to be identified as part of the building design (long-prior to a fire event) and would require ongoing maintenance and monitoring of the system (to ensure the fitness for use), and be clearly marked for Fire Service use. However, blackwater would not be appropriate for such purposes.

9.9 Increased Indoor Environmental Quality – Daylighting/Natural Lighting

9.9.1 Slanted and Shaped Ceilings

Slanted and shaped ceilings in rooms, as part of an advanced daylighting design (Keeler and Burke, 2009, Yudelson, 2009, Kibert, 2008, Johnston and Gibson, 2008), may have such unintended fire-safety related effects as:

- Ensuring such geometry is included in the fire-safety engineering design and analysis, as it would affect:
    - Conditions estimated at locations above the floor, as used in tenability assessments etc.
    - Response of fire detectors.
    - Potential shielding of the fire from sprinklers.

9.9.2 Core Daylighting, Natural Light Wells and Atria

Smoke control in atria has been a known hazard in buildings (Klote, 1994; Milke and Klote, 1998; Morgan et al, 1999; Hinkley, 1988). Therefore atria and other similar geometries that form vertical paths between floors that are designed or retrofitted with other objectives at the fore of the design process (Chow and Chow, 2005; Gryc, 2011a), have a potential to introduce unintended fire-safety hazards.

Core daylighting, e.g. using a central well or atrium etc as part of an advanced daylighting design (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008; Johnston and Gibson, 2008), may have unintended fire-safety related effects concerning:

- The introduction of vertical openings for smoke travel and fire spread between floors.
- An increase in the number of fuel-controlled fires in large open spaces of buildings that the Fire Service may need to incorporate into equipment, strategy and training planning considerations (Tidwell and Murphy, 2010).
- Windows, used for thermal control and energy conservation, associated with large spaces need to be integrated with fire alarm systems and be available for control during fire fighting operations (Tidwell and Murphy, 2010).

Solutions for problems dealing with evacuation where an atrium is included in the design include suggestions of increasing the number of exists (that may have security implications) and/or installation of a smoke management system (e.g. Chow and Chow (2005), Wang (2011)). There may be several fire-safety solutions to the atria design, the question would be for which building design objectives to optimise while identifying other design objectives that may be inadvertently impacted.

9.9.3 Glass Interior Walls

Glass interior walls used to increase daylight in central spaces within the building, as part of an advanced daylighting design (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008), may have unintended fire-safety related effects concerning:

- Changes in fire spread between compartments.

- Changes in fire ratings of systems between compartments, e.g. if fire resistant glazing is used as a potential solution required fire ratings might be able to be achieved, however the insulating rating may still be an important consideration and may need a broader reaching design solution.

9.9.4 Reflective Roofing on Sawtooth Clerestories as Part of an Advanced Daylighting Design

Reflective surfaces as part of a roofing system that are intended to be used for increased lighting quality of internal spaces may have unintended fire-safety related effects concerning such as:

- Potential slippery surfaces for walking on during firefighting operations. (Again, it is to be noted that manual roof venting strategies that require firefighters to be located on a roof are more common in US firefighting operations than NZ. However there may be other reasons to manually access these locations, depending on the building design, the fire event and the associated needs for suppression and rescue operations.)

9.9.5 Extended Windows as Part of an Advanced Daylighting Design

Window size increased to capitalise on available natural light in external areas that are shaded or shielded from sunlight, e.g. due to an adjacent property wall etc, may contribute to unintended fire-safety related effects including:

- Increased radiation to other property.
- Potential for external vertical fire spread.

9.9.6 Skylights and Solar Tubes

Skylights (with or without trackers) and solar tubes are intended as part of an advanced daylighting design to deliver additional natural light to spaces using vertical connections from the roof to the space. For example, solar tubes may consist of a length of expandable aluminium foil tubing that extends from the portal in the roof through to the ceiling of one of the floors directly below. Fire-safety design concerns of unintended effects include:

- Introduction of unprotected vertical openings for fire and fire-effluent spread between spaces, including the roof cavity and other spaces the solar tube passes through.

As an example, considering residential detached dwellings in New Zealand, except between an attached garage and other spaces, there are no fire or smoke separation requirements to protect the openings formed to pass the tube from the roof to the space to be lighted (e.g. which may result in directly joining the ceiling space, upper and lower floors of a multi-storey house and a kitchen space to an upper bedroom space etc) (DBH, 2011b). Therefore the level of fire- and smoke-separation relies on the manufacturer's installation instructions, the installer and the owner of the detached dwelling.

Furthermore, there is no direct limitation on the area of the roof that may be a skylight in residential detached dwellings in New Zealand. Any limitation is related to protection of other property in terms of separation distances and percentages of uninsulated areas (DBH, 2011b). In comparison, the Australian Building Code for example, has a provision for skylights containing combustible materials in terms of limitations of the total area of the roof and separation distance (ABCB, 2010a).

9.10 Increased Indoor Environmental Quality – Increased Natural Ventilation

9.10.1 Passive Ventilation Design

Passive ventilation designs may incorporate design features such as a thermal chimney, venturi and windcatchers. These types of building features may have unintended fire-safety related consequences concerning:

- Vertical openings for smoke travel and fire spread between floors.

9.10.2 Location of Buildings to Assist in Air Intake Speeds

Intentional location of buildings on a site to locally increase prevailing wind speeds used at air intakes to the buildings may result in unintended fire-safety effects including:

- Changes to expected external vertical and horizontal flame and smoke spread.

9.10.3 Carbon Dioxide Sensors for Fresh Air Intake Control

Carbon dioxide sensors used as an indicator of how many people are in the building for control of fresh air intake may have unintended fire-safety related effects concerning:

- Increased carbon dioxide sensor levels associated with a fire that is delayed before detection may trigger increases in the building air circulation system and subsequently increase fire effluent transport through internal building spaces before system shutdown as part of an fire detection and alarm system.

9.11 Increased Indoor Environmental Quality – Increased Forced Ventilation

9.11.1 High Volume, Low Speed Fans

High volume, low speed fans are large-diameter fans designed to improve occupant comfort in an energywise manner by mixing the air throughout the space. Unintended fire-safety consequences may include:

- Potential interaction with fire sprinkler systems by obstruction or change in shape of sprinkler spray and/or change in droplet size and geometry (Tidwell and Murphy, 2010; AFEP, 2011).
- Potential interaction with smoke and heat detector activation times.
- Additional forced convection and airflow in non-natural buoyancy directions that may result in unexpected fire spread and may assist fire spread in unsprinklered spaces (Tidwell and Murphy, 2010).
- Potential distribution of cold smoke throughout the space (Tidwell and Murphy, 2010).

9.12 Increased Indoor Environmental Quality – Reduction of Contamination Sources

9.12.1 Adhesives, Sealants and Finishes with Low VOCs

Selection of adhesives, sealants and finishes based on low volatile organic compounds (VOCs) may lead to unintended fire-safety related effects including:

- Fire protection properties for openings and interaction with the surrounding construction, if replacement of sealants in fire separations occurs without testing of the new products in the systems intended for use.
- The reaction to fire, unless the new adhesive products have been tested as a component of the systems to be used in construction.
- Flame spread properties, unless the new finishing products have been tested in the manner in which they will be used.

For example, Kibert (2008) reported that, in general, the VOC emission potential is directly related to the proportion of base resins and solids in the adhesive or sealant. Natural resins typically have a lower VOC emission, whereas synthetic resins have a wide range of VOC emission levels. Water-based adhesives and sealants made from non-toxic components with low VOC emissions are available. Two examples of low VOC emission alternatives on the market include a vinyl adhesive sealant for interior use and an acrylic latex exterior sealant for building joints.

Similarly, Kibert (2008) stated that the finishes available at the time of publishing of his book which had been adapted for low VOC emissions generally do not perform as well as their counterparts, requiring more applications to achieve similar results to their counterparts with higher VOC emissions. Therefore there may be a thicker coating than expected, based on experience with commonly used finishes. In addition, water-based solvents, while having lower VOCs than organic solvents, require additional preservatives and fungicides that can also be hazardous materials. These additives may be released during burning, producing more or different toxic fire effluent and residuals after the fire than expected from previously common finishes.

