Sustainable Asset Valuation Tool

BUILDINGS

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Sustainable Asset Valuation Tool: Buildings

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Written by Andrea M. Bassi, Kieran McDougal and David Uzsoki

This document is not meant to be an original contribution. Instead, it is a review that summarizes available knowledge in the literature for a given infrastructure type, including, for instance, the policy landscape and data availability. As a result, this document (both the light screening and in-depth review) were utilized to inform the creation of the SAVi model, a simulation tool that integrates knowledge from various disciplines and sectors for sustainable asset valuation.

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- "A sustainable building has to have high efficiency in the use of energy, water and materials, and reduced impacts on health and the environment throughout its life cycle" (Berardi, 2013). Attention must be paid to the construction, material manufacture, operation and management, and demolition process of buildings (UNEP, 2011b)
- As a result, the definition of sustainable building accounts for economic and social outcomes in addition to environmental outcomes.
- This implies that the sustainable design of buildings should be guided by (a) passive design (buildings that account for their local context and environment) and (b) active design (use of technologies to reduce energy and water consumption).
- Green growth in the building sector is aimed at both retrofitting existing buildings and the construction of new buildings. Technologies considered include:
o Solar photovoltaic (PV)
o Heating, ventilation and air conditioning
o Solar heat water
o Lighting
o Floor heating
o Construction materials
o Thermal insulation (including windows)
o Water recycling
o Efficient appliances
</td></tr>
<tr><td>Indicators used to measure performance</td><td>
- The BPIE data hub includes data on building stock, energy consumption, heating and building policies for European countries (https://www.buildingsdata.eu/).
- The Green Buildings Performance Network collected information on the quality of data that relates to the energy performance of buildings. "The parameters considered were floor area, number of buildings, energy use, heating, cooling, hot water, lighting/appliances, age profile, retrofit rates, urban/rural split, new building energy use, yearly construction, fuel mix, ownership (private/public) and tenure" (Dell & Egger, 2015, p. 4)..
- Life-cycle analysis:
o Including building and material construction, should consider "raw material availability, land and water availability, minimal environmental impact, embodied energy efficiency (production and process energy requirements), transportation, product lifespan, ease of maintenance, potential for product re-use, and material durability and recyclability" (UNEP, 2011b, p. 353).
o Life-cycle inventory (LCI) impact categories are indicators of the contribution of a product to a specific environmental problem, including global warming potential, acidification potential, eutrophication potential, fossil fuel depletion, smog formation potential, ozone depletion potential, ecological toxicity and water use (Bayer, Gambel, Gentry, & Joshi, 2010).
o The U.S. Life Cycle Inventory (LCI) Database compiles life-cycle assessment data on individual materials and products in the United States (National Renewable Energy Laboratory, http://www.nrel.gov/lci/).
o "In the United States, for example, the FTSE Group, the U.S. Green Building Council and the National Association of Real Estate Investment Trusts have jointly developed a green property index for institutional and retail investors. Similarly, in the U.K., the Investment Property Databank (IPD) has developed the EcoPortfolio Analysis Service (EcoPAS), which seeks to enable investors to understand potential environmental risks in their portfolios" (World Green Building Council, 2013, p. 86).
- Operation (energy efficiency): energy consumption "during a period of occupation, ideally a minimum of two years. A dearth of accurate data is hampering our understanding of impacts such as occupation, design and technological components" (UNEP, 2011b, p. 341).
</td></tr>
<tr><td>Shortcomings of business-as-usual investments</td><td>
- Buildings currently account for 40 per cent of energy use in many countries" (UNEP, 2011). "Whether existing building stock or projected growth of building stock, this sector is already the single largest contributor to global greenhouse gas (GHG) emissions. Approximately one third of global energy end use takes place within buildings (IEA, 2010)." (UNEP, 2011b, p. 341) Many developed countries have low population growth rates and are already highly urbanized, meaning energy demands of buildings will not grow as much. However, urbanizing developing countries with high population growth rates are rapidly expanding their building stock, and the energy required for the sector (UNEP, 2011b).
- "As investors and occupants become more knowledgeable about and concerned with the environmental and social impacts of the built environment, buildings with better sustainability credentials enjoy increased marketability" (Tam, 2017). "Studies around the world show a pattern of green buildings being able to more easily attract tenants and to command higher rents and sale prices. In markets where green has become more mainstream, there are indications of emerging "brown discounts," where buildings that are not green may rent or sell for less" (World Green Building Council, 2013).
- Conventional buildings have been shown to cost more money through increased energy and water use and higher long-term operations and maintenance costs (World Green Building Council, 2013).
- Buildings have impacts in four stages (Bayer, Gambel, Gentry, & Joshi, 2010):
o Procurement: extraction of resources, manufacturing processes, transportation
o Construction: use of tools and equipment, energy use, impacts to building site
o Operation: energy consumption, water use and environmental waste generation
o Decommissioning: energy consumed and waste produced during demolition
</td></tr>
</table>

Advantages of green investments	- The advantages of sustainable buildings include (UNEP, 2011b): o Sustainable buildings use less energy, which in turn leads to lower energy costs and reduced emissions of pollutants. Energy savings come from reduced space and water heating costs, energy-efficient lighting and appliances. o Additional energy savings can be achieved through the installation of small-scale energy generation capacity (e.g., solar PV) on buildings. o Sustainable buildings use less water, resulting in lower costs and less strain on water resources. Water reductions come from a combination of water efficiency, rainwater harvesting, water recycling and sewer mining. o Sustainable buildings are a cheap source of carbon dioxide abatement. Net economic benefits are estimated per tonne of carbon dioxide for the average cost of abatement options including retrofits, water heating changes, lighting and HVAC. The abatement cost reflects the annualized cost of abatement measures in a given year per tonne of carbon saved compared with the BAU technology. o Sustainable buildings are designed with the potential for product re-use and recyclability in mind. As a result, less waste is produced during construction and during demolition. o Sustainable buildings can also provide social and health benefits, including improved worker productivity and work quality, and improved public health due to reduced indoor and outdoor air pollution. These benefits may be larger than the climate and energy benefits. o Sustainable buildings can also change employment patterns in a country, resulting in new jobs, job substitution and job transformation. - "Looking only at the cost differential between constructing green and conventional buildings, a study by Greg Kats (2010) suggests that cost premiums are considerably lower than generally perceived. On average, green buildings in the United States cost 1.5 per cent more in upfront costs than conventional buildings, with a price premium ranging from USD 0/m² to USD 764.2/m², with a median of USD 36.6/m². However, public perception is that the additional costs of going green are 17 per cent." (UNEP, 2011b, p. 349)
Main roadblocks for the adoption of green infrastructure	- "Upfront investment cost and payback period: Although buildings can be greened at low or zero net cost over the lifetime of the investment, the initial additional capital outlay, the so-called "first cost," could be a deterrent for those who demand finance for greening buildings." (UNEP, 2011b, p. 361) Affordability is a particular concern in developing countries, especially in low-income areas where people already have trouble affording conventional housing (UNEP, 2011b). - There may be hidden costs associated with the transition to sustainable buildings, including transaction costs "associated with securing energy-efficient solutions and risks around replacement technologies (Westling, 2003; Vine, 2005). Transaction costs are often high owing to the fragmented structure of the building sector with many small owners and agents" (UNEP, 2011b, p. 361). - "Another aspect of the fragmentation is reflected in the differing interests of individual households and utilities. While householders may be intrigued by the prospect of greening their homes and reaping energy savings and health benefits, utilities face a potential reduction in their sales revenue and therefore may have little interest in supporting investment in green buildings" (UNEP, 2011b, p. 362). - "Market failures can take the form of misplaced incentives, such as when building tenants (as bill-payers) have an interest in environmental improvements that are not shared by the building owners. While low-energy prices may give little incentive for affluent households and businesses in developed countries to change their behaviour, subsidies often keep energy prices in developing countries artificially low and again take away any incentive to change" (UNEP, 2011b, p. 361). - "Institutional investor offering: For financial institutions, energy-efficiency projects in buildings are often associated with the following major hurdles: low financial returns, credit risks, uncertainty, and difficulty in evaluating the added financial value of green buildings" (UNEP, 2011b, p. 362).

Policy interventions	- The International Energy Agency's (IEA) Building Energy Efficiency Policies (BEEP) database contains detailed information on energy-efficiency policies across countries. Policies include building codes, incentive programs and green labels. These policies can be mandatory, voluntary or provide a model. Policies can also apply to new or existing buildings, both residential and non-residential (https://www.iea.org/beep/). - Building codes for energy efficiency can move the building stock toward zero energy. Several countries have been successful in implementing building codes to encourage sustainable buildings. A few themes are necessary for the policy to be successful. "These themes include a holistic approach, a dynamic approach, good enforcement, individual elements of performance and overall performance" (McDonald & Laustsen, 2013). - "Regulatory and control mechanisms, such as standards and product labelling: Regulatory and control mechanisms have to be monitored, evaluated and updated regularly to remain in touch with technological developments and market trends. They are easier to enforce with respect to new rather than existing buildings Examples of such measures are appliance standards, building codes, procurement regulations, energy-efficiency obligations or quotas, mandatory audit programs and utility demand-side management programs" (UNEP, 2011b, p. 362). - Economic and market-based instruments: "These instruments include energy performance contracting, cooperative procurement, efficiency certificate schemes and credit schemes such as flexible mechanisms" introduced under the UNFCCC and most recently, cap-and-trade schemes (Berardi, Michalowicz, Kerber, 2013). - Fiscal instruments and incentives: "These instruments include energy or carbon taxes, tax exemptions and reductions, public benefits charges, and capital subsidies, grants, subsidized loans and rebates. They target energy consumption and/or upfront investment costs" (Berardi et al., 2013, p. 144). - "Capacity support, information and voluntary action: This category of instruments includes voluntary certification and labelling programs, voluntary and negotiated agreements, public-leadership initiatives, awareness raising and education, as well as detailed billing and disclosure programs" (Berardi et al., 2013, p. 145).
	Grey Infrastructure - Regulatory: New regulations may mandate higher standards than are found in conventional buildings. Regulations requiring disclosure of energy use may result in lower rents for energy-inefficient buildings. - Market: Conventional buildings do not maintain their asset value as well as sustainable buildings. Rental premiums are lower for conventional buildings than sustainable buildings. Insurers are less likely to provide flood insurance for buildings in flood-prone areas. Future energy and water prices are uncertain. - Technical: Higher operating costs. Less ability to withstand extreme weather events related to climate change. - Social Pressure: Pressure on governments to set higher sustainability standards, and on real estate developers to adopt higher standards. Risks to a company's brand. Tenants may not renew leases or rent from conventional buildings. The more sustainable the general building stock becomes, the less desirable conventional buildings become.
	Green Infrastructure - Regulatory: Uncertainty of green retrofit/building subsidies. Changes to standards could result in punitive damages if standards are not met - Market: Landlords hesitant to spend on retrofits. Potential that material manufacturers do not live up to set standards. - Technical: Wide array of standards makes understanding, gathering data and coordinating difficult. Implementation of new technology can create extra costs for construction and operation, schedule setbacks. Use of new technology/design increases risk of building failure. Leadership in Energy and Environmental Design (LEED) introduced resilience pilot credits in 2015, meaning that sustainable buildings may face less risk from floods, earthquakes, etc. - Social pressure: Potential failure to meet desired standard creates legal concerns.
Actors involved	- Government to set standards and construction policy, as well as funding for social housing. - Private sector: Includes material and product manufacturers, architectural and engineering firms, landlords, contractors and construction firms. - Individual households are involved in residential construction and retrofitting.
Existing sustainability standards	- LEED: http://www.usgbc.org/leed - Green Globes: http://www.greenglobes.com/home.asp - ASHRAE/USGBC/IESDNA Standard 189: https://www.ashrae.org/resources--publications/bookstore/standard-189-1
Main organizations working on the assessment of infrastructure	- UNEP–SBCI (Sustainable Buildings and Climate Initiative): http://www.unep.org/sbci/index.asp - International Initiative for a Sustainable Built Environment (IISBE): http://www.iisbe.org/ - Global Buildings Performance Network (GBPN): http://www.gbpn.org/ - International Council for Research and Innovation in Building and Construction (CIB): http://www.cibworld.nl/site/home/index.html - International Union of Architects: http://www.uia.archi/en - World Green Building Council: http://www.worldgbc.org/ - Green Building Initiative: http://www.thegbi.org/

Table 1. Assessment of selected green economy interventions in the energy sector (H = households; P = private sector; G = government)