9.12.2 Particleboard and Plywood

Emissions of formaldehyde are of concern regarding indoor air quality. Adhesives made with urea formaldehyde have higher emissions than phenol formaldehyde. Surface area, temperature, humidity and other compounds can all affect the concentration of formaldehyde emissions (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008; Johnston and Gibson, 2008).

Particleboard made with adhesives containing urea formaldehyde account for approximately 98% of the market (Kibert, 2008). Phenol formaldehyde adhesive-containing particleboard is used in high-moisture environments, such as bathrooms and kitchens. If particleboard is covered and remains separated from occupied space, then the formaldehyde emissions affecting the indoor air quality are low or delayed as long as the separation remains intact. However, formaldehyde is environmentally moderately persistent, taking several months or even years to be broken down. (Kibert, 2008; Johnston and Gibson, 2008)

The finishes or sealants used on plywood may compound the off-gassing of the urea formaldehyde containing adhesive between the plies (Kibert, 2008; Johnston and Gibson, 2008).

Particleboard is commonly used for core materials for doors, cabinets, furnishings, prefabricated wall systems and non-structural elements in wood-framed housing (e.g. floor underlayment etc). Plywood is commonly used for wall and roof sheathing, siding, concrete framework, roof decking and subflooring. Therefore changes to this commonly used construction material or substitution by other materials, would need to be assessed from a number of perspectives as to how fire-safety may be inadvertently influenced.

9.12.3 Carpet, Resilient Flooring and Wall Coverings

Carpet, resilient flooring and wall coverings may contain components with VOC emissions as well as using VOC-emitting adhesives during installation.

Typical elements of a carpet that contain VOC-emitting materials are the adhesives used between one or a number of combinations of fibres and backing, first backing layer and an additional backing layer for strength and stability, and carpet system and substrate. Another consideration of carpet performance relating to indoor air quality is the release of small fibres, for which wool has more of a tendency than synthetic alternatives such as nylon, olefin, polyester and polyethylene terephthalate. (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008; Johnston and Gibson, 2008)

Tile and sheet resilient flooring can be composed of vinyl, rubber or linoleum. Linoleum is a natural biodegradable product, with low VOC emissions, whereas vinyl and rubber flooring may contain plasticisers with higher VOC emissions. However, the main source of VOC emission concern is the adhesive used to apply the tile or sheet to the substrate. (Kibert, 2008)

Alternative wall coverings than paint include paper, fabric and vinyl. Paper coverings contain little or no components that impact indoor air quality; however the adhesives may include the VOC, formaldehyde. Fabric coverings may contain formaldehyde for resistance to fading and water, and may also absorb VOCs only to re-emit them into the space. Vinyl coverings may contain plasticisers that emit VOCs. In all cases the primary potential source of VOC emission is the adhesive used to apply the tile or sheet to the substrate. (Kibert, 2008; Johnston and Gibson, 2008)

As the primary concern regarding indoor air quality in terms of potential sources of VOC emissions for floor coverings is related to the adhesives, then if the adhesives are changed unintended fire-safety related effects may include:

- The ease of ignition and flame spread of products containing the alternative adhesive(s).
- Reaction to fire:
    - If the adhesive fails earlier than the counterpart product, in terms of the covering potentially providing protection or earlier exposure to the substrate construction.
    - If the adhesive fails later than the counterpart product, in terms of providing an insulating barrier by delaying exposure to the substrate construction.

9.12.4 Insulation

Insulation may incorporate a range of adhesives and fibrous materials that impact indoor air quality by emitting VOCs and releasing small fibres. Insulation is typically made from fibreglass, mineral wool, cellulose (recycled wood) or spray foam. (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008; Johnston and Gibson, 2008)

Fibreglass and mineral wool produce small fibres when the product is disturbed. Fibreglass is listed by the International Agency for Research on Cancer as a possible carcinogen (WHO, 2012).

Spray foam has environmental impacts as well as VOC emissions affecting indoor air quality (Kibert, 2008).

Cellulose insulation is generally spray-applied and may be generally considered to be a non-toxic material. (Kibert, 2008; Johnston and Gibson, 2008)

Considering changes in insulation driven by sustainability issues, unintended fire-safety related effects may include:

- The change in fire hazard when cellulosic materials are used as insulation materials in terms of the potential for fire starts and fire load because of the material and also the geometry given the spray application and any settling or movement over time.
- Changes of expected fire effluent flows through construction, where insulation has been retrofitted into cavities and balloon construction (Averill, 2010).

9.12.5 Tobacco Smoke Control

In residential buildings, in order to reduce the impact of tobacco smoke on indoor air quality, one suggestion is to prohibit smoking in common areas and to have all doors to interior corridors weatherstripped to minimise leakage into corridors (Kibert, 2008; USGBC, 2011), From such changes, unintended fire-safety related effects may include:

- Undesirable changes in airflow paths and pressures required for venting to maintain tenability during a fire event.
- Desirable changes in the smoke protection of sections of exitways, depending on the products selected and the specific design.

9.12.6 Ventilation Rate of Internal Spaces

Ventilation rates to occupied spaces correlate to good indoor air quality, therefore increasing the ventilation rate may be used to raise the indoor air quality in a design. (Keeler and Burke, 2009; Yudelson, 2009; Kibert, 2008) This may lead to unintended fire-safety related effects that include:

- High ventilation rates having the undesirable effect of more rapid transport of fire effluent before detection and subsequent shutdown of HVAC systems.

However, flow rate and carbon dioxide monitoring systems – that are required to earn points related to ventilation increasing indoor air quality for some assessment methods (Kibert, 2008), e.g. LEED-NC, Green Globes V1 – may have the desirable attribute of providing multiple points of monitoring at occupant-relevant heights in occupied spaces that could be integrated into a fire-safety system.

9.12.7 Ventilation Intake

Design features and filters are used to limit the entrainment of pollutants in the ventilation air takes (e.g. Green Globes V1) (Kibert, 2008). This may lead to unintended fire-safety related effects that include:

- Design of the HVAC system such that the capacity required to provide the pressures and air flow rates for ventilation of areas (such as exitways) during a fire event may not be achievable.

However, there may be positive unintended fire-safety related effects regarding limiting the contamination of exitways with fire effluent that may be capitalised on through collaboration of the building sustainability and fire-safety design teams.

9.12.8 Indoor Chemical and Pollutant Source Control

To limit the introduction of dirt, pesticides and other materials into a building, devices such as grilles and grates are used (Kibert, 2008). This may lead to unintended fire-safety related effects that include:

- Considering protection against a potential case of arson, depending on the specific design and location, such pollutant catchment devices at building entrances may act inadvertently as a reservoir for accelerants that may change the potential for and extent of pool fires in an exit route.

When hazardous gases and chemicals may be present or used, the area must be segregated and a separate exhaust system must be used (to earn points related to increasing indoor air quality for some assessment methods, e.g. LEED-NC) (Kibert, 2008). This may lead to positive unintended fire-safety related effects that may be capitalised on through collaboration of the building sustainability and fire-safety design teams.

9.13 Increased Indoor Acoustic Quality

9.13.1 Acoustic Comfort

Designing for noise attenuation in the structure and appropriate ambient noise levels may provide positive unintended fire-safety related effects regarding the evacuation notification of occupants, particularly of announcements, that may be capitalised on through collaboration of the building sustainability and fire-safety design teams.

9.14 Building Analysis, Performance and Monitoring

9.14.1 Smart Buildings

Opportunities exist for integration of typical Smart Building features with fire-safety systems, procedures and strategies that would benefit both design and usage perspectives in different ways.

9.15 Sustainability-Induced Changes to Fire-Safety Systems

9.15.1 Halon Replacements

In the context of sustainability design, Halon replacements tend to be described as "complicated" (Kibert, 2008), "not widely understood, relying on proprietary solutions" (Kibert, 2008) and costly. These types of published statements indicate a need exists for improved communication between the perspectives of fire-safety and sustainability designs of potential solutions and associated fire-safety, life safety and potentially, so-far-uncounted, sustainability related contributions not solely associated with Halon replacements, but holistic fire-safety design solutions that may achieve the objectives using a range of fire-safety features, systems, procedures and strategies.