		Market support			Multi-criteria analysis		
Goal	**Policy**	**Awareness**	**Demand**	**Supply**	**Investment**	**Avoided cost**	**Added benefit**
New buildings	Incentives for building environmentally efficient buildings			x	Private and public investment (P, H, G)	Reduced energy bill, water bill, heating and cooling bill (P, H) Avoided energy and water consumption (P,H) Avoided material use (P) Reduced health care spending due to indoor air quality (G, P, H)	Lower emissions of GHG and air pollutants (G,H), Green industry support (P), Green industry skill development (P) Avoided impact on soil and water quality (G, H), Reduced water treatment expenditure (G) Reduced power generation capacity expenditure (G) Increased government revenues from real estate taxes (G)
Retrofitting	Incentives for building retrofits and efficiency appliances		x		Public incentive (G), Purchase of products or retrofits (P,H)	Electricity and energy bill (H,P), Reduced fossil fuel use (H,P),	Lower emissions (G), Employment creation (H), Green industry skill development (P) Higher savings/ consumption (H,G) Reduced water treatment expenditure (G) Reduced power generation capacity

Note: P – Private sector; G – Government; H - Households

PART II: IN-DEPTH REVIEW

1.0 DEFINITION OF SUSTAINABLE INFRASTRUCTURE

A sustainable building is one that accounts for environmental, social and economic outcomes. On the environmental side, a sustainable building must have high efficiency in the use of energy, water and materials, as well as reduced impacts on health and the environment throughout its life cycle. Environmental concerns must be addressed throughout the process of manufacturing materials, construction, operation and management, and the demolition of a building. Sustainable buildings must also account for the health and well-being of occupants and inhabitants (UNEP, 2011a; Berardi, 2013)

The International Institute for Sustainable Development (2015) defines sustainable infrastructure as assets that optimize value for money economy-wide, and hence for all taxpayers. In the case of sustainable buildings, this requires that externalities such as health costs are accounted for in all stages of the building's life, in addition to the upfront costs of building construction and operation and management costs. Buildings are made up of a number of higher-order products, incorporating many different technologies and processes. Sustainability must therefore be evaluated across individual subcomponents, as well as the integration of subcomponents into functional units (Berardi, 2012)

In the case of buildings, the following technologies are considered:

- Solar photovoltaic (PV)
- Solar heat water
- Heating, ventilation and air condition
- Lighting
- Floor heating
- Construction materials
- Thermal insulation
- Water recycling
- Efficient appliances

Table 2. Overview of required inputs and outputs generated by buildings

Inputs	Outputs
• Construction o Capital o Labour o Raw materials (e.g., aluminum, steel, concrete, glass) o Water o Energy • Operation o Labour o Electricity use o Water use o Heating / cooling	• Revenues (rent, taxes) • Air emissions (CO_2, SO_2, NO_x, CH4) o Human health (mortality and morbidity) o Crop yield reduction o Global warming • Water pollution • Visual impact • Competition for land use • Energy production (e.g. rooftop PV)

1.1 SHORTCOMINGS OF BUSINESS-AS-USUAL INVESTMENTS

Buildings are typically built with the goal of minimizing upfront construction costs, in relation to the target future owner of the building (e.g., income level, family size, location of the property). New sustainable construction techniques or building technologies often increase construction costs, although the costs are not as high as often perceived (World Green Building Council, 2013). These technologies, being innovative and recently marketed, can also present difficulties in terms of knowledge and experience. As a result, conventional buildings are still being prioritized over sustainable buildings.

On the other hand, conventional buildings have several drawbacks in the procurement and construction, operation and decommissioning stages in comparison to sustainable buildings.

Procurement and construction: Building materials are a major consumer of energy and materials worldwide, and the demand for new buildings is increasing. Conventional building projects do little to reduce the energy use of materials and construction, focusing on low cost rather than high efficiency.

> ***Example:***
>
> About 10 per cent of the global energy supply is used in the manufacture of building materials. Construction in Asia, particularly in China and India, is creating unprecedented demand for construction materials and products. “In India, for example, the volume of new construction doubled from 2000 to 2005, while 50 per cent of all new construction globally is occurring in China” (Goodland & Tanner, 2013). At such rates, the implication is that the majority of buildings that will exist in Asia in 2030 are not yet built. “This pressure is further accentuated by often poorly maintained and deteriorating existing building stock. Many buildings constructed in recent decades have been rapidly assembled with little consideration for durability, sustainability or environmental health” (UNEP-SBCI, 2010, Ch. 3, p. 1). While the construction trend has slowed in recent years, emerging markets in the Assocaition of Southeast Asian Nations continue to drive growth in the industry (BMI Research, 2016).

Operation: The global building stock uses a large amount of energy, which in turn means that buildings contribute a substantial amount to global greenhouse gas (GHG) and other pollutant emissions, depending on the fuel mix that is used for heating, cooling and cooking. The building sector is also a major user of water. Increased energy and water use leads to higher costs. This in turn can lead to decreased rent and sale prices as investors and occupants become more aware of environmental and social costs.

> ***Example:***
>
> Whether existing building stock or projected growth of building stock, this sector is already the single largest contributor to global GHG emissions. Approximately one third of global energy end use takes place within buildings. “Nearly 60 per cent of the world’s electricity is consumed in residential and commercial buildings, although this usage varies widely according to consumption patterns, climate and geographical location” (UN-HABITAT, 2012).
>
> “Indoor air pollution in residential buildings in developing countries from poorly combusted solid fuels combined with poor ventilation is a major cause of serious illness and premature deat”h (UNEP, 2011b). “Approximately 42 per cent of the world’s population was exposed to household air pollution from solid fuels in 2013. Household air pollution was responsible for 2.9 million deaths in 1990, a number that remained constant over time, with 2.9 million deaths globally in 2013. Exposure to household air pollution has declined, as solid fuel is used less frequently. While the number of deaths per 100,000 people has declined steadily, the total number of deaths has remained constant due to population growth and population aging” (World Bank & IHME, 2016).
>
> “Based on best available estimates, buildings are responsible for between eight and 16 per cent of global freshwater consumption and in urban areas, and they generate approximately 20 per cent of wastewater production. Most calculations exclude water required for electricity production and manufacturing building materials. Freshwater use in buildings is in turn responsible for 2–3 per cent of world energy consumption, predominantly for pumping and treatment (Roodman & Lenssen, 1995; James, Campbell, & Godlove, 2002; Graham, 2003). [...]Building-related water use is estimated at 12 per cent in Mexico, the United States and Canada (CEC, 2007). However, there are significant regional variations depending on the level of urbanization in a country and the size of its agricultural and industrial bases. Building-related water use in Singapore, for example, has been estimated at 53 per cent (U.S. Department of Commerce, 2000). Most Indian cities rely heavily on groundwater for use in buildings” (UNEP-SBCI, 2010).

> "Evidence from studies carried out over the past decade, primarily based on data gathered from LEED-certifed office buildings in the United States, has shown that green buildings tend to have higher asset values than their conventional code-compliant counterparts.
>
> This differential in asset value is seen in higher sale prices, which are in turn related to higher rental rates, lower operating expenses, higher occupancy rates" (World Green Building Council, 2013)

Decommissioning: Demolition of conventional buildings produces large amounts of waste, as they are not designed with recyclability in mind. Accounting for the recyclability of construction materials bears a considerable energy-saving potential, especially when it comes to steel and aluminum (EIA, 2014).

> ***Example:***
>
> Building construction and demolition waste contributes about 30 per cent of solid waste streams in developed countries, with most waste associated with the demolition phase. "Although recycling building materials requires energy consumption, studies for some materials show that recycling materials still delivers net emissions savings. For example, following a life-cycle approach, Balázs Sára compared carbon dioxide emissions from produced recycled clay/gravel with and without selective dismantling and classification. The research indicates that carbon dioxide emissions were reduced from 107.7 kg to 6 kg per tonne of recycled clay/gravel produced. Assuming data can be collected, recycling rates of specific materials that are significant in construction, and demolition waste streams could be a useful sustainability indicator" (UNEP-SBCI, 2010).

1.2 ADVANTAGES OF GREEN INVESTMENTS

The advantages of sustainable buildings include the following:

Procurement and Construction: Sustainable buildings create green jobs and support green industries. Retrofitting and construction of new, sustainable buildings offer the opportunity to create good local jobs. The building sector is unique in that it includes workers from across the socioeconomic and skill spectrum, as well as all sizes of businesses.

> ***Example:***
>
> "The U.S. Department of Labour estimates that new standards for water heating and fluorescent lamps (among other products) could generate 120,000 jobs through 2020" (UNEP-SBCI, 2012).

The construction costs of sustainable buildings are generally higher than conventional buildings, but not as high as is commonly thought. Most importantly, retrofitting is certainly more expensive than building a new sustainable property. Nevertheless, the economic returns are very positive in both instances.

> ***Example:***
>
> "Actual design and construction costs have been documented to be in the range of -0.42 to 12.5 per cent, with the latter value corresponding to a zero carbon building project. The results from these studies, published between 2000 and 2012, are based on a wide variety of building types and present data from the United States, United Kingdom, Australia, Singapore and Israel" (World Green Building Council, 2013).
>
> "Looking only at the cost differential between constructing green and conventional buildings, a study by Greg Kats (2010) suggests that cost premiums are considerably lower than generally perceived. On average, green buildings in the USA cost 1.5 per cent more in upfront costs than conventional buildings, with a price premium ranging from USD 0/m^2 to USD 764.2/m^2, with a median of USD 36.6/m^2. However, public perception is that the additional costs of going green are 17 per cent" (UNEP, 2011b).

Operation and management: Sustainable buildings use less energy, which in turn reduces emissions of GHGs and other air pollutants. Sustainable buildings are also a low-cost source of carbon dioxide abatement when compared with other options across sectors. The abatement cost reflects the annualized cost of abatement measures in a given year per tonne of carbon saved compared with business-as-usual technology.

Example:

"LEED-certified buildings have been proven to use 25 per cent less energy and a 19 per cent reduction in aggregate operational costs in comparison to non-certified buildings" (GSA, 2011).

"Approximately 75 per cent of the total abatement potential (including retrofits to HVAC systems, building envelopes and appliances) in the buildings sector shows net economic benefits, with the remainder available at very low cost. Lighting options, particularly the introduction of LED bulbs, yield high net profits to society. The net economic benefits of the abatement potential in this sector overall is due to high energy savings over the full lifetime of investments. The average cost for the overall abatement potential is negative throughout the period of 2015 to 2030" (McKinsey, 2009).

The results of a green roof model based on the DOE-2 simulation program are shown in Figure 1. "It is encouraging to see the improved savings that result from more intensive planting for the non-insulated roof. The turf scenario best represents an extensive roof system. For an insulated roof with a U-value of 0.51 watts per square metre kelvin (W/m^2 K), a covering of turf reduced the annual energy consumption by only 0.6 per cent. […] The uninsulated (exposed roof) shows a covering of turf can produce a 10.5 per cent annual energy saving compared with a non-greened, exposed roof. This shows how the green roof better benefits buildings with poorer roof insulation" (Castleton, Stovin, & Davison, 2010).

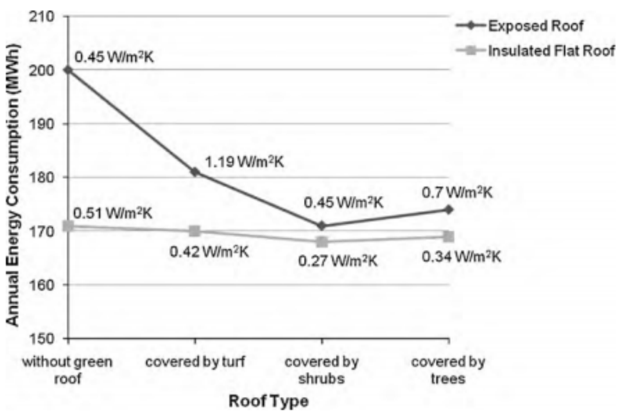


Figure 1. Energy savings of different roof types (Castleton, Stovin, & Davison, 2010)

A study of building envelopes in Greece found that "thermal insulation (in walls, roof and floor) and low infiltration strategies reduced energy consumption by 20–40 per cent and 20 per cent respectively. According to the same study, external shadings (e.g., awnings) and light-coloured roof and external walls reduced the space cooling load by 30 per cent and 2–4 per cent, respectively (Balaras, Droutsa, Argirlou, & Asimakopoulos, 2000)" (Sadineni, Madala, & Boehm, 2011)

Sustainable buildings use less water than conventional buildings. Methods for reducing water use include green roofs, pervious pavement and water-efficient appliances. This reduces stress on freshwater sources as well as reducing the amount of polluted water that needs to be treated.

> ***Example:***
>
> "In India, innovation in indigenous and green building approaches include rainwater harvesting with segregation of surface and rooftop runoff, the use of pervious paving to maximize groundwater recharge, as well as the introduction of waterless urinals (UNEP-SBCI, 2010). In Mexico, a Green Mortgages program of the public fund INFONAVIT provides credit for water and energy-conservation measures, including the introduction of solar water heating and low-flow showers (UNEP SBCI, 2009). [...]Using water-efficient appliances in the home can result in signifcant water savings. For example, modern water-efficient dishwashers and toilets can use as much as a 50 per cent less water than less efficient older models or even no water use in the case of waterless toilets and urinals (Waterwise, 2011a; Waterwise, 2011b)" (UNEP, 2011b).
>
> "According to Kats (2010), the net present value of 20 years of water savings in a typical green building in the United States ranges from US$5.4 to USD 21.5 per square metre" (UNEP, 2011b).