10. IMPACT OF FIRE-SAFETY ON SUSTAINABILITY OUTSIDE OF NORMAL OPERATING CONDITIONS – DURING AND RECOVERY AFTER A FIRE EVENT

The potential for positive impacts of fire-safety design on the sustainability of a building has been investigated in a number of preliminary studies, proposed building assessment methodologies and demonstrations of concept (Robbins et al, 2008; Robbins et al, 2010; Moore et al, 2007; Gritzo et al, 2009; Wieczorek et al, 2010). Following is a summary of a selection of published studies that incorporate various aspects of both sustainability and fire-safety influences when assessing either a building or, more broadly, a type of building stock.

10.1 Sustainability Building Assessment Methodologies for Fire-Safety Aspects During and After a Fire Event

A cost effectiveness analysis was broadened by Robbins et al (2008) to quantitatively include sustainability issues based on a lifecycle assessment (LCA) approach. The study indicated the inclusion of sustainability issues in assessment of the demonstration fire-safety system (home sprinkler systems) provided a broader insight into the overall costs and benefits, including aspects that currently have no monetary equivalent (Robbins et al, 2008).

A building's carbon emission analysis was broadened by Gritzo et al (2009) by the development of a risk factor methodology that included conditions of potential fire and natural hazard risks. Example demonstrations of the application of the proposed methodology indicated that, depending on the level of risk, fire and natural hazards may contribute significantly to a building's lifetime carbon emission total and that mitigation strategies can be designed to reduce these emissions. For example, carbon emissions associated with an extensive fire without effective fire protection in a representative average office building could represent up to 14% of the carbon emissions over the lifetime of the building, whereas in the case of sprinklers being included as one effective fire protection strategy the total carbon emissions were significantly reduced. For all occupancies considered, from residential to high hazard facilities, a lack of effective fire-safety designed into a building statistically increases carbon emissions over the lifecycle of the building. (Gritzo et al, 2009; Gritzo et al, 2011)

A tool for estimating greenhouse gas (GHG) emissions from home fires was developed by Robbins et al (2010) that considers the gaseous emissions of house fires for the New Zealand national housing stock in terms of an equivalent gaseous carbon dioxide yield. The estimation tool was developed to provide comparative results to enable investigation of the potential impact of different fire-safety strategies or fire scenarios (e.g., different timings for Fire Service intervention versus the situation of no Fire Service intervention being available, versus mandatory home sprinkler systems throughout the nation etc). This tool was designed to act as an additional cost effectiveness module, so the cost effectiveness analysis approach previously developed (Robbins et al, 2008) could be further extended to incorporate a broader range of sustainability issues. (Robbins et al, 2010)

Considering fire sprinkler systems as an example, the manufacture and installation of an automatic fire protection system is not a "carbon zero" process (Wieczorek, 2011), however a cradle-to-grave analysis of an automatic fire sprinkler system that incorporates a measure of the likelihood and impact of fire – building on aspects of the methodologies such as those proposed by Robbins et al (2008) and Gritzo et al (2009) – would provide a more complete measure of the costs and benefits of the system in the context of a building's lifetime.

10.2 Selection of Examples of Sustainability of Individual Fire-Safety Aspects

Following is a brief selection of examples of the potential sustainability impact of individual building fire-safety features or systems. This small sample is not intended to be an exhaustive list of potential candidates or to be representative of the range of potential for positive sustainability related impacts of fire-safety building design. Instead, this selection of examples provides a demonstration of some of the potential for assessing the overall value of fire-safety aspects to include fire-safety design objective and sustainability design objectives.

10.2.1 Sprinkler and Fire-Water Runoff

A preliminary study was completed into the impact of fire-water from building fires on the environment recommended prevention, diversion and filtration of that water entering local stormwater systems or other waterways or bodies, especially where the fire-water would undergo little dilution. It was suggested that control of a fire with an effective sprinkler system could reduce the overall environmental impact related to fire-water runoff compared to the reliance on Fire Service intervention alone, based on results from controlled fire exercises. (Moore et al, 2007)

Large-scale experiments were conducted to compare the environmental impact of sprinkler control of a furnished residential living room. Two identically-constructed and furnished mock-up rooms were tested. Fire Service intervention was used to extinguish the fire in both cases. One mock-up was installed with a sprinkler system that controlled the fire until final extinguishment was achieved by the Fire Service. Measurements used to estimate environmental impact included total greenhouse gas production, quantity of water used to extinguish the fire, quality of fire-water waste and mass of materials needing post-fire disposal. The measured values used to estimate environmental impact reported for the sprinklered test were significantly lower than that for the non-sprinklered test. That is the sprinkler system reduced in the environmental impact of the test compared to the non-sprinklered case. (Wieczorek et al, 2010; Wieczorek et al, 2011)

These results continue to provide evidence that fire-safety design can positively contribute to achieving building design sustainability objectives, while also achieving fire-safety objectives.

10.2.2 Photoluminescent Wayguidance Systems in Exitways

Photoluminescent materials store energy when exposed to normal lighting systems and emit this energy as light. When the availability of electrical light is diminished, the photoluminescent materials continue to emit light until the stored energy is depleted. The photoluminescent material is not directly actively powered, needing no wiring or electrical power source and may be in the form of paint, plastic strips or signs.

Results from a study (Proulx et al, 2000) indicated the potential effectiveness of using photoluminescent signs and wayfinding systems as supplemental or replacement of traditional luminaries used in occupant evacuation. Some suggested advantages of photoluminescent systems over traditional electrical emergency systems included continued use during power failure or smoke logging of high-mounted laminated lights. However, one disadvantage of the photoluminescent systems raised was the requirement for the systems to be installed in locations where permanent full lighting is provided to charge the material, the photoluminescent material does not provide as much brightness as lamps and the brightness of the material decreases as the stored energy is emitted as light. Proulx, Kyle and Creak (2000) recommended that more field studies were needed to assess the performance of photoluminescent systems for different types of occupancies and types of occupants. Further in-field simulations have been investigated, (e.g. Proulx and Benichou (2010)), that have been used to develop guidance for the performance and installation of photoluminescent systems (Proulx et al, 2008; Benichou and Burrows, 2010).

10.3 Summary

Unless intentionally integrated into other building systems, the value of fire-safety features, systems and procedures may remain dormant until a fire event for which they are designed. Therefore the sustainability-related value of fire-safety features, systems and procedures, as well as other hazard-mitigation building aspects, may be inadvertently overlooked during the traditional sustainability assessment of a building. However, when an holistic approach is taken to defining the lifetime of a building to include possible events that are outside of intended “operating conditions” then hazard-mitigation building design aspects can provide a significant reduction in the building’s environmental impact.

11. ANALYSIS – FIRE-SAFETY AND SUSTAINABILITY INTER-RELATIONSHIPS

Conflicts, parallels and opportunities for more efficient solutions in resulting building design features, systems and procedures from the perspectives of fire-safety and sustainability, as introduced in the section "Comparison of an Overview of Building Design Assessment from Fire-Safety and Sustainability Viewpoints" are continued to be drawn together in this section.

11.1 Assessment Timeframes

The timeframe used for building sustainability assessment may include one or a number of the building's phases (as shown in Figure 1), such as:

- Planning and design.
- Materials and product manufacture.
- Transport to site of construction materials and products.
- Assembly onsite and clean-up of site (that may be ongoing) before commissioning.
- Intended use of the building, including operations and maintenance.
- Repurposing (which may require additional phases such as planning, partial deconstruction, material and product transport, construction and commissioning before the next intended use phase).
- Deconstruction and/or demolition at the end of the useful life of the building.