Sustainable buildings provide social benefits through improved health. This translates to increased worker productivity and work quality for commercial and industrial buildings. Labour costs outweigh energy costs by a wide margin for most businesses, particularly in developed countries. Savings resulting from increased labour productivity can therefore significantly outweigh savings due to energy-efficiency improvements. Work quality may be improved due to the design of the building or the reduction of sick days due to poor ventilation.

> ***Example:***
>
> "A study of conventional and green buildings in Taiwan found that only 59% of the respondents in the conventional building group sensed the Indoor Environmental Quality (IEQ) as comfortable, whereas 75% in the green building group claimed the same perception. The mean score of votes on IEQ in the green building group was 1.18 (i.e., equivalent to a sensation in between slight satisfaction and satisfaction), 0.37 higher than the mean of 0.81 reported for the conventional building group (between neutral and slight satisfaction)" (Liang, et al., 2014).

Sustainable buildings provide health benefits through reduced emissions and wastes. Air pollution, both from ambient concentrations and within the household, causes illness and premature death. Poor design may also lead to mold and other problems in the interior. Health impacts for tenants are most dependent on the design and operation of the building, but construction and procurement can also contribute to air pollution and waste streams that have a negative impact on health.

> ***Example:***
>
> "In developing countries, the health benefits of investment in the green buildings, specifically in technologies and appliances for heating and cooking, directly contribute to improved human well-being. Indoor pollution is a major cause of serious illness and premature death in developing countries. Greening the building sector, in this context, is expected to derive its main benefits from reducing indoor pollution and improving the health of the poor, particularly women and children" (UNEP, 2011b).

Increased water and energy efficiency reduces operation and management costs (e.g., stop flush in the toilet or specific shower heads have the potential to decrease the use of fresh water, some even up to between 50 and 70 per cent), while raising rents, resale value and occupancy rates. Decreased water and energy bills are attractive to tenants and to potential buyers, not only for the associated economic savings, but for the social value placed on environmentally friendly products and lifestyles.

> ***Example:***
>
> When surveyed, 76 per cent of corporations from around the world revealed that lower operating costs were an important reason for building sustainable buildings. Higher building value at point of sale (38 per cent), higher rental rates (27 per cent) and higher occupancy rates (25 per cent) were also major benefits of sustainable buildings (McGraw Hill Construction, 2013).
>
> An office building registered with LEED or Energy Star rents for a three per cent
>
> premium. "When endogenous rent-setting policies are taken into account, the results suggest that the effect of a green label is even larger" (Eichholtz, Kok, & Quigley, 2010, p. 17). "Labelled buildings have effective rents that are almost 8 per cent higher than those of otherwise identical nearby non-rated buildings. This reflects the higher occupancy rates, on average, in labelled buildings. The economic implications of a green rating are somewhat stronger for buildings with a "triple net" rental contract, which indicates that tenants prefer incurring utility costs separately when leasing space in green buildings.[...] Quite clearly, the energy efficiency of Energy Star-certified buildings is reflected in the effective rents these buildings command. Among Energy Star-certified buildings, those that use less site energy, controlling for building size and the climate in the metropolitan area, command substantially higher effective rents" (Eichholtz, Kok, & Quigley, 2010).

Decommissioning: Sustainable buildings are designed with the potential for product re-use and recyclability in mind, which results in less waste during both construction and demolition. Organic materials, such as sustainably sourced wood, have low embodied energy, while metallic materials perform well in terms of lifespan and recyclability. Construction with reused materials can be particularly sustainable as compared to construction using all new materials.

> ***Example:***
>
> The energy-saving potential for steel recycling is up to 74 per cent (EIA, 2014), and for aluminum about 90–95 per cent of the energy that is used for primary production can be saved through recycling. Cement, although not directly recyclable, can be ground to gravel after the demolition of buildings and used as input for the construction of infrastructure. Furthermore, if used as input for the cement production, it has the potential to significantly reduce process-related carbon dioxide emissions. Large amounts of cement, steel and aluminum are used in buildings, which, combined with the increase in demand for buildings, makes planning for the recyclability of those materials an imperative for sustainable buildings.
>
> "Although recycling building materials requires energy consumption, studies show that recycling materials still delivers net emissions savings. Following a life-cycle approach, Sára (2001) compared carbon dioxide emissions from produced recycled clay/gravel with and without selective dismantling and classification. The research indicates that carbon dioxide emissions were reduced from 107.7 kg to 6 kg per tonne of recycled clay/gravel produced. Recycling rates of specific materials that are significant in construction and demolition waste streams can be significant indicators of sustainability" (UNEP, 2011b).

2.0 RISKS TO PROJECT FINANCING AND OPERATIONS AND MAINTENANCE

Table 3. The impact of project risks on green/ grey infrastructure

	Grey infrastructure	Green infrastructure
Regulatory		
Changing sustainability standards	-	+
Energy-/water-use disclosure standards	-	+
Uncertainty of green retrofit/building subsidies	+	-
Market		
Asset value maintenance	-	+
Water/energy price uncertainty	-	+
Material manufacturers (of new sustainable technologies) may not live up to standards	+	-
Landlords hesitant to spend on retrofits	-	+
Technical		
Operating costs	-	+
Extreme weather	-	+
Wide array of standards leads to knowledge, data gaps	+	-
Use of new technology leads to increased costs	+	-
Use of new technology increase risk of building failure	+	-
Social Pressure		
Pressure to set/adopt higher standards	-	+
Attitudes of tenants /investors changing toward sustainability	-	+
Failure to meet desired standard creates legal/ brand issues	+	-

2.1 GREY INFRASTRUCTURE

Regulatory: New regulations may mandate higher standards than are found in conventional buildings. Regulations requiring disclosure of energy use may result in lower rents for energy-inefficient buildings.

> ***Example:***
>
> "Minimum standards for building codes are progressively becoming stricter as well, which means that the baseline requirements and associated costs that represent 'business as usual' are progressively getting higher, narrowing the gap between the cost of code-compliant buildings and the cost of green buildings" (World Green Building Council, 2013).

Market: Conventional buildings do not maintain asset value as well as sustainable ones. Rental premiums are lower. Insurers are less likely to provide flood insurance for buildings in flood-prone areas (which is where a building defined as "sustainable" would not be built). There is uncertainty about future energy and water prices, and, in case of an increase, conventional buildings will be affected the most.

> ***Example:***
>
> "The financial performance and valuation of a real estate asset is, to a large degree, determined by the security of its cash flow. The likelihood that tenants might leave a building, or not lease it in the first place because of its inadequate sustainability performance, is recognized as a key risk by investors. One study contends that, as more green buildings become available and occupiers become less willing to occupy non-green buildings, it will increase the speed of depreciation for non-green buildings at an exponential rather than linear rate" (World Green Building Council, 2013).
>
> "One of the key risks that investors face in regard to climate change is the insurability of buildings—without this, a building's value could be substantially reduced, even to nil. Some insurers have taken the view that, in certain locations such as the U.K. and Australia, it is no longer economically viable to provide flood protection cover against risks to buildings and the businesses that operate from these buildings" (World Green Building Council, 2013).

Technical: As the environment changes, conventional buildings may face higher operating costs, as they are less adaptable. Conventional buildings may not be designed to withstand extreme weather events that are not common now, but will become more common due to climate change.

> ***Example:***
>
> "Notwithstanding any societal adjustments that climate change may bring, real estate investment decision making will have to evolve to reflect changes in the economic
>
> viability of different locations, and the ability of different building types and designs to stand up to a changing environment. A useful risk-management context within which to consider this is in terms of resilience and the extent to which investments are future-proofed. As experienced recently in New York, Australia, Europe and many other places around the world, there are many physical risks that are associated with climate change. Investors will increasingly need to factor the ability of buildings to withstand predicted impacts into their decision making. Perhaps chief among these impacts will be extreme weather events, flooding, subsidence and the ability of building skin and systems to cope with increased ambient temperatures and changing rainfall patterns.
>
> Investors will also have to consider the issue of building comfort and the ability of buildings' systems to ensure that occupiers will view premises as desirable; with increased temperatures predicted, there is a cash-flow risk for buildings that are not sufficiently resilient to ensure future occupier satisfaction" (World Green Building Council, 2013).

Social pressure: There is continual pressure on governments to set higher sustainability standards, and on real estate developers to adopt higher standards. This may make "conventional" buildings obsolete. There are risks to a company's brand if they do not adopt high standards for new buildings.

> ***Example:***
>
> "In all business sectors, there are potential risks to a company's brand and performance arising from the activities and associations of its investment partners. A study by Bauer and Hahn (2011) confirms that companies with better environmental performance exhibit cheaper debt financing costs, supporting the contention that firms with more socially responsible practices have higher valuation and lower risk.
>
> The impact of real estate investors' asset and portfolio-level sustainability performance—and their management of the associated risks—can be felt in their ability to attract equity and debt at competitive rates. It is for this reason that an increasing number of real estate fund managers and their investors subject their portfolios to sustainability benchmarking. Although there is limited evidence of investors deciding not to invest in funds based on sustainability criteria alone, some investors are including sustainability performance to identify 'best in class' opportunities" (World Green Building Council, 2013).

2.2 GREEN INFRASTRUCTURE

Regulatory: There is uncertainty in green retrofit/building subsidies. Changes to standards could result in punitive damages if standards are not met.

> ***Example:***
>
> "An increasing number of municipalities and states are incorporating building codes and mandates associated with green construction. While these new rules are typically accompanied by some sort of financial incentive, they can also represent an increase in liability to everyone involved in the green construction process" (Zurich, 2011).
>
> "As previously reported, past cases in America demonstrate industry resistance to the introduction of stringent energy-efficient building codes. At least two cases have emerged which differ in their interpretation of an American legal theory known as "pre-emption," which refers to the inability of a lower level of government to legislate in an area already occupied or controlled by a higher level of government. In 2012, the federal district court determined that a separate performance path could not be severed and was therefore invalid along with the prescriptive path. The dispute took four years but ultimately removes the ability of the City of Albuquerque to enforce its proposed green building code. The cases demonstrate two things; first, that not all industry groups are completely onside with the movement towards energy-efficient building codes; and second, the potential difficulty in creating local green building regimes without considering their integration at a national level" (British Columbia Construction Association [BCCA], 2012).

Market: Landlords may be hesitant to spend on retrofits, as the costs are upfront and rent increases may not be able to cover the retrofit costs. In some cases, tenants may pay for energy use, giving even less incentive for landlords to undertake retrofits. There is the potential that manufacturers do not live up to standards required for building components, as the technologies are new and have not been widely field tested. Manufacturers may also face patent disputes over new technologies. Financial costs of sustainable buildings may be too high for some companies, effecting their ability to complete projects on time.

> ***Example:***
>
> A forum of 55 construction industry executives found that the financial risks pertaining to green construction represented the greatest area of concern. "The additional costs associated with the design, construction and ownership of green buildings may prove to be too costly for some companies and therefore affect their ability to complete projects on time within a specified budget. Some examples of the financial risk issues discussed include: the cost justification of building green during an economic slowdown, the availability of reasonably priced insurance, the availability and cost of surety bonds, commodity price volatility and the cost of LEED certification process, to name a few" (Zurich, 2011, pp. 3–4).
>
> A survey of the green building industry in Australia found that "the second and third ranked risks were "higher investment costs to go green" and "costs of investment in skills development" respectively, and identified that added costs to "go green" serve as very important risks in green building development. The GBCA (Green Building Council of Australia) identified similar results, acknowledging that the perception that "green building goes hand-in-hand with higher upfront costs" is an impression "deeply ingrained in the [construction] industry"" (Zou & Couani, 2011).
>
> "Additionally, the performance of new products and technologies that are being developed for green construction can also pose a risk. Many of these products are being developed quickly and are not being properly field tested. This can lead to legal disputes over who is responsible if the product fails or does not perform to expectations. While the responsibility for product failure typically falls on the manufacturer, the engineer may also find that they are liable for selecting the product" (Zurich, 2011, p. 4).
>
> A survey of designers, subcontractors, contractors, clients, manufacturers and suppliers in the Australian green building industry found that the primary risk in green building development is ""a lack of commitment in the supply chain to go green." The fact that this is typically considered "very important" by all supply chain members lays the dependence of green building performance on the performance and commitment of the entire construction supply chain" (Zou & Couani, 2011).
>
> A roofing product qualified for LEED made from recycled tires faced a patent dispute in the United States. The plaintiff, Clearline Technologies Ltd., alleged that the defendant, Cooper B-Line, had misrepresented and infringed Clearline's patent. In response, Cooper B-Line was able to get a summary judgment dismissing the allegations. The rise in green building products will likely continue to result in patent disputes among material suppliers (BCCA, 2012).

Technical: A wide array of standards makes understanding, gathering data and coordinating difficult. Implementation of new technology can create extra costs for construction and operation, as well as schedule setbacks. Use of new technology/design increases risk of building failure. LEED introduced resilience pilot credits in 2015, meaning that sustainable buildings may face less risk from floods, earthquakes, etc.

> ***Example:***
>
> "A forum of 55 construction industry executives agreed that an area of concern was that many of the consultants/subconsultants and subcontractors involved in the building industry are not experienced in green construction. The group's concern was that the lack of experience could result in problems obtaining LEED certification, delays and improper material specifications" (Zurich, 2011, p. 4).
>
> New technologies may not be as durable or well tested as more conventional technologies. "Claims arose out of allegations that "Parallams" (supplied by and treated by Weyerhaeuser) had been exposed to exterior weather conditions resulting in deterioration to the point of posing a risk of death or serious injury. According to the court documents, the building experienced problems relatively early on and the owners took steps to identify, understand and remediate the problem. The allegations were based upon water ingress either due to improper sealant, supplied building material, or both ... What this case demonstrates most fundamentally is the risk tied to novel green building materials and design. Weyerhauser, as the material supplier, was able to avoid liability, but all other parties are now left to determine who will incur the costs of remediation" (BCCA, 2012, pp. 4, 7).

Social Pressure: Potential failure to meet the desired standard creates legal concerns.

> ***Example:***
>
> "Increasingly, LEED certification is becoming the industry standard in the design and construction of green buildings. Many building owners, tenants and other third parties, such as the federal and state governments and municipalities, are increasingly mandating that buildings meet a certain level of LEED certification. With these mandates comes an increased risk of legal liability for green building design and construction professionals in the event that the building does not meet the specified LEED certification requirements.
>
> An example of this can be seen in the case of *Southern Builders v. Shaw Development*, one of the first cases of major green building litigation in the United States. In this case, Shaw Development was working on a condominium project that was required to obtain at least a LEED silver rating. The silver rating was essential due to a state program that offered an 8 per cent green building tax credit for silver-rated buildings. The owner charged that Southern Builders breached its contractual obligations when it failed to meet the LEED silver rating. The owner sued Shaw Development for USD 635,000, which was the amount of the tax credit that it failed to obtain. This case was settled; however, many expect that this was just the beginning of an increase in disputes of this nature" (Zurich, 2011, p. 4).
>
> As perhaps one of the more ambitious "green" developments around, the Destiny USA centre has drawn a great deal of media attention, both positive and negative. "The project was initially supported by 'green building' provisions of the federal American Jobs Creation Act of 2004 and through a tax exempt bond program controlled by the Syracuse Industrial Development Agency (SIDA)... To qualify for the USD 238 million loan, the project had to seek LEED certification for 75 per cent of its square footage, be 'reasonably expected' to receive certification and incorporate other sustainable features. Some of the sensational features publicly touted by the developer to qualify for the loan were dropped, including a 45 megawatt biofuel plant and 290,000 square feet of photovoltaic cells.
>
> In an apparent win for investors holding the green bonds, the project recently obtained a favourable review by the IRS, which affirmed the continued tax exempt status of the bonds. If the status had been lifted, the developer would have had to forfeit over USD 2 million held in reserve by SIDA and face potential recourse from investors. According to the IRS, the sustainable features initially promised were not required to materialize due to the downturn in the American economy" (BCCA, 2012).

3.0 CHALLENGES AND OPPORTUNITIES

3.1 MAIN ROADBLOCKS FOR THE ADOPTION OF SUSTAINABLE INFRASTRUCTURE

Roadblocks for sustainable buildings include upfront costs, uncertainty about the costs of new technologies, as well as the differing interests of groups involved in building construction, investment and rental.

Upfront investments are often higher for sustainable buildings, and are generally perceived to be even higher than they actually are. While the long-term costs of sustainable buildings are lower, the payback period may not be short enough for investors.

> ***Example:***
>
> "Although buildings can be greened at low or zero net cost over the lifetime of the investment, the initial additional capital outlay, the so-called "first cost," could be a deterrent for those who demand finance for greening buildings. Affordability is a particular concern in developing countries, especially in low-income areas where people already have trouble affording conventional housing" (UNEP, 2011b).

The use of emerging technologies in the construction of sustainable buildings may include hidden and unknown costs.

> ***Example:***
>
> "There may be hidden costs associated with the transition to sustainable buildings, including transaction costs associated with securing energy-efficient solutions and risks around replacement technologies (Westling, 2003; Vine, 2005). Transaction costs are often high, owing to the fragmented structure of the building sector with many small owners and agents" (UNEP, 2011b).

Due to limited experience, there is a lack of information around new technologies, building techniques and standards systems.

> ***Example:***
>
> "In 2006, the Green Building Council of Australia (GBCA) published the first-ever survey of the green building market in Australia. The Green Building Market Report found that 91 per cent of construction industry participants believe that "current information sources do not fulfill green building information needs" and that information on "green products" serves as the prime information need for green building in Australia (GBCA, 2006)" (Zou & Couani, 2011).

Tenants and building owners may be interested in reducing operation costs by greening their homes/buildings. However, utilities may suffer financial losses from lower levels of use due to efficiency upgrades, which may disincentivize them from supporting sustainable investments.

> ***Example:***
>
> "Another aspect of the fragmentation is reflected in the differing interests of individual households and utilities. While homeowners may be intrigued by the prospect of greening their homes and reaping energy savings and health benefits, utilities face a potential reduction in their sales revenue, and therefore may have little interest in supporting investment in green buildings" (UNEP, 2011b).

Tenants and building owners often have different incentives for retrofitting or building sustainable buildings. Tenants may be interested in reducing utility bills, whereas owners may not see enough of a rent increase to offset the upfront costs.

> ***Example:***
> "Market failures can take the form of misplaced incentives, such as when building tenants (as bill-payers) have an interest in environmental improvements that are not shared by the building owners. While low-energy prices may give little incentive for affluent households and businesses in developed countries to change their behaviour, subsidies often keep energy prices in developing countries artificially low and again take away any incentive to change" (UNEP, 2011b).

Uncertainty around the benefits and risks of sustainable buildings may dissuade institutional investors.

> ***Example:***
> "For financial institutions, energy-efficiency projects in buildings are often associated with the following major hurdles: low financial returns, credit risks, uncertainty and difficulty in evaluating the added financial value of green buildings" (UNEP, 2011b).

3.2 POLICY INTERVENTIONS

The main policy interventions to encourage green retrofits and new buildings fall into the categories of regulatory and control mechanisms, economic and market mechanisms, fiscal and incentive instruments, and capacity building and awareness. These policies can be mandatory, voluntary, or provide a model of action. Policies can also be applied to new or existing buildings, in either the residential or commercial sectors.

Regulatory and control mechanisms include policies such as building-efficiency standards, government procurement and product labelling. Evaluation and monitoring are vital to the success of these policy measures, as is regular review to ensure that standards remain up-to-date with market trends and technological developments. These instruments are more easily enforced when it comes to the construction of new buildings than they are with existing buildings (UNEP, 2011b). Several countries have been successful in implementing building codes to encourage sustainable buildings. For building code policies to be successful, they should include a holistic and dynamic approach, good enforcement, individual elements of performance and overall performance (McDonald & Laustsen, 2013). Government procurement policies are not only aimed at the direct social and environmental benefits that come along with green buildings, but also at encouraging green procurement and investment in the private sector (Simcoe & Toffel, 2012). Governments are owners of a large and varied number of buildings, such as offices, public housing, schools, hospitals, and service or operation centres. As regular procurers of building sector services, governments play a key role in implementing energy and resource efficiency options (UNEP-SBCI, 2012).

> ***Example:***
> "The European Union (EU) is actively engaged in realizing the energy-saving potential of energy efficiency in buildings. The EU's 2002 Energy Performance of Buildings Directive (EPBD) (Directive 2002/91/EC, 2002) is a framework directive transposed into national legislation and implemented by all 27 member countries. The EPBD was revised in 2010 to significantly strengthen the energy performance levels of both new and existing buildings.
>
> A key provision of the revised directive is that all new buildings after 2020 (or after 2018 for public authorities) must be nearly-zero-energy buildings (nZEBs). The EPBD mandates that minimum energy performance requirements must be set not only for new construction but also for existing buildings undergoing major renovations; the level of the performance standards are left to the individual member countries. There is also a cost-optimality calculation methodology that all member states are to use in revising their building codes" (GBPN, 2013).
>
> France updated mandatory building codes for new and existing non-residential buildings in 2012. The policy updated energy performance requirements for insulation (average U-value <=0.36 W/m^2K), air leakage, space heating (connected to urban heating system supplied by 50 per cent renewable energy), water heating (solar or electric hot water), lighting and renewable energy use (International Energy Agency, 2016a).

Market and economic mechanisms include policies such as energy performance contracting, cooperative procurement and cap and trade (UNEP, 2011b). These instruments encourage the development of markets or market incentives that make sustainable buildings more amenable to investors. One such market is the Energy Service Company (ESCO) market. These companies provide energy-efficiency-related services within a performance contract. ESCO guarantees a certain energy and monetary savings, and compensation is tied to performance. Services may include lighting retrofits, HVAC retrofits, the installation of onsite generation technologies and the installation of water conservation technologies (Lawrence, 2014). Another market instrument, energy-efficiency certifications, is valuable to all building sector stakeholders. Buyers and tenants can compare the performance of different buildings, while developers that build sustainable buildings see rent increases, increased occupancy, or higher sale prices (International Energy Agency, 2010).

> ***Example:***
>
> "84 per cent of ESCO revenues in the United States in 2011 came from the public and institutional sector, which includes the federal government. Historically, the bulk of ESCO revenue has come from the Municipal, University, School and Hospital (MUSH) and federal markets. Federal, state and local government energy-use reduction goals are drivers in the use of Energy Savings Performance Contracting (ESPCs) on large projects that are authorized to have contract terms of up to 20 years. … The MUSH markets, which are comprised of state and local government, universities/colleges, K–12 schools and healthcare facilities, represented about 64 per cent of industry revenue in 2011" (Stuart, Larsen, Goldman, & Gilligan, 2013).

Fiscal and incentive instruments include policies such as carbon/emission taxes, tax exemptions, subsidies and grants. These instruments are aimed at energy or water consumption by increasing prices and therefore discouraging overuse. Incentive programs can also be targeted at paying a portion of upfront costs, which reduces the payback period (UNEP, 2011b).

> ***Example:***
>
> "A range of Commonwealth, state/territory and retailer programs is available across Australia to target energy-efficiency advice, retrofits and assistance to people with low incomes. The largest is the New South Wales (NSW) government's AUS 63 million Home Power Savings Program, which provides behaviour-change assistance and an energy savings kit, which includes small energy-efficiency items including showerheads and draught excluders. The Commonwealth's AUS 50.5 million Home Energy Saver Scheme, funded through the Clean Energy Future package, provides behaviour-change information, access to financial advice and microfinance for efficient appliances" (Australian Council of Social Service, 2013).

Capacity support and awareness-building instruments include policies such as voluntary certification, public-leadership initiatives and detailed disclosure programs. These policies encourage voluntary action and are aimed at changing consumer and investor behaviour (UNEP, 2011b).

> ***Example:***
>
> "Over the last three years through the K-I-C Start school program, takeCHARGE has provided energy-efficiency and conservation education support to schools throughout Newfoundland and Labrador by delivering classroom presentations and an annual contest for primary and elementary students. In total, over 11,000 students in 106 schools throughout the province participated in 448 presentations about energy efficiency and conservation" (Government of Newfoundland and Labrador, 2015).

The IEA has developed a Building Energy Efficiency Policies (BEEP) database that contains detailed information on energy-efficiency policies across countries. Policies include building codes, incentive programs and green labels. These policies can be mandatory, voluntary, or provide a model. Policies can also apply to new or existing buildings, both residential and non-residential (International Energy Agency, 2016a).