Unintended hazards, such as a fire event, are not typically included in the whole lifetime of a building during a sustainability assessment. As proposed in previous preliminary studies (Robbins et al, 2008; Robbins et al, 2010), fire-safety design has the potential to reduce environmental impact during and after a fire event. These approaches to timeframes for sustainability assessments that would include unintended hazards, such as a fire event, are shown schematically in Figure 2. Building designs that eliminate and mitigate hazards and reduce subsequent consequences would change the potential timeframe for the lifetime of a building, reducing the likelihood of a catastrophic outcome (such as Post-Hazard Option A, Figure 2) or, further, reducing the need for repair and/or reconstruction (such as Post-Hazard Option B compared to Option C, Figure 2).

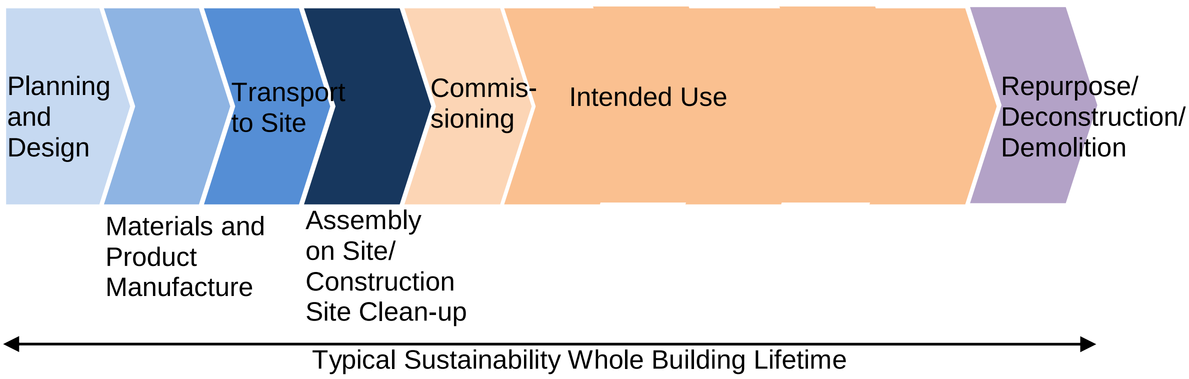

Figure 1: An example of the whole building lifetime that is typically used for building sustainability.

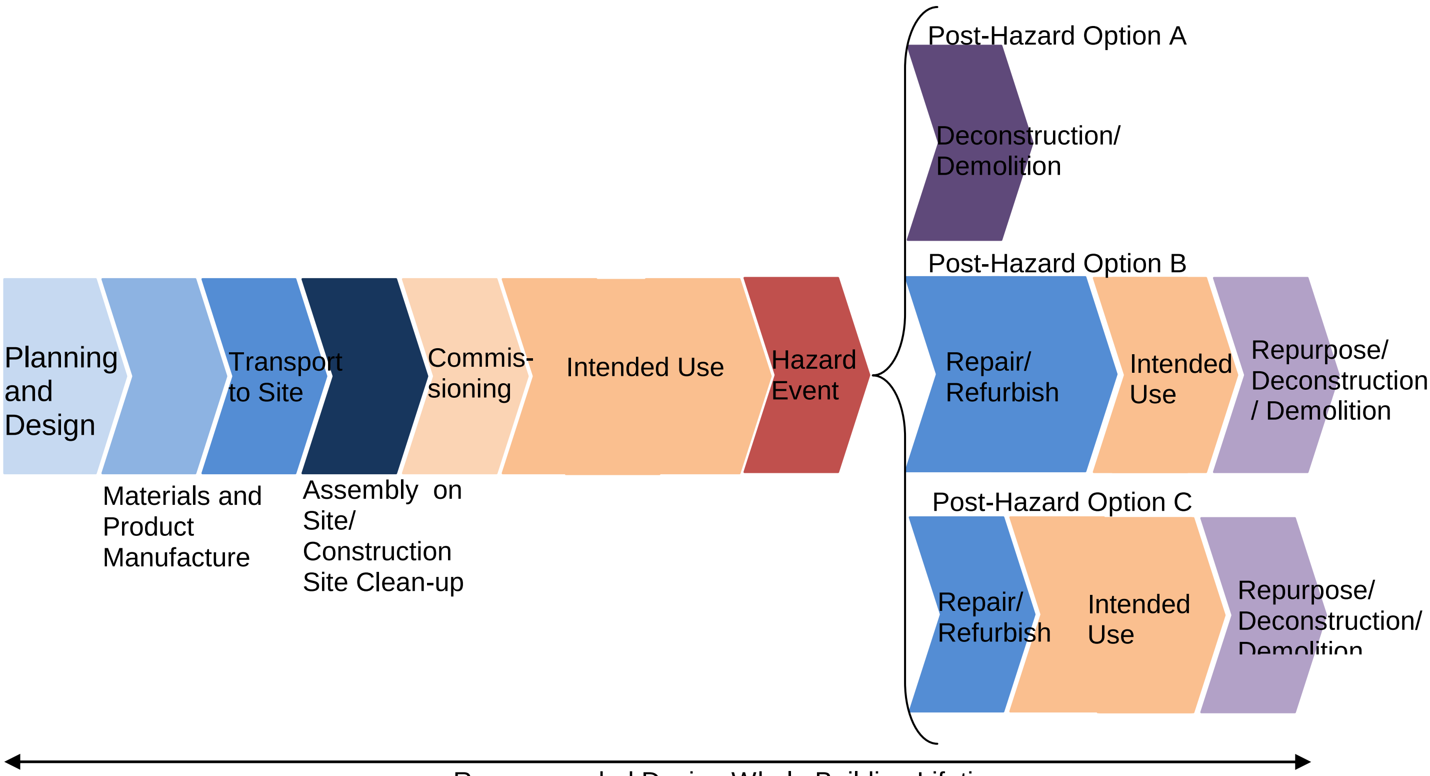

Figure 2: Potential building lifetime including observance of the occurrence of a hazard, with various options depending on the extent of the event and the hazard mitigation included in the building design.

For comparison, a fire-safety design assessment timeframe typically focuses only on the fire event (from fire start to evacuation of the building or extinguishment of the fire, represented by the red-arrow phase in Figure 2) or only specific parts of the fire event, and may include phases directly following the event, if the limits of damage and repair/replacement or time to business continuation etc are included in the design objectives and assessment methodology.

Each phase of the building timeframe included in an analysis approach would have a range of building sustainability aspects, such as siting, water efficiency, energy efficiency, materials and resources, indoor environmental quality, social and behavioural impacts, and building monitoring (as listed in Section 8.1).

11.2 Summary of Factors Considered During Fire-Safety Design Assessment

The following Table 6 contains a summary of model factors that may be included for consideration during a fire-safety design assessment. These factors are based on a proposed methodology (Robbins et al, DRAFT) that considered a general approach for assessment of different potential fire-safety design objectives. This summary is included here to provide a context for comparison with sustainability-related factors, presented in the following section, and to investigate potential grounds for identifying building design aspects that could result in unintended negative consequences as well as opportunities for combined design solutions.

Table 6: Examples of model parameter qualitative ranges, values or statuses associated with fire-safety design

Description of Fire-Safety Model Factor for Consideration	Examples of Qualitative Ranges of Fire-Safety-Associated Model Factors
Building Layout	Identify the geometry of internal and external spaces Identify locations of functionality and usage Identify exit routes: Including, but not limited to, lifts/elevators and stairwell design
Non-Emergency Environmental Conditions	Describe range of expected environmental conditions
Fire Start	
Potential Fire Hazards/Ignition Sources	Descriptive values for intended functionality, contents and usage of the spaces in relation to potential fire starts
Location of Ignition	Descriptive value of the internal or external space
Relative Time of Day for Event Start	Descriptive values: During peak/off-peak usage, during/out-side-of business hours, during/in-between/after a regular/one-off function etc
Population	
Size	Descriptive value: small, medium, large, crowd, skeleton crew etc
Location	Space in building layout Assignments to rooms within the building
Characteristics/Distribution	Age: children, adolescents, adults, elderly Gender: male/female Fitness: BMI etc
Impairments	Physical: able-bodied to disabled (wheelchair movement) Hearing: none, partial, deafness Visual: none, partial, blindness Cognitive: none, partial, cognitive impairments requiring full-time care Temporal applicability of impairment: temporary (expected to heal fully in the short-term) to permanent
Activities/Status	Commitment to activity: none, low, medium, high Status: awake, drowsy, asleep Intoxication: none, minor, medium, major
Commitment/Engagement/ Habituation	Working/living in the building for a long time, short period of time (need to define), visitor of the building
Language/Cultural	English language, other language
Social Role/Affiliation	Loose, medium, strong
Familiarity	With others, see affiliation With building: none, low, medium, high
Training/Experience (of fire-safety-related building features and procedures)	None, low, medium, high
Visual Access	None, low, medium, high

Table 6 (continued): Examples of model parameter qualitative ranges, values or statuses associated with fire-safety design

Description of Fire-Safety Model Factor for Consideration	Examples of Qualitative Ranges of Fire-Safety-Associated Model Factors
Fire-Safety Systems, Features, Strategies and Procedures	
Technical – General	Initial status: present, not present Performance: performs as designed or with a reduced quality or degree of performance Reliability: poor, moderate, high
Technical – Detection	(See examples for "Technical – General" above)
Human – Detection	Time to detection: short, medium, long
Technical – Notification	Information level for occupants: insufficient, or sufficient information (See examples for "Technical – General" above)
Human – Notification	Information level for occupants: insufficient, or sufficient information
Human – Evacuation Procedure/Strategy	(See examples for "Technical – General" above)
Technical – Compartmentation	(See examples for "Technical – General" above) Compartment size range: small, medium, large Initial status: as designed or compromised by penetrations or in other ways Example – openings: • Initial status: as new or degraded, status • Status at start and during fire: open or closed Example – walls/ceiling/floor assemblies:
Technical – Suppression Systems	(See examples for "Technical – General" above)
Human – Suppression, Including Fire Fighting	Occupant efforts: • Response time • Intervention time • Effectiveness of operations Firefighter operations: • Response time • Intervention time • Effectiveness of operations
Human Response	
Human Response Factors – in General	Incorporated in possible modelling approach, only available as a single value model input or incorporated indirectly in a model input
Pre-Evacuation	Times: range Behaviours include: information seeking, preparation, helping others (including warning others) and evacuating
Assumed Travel Speeds	Single values, or distributions Range: unimpaired, impaired
Attainable Speeds	Range: low, moderate, high
Route Use	Descriptive value: one familiar route, nearest etc
Flow Constraints	Range: low, moderate, high

Table 6 (continued): Examples of model parameter qualitative ranges, values or statuses associated with fire-safety design

Description of Fire-Safety Model Factor for Consideration	Examples of Qualitative Ranges of Fire-Safety-Associated Model Factors
Fire and Smoke Development and Spread	
Type of Fire	Range: flaming or smouldering
Distribution and Types of Fuels/Fire Load Density	Contents and furnishings: • Initial status: as new or degraded by age or vandalism, distribution • Initial distribution: uniform, stacked etc • Interior and exterior finishing • Initial status: as new or degraded by age or vandalism or compromised Materials control • Status: as new or degraded by age or vandalism
Internal Ventilation Conditions	Status: under-ventilated, fully ventilated
External Environmental Conditions	Descriptive range of expected environmental conditions
Fire Size	Growth rate: slow, moderate, fast, ultra-fast Range: whether secondary items ignited by fire etc
Criteria for Fire Spread	Spread rate: none, slow, moderate, fast etc
Status of Exit Routes, Including Opening/Closing Doors	Blocked exit routes Which exit routes are used and how heavily etc
Building Structure	
Structural Members	Initial status: as designed or compromised
Structural Loads (e.g. Live, Dead, Wind Loads etc)	Range: low, medium, high
Characteristics of Elements and Connections	Elements: column, beam, slab, shell etc Connections: fixed, free etc
Restraint Conditions	Fixed, free etc
Thermal and Mechanical Material Properties	Ranges: low, medium, high thermal and mechanical susceptibility

11.3 Summary of Factors Considered during Sustainability Design Assessment

The following Table 7 contains a summary of model factors that may be included for consideration during a traditional sustainability design assessment. Table 8 contains a suggested list of additional model factors that may be included in a sustainability design assessment that includes consideration of a fire event, to demonstrate the concept on including unintended hazards in the whole lifetime of a building.

Table 7: Examples of model parameter qualitative ranges, values or statuses associated with sustainability design

Description of Sustainability Model Factor for Consideration	Examples of Qualitative Ranges of Sustainability-Associated Model Factors
Building Layout	Identify the geometry of internal and external spaces Identify locations of functionality and usage
Environmental Conditions	Describe range of expected environmental conditions
Population	
Size	Descriptive value: small, medium, large, crowd, skeleton crew etc
Location	Space in building layout Assignments to rooms within the building
Activities/Status	Descriptions of activities associated with locations in the building in relation to required resources: Energy: none, low, medium, high Lighting: low, medium, high, user-controllable Air quality: low, medium, high, ultra-pure Thermal comfort: range and proportion of the year to be achieved Acoustic quality: low, medium, high
Commitment/Engagement/Habituation	Working/living in the building for a long time, short period of time (need to define), visitor of the building
Language/Cultural	English language, other language
Familiarity	With building: none, low, medium, high
Training/Experience	Of sustainability-related building features and procedures: none, low, medium, high
Energy Efficiency	
Reduction in Heating/Cooling Loads	Insulation of external walls (e.g. external wall cladding material selection, geometry/design of cavity walls, insulation material selection, shading of external walls etc) Insulation of external windows (e.g. laminated glass, double and triple-glazing, reflective glass coatings etc) Insulation of roof (e.g. reflective coatings, green roof – see also protection of local environment, stormwater management etc) Passive use of local resources (e.g. passive cooling design, passive ventilation for cooling spaces – see also indoor air quality, amount of fresh air, radiant cooling etc)
Reduction in Artificial Lighting Power Usage	Sensor control of lighting to compliment natural levels and motion detection for occupancy of spaces User-controllable artificial lighting (e.g. desktop lighting etc) See indoor lighting quality for increased natural lighting
Reduction in Appliance Power Usage	Selection of appliances
Use of Alternate Power Sources	Collection and storage of renewable energy onsite (e.g. solar, wind etc) Solar water heating

Table 7 (continued): Examples of model parameter qualitative ranges, values or statuses associated with sustainability design

Description of Sustainability Model Factor for Consideration	**Examples of Qualitative Ranges of Sustainability-Associated Model Factors**
Water Efficiency	
Reduction in Use of Potable Water	• Installation of low-water-use appliances (e.g. low flow shower heads, low-water-usage toilets, waterless urinals etc) • Sensor-operated water-usage appliances (e.g. toilets, hand basins etc) • Rainwater harvesting • Greywater systems
Indoor Lighting Quality	
Increased Natural Light in Peripheral Spaces	• Size of windows • Room geometry (e.g. shape of ceilings, windows in the vertical sections of a sawtooth roof etc) • Blinds and shades to reduce glare in occupied spaces • Reflective surfaces to increase light through windows (e.g. reflective surfaces on roof to increase light through windows in a sawtooth roof etc)
Increased Natural Light in Internal Spaces	• Penetration of direct light (e.g. atriums, lightwells etc) • Extension of natural light (e.g. glass walls between spaces, geometry of spaces etc)
Indoor Air Quality	
Reduction or Elimination of VOCs	• Material selection • Selection of adhesives
Reduction or Elimination of Other Air-Borne Irritants and Health Hazards	• Tobacco smoke control (e.g. prohibiting smoking around access areas and ventilation intake areas, use of weather sealing around residential unit doors to protect common spaces etc) • Filtering of circulated air • Maintenance of HVAC system to eliminate opportunities for contamination
Ventilation Rates	
Amount of Fresh Air	• Air intake design (e.g. locations of buildings to take advantage of prevailing winds, use of natural chimneys etc)
Monitoring	• Of carbon dioxide, temperature, humidity etc
Indoor Acoustic Quality	
Acoustic Insulation to the Outside	• From the outside to the internal spaces • From the internal spaces to the surrounding area
Acoustic Insulation Between Internal Spaces	• Internal space geometry and material selection
Acoustic Quality Within Spaces	• Internal space geometry and material selection
Protection of Local Environment	
Siting	• Use of rehabilitated black- or grey-land
Stormwater Management	• Reduced water runoff (e.g. pervious concrete, green roof, swales etc) • Local catchment (e.g. rainwater harvesting, filling of local ponds etc)
Landscaping	• Native flora • Continuity with natural land shapes (e.g. keeping ponds, natural rain catchment areas etc)
Reduction of Sewerage and Blackwater Release	• Reduction in production • Onsite treatment
Use of Local, Renewable Materials	• Material selection to reduce the impact of the materials used in construction