Table 4. Policies to encourage deployment of energy efficiency and renewable energy in buildings (UNEP, 2011b)

Policy	Definition
Regulatory mechanisms	
Appliance standards	Requirements that appliances perform at a certain standard in terms of energy/ water use
Building codes	Set standards of efficiency, safety, health, etc. that all buildings must adhere to. May be either prescriptive or performance based.
Procurement regulations	Policies that require government buildings to be built to a certain standard may reference a private standard such as LEED.
Energy-efficiency obligations	Energy companies are required to achieve yearly energy savings of some percentage of annual sales to consumers (1.5 per cent in the EU). To reach this target, companies carry out measures to help consumers improve their energy efficiency.
Mandatory certification and labelling	Products (such as appliances), materials and buildings as a whole may be held to mandatory standards for energy use, water use, etc.
Utility demand-side management programs	The goal of utility demand-side management is to encourage consumers to use less energy. Demand-side management programs may include setting of peak hours or education.
Market and economic instruments	
Energy-efficiency certificate schemes	Performance certification is a means of rating individual buildings on how efficient they are in relation to the expected amount of energy needed to provide users with comfort and functionality. Certifications allow building to be assessed against one another, and to see where certain buildings fall short.
Carbon credit trading schemes	Those who reduce emissions below a baseline or cap earned credits that can then be sold to those who are unable, or for whom it is too expensive.
Energy performance contracting	An energy service company as an implementing agent guarantees certain energy savings over a period of time, implements improvements and gets paid out of the energy savings.
Incentives and fiscal instruments	
Rebates	Give credits to homeowners for adopting specific energy-saving measures rather whole-building performance
Feebates	Homeowners who maintain energy-efficient homes or carry out upgrades prior to sale are able to pay less in sale or other fees.
Green mortgages	Credits based on a home's energy efficiency are factored into the mortgage, allowing individuals to finance energy-efficient improvements in their property
Tax exemptions	A reduction or temporary freeze in property taxes that is tied to the energy efficiency of a building
Public benefits charges	A special form of energy tax whose revenues are invested in efficiency improvements.
Subsidies	A direct provision of capital in order to offset the costs of retrofits
Capacity support and awareness	
Voluntary labelling	Labels are a source of inspiration and social pressure to make buildings more sustainable
Leadership programs	Government agencies can act as an exemplar for environmental targets, demonstrating new technologies and techniques, and reducing the risks for the private sector to follow suit.
Information and awareness-raising initiatives	Information can be in the form of billing and disclosure programs that make clear the consumption and costs of energy/water use. Education and training on sustainability issues and new technologies.

4.0 ACTORS INVOLVED

The main social actors involved in the building sector are:

Governments: To set standards and construction policy and provide funding for social housing. Procurement for government buildings not only fosters the industry, but also encourages the private sector to more fully engage with sustainable building. Federal, state/provincial and municipal governments all have a role in the sustainable building sector.

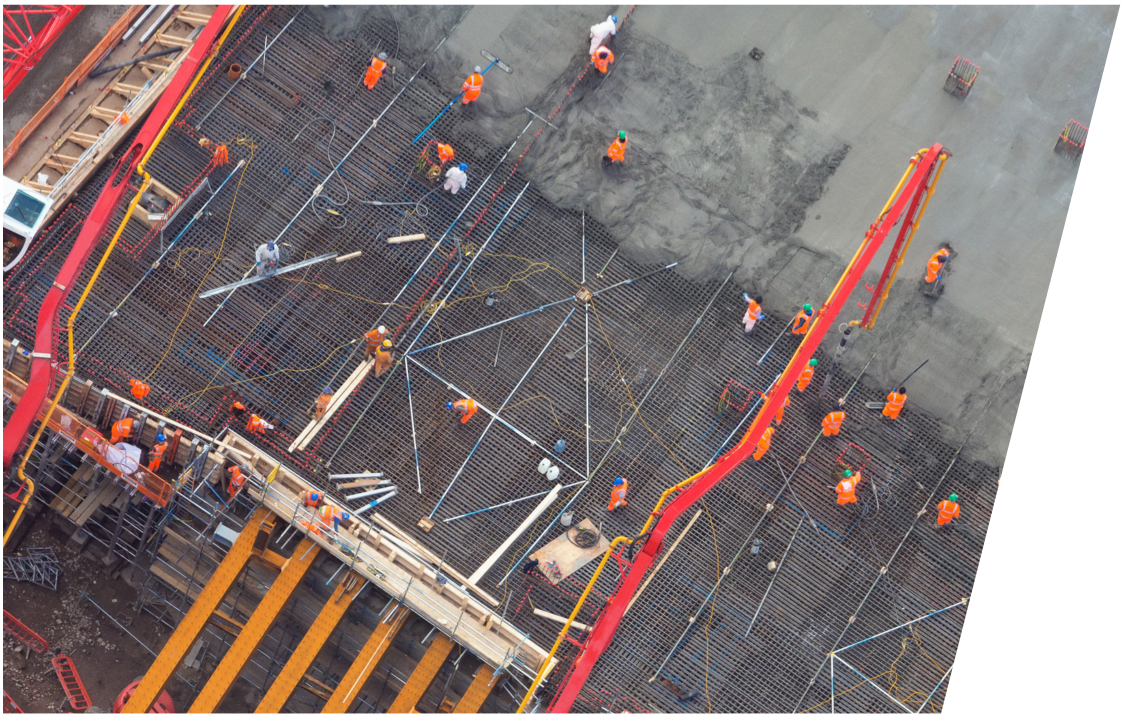
> ***Example:***
>
> "Some government green procurement policies have focused on government buildings, spurred in part by their substantial aggregate energy consumption (Coggburn & Rahm, 2005; Commission of the European Communities, 2008). Several U.S. states and a growing number of municipalities have also implemented green building procurement policies, most of which refer to the LEED standard (Environmental Law Institute, 2008; Rainwater, 2009). Because government purchases account for 10–15 per cent of GDP in developed countries, government procurement policies can substantially bolster demand for targeted goods and services.
>
> Beyond directly increasing government-sector demand, some public procurement policies seek to spur private demand (Marron, 2003) or to spark cost-reducing innovation among suppliers (Brander, Olsthoorn, Oosterhuis, & Fuhr, 2003). The European Union, for example, justifies its environmental procurement policy not only on the basis of leveraging government demand to "create or enlarge markets for environmentally friendly products and services" but also on the basis of stimulating "the use of green standards in private procurement"" (Simcoe & Toffel, 2012)
>
> "The Public Sector influences property markets in three ways; regulations of building construction and management, which is more likely to occur on the municipal level; taxation and environmental regulation that alter market dynamics through Federal regulation; and, the occupancy and construction of their own facilities. This concept of leading by example can raise awareness and provide experience, both essential to facilitating a culture of change … While federal governments are most likely to affect change in Europe, countries within North America are most likely to affect change through municipal legislation. This, however, is not to say that the Canadian federal government is immune from action. Other countries have introduced legislation that is adaptable to the Canadian federal system. India, a country facing pressure from the West to adapt to climate change, has made changes to its own government stock through the Energy Conservation Act of 2002. In addition, Japan requires all buildings to post their Comprehensive Assessment System for Built Environment Efficiency (CASBEE) rating to the general public, despite not mandating a particular level for compliance measures" (Boehm, 2010, p. 7–8).

Private sector: including material and product manufacturers, architectural and engineering firms, landlords, contractors and construction firms. Private sector engagement is increasing and is being driven by a business imperative.

> ***Example:***
>
> Up from only 13 per cent in 2009, 28 per cent of architects, engineers, contractors, building owners and building consultants around the world report that they are focusing their work on sustainable design and construction by doing at least 60 per cent of their projects green. The reason for this growth is that green buildings are becoming a business opportunity in an increasingly competitive global market place. In 2012, business drivers, such as client and market demand, are strongly influencing the market (McGraw Hill Construction, 2013).
>
> "Architects are increasingly interested in characterizing and reducing the environmental impacts of the buildings they design. Tools like energy modelling assist in predicting and, through good design, reducing the operational energy in buildings. Life-cycle assessments allow architects and other building professionals to understand the energy use and other environmental impacts associated with all life-cycle phases of the building: procurement, construction, operation and decommissioning" (Bayer, Gambel, Gentry, & Joshi, 2010).

Individual Households: Residential buildings use substantial amounts of energy; involved in residential construction and retrofitting.

> ***Example:***
>
> "A first generation building code, the Energy Conservation Building Code (ECBC), came into effect in 2007 in India. Currently, ECBC applies to buildings that have a connected load greater than 100 kW or contract demand greater than 120 kVA" (Bureau Of Energy Efficiency, 2011). In practice, ECBC requirements are generally only applied to buildings with air-conditioned floor areas of over 1,000 m^2. In principle, the ECBC also applies to large residential complexes, when their connected load or contract demand exceeds the thresholds. However, the current national policy priority is to enforce the code at the state level for large commercial buildings only.
>
> "The Bureau of Energy Efficiency has introduced the Energy Conservation Building Code, with effective adoption and enforcement of this code, commercial energy use is predicted to grow from 0.656 Exajoule (EJ) in 2005 to 2.648 EJ in 2030.
>
> Single family and multi-family households are expected to show the highest growth rates between 2005 and 2050. Furthermore, CEU projections show that most of the growth in energy consumption will occur in residential buildings. Changes in the residential sector must therefore be handled effectively to secure a low-energy future. Ensuring efficiency in this sector can produce a large number of additional advantages, as well as a reduction in energy use" (GBPN, 2014).
>
> "Primary energy consumption in the residential sector totalled 20.99 quadrillion Btu (quads) in 2009, equal to 54 per cent of consumption in the buildings sector and 22 per cent of total primary energy consumption in the United States. Nearly half (49 per cent) of this primary energy was lost during transmission and distribution (T&D). Energy consumption increased 24 per cent from 1990 to 2009. However, because of projected improvements in building and appliance efficiency, the Energy Information Administration's 2012 Annual Energy Outlook forecast a 13 per cent increase from 2009 to 2035" (Department of Energy, 2012).



5.0 MEASUREMENT STANDARDS AND DATA

5.1 EXISTING SUSTAINABILITY STANDARDS

Sustainability assessment systems generally fall into three categories: cumulative energy demand systems, which look at energy consumption; life-cycle analyses, which look at environmental aspects; and total quality assessment systems, which look at ecological, economic and social aspects. These categories are not strict and many assessment systems have aspects of more than one (Berardi, 2012). The majority of the following standard systems are total quality assessment systems. A complete list of assessment criteria can be found in Annex 1.

Leadership in Energy and Environmental Design (LEED) http://www.usgbc.org/leed

The US Green Building Council (GBC) released LEED in 1998. This system is currently available for 10 building typologies. LEED standards apply to construction and design, operation and maintenance, interior design and construction, homes, and neighbourhood development. There are nine evaluation categories: integrative process, location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation and regional priority. Points are accumulated over the categories, and a project earns a distinction of certified, silver gold, or platinum depending on the number of points accumulated. Although released in the United States, the LEED program has spread across the world, and the GBC has opened regional chapters in countries in Europe, Africa, America and Asia. More than 79,000 projects are participating in LEED across 160 countries and territories (Berardi, 2012; U.S. Green Building Council, 2016).

British Research Establishment's Environmental Assessment Method (BREEAM) http://www.breeam.com/

The United Kingdom was the first country to release a multi-criterion system for sustainability assessment. BREEAM was planned at the beginning of the 1990s by the British Research Establishment, and was released in 1993. BREEAM has moved beyond the United Kingdom, with more than 2 million buildings now registered in 77 countries. The assessment process compares the procurement, design, construction and operation of a development against performance targets. The system is applied to 11 building typologies and its evaluations are expressed as a percentage of successful over total available points: 25 per cent for pass classification, 40 per cent for good, 55 per cent for very good, 70 per cent for excellent, 85 per cent for outstanding. There are 10 evaluation categories: energy, health and well-being, innovation, land use, materials, management, pollution, transport, waste and water (Berardi, 2012; BREEAM, 2016).

Green Mark https://www.bca.gov.sg/green_mark/

The Building and Construction Authority (BCA) of Singapore launched the Green Mark Scheme in 2005 in order to promote sustainability in the built environment and raise environmental awareness in the building industry. Green Mark applies to 10 building typologies as well as parks, neighbourhoods and general infrastructure (BCA, 2016). Green Mark is applied to both new and existing buildings. Points are awarded in the assessment, with a score of 50 to 60 being a Gold rating, 60 to 70 being a Gold Plus rating, and 70 and above being a Platinum rating. Assessment criteria is divided into five sections (smart and healthy, climatic responsibility, energy performance, advanced green efforts and resource stewardship), with 16 criteria and 52 sustainability indicators (BCA, 2016).

Comprehensive Assessment for Built Environment Efficiency (CASBEE) http://www.ibec.or.jp/CASBEE/english/

CASBEE was developed in Japan in 2001 by a committee of academics, industry and national and local governments. CASBEE assessment is applied to pre-design, new construction, existing buildings and renovations. There are five grades for assessment: superior, very good, good, slightly poor and poor. The

CASBEE system is based on the principles of life-cycle assessment, assessment of the built environmental quality and environmental load, and use of the Built Environment Efficiency. The Built Environment Efficiency indicator takes into account the environmental quality (improvements in living amenity for building users) and the environmental load (impacts beyond the physical space of the building). CASBEE is primarily utilized in Japan, but a building in China was recently accredited (Berardi, 2012; Japan Sustainable Building Consortium & Institute for Building Environment and Energy Conservation, 2016).

Green Rating for Integrated Habitat Assessment (GRIHA) http://grihaindia.org/

GRIHA was founded by the Energy and Resources Institute in New Delhi. The system was initially developed for new commercial, institutional and residential buildings, and was modified after it was adopted by the Ministry of New and Renewable Energy. GIRHA became the national rating system for green buildings in India in 2007. Assessment takes place over the whole life cycle of a building: pre-construction (proximity to public transit, soil, existing fauna and flora, the existing landscape, etc.), building planning and construction (resource use and conservation, water use, energy use, etc.), and operation and management (health and well-being of occupants, continuing energy use, etc.) (GRIHA, 2016).

Green Star http://new.gbca.org.au/green-star/

Green Star was launched by the Green Building Council of Australia (GBCA) in 2003. Green Star assessments include: Design and As Built, Interiors, Communities and Performance. Nine assessment categories are used: management, indoor environment quality, energy, transport, water, materials, land use and ecology, emissions and innovation. Green Star uses a one to six star rating system (minimum practice, average practice, good practice, best practice, Australian excellence and world leadership). For the Design and As Built, Interiors, and Communities assessments, Green Star certification requires at least 4 stars (best practice) (GBCA, n.d.).

High Quality Environmental standard (HQE) http://www.behqe.com/

HQE was developed in France and is operated by the HQE Association within France. Cerway operates HQE globally. Certification is available for newly constructed buildings, buildings in operation, and urban planning and development. Assessment is based on research by the Scientific and Technical Centre for Buildings, and is based on performance in the themes of energy, environment, health and comfort. Within these four themes are 14 targets: site, components, worksite, energy, water, waste, maintenance, hydrothermal comfort, acoustic comfort, visual comfort, olfactory comfort, spaces quality, air quality and water quality (Cerway, n.d.).

Green Globes http://www.greenglobes.com/home.asp

Green Globes was developed following the release of BREEAM Canada in 1996. Green Globes for Existing Buildings was developed by ECD Energy and Environment Canada in 1996, and was followed shortly thereafter with Green Globes for New Buildings. Green Globes is primarily used in Canada (Building Environmental Standards [BOMA BEST]) and the United States (Green Building Initiative). There were more than 3,000 certified buildings as of 2013. Green Globes is primarily based on ASHRAE and ANSI/GBI 01-2010: Green Building Assessment Protocol for Commercial Buildings. Both new and existing buildings are included in the assessment (Green Globes, 2016). There are seven assessment categories, for a total of 1,000 possible points: project management, site, energy, water, materials and resources, and emissions. The assessment continuum is meant to reflect the life cycle of the building (ECD energy and Environment Canada, 2014).

5.2 DATA

Data on construction, operation and demolition is required to model the building sector, including cost estimates, employment, emissions and pollution, material use, and rental and sale premiums. Data is generally available for individual technologies, as well as whole buildings. Included technologies are:

- Solar PV
- Solar heat water
- Heating, ventilation and air condition
- Lighting
- Floor heating/geothermal
- Construction materials
- Thermal insulation/building envelope
- Water recycling
- Efficient appliances

Table 5. Data requirements

Construction/ renovation	Operation	Demolition
Material/component cost	O & M costs	Demolition costs
Material/component emissions and pollution	Operational emissions and pollution	Solid waste
Employment	Health impacts	
Water use	Productivity impacts	
Resource use	Rental and sale price premiums	

Data availability for resource use and emissions in the building sector is inconsistent across countries. There is a lack of data on building stock, patterns of energy use, GHG emissions and building-related water consumption. Reporting on GHG emissions for the building stock has taken place in Mexico, South Africa and India, as well as a number of developed countries. UNEP-SBCI is developing the Common Carbon Metric in order to provide a consistent indicator for emissions in the building sector.

Whole-building data

- Design and construction costs for green buildings have been documented to be in the range of -0.42 to 12.5 per cent (World Green Building Council, 2013)
- On average, green buildings in the United States cost 1.5 per cent more in upfront costs than conventional buildings, with a price premium ranging from USD 0/m^2 to USD 764.2/m^2, with a median of USD 36.6/m^2 (UNEP, 2011b).
- Approximately one third of global energy end use and 60 per cent of electricity use takes place within buildings. For developed countries in cold climates, space heating is 60 per cent of residential energy use; water heating is 18 per cent (UNEP, 2011b).
- LEED-certified buildings use 25 per cent less energy and have a 19 per cent reduction in aggregate operational costs in comparison to non-certified buildings (GSA, 2011).
- Life-cycle impacts of a typical house in Australia (Table 6), life-cycle cost (Table 7).

Table 6. Life-cycle impact category indicators of a case study house (Islam, Jollands, & Setunge, 2015)

Impacts	Unit and %	Construction	Operation	Maintenance	Disposal	Total
Greenhouse gas (GHG)	Tonne CO_2	26.0	48.0	6.43	−4.21	76.2
	Percentage (%)	34.0%	63.0%	8.43%	−5.52%	100
Cumulative energy demand (CED)	GJ	380	560	127	13.0	1080
	Percentage (%)	35.1%	51.9%	11.7%	1.20%	100
Water use	kL (H_2O)	1940	65.4	1090	0.29	3100
	Percentage (%)	62.6%	2.11%	35.2%	0.01%	100
Solid waste	Tonne	3.86	1.63	4.95	70.3	80.8
	Percentage (%)	4.78%	2.02%	6.13%	87.0%	100

Table 7. Life-cycle cost ($) of case study home (Islam, Jollands, & Setunge, 2015)

House name and %	Construction	Operation	Maintenance	Disposal	Total
Case study house	129,000	20,000	54,000	5600	209,000
Percentage	61.7%	9.74%	25.9%	2.69%	100

- Energy consumed in the average Canadian home is divided into five sections: space heating, 63 per cent; water heating, 19 per cent; appliances, 12 per cent; lighting, 4 per cent; and space cooling, 1 per cent. (Natural Resources Canada, 2016)
- The U.S. Energy Information Administration publishes monthly data on energy consumption by fuel type by sector (U.S. Energy Information Administration, 2017)

Table 8. Energy consumed by the U.S. residential sector (U.S. Energy Information Administration, 2017)

Month	Coal Consumed by the Residential Sector	Natural Gas Consumed by the Residential Sector (Excluding Supplemental Gaseous Fuels)	Petroleum Consumed by the Residential Sector	Geothermal Energy Consumed by the Residential Sector	Solar Energy Consumed by the Residential Sector	Biomass Energy Consumed by the Residential Sector	Total Energy Consumed by the Residential Sector
	(Trillion Btu)	(Trillion Btu)	(Trillion Btu)	(Trillion Btu)	(Trillion Btu)	(Trillion Btu)	(Trillion Btu)
2016 January	Not Available	920.502	126.784	3.724	8.333	32.675	2442.622
2016 February	Not Available	721.922	119.691	3.484	9.538	30.567	2030.687
2016 March	Not Available	473.175	96.557	3.724	12.996	32.675	1611.85
2016 April	Not Available	341.506	84.754	3.604	14.574	31.621	1367.875
2016 May	Not Available	202.219	80.904	3.724	16.164	32.675	1318.049
2016 June	Not Available	127.837	64.963	3.604	16.689	31.621	1556.826
2016 July	Not Available	111.243	70.65	3.724	17.455	32.675	1853.741
2016 August	Not Available	105.224	61.745	3.724	17.096	32.675	1803.756

Table 9. Energy consumption by the commercial sector (U.S. Energy Information Administration, 2017)

Month	Coal Consumed by the Commercial Sector	Natural Gas Consumed by the Commercial Sector (Excluding Supplemental Gaseous Fuels)	Petroleum Consumed by the Commercial Sector (Excluding Biofuels)	Conventional Hydroelectric Power Consumed by the Commercial Sector	Geothermal Energy Consumed by the Commercial Sector	Solar Energy Consumed by the Commercial Sector	Wind Energy Consumed by the Commercial Sector	Biomass Energy Consumed by the Commercial Sector	Total Energy Consumed by the Commercial Sector
	(Trillion Btu)	(Trillion Btu)	(Trillion Btu)	(Trillion Btu)	(Trillion Btu)	(Trillion Btu)	(Trillion Btu)	(Trillion Btu)	(Trillion Btu)
2016 January	6.227	524.593	74.679	0.05	1.669	4.366	0.107	10.723	1761.663
2016 February	5.644	430.805	71.552	0.046	1.561	5.03	0.114	9.821	1545.825
2016 March	5.133	309.519	56.039	0.054	1.669	6.432	0.121	11.167	1434.909
2016 April	3.773	241.806	49.662	0.05	1.615	6.677	0.116	10.447	1346.807
2016 May	3.833	177.611	47.052	0.057	1.669	7.325	0.115	10.181	1377.48
2016 June	1.571	143.898	36.805	0.055	1.615	7.467	0.105	9.839	1467.356
2016 July	1.591	140.892	39.442	0.054	1.669	7.735	0.103	10.464	1560.16
2016 August	1.558	143.681	34.172	0.049	1.669	7.396	0.081	10.494	1562.657

- The building sector accounts for 19 per cent of global GHG emissions, when accounting for direct and indirect emissions (Intergovernmental Panel on Climate Change, 2014).
- Buildings are responsible for between 8 and 16 per cent of global freshwater consumption (excluding energy generation and manufacture of building materials). Freshwater use in buildings is responsible for 2 to 3 per cent of world energy consumption, for pumping and treatment. Water use varies significantly depending on urbanization, agricultural and industrial activity (UNEP-SBCI, 2010)
- Buildings contribute 30 per cent to solid waste streams in developed countries, primarily from demolition (UNEP-SBCI, 2010).
- Rental premium: 3 per cent for LEED and Energy Star in the United States (Eichholtz, Kok, & Quigley, 2010).
- In the Netherlands, buildings with a green energy label receive a 6.5 per cent higher rent on average than a similar building with a non-green label (Kok & Jennen, 2012).
- Relationship between energy saving and rent premium/sale price: Energy Star: $1 dollar saving = 3.5 per cent higher rent/4.9 per cent higher sale (Eichholtz, Kok, & Quigley, 2010).
- Sale Price Premium: 13 per cent for LEED and Energy Star in the United States (Eichholtz, Kok, & Quigley, 2010).
- A business case study examining the San Diego real estate market showed that the overall vacancy rate for green buildings was 4 per cent lower than for non-green properties—11.7 per cent, compared to 15.7 per cent—and that LEED-certified buildings routinely commanded the highest rents (CBRE Global Research and Consulting , 2012).

Solar PV data

- Costs for solar PV in the United States are USD 2.93 per watt of direct current (Wdc) for residential systems, USD 2.13 Wdc for commercial systems, and $1.42 Wdc for utility-scale systems for fixed-tilt utility-scale systems, and USD 1.49 Wdc for one-axis-tracking utility-scale systems (National Renewable Energy Laboratory, 2016).
- Typical cost and performance for solar PV is displayed in Table 10.

Table 10. Typical cost and performance for Solar PV (International Renewable Energy Agency, 2012)

	Module cost, factory gate or spot (2010 USD/W)	Installed cost (2010 USD/W)	Efficiency (%)	Levelised cost of electricity (2010 USD/kWh)
Residential				
c-Si PV system	1.02 – 1.24	3.8 – 5.8	14	0.25 – 0.65
c-Si PV system with battery storage	1.02 – 1.24	5 – 6	14	0.36 – 0.71
Utility-scale				
Amorphous Si thin film	0.84 – 0.93	3.6 – 5.0	8 – 9	0.26 – 0.59

Solar water heater data

- A solar water heater costs between USD 2,039 and USD 4,619 to install in the United States (Home Advisor, 2016)
- Replacing gas water heaters with tankless or condensing heaters would reduce energy consumption by 30 per cent, and solar water heaters reduce consumption by 75–85 per cent. Replacing standard water heaters with heat pumps save 60 per cent, while solar water heaters save 65–80 per cent (McKinsey, 2009).
- Global Warming Potential is estimated at 34 g for flat plate collectors and 39 g CO_2e/kWh for evacuated tube collectors .The operation stage is the main contributor (around 45–50 per cent) due to the use of electricity for the pump. System manufacture contributes another 30 per cent (Greening & Azapagic, 2014).
- The values for Freshwater Aquatic Eco Toxicity Potential for the flat plate collector and evacuated tube collector systems are similar: 18.0 and 17.9 g DCB eq./kWh, respectively. The major source of this impact is the manufacturing stage (around 94 per cent) due to heavy metal emissions to fresh water of nickel, and to a lesser extent cobalt, during the production of stainless steel (Greening & Azapagic, 2014).