Table 8: Additional model parameter qualitative ranges, values or statuses associated with sustainability design that include fire-safety design features and potential costs of a hazard, such as a fire event

Description of Sustainability Model Factor for a Fire Event for Consideration	Examples of Qualitative Ranges of Sustainability-Associated Model Factors for a Fire Event
Sustainability Cost of the Fire-Safety Design Features, Systems and Procedures	
Sustainability Impact	• Would be expected to be included in the assessment for the whole building design, since the fire-safety design features, systems and procedures are fundamentally part of the intended building design
Sustainability Cost of Hazard – Fire Event	
Location of Event	• Building spaces affected
Time of Event	• Relative to intended building usage and expected operation of the building features, systems and procedures
Extent of the Event (Results from a Fire-Safety Design Analysis)	• Extent of fire and fire effluent spread • Event duration • Extent of activation of active fire protection • Extent of containment/destruction of passive fire protection • Materials available to be potentially involved in the event • Extent of occupancy involvement and evacuation • Extent of Fire Service involvement
Emissions to Environment	• Design features, systems and procedures that: ○ Limit atmosphere emissions during and after event ○ Limit water contamination during and after event ○ Contain or reduce water runoff into surrounds ○ Limit amount of material requiring disposal after event And the extent of limitations and reduction provided compared to other options or no fire-safety provisions
Water Efficiency	• Design features, systems and procedures that: ○ Reduce water usage during event ○ Reduce potable water usage during event And the extent of limitations and reduction provided compared to other options or no fire-safety provisions
Energy Efficiency	• Design features, systems and procedures that reduce the amount of damage caused during event and subsequently reduces the amount of building and contents repair, replacement and refurbishment required And the extent of limitations and reduction provided compared to other options or no fire-safety provisions
Community	• Design features, systems and procedures that: ○ Reduce civilian casualties ○ Reduce firefighter casualties ○ Reduce reliance on firefighting intervention ○ Reduce time required to maintain business continuity And the extent of limitations and reduction provided compared to other options or no fire-safety provisions

Considering the list of potential model factors in a building sustainability assessment that includes a fire event, such as an unintentional building hazard, it is obvious that a building sustainability assessment would require input from a building fire-safety assessment to appropriately include the inter-relationships between the different aspects of design and potential impact of fire-safety features, systems and procedures.

11.4 Inter-Relationships Between Fire-Safety and Sustainability Design

The relationships between building features, systems and procedures for fire-safety and sustainability design can range from being independent to being inter-related from a number of design considerations.

One approach to demonstrate the inter-relationships between fire-safety and sustainability building design may be to link the features, systems and procedures from each of the design perspectives back to the building, consisting of the built environment and the occupants. This approach may be useful for determining how specific building products and systems etc interact with building design objectives for the different perspectives. This would be an approximate bottom-up approach to gaining an overview of the inter-relationships.

Another approach to demonstrate the fire-safety and sustainability building design inter-relationships may be to link the aspects from each of the design points of view (that are determined by specific design objectives for each) and aspects of the built environment for each phase of the intended building lifetime. This approach may be considered an approximate top-down approach to gaining an overview of the inter-relationships. This approach is described in more detail below, with an example demonstration of concept for a selection of fire-safety design and sustainability design aspects.

11.4.1 Relationships of Design Aspects Based on the Built Environment and Occupants

Tying design aspects to parts of the general building (in terms of the phases of the life of the building and the built environment) instead of aspects of a specific building design analysis may be one way to find common ground from which combined solutions may be found and unintended consequences may be averted.

A summary of the components considered in this attempt to identify connections between sustainability and fire-safety building design includes:

1. Building lifetime phases:
    - Planning and design.
    - Materials and products manufacture and transport to site.
    - Assembly on site/construction/site clean-up.
    - Commissioning.
    - Intended use and operation.
    - Unintended, but possible, hazard (e.g. a fire event).
    - Repair/refurbishment.
    - Repurpose/deconstruction/demolition.

2. Built environment (BE) aspects:
   - BE1. Construction site with materials storage etc.
   - BE2. Location of site and landscape.
   - BE3. Local environment and weather conditions.
   - BE4. Building layout (geometries of internal and external spaces).
   - BE5. Population (regular occupants, visitors etc).
   - BE6. Intended operations (various usages and functionalities and day/time of day).
   - BE7. Possible hazards.
   - BE8. Building systems, features, strategies and procedures for intended operations as well as mitigation of identified hazards.
3. Building design aspects:
   a. Aspects of sustainability design (SD):
      - SD1. Siting and landscaping.
      - SD2. Water efficiency.
      - SD3. Energy efficiency.
      - SD4. Materials and resources.
      - SD5. Indoor environmental quality.
      - SD6. Social and behavioural impacts.
      - SD7. Building analysis, performance and monitoring.

   b. Aspects of fire-safety design:
      - FD1. Possible fire-events/design fire-safety scenarios:
        - Descriptions of the state of the building and occupants at the start of a fire event, such as:
          - Time of day.
          - Building current layout and usage.
          - Location and activities of occupants.
          - Location of fire start.
          - Type of fire.
          - State of building maintenance.
          - State of building contents.
          - State of building fire-safety systems, features etc.
          - Etc.
      - FD2. Human response.
      - FD3. Internal fire and smoke development and spread.
      - FD4. Structural stability.

FD5. External fire spread.

FD6. Building fire-safety systems, features, strategies and procedures.

FD7. Firefighting operations.

An example schematic that shows a simplified version of the complex inter-relationships between the built environment (BE) aspects, fire-safety building design (FD) and sustainability building design (SD) aspects is shown in Figure 3. The details of such a schematic would change with the various building lifetime phases. Building further from this type of schematic, a web-based hub that could be used to follow the potential paths of interactions combined with a database of currently available building features and systems may be a useful tool for the building industry to share information in an accessible way.