HVAC data

- Installing new energy-efficient HVAC systems in existing buildings provides energy savings. Replacing gas and oil heaters could reduce energy use by 20 per cent. Electric furnaces can be replaced with electric heat pumps for 35–50 per cent reductions (McKinsey, 2009).
- Costs for heat generation are displayed in Table 11

Table 11. Cost and efficiency of heat generation technologies (Commission of the European Communities, 2014)

Technology	Description	Capacity	Efficiency		Capital costs, 2007 [€$_{2005}$/kW], VAT excl.			Annual O&M costs (VOM+FOM) [€$_{2005}$/kW], VAT excl.			Life-time	Lifecycle GHG emissions	
		[kW]	[%]	*References*	REF	Range	*References*	REF	Range	*References*	[year]	t_{CO_2}/toe	*References*
Natural gas boiler	Natural gas fuelled boiler, large size, combi, floorstanding	75	89%	[112], [117], [116]	110	95 ÷ 135	[112], [118]	9	9 ÷ 10	[112], [118]	17	3.3	[95]
	Natural gas fuelled boiler, medium/small size, combi, wall-hung	20	86%	[112], [117], [116]	125	100 ÷ 130	[112]	13	11 ÷ 14	[112]	17	3.4	[95]
	Natural gas fuelled condensing boiler, medium size, combi, wall-hung	20	104%	[112], [117], [116]	145	115 ÷ 155	[112]	11	10 ÷ 12	[112]	17	2.9	[95]
Heating oil boiler	Heating oil fuelled boiler, large size, combi, floor standing, with oil reservoir	75	86%	[112], [117], [116]	190	160 ÷ 240	[112], [110], [118]	12	11 ÷ 14	[112], [118]	17	4.2	[95]
	Heating oil fuelled boiler, medium/small size, combi, floorstanding, with oil reservoir	20	80%	[112], [117], [116]	325	265 ÷ 355	[112]	18	15 ÷ 19	[112]	17	4.5	[95]
	Heating oil fuelled condensing boiler, medium size, combi, floorstanding, with oil reservoir	20	99%	[112], [117], [116]	390	310 ÷ 425	[112]	13	11 ÷ 14	[112]	17	3.6	[95]
Coal boiler	Solid fuel fuelled boiler, large size, with heat buffer	50	75%	JRC	340	310 ÷ 410	JRC	13	12 ÷ 15	JRC	17	6.1	[95],[103]
Wood chips boiler	Wood chips fired boiler, large size, with hot water reservoir and heat buffer	50	79%	[110]	385	325 ÷ 440	[109], [110], [111]	16	14 ÷ 18	[110]	17	0.3	[59], [95]
	Wood chips fired boiler, medium size, with hot water reservoir and heat buffer	35	79%	[110]	575	490 ÷ 665	[109], [110], [111]	22	20 ÷ 25	[110]	17	0.3	[59], [95]
Pellets boiler	Pellets fired boiler, large size, with hot water reservoir and heat buffer, inc. pellets silo	50	84%	[110]	355	300 ÷ 410	[109], [110], [111]	15	13 ÷ 17	[110]	17	0.7	[95]
	Pellets fired boiler, medium size, with hot water reservoir and heat buffer, inc. pellets silo	35	84%	[110]	505	430 ÷ 585	[109], [110], [111]	19	17 ÷ 22	[110]	17	0.7	[95]
	Pellets fired boiler, small size, with hot water reservoir and heat buffer, inc. pellets silo	15	84%	[110]	940	800 ÷ 1080	[109], [110], [111]	34	29 ÷ 38	[110]	17	0.8	[95]
Solar heat	Water heating system	3.5	98%	[135]	980	340 ÷ 2800	[92]	16	-	[92]	20	0.3	[95]
Geothermal heat pump	Large size electrical operated heat pump with geothermal heat source	100	100%	[116]	500	200 ÷ 1150	[92]	39	34 ÷ 60	[92]	25	0.2 ÷ 3.7	[95]
	Medium size electrical operated heat pump with horizontal or water ground heat source	15	100%	[116]	640	550 ÷ 720	[115]	55	54 ÷ 69	[112]	17	0.3 ÷ 5.9	[95]
Electrical heating	Electric combi heating/water boiler, medium/small size, wall-hung	20	100%	JRC	75	65 ÷ 90	JRC	5	-	JRC	17	0.7÷14.8	[95]
	Resistance heaters with fan assisted air circulation	2	97%	[123]	140	30 ÷ 300	JRC	n/a	-	[123]	10	0.7÷15.2	[95]

Lighting data

Table 12. Comparison between bulb types (Department Of Energy, 2016b)

	60W traditional incandescent	43W Energy-saving incandescent	15W CFL		12W LED	
			60W traditional	43W halogen	60W traditional	43W halogen
Energy $ saved (%)	-	~25%	~75%	~65%	~75-80%	~72%
Annual energy cost (2 hrs/day at 11 cents/kWh USD)	$4.80	$3.50	$1.20		$1.00	
Bulb life	1000 hours	1000 to 3000 hours	10,000 hours		25,000 hours	

Table 13. Cost comparison between LEDs, CFLs and incandescent bulbs (Earth Easy, 2016)

	LED	CFL	Incandescent
Light bulb projected lifespan	50,000 hours	10,000 hours	1,200 hours
Watts per bulb (equiv. 60 watts)	10	14	60
Cost per bulb	$35.95*	$3.95	$1.25
KWh of electricity used over			
50,000 hours	500	700	3000
Cost of electricity (@ 0.10per KWh)	$50	$70	$300
Bulbs needed for 50k hours of use	1	5	42
Equivalent 50k hours bulb expense	$35.95	$19.75	$52.50
Total cost for 50k hours	$85.75	$89.75	$352.50

Floor heating/geothermal data

- “With the use of heat pumps, geothermal heating and cooling systems extract heat energy and transfer it into buildings, saving approximately 50 to 60 per cent on heating and cooling costs … A geothermal system for an averaged size home (2,000 sq. ft.) would cost approximately CAD 25,000 to install, in exchange for a monthly saving of about 50 per cent” (Ecohome, 2014).
- Standard air-source HVAC systems cost around USD 3,000 per tonne of heating or cooling capacity, during new construction (homes usually use between one and five tonnes). Geothermal HVAC systems start at about USD 5,000 per tonne, and can go as high as USD 8,000 or USD 9,000 per tonne (Egg, 2013).
- “Geothermal heat pumps use 25 percent to 50 percent less electricity than conventional heating or cooling systems.” This translates into a GHP using one unit of electricity to move three units of heat from the earth. “The Environmental Protection Agency geothermal heat pumps can reduce energy consumption—and corresponding emissions—[up to 44 per cent compared with air-source heat pumps and] up to 72 per cent compared with electric resistance heating with standard air-conditioning equipment. Geothermal cooling improves humidity control by maintaining about 50 percent relative indoor humidity, making GHPs very effective in humid areas” (Department of Energy, 2016a).

Appliance Data

- Energy-efficient residential appliances provide 35 per cent energy reductions over standard appliances. Energy-efficient commercial fridges and freezers provide 15–20 per cent energy reductions over standard units (McKinsey, 2009).

Green roof data

- Green roofs have an equivalent albedo of 0.7–0.85, compared to 0.1–0.2 for a bitumen/tar/gravel roof. In Toronto, green roofs reduce heat gain by 70–90 per cent in the summer and heat loss by 10–30 per cent in the winter (Castleton, Stovin, & Davison, 2010).
- In Athens, green roofs saved 2 per cent in annual energy over a well-insulated roof, 3–7 per cent over a moderately insulated roof and 31–44 per cent over a non-insulated roof (Nichau & al., 2001).

Table 14. Energy saving potential of green roof in Athens, Greece (Nichau & al., 2001)

Roof construction	U-Value without green roof (W/m² K)	U-Value with green roof (W/m² K)	Annual energy saving % for heating	Annual energy saving % for cooling	Total annual energy saving
Well insulated	0.26–0.4	0.24–0.34	8–9%	0	2%
Moderately insulated	0.74–0.80	0.55–0.59	13%	0–4%	3–7%
Non insulated	7.76–18.18	1.73–1.99	45–46%	22–45%	31–44%

Envelope data

- Ventilated walls can reduce energy use by 40 per cent in the summer. Reflective glazing of windows reduced energy use by 54 per cent in Greece (Sadineni, Madala, & Boehm, 2011).

Table 15. Insulation comparison (Advanced Buildings, n.d.)

Insulation Type	R-value/in	Cost/ft²	Advantages	Disadvantages
LOOSE-FILL ("BLOWN-IN") For use in finished walls or cathedral ceilings, unfinished attic floors, hard to reach places. Also can be used for retrofits of existing uninsulated walls.				
Cellulose	3.1–3.7	Low $0.38 (R-13)–$1.12 (R-38)	- Forms better air barrier - Continuous insulation barrier for maintaining rated R-value - High use of recycled content	- Weight may cause settling and reduction in R-value over time - High installation costs for wall-cavity - Requires fire-retardant chemicals, which may be impacted by water vapor sorption
Fiberglass	2.2–2.9 (3.4–4.2) dense-pack	Low $0.49 (R-11) $1.22 (R-26)	- Provides better air barrier - Continuous insulation allows for installation to achieve rating	-May settle over time, though less settling occurs than with cellulose - Higher installation costs
Mineral Wool (Rock wool or slag wool)	2.2–2.9	Low $0.54-0.99	- Non-combustible - Good sound attenuation relative to fiberglass	- Potential creation of airborne respirable particles
BATTS Insulation fitted between frame studs joists and beams. Allows for easy installation, but gaps and compression may result in a lower effective R-value.				
Fiberglass Batts	2.2–2.9	Low $0.48 (R-11)–1.20 (R-38) unfaced; $0.48–1.21 kraft-faced	- Low cost and very low installation cost - Good fire protection	- Known carcinogen
Cotton Batts	3.0–3.7	Medium $0.50 (R-11)–$0.70 material cost only	- High recycled content (~75%) - Recyclable material - Easier handling for installer - Good sound absorption - Causes fewer respiratory problems than fiberglass during installation	- Unfaced only: vapor retarder must be added separately - Water leakage can affect fire retardant - not readily available in some areas
Plastic fiber (PET) Batts	3.8–4.3	N/A	- Recycled content - Less skin irritation	- Melts at a lower temperature - More difficult to handle
SPRAY-IN FOAMS For use in unfinished walls, attics, and floors and steel framing. EPS can be used in basement masonry walls and floors. This type costs more than batt insulation, but provides coverage near obstructions and provides a good air barrier.				
Polyurethane foam	5.6–6.2	$1.75	- High R-value/inch - Provides a vapor barrier	- More expensive than batt or loose-fill installations - Use fluorocarbons during production and installation
Low-density urethane foam	3.6	$1.30	- Use water or CO_2 as blowing agent	
Icynene foam	3.6–4.3	N/A	- Suitable for different construction types - Water-blowing agent causes no VOC emission - Good sound attenuation	- More expensive than batt or loose-fill installations
Wet-spray cellulose	2.9–3.4	Low*	- High recycled content - Suitable for unfinished spaces with exposed studs	- May take a couple months to fully dry after installation; excess water may lead to rot or mildew
Spray-in fiberglass	3.7–3.8	Low*	- Popular choice for hard to reach areas	- "Overfluffing" may allow insulation to reach the desired depth, but with less material, reducing the R-value
Cementitious	3.9	$1.50	- Best for coverage near obstructions - Works well at low temperatures - Non-toxic - Non-flammable - No dust	- Costly to retrofit
RIGID FOAMS For use in basement masonry walls and floors, exterior walls, structural panels. Rigid panels also provide a continuous thermal insulation barrier. Rigid foams are also used as an outer layer of insulation.				
Expanded Polystyrene	3.9 (1 lb/ft³) 4.2 (2 lb/ft³)	Low–Medium $0.62–$1.08	- Good moisture resistance - Maintains its rated R-value	
Extruded Polystyrene	5.0	Medium $0.84 (R-5)–$1.57 (R-15)	- Excellent moisture resistance - R-value increases with low temperatures - Suitable for use in below-grade applications	
Polyisocyanurate	5.6–7.0	Medium $0.79 (R-3.9)-$2.02 (R-28.8)	- High R-value/in - Good compressive strength	- R-value degrades over time
Polyurethane	5.6–7.0	N/A	- High R-value/in	
Phenolic	8.2 (closed) 4.4 (open cell)	N/A	- Good fire resistance - Uses air as a blowing agent	- Shrinkage occurs over time

Costs are total installed costs / ft² from RS Means 2002 Construction Data, including O&P, unless otherwise specified.
** Relative cost to other insulation materials of the same insulation type.*

GHG abatement costs

- Abatement costs in the building sector are low or negative for many technologies (Figure 2).