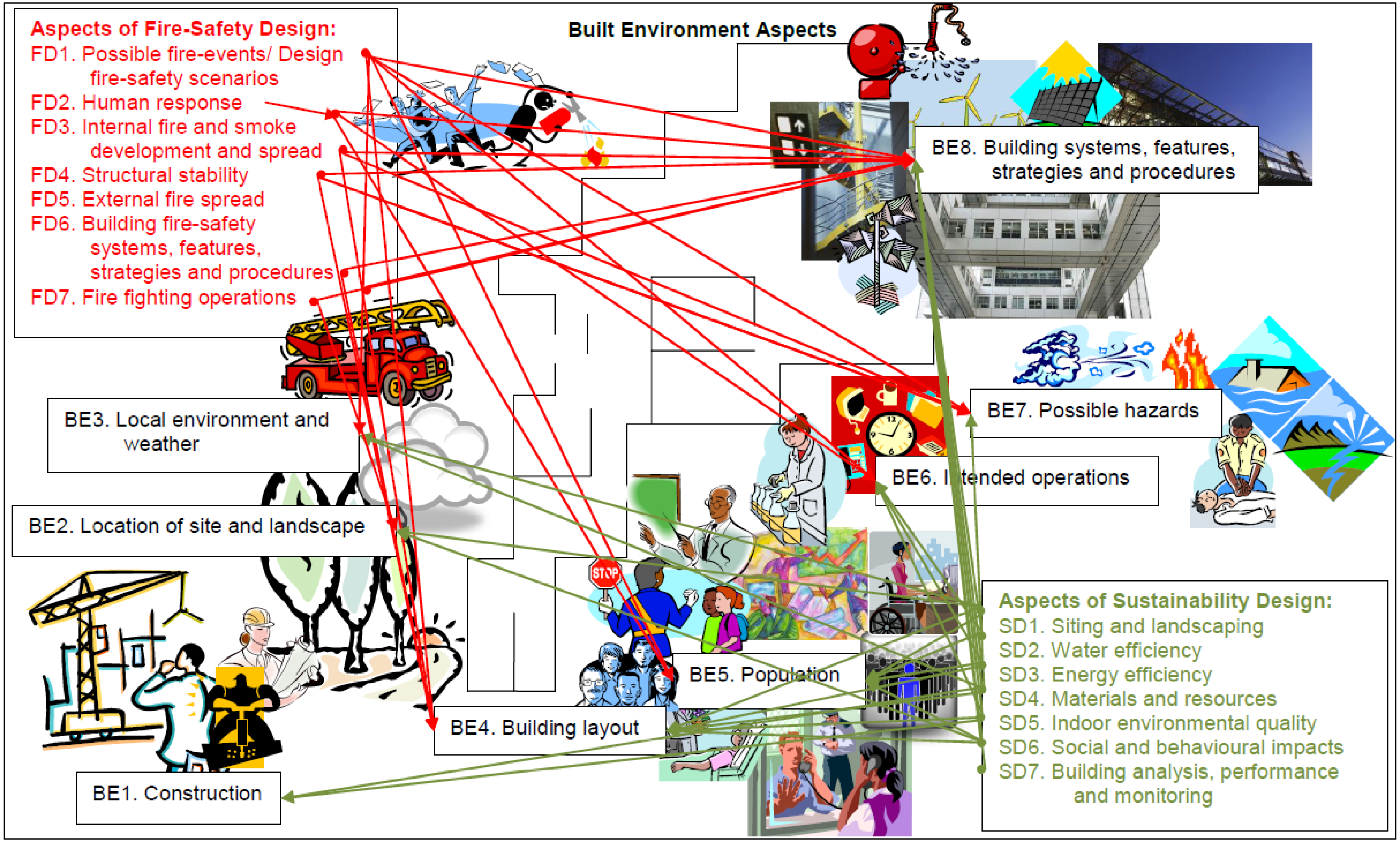

Figure 3: An example schematic of the inter-relationships between fire-safety design, sustainability design and aspects of the built environment for an example phase in the lifetime of a building.

12. SUMMARY

12.1 Potential Positive Sustainability Impact of Fire-Safety

Fire-safety design has the potential to reduce the lifetime environmental impact of a building if the whole lifecycle includes the consideration of conditions of possible fire events along with the traditionally-considered intended “operating conditions”.

12.2 Assessment of Sustainability

Where mandatory regulations are not applicable, green rating tools for assessing the sustainability of a building design define the relative weightings and focus of the specific sustainability aspects. Otherwise the importance of each of the non-mandatory sustainability aspects would be rated by the stakeholders and design team at the beginning of the design project. The important aspects would be reflected in the sustainability design objectives.

In parallel with a building assessment tool (which would focus the importance of the measures of sustainability that simplifies the complex consideration processes surrounding building sustainability issues), three additional areas suggested that companies involved in the broader construction industry consider to contribute to sustainability of the overall industry are (DBIS, 2010b):

1. Reduce the environmental impacts and increase the sustainability positive contributions of their own business.
2. Provide owners and occupants with both new and retrofitted buildings that enable them to lead more energy, water and material efficient lives.
3. Provide infrastructure that enables the supply of clean energy and sustainable practices in other areas of the economy, such as transport and agriculture.

12.2.1 Defining Building Sustainability Design Objectives

Marketplace drivers for an increase in sustainability of buildings may be derived from implicit or explicit international agreements with long-term metrics, such as climate change acts of several nations, e.g. Climate Change Response Act 2002, New Zealand (PCO, 2011), or from shorter-term locally-focused commercial ventures. These perspectives are associated with inherently different measures of sustainability objectives, therefore it is important to define the intent and performance criteria of the sustainability objectives that a specific building is designed in accordance with.

When the sustainability objectives are clearly stated and the performance metrics and criteria are defined along with all other design objectives, including fire-safety for a specific building, then the potential interactions, unintended consequences and opportunities to create more efficient combined solutions of the features, systems, procedures of the building for each design objective can be assessed.

12.3 Building Design Solutions Through Collaboration

If a true integrated approach were used in sustainability designing of buildings that included fire-safety specialists, then there would be valuable opportunities to develop solutions that would benefit more than just fire-safety problems. Therefore, in principle fire-safety should be incorporated into the design process for sustainability design from the outset (Carter et al, 2011). However, as Kibert (2008) acknowledges, in practice there can a lack of co-ordination among design team members that has resulted in designs that were problematic to build and do not provide an actual holistic solution. The sustainability design movement has begun to emphasise co-ordination and collaboration as the true foundation of a high-quality building. Therefore we need to educate and ensure that fire-safety is known to be necessary for inclusion in this collaborative design approach, ensuring key objectives and criteria are met while also capitalising on, so far uncounted, multilayered benefits.

In theory, this integrated design approach is intended to incorporate fire-safety considerations, specialists and solutions into the final building design throughout the design process. Therefore it is the responsibility of the fire-safety professional and industry to educate the sustainability professionals of the importance of fire-safety and to facilitate collaboration by providing information on appropriate lines of contact and a basis for asking the questions that are useful in establishing an holistic design team.

> "*Designing a window without the building, a light without the room, or a motor without the machine it drives works as badly as designing a pelican without the fish. Optimizing components in isolation tends to pessimize the whole system — and hence the bottom line. You can actually make a system less efficient while making each of its parts more efficient, simply by not properly linking up those components. If they're not designed to work with one another, they'll tend to work against one another*." (Hawken et al, 2000)

Applying sustainability principles to fire-safety solutions in isolation may not produce a more efficient overall solution for the building. Conversely, applying sustainability principles to a building design without incorporation of all intended usage, functionality and building design objectives, including fire-safety, similarly may not maximise efficiency in the overall building solution produced and certain features may even unintentionally work in conflict to counteract beneficial actions of others.

A common perception within fire protection engineering, and reported for a sample interview of the Australian industry (Carter et al, 2011), is that building designs are worked to meet the minimum mandatory requirements at the lowest possible cost. This design environment would not be conducive for collaboration across multiple design fields and poses an obstacle that would need to be overcome before productive collaboration would be seen within the industry at a project level. However, there are mutually-beneficial opportunities for both fire-safety and sustainability building design to be undertaken in parallel, stemming from a co-operative initial planning phase.

12.3.1Pathways to Collaborative Building Designs

The fire-safety design industry has a responsibility to provide education and to participate in the sustainability design industry to ensure that fire-safety is appropriately included in the holistic sustainability-design approach. This education and participation must take an approach that directly tackles the disparity between the intent that theoretically fire-safety would naturally be included in an holistic design through ideal collaborative design practices across all design aspects of a building, while acknowledging real-world practices.

Principal barriers to successful integration of fire-safety and sustainability issues to ensure the best building designs include:

- An industry-wide definition of sustainability.
- Silo-based building design versus one building design with multiple design objectives.
- Different building design lifetimes considered for different design aspects of a building.
- Industry-wide multi-disciplinary awareness and education:
    - A need for a central information hub for quick dissemination of information and formation of linkages of information.
    - A need to establish communication pathways between design fields.

12.3.1.1 Industry Definition of Sustainability

Isolated sustainability-related regulatory building design requirements, various reports and initiatives undertaken by a range of organisations and special interest groups with different definitions of and metrics for building sustainability and a lack of drivers for a change in customer demand induces a lack of confidence to invest in new products, services and processes for which there may be no market at a profiTable price.

Leadership is needed to provide a single coherent definition of sustainability that combines all aspects of sustainability and is applicable and accessible to all aspects of the building industry.