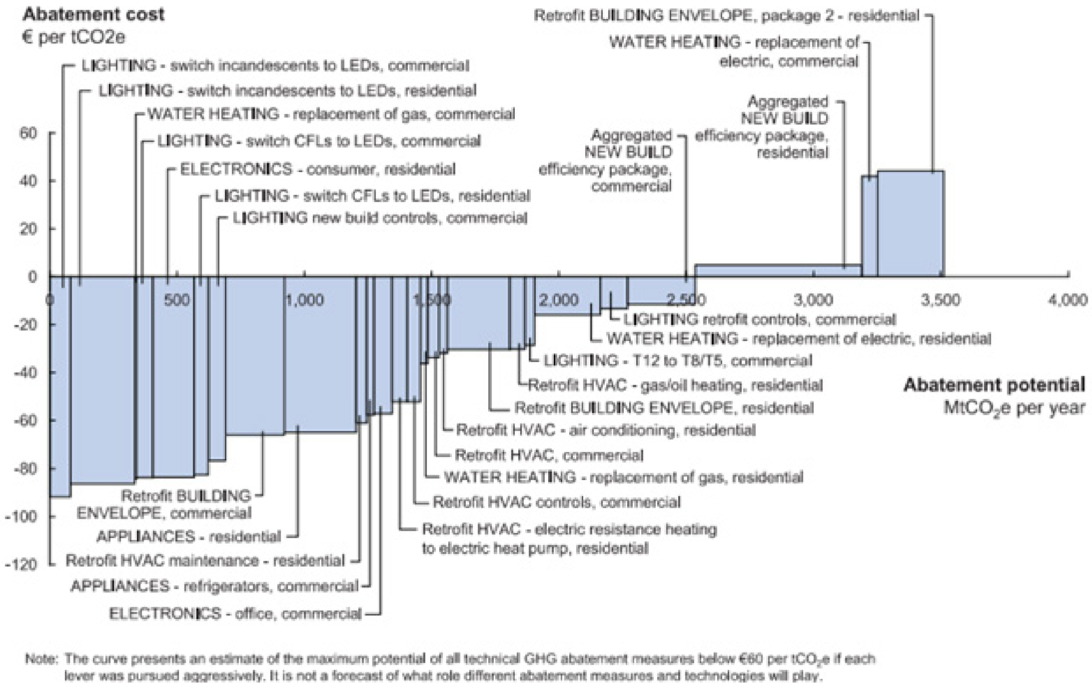


Figure 2. Global GHG abatement cost curve for the buildings sector (McKinsey, 2009)

Construction and employment data

- The Dodge Construction Outlook provides construction starts and market trends of the construction industry in the United States: (Dodge Research and Analytics, 2017)
- The U.S. Department of Labour estimates that new standards for water heating and fluorescent lamps could generate 120,000 jobs through 2020 (UNEP-SBCI, 2012)

Policy impacts

- Cities with a green procurement policy had roughly 90 per cent more LEED registrations than matched control cities (Simcoe & Toffel, 2012)

Health impacts

- 2.9 million deaths caused by indoor air pollution globally in 2013 (has remained steady since 1990). Deaths per 100,000 decreased from 54 per 100,000 in 1990 to 40 per 100,000 in 2013 (World Bank & IHME, 2016).
- Welfare losses due to household air pollution were 1,516 billion in 2013 (Table 16).
- Improved lighting design has been measured to lead to a 27 per cent reduction in the incidence of headaches, which accounts for 0.7 per cent of the overall cost of employee health insurance (Aaras, 1998).

Table 16. Welfare losses from household air pollution by region, 2011 USD, billions, PPP adjusted (World Bank & IHME, 2016)

Region	1990	1995	2000	2005	2010	2013
East Asia and Pacific	146	250	338	540	780	948
Europe and Central Asia	31	20	18	24	23	23
Latin America and Caribbean	61	52	46	53	64	67
North America	0	0	0	0	0	0
Middle East and North Africa	10	10	7	7	6	5
South Asia	98	125	145	204	335	396
Sub-Saharan Africa	45	47	57	63	73	77
Total	391	503	612	891	1,281	1,516

- Foregone labour output from household air pollution was USD 13.1 billion in 2013 (Table 17).

Table 17. Foregone labour output from household air pollution by region, 2011 USD, billion, PPP adjusted (World Bank & IHME, 2016)

Region	1990	1995	2000	2005	2010	2013
East Asia & Pacific	17.5	20.4	23.9	27.4	31.1	33.8
Europe & Central Asia	3.1	2.3	1.5	1.3	1.1	1.0
Latin America & Caribbean	7.7	5.5	4.1	3.9	3.9	3.6
Middle East & North Africa	1.3	1.1	0.6	0.4	0.3	0.2
South Asia	25.1	25.7	25.1	26.7	36.8	42.6
Sub-Saharan Africa	11.2	11.1	11.6	11.5	12.4	13.1

- EPA studies indicate indoor levels of pollutants may be up to 10 times higher than outdoor levels (Environmental Protection Agency, 2017).)
- In terms of health care costs, building retrofits that improved the indoor environment of a building resulted in reductions of: communicable respiratory diseases of 9–20 per cent; allergies and asthma of 18–25 per cent; and non-specific health and discomfort effects of 20–50 per cent (Fisk, 2000).

6.0 MAIN ORGANIZATIONS WORKING ON THE ASSESSMENT OF INFRASTRUCTURE FOR SUSTAINABLE BUILDINGS

- **Sustainable Buildings and Climate Initiative (UNEP–SBCI):** "The UNEP-SBCI is a partnership of major public and private sector stakeholders in the building sector, working to promote sustainable building policies and practices worldwide." UNEP-SBCI has created an Energy and Emissions Technical Advisory Committee and a Materials and Water Technical Advisory Committee. UNEP-SBCI is currently developing the Common Carbon Metric, which measures energy intensity (kWh/m^2/year) and carbon intensity (kgCO_2e/m^2/year). A Sustainable Building Protocol is also being developed to measure resource use, depletion, use of recycled materials, use of renewable materials and design material efficiency of buildings. http://www.unep.org/sbci/index.asp

- **International Initiative for a Sustainable Built Environment (iiSBE):** "iiSBE is an international non-profit organization whose overall aim is to actively facilitate and promote the adoption of policies, methods and tools to accelerate the movement towards a global sustainable built environment. iiSBE has an international Board of Directors from almost every continent and has a small Secretariat located in Ottawa, Canada." http://www.iisbe.org/

- **Global Buildings Performance Network (GBPN):** "The Global Buildings Performance Network (GBPN) is a globally organised and regionally focused organisation whose mission is to provide policy expertise and technical assistance to advance building energy performance and realise sustainable built environments for all." http://www.GreenBuildingsPerformanceNetwork.org

- **International Council for Research and Innovation in Building and Construction (CIB):** "CIB has developed into a worldwide network of over 5000 experts from about 500 member organisations active in the research community, in industry or in education, who cooperate and exchange information in over 50 CIB Commissions covering all fields in building and construction related research and innovation." http://www.cibworld.nl/site/home/index.html

- **International Union of Architects (UIA):** "The UIA's goal is to unite the architects of the world without any form of discrimination. From the 27 delegations present at the founding assembly in Lausanne, Switzerland, in 1948, the UIA has grown to encompass the key professional organisations of architects in 124 countries and territories, and now represents, through these organisations, close to one million three hundred thousand architects worldwide." http://www.uia-architectes.org/en

- **World Green Building Council (WGBC):** "The World Green Building Council is a network of national green building councils in more than one hundred countries, making it the world's largest international organisation influencing the green building marketplace. The World GBC's mission is to strengthen green building councils in member countries by championing their leadership and connecting them to a network of knowledge, inspiration and practical support." http://www.worldgbc.org/

- **Green Building Initiative (GBI):** "The Green Building Initiative® (GBI) seeks to be innovative and provide responsive customer service as we collectively move the needle toward a sustainable built environment. We recognize that credible and practical green building approaches for commercial and governmental construction are critical in this effort." http://www.thegbi.org/

Table 18. **Reports and indicators by organization**

Organization	Indicator/ report	Source
UNEP-SBCI	Common Carbon Metric	http://www.unep.org/SBCI/pdfs/CCM_PilotTesting_220410.pdf
	Materials and water technical advisory committee	http://www.unep.org/sbci/Activities/materials_water.asp
	State of Play reports	http://www.unep.org/sbci/resources/Publications.asp
	Sustainable Buildings Protocol	http://www.unep.org/sbci/Activities/SBIndex.asp
GBPN	Data Hub for Energy Performance of Buildings (EU)	http://www.gbpn.org/databases-tools/data-hub-energy-performance-buildings
	Building energy performance scenarios	http://www.gbpn.org/databases-tools/mrv-tool/about
	Policy Tool for Renovation	http://www.gbpn.org/databases-tools/purpose-renovation-policy-tool
	Policy Tool for New Buildings	http://www.gbpn.org/databases-tools/purpose-policy-tool-new-buildings
WGBC	City market briefs	http://www.worldgbc.org/index.php/infohub/city-market-briefs/
	World Green Building Trends	http://www.worldgbc.org/index.php/infohub/global-green-building-trends/
GBI	Green Resources Library	http://www.thegbi.org/training/green-resource-library/

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ANNEX 1: SUSTAINABILITY STANDARD ASSESSMENT CRITERIA

	LEED	BREEAM	Green Mark	Green Star	CASBEE
Energy	Fundamental commissioning and verification	Reduction of energy use and carbon emissions	Air condition total system efficiency	GHG emissions	Building thermal load
	Minimum energy performance	Energy monitoring	Lighting system efficiency	Peak electricity demand reduction	Direct use of natural energy
	Building-level energy metering	External lighting	Carpark system energy		Converted use of renewable energy
	Fundamental refrigerant management	Low-carbon design	Receptacle energy		Efficiency of building service system
	Enhanced commissioning	Energy-efficient cold storage	Building energy		Monitoring
	Optimize energy performance	Energy-efficient transportation systems	Solar energy feasibility study		Operation and management system
	Advanced energy metering	Energy-efficient equipment	Solar ready roof		
	Demand response	Drying space	Adoption of renewable energy		
	Renewable energy production				
	Enhanced refrigerant management				
	Green power and carbon offsets				
Water	Outdoor water-use reduction	Water consumption	Water-efficient systems	Potable water	Water saving
	Indoor water-use reduction	Water monitoring	Water monitoring		Rainwater and greywater
	Building-level water metering	Water leak detection			
	Cooling tower water use	Water-efficient equipment			
	Water metering				

	LEED	BREEAM	Green Mark	Green Star	CASBEE
Material and waste	Storage and collection of recyclables	Life-cycle impacts	Sustainable construction	Life-cycle impacts	Reducing usage of materials
	Construction and demolition waste management planning	Hard landscaping and boundary protection	Sustainable products	Responsible building materials	Continuing use of existing structural frame
	Building life-cycle impact reduction	Responsible sourcing of materials	Environmental construction management plan	Sustainable products	Use of recycled materials
	Environmental product declarations	Insulation	Operational waste management	Construction and demolition waste	Timber from sustainable forestry
	Sourcing and materials	Designing for durability and resilience			Efforts to enhance the reusability of components
	Material ingredients	Material efficiency			Use of materials without harmful substances
	Construction and demolition waste management	Construction waste management			Elimination of CFCs and halons
		Recycled aggregates			Consideration of global warming
		Operational waste			Air pollution
		Speculative floor and ceiling finishes			
		Adaptation to climate change			
		Functional adaptability			

	LEED	BREEAM	Green Mark	Green Star	CASBEE
Building site and transportation	Sensitive land protection	Public transport accessibility	Envelope and roof thermal transfer	Ecological value	Conservation and creation of biotope
	High priority site	Proximity to amenities	Air tightness and leakage	Sustainable sites	Townscape and landscape
	Surrounding density and diverse uses	Bicycle facilities	Bicycle parking	Heat island effect	Attention to local character and improvement of comfort
	Access to quality transit	Maximum car parking capacity		Storm water	Improvement of the thermal environment
	Bicycle facilities	Travel plan		Light pollution	Heat island effect
	Reduced parking footprint	Site selection		Microbial control	Load on local infrastructure
	Green vehicles	Ecological value of site and protection of ecological features		Refrigerant impacts	Noise, vibration and odour
	Construction activity pollution prevention	Minimizing impact on existing site ecology		Sustainable transport	Wind damage and daylight obstruction
	Site assessment	Enhancing site ecology			Light pollution
	Protect or restore habitat	Long-term impact on biodiversity			
	Open space	Impact of refrigerants			
	Rainwater management	NOx emissions			
	Heat island reduction	Surface water runoff			
	Light pollution reduction	Reduction of nighttime light pollution			

	LEED	BREEAM	Green Mark	Green Star	CASBEE
Health and well-being	Minimum indoor air quality performance	Reduction of noise pollution	Occupant comfort	Indoor air quality	Noise
	Environmental tobacco smoke control	Indoor air quality	Outdoor air	Acoustic comfort	Sound insulation
	Enhanced indoor air quality strategies	Safe containment in laboratories	Indoor contaminants	Lighting comfort	Sound absorption
	Low-emitting materials	Thermal comfort	Lighting	Visual comfort	Room temperature control
	Construction indoor air quality management plan	Acoustic performance	Acoustics	Indoor pollutants	Humidity control
	Indoor air quality assessment	Safety and security	Well-being	Thermal comfort	Air conditioning system
	Thermal comfort				Daylighting
	Interior lighting				Anitglare measures
	Daylight				Illuminance level
					Lighting control
					Air quality control
					Ventilation
					Air quality operation plans
Management		Project brief and design	Energy monitoring	Green Star accredited professional	Functionality and usability
		Life-cycle cost	Demand control	Commissioning and tuning	Amenity
		Responsible construction practices	Integration and analytics	Adaptation and resilience	Maintenance management
		Commissioning and handover	System handover and documentation	Building information	Earthquake resistance
		Aftercare		Commitment to performance	Service life of components
				Metering and monitoring	Reliability
				Construction environmental management	Spatial margin
				Operational waste	Floor load margin
					System renewability