12.3.1.2 Silo-Base Building Design vs One Building Design, Multiple Design Objectives

The structure of the construction industry in terms of silo-based building design and the lack of collaboration of the supply chain do not support an approach to design or construction of buildings that provides solutions for a building design with multiple design objectives. Building evaluation approaches need to incorporate fire-safety contributions (and other building design perspectives) into sustainability objectives and vice-a-versa over a building's entire lifetime. It may be possible to incorporate a fire-safety building rating with sustainability building ratings into one overall building rating using appropriately weighted building design objectives.

12.3.1.2.1 Different Building Design Lifetimes

There is a distinct difference in the building lifecycles considered for different aspects of a building design. For example, some aspects may only consider the building during an event (e.g. a fire event) and may or may not include the recovery time after the event. Whereas other aspects may consider cradle-to-gate impacts, initial capital cost or the environmental impact of the building operation over its entire lifetime, including hazards such as fire etc.

The different lifecycles that are considered for different aspects of the design must be clearly defined to ensure they are appropriately combined and that over-lapping timeframes and voids in the lifecycle are avoided.

12.3.1.3 Industry Education and Communication

There is a growing need for industry-wide multi-disciplinary awareness and education to achieve practical multi-disciplinary design teams, adaptability of design approaches and behavioural changes within the industry. There is also a need for general education of people in all parts of the industry supply chain to address the design, construction and operation of buildings that incorporate sustainability-related objectives.

A central knowledge hub that can be used to collect and disseminate learning gained from within New Zealand and internationally, and to provide leadership for the entire industry in language appropriate for each of the various design disciplines, would form a central location for education and information dissemination for the industry. Such a central information hub would be especially useful for identifying similarities and commonalities to assist in the development of combined design solutions across various building design disciplines, while acknowledging that no individual (designer or stakeholder) can be an expert in all aspects of building design and knowledgeable of all potentials for combined solutions.

12.3.1.3.1 Communication Pathways Between Design Fields Within Building Industry

There needs to be clear and known communication paths between all design building fields, so that new developments, trends and changes in applications of building features, systems, strategies and procedures can be identified rapidly and considered in terms of potential unintended impacts within other design fields. These communication paths would be most useful if designed to facilitate two-way communication to enable unintended consequences to be rectified or mitigated.

For example, as part of the regular ongoing updating of prescriptive codes, changes for review in prescriptive requirements for other aspects of the built environment may serve as an obvious automatic trigger for consideration of potential impact of changes for other design objectives on fire-safety. These triggers for consideration are necessary, but also occur late in the regulatory-cycle and education-cycle of the industry. Therefore additional early-stage triggers would be useful.

Further quick communication is also required to provide industry-wide notification of changes and design approaches to increase the adaptability through education at the multiple levels of the industry required to implement practical changes. Such communication will benefit the entire industry by enabling information to be rapidly exchanged across different design fields, sectors and aspects of the building industry. However, the level of success of such a communication network depends on it being used, which relies on it being practical and accessible to all participants. A co-ordinated approach for selected issues utilising the BRANZ range of industry communication products may provide a New Zealand-wide solution that could be co-ordinated with a feedback component to complete the communication loop. Creating an option to tag discussion issues with aspects of the built environment may be one way to create communication lines across and between fields of interest. For example, instead of tagging an issue as a fire or fire-sprinkler issue, it might also be tagged with residential/commercial, water supply, concealed ceiling space etc, depending on the specific issue and related aspects of the building features, systems, strategies and procedures. Tags could be added from a pre-defined list to each discussion item by members of the community as they find the issues that relate to their areas of interest and specialities.

In terms of communication intent, there would be a difference between starting with a set of building design objectives compared to starting with a building product or system. The thinking would be different and a key factor to facilitating quick communication may be to link a product with aspects of the intended building function and usage, and conversely for building objectives being associated with aspects of each type of design, and then each of these to be linked with appropriate aspects of building function, usage, features, systems, strategies and procedures. Then building designers could access the information from either direction depending on the specific problem that they are considering, i.e. from a building function/usage perspective, a new building product could be integrated into a design solution etc Commercially-available listings of products are currently available; however these were outside the scope of the initial research summarised within this report.

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APPENDIX A GLOSSARY

Following are a selection of terms and definitions either used within this report or are considered to be useful related knowledge for the subject of this report.

Term	Definition
Net metre	is a residential installation of a supply metre for building-generated power (e.g. solar, wind etc) with no batteries onsite, so that unused generated power contributes to the local network and is acknowledged by the metre running backwards and when insufficient power is generated for onsite use, then the power is drawn from the local power grid and the metre runs forward (CFF, 2011a).
High-performance building	that includes design attributes of energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality and operational considerations (NIBS, 2010).
Biomimicry	is the direct application of ecological concepts to the production of industrial objects, through the imitation of energy and material production and use in nature.
Carrying capacity	is used to define a specific land's limits to support people and their activities.
Construction ecology	is a subset of industrial ecology. It is the study of physical, chemical and biological inter-reactions and inter-relationships between the built environment and ecological systems.
Cradle-to-cradle	is the lifecycle of a process, service or product that contributes positively to the lifecycle of other processes, services or products, from extraction of the raw materials, processing, manufacturing, transportation, installation, operation, maintenance, repair and then the end of the current usefulness, where it can be reused, recycled or downcycled, instead of being placed in landfill.
Cradle-to-gate	is the lifecycle of a material from extraction of the raw materials, processing, manufacturing and transportation to installation.
Cradle-to-grave	is the lifecycle of a material from extraction of the raw materials, processing, manufacturing, transportation, installation, operation, maintenance, repair and disposal.
Ecological economics	includes considerations of resource limitations and the environmental impact of waste and toxic substances.
Ecological footprint	refers to the equivalent land area required to support a certain population or activity. It can also be used as a measure for total resource consumption, allowing for relative comparison of lifestyles.
Ecological rucksack	is an estimate of the mass of materials that must be moved in order to extract a specific resource.

Factor 10	reduction of a building's energy usage to one-tenth or less than a conventional building design.
Factor 4	reduction of a building's energy usage to one-quarter or less than a conventional building design.
Front-loaded design	is a concept of investing greater effort during the design phase to ensure recovery, reuse and/or recycling of the product's components.
Industrial ecology	is the study of physical, chemical and biological inter-reactions and inter-relationships between industrial and ecological systems.
Integrated design	a collaborative solution produced from a multi-disciplinary team of specialists, designers, architects, engineers, building owners, intended users and regulatory authorities from the outset of the project.
Materials intensity per unit service (MIPS)	is an estimate of how efficiently with which a material is used and provides a measure of how much service a product delivers. MIPS is also used as an indicator of resource productivity, with higher values associated with greater service or productivity.
Passive design	intentionally utilises the surrounding landscape, environmental conditions, siting of a building within and on a site, construction materials etc to provide services, or partial services, for the building and occupants without the need, or at a reduced demand, for active systems.
Sustainability design	is a process that integrates environmental considerations into product and process engineering procedures, considering the entire lifecycle. Other terms that are used interchangeably include design for the environment or green design (See definitions for conventional, green sustainable, restorative, reconciliatory and regenerative terminology for a qualitative comparison of relative levels of sustainability).
Sustainability	is a long-term view that considers economic, social and environmental impacts, with a view to avoid, mitigate, balance or reverse these impacts (TJCGNC, 2001).
Restorative	as applied to the built environment, a design and implementation approach such that the building and human occupants assist nature (Reed, 2006).
Reconciliatory	as applied to the built environment, a design and implementation approach such that the building and human occupants are an integral part of nature (Reed, 2006).
Regenerative	as applied to the built environment, a design and implementation approach such that the building and human occupants participate in nature (Reed, 2006).
Smart buildings	refers to automated building design and operation that incorporates feedback from building monitoring and sensors to analyse performance and then identify and implement improvements.

Sustainable	as applied to the built environment, a design and implementation approach such that the building and human occupants have a neutral impact on resources and nature (Reed, 2006).
Green	as applied to the built environment, a design and implementation approach such that the building and human occupants have a reduced impact on nature and resources when compared to traditional design, e.g. the minimum requirements of a "green" rating system (Reed, 2006).
Conventional practice	as applied to the built environment, a design and implementation approach such that the building and human occupants have maximum allowable impact on nature and resources as allowed by law (Reed, 2006).