The Potential for Energy Diversification to Optimise Buildings' Energy Performance beyond Green Ratings

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***Abstract*—In the broader context of increasing demands for energy associated with expanding population and urbanisation, green building measures are an effective approach to relief the conflict between lowering ecological footprints of buildings and their rapidly growing energy demand. This paper assesses the green building rating tools and the fraction of Energy criterion as contributor to green star rating. The options that can be applied to improve building's energy consumption profile and, with that, contribute to greater green star rating of the building are further reviewed. Outdoor energy sources such as solar energy, as well as indoor energy sources, e.g. piezoelectric energy, are presented. The conclusion of this study is that it may be possible to achieve low carbon building footprint through the application of renewable energy sources, although some of the technologies remain as components of a concept that is yet to be fully and successfully demonstrated in practice.**

Keywords-sustainable building; renewable energy; BIPV; piezoelectric; bioenergy.

I. INTRODUCTION

Green building measures are defined as a sustainable, integrated approach, balancing environmental, economic, and social considerations with large scale of implemented innovative renewable technologies. However, the level of sustainability a building achieves is hard to be benchmarked.

A range of building rating tools have been developed to complement the knowledge about the level of sustainability and these rating systems are still in the process of improvement [1]. The most widely used building rating methods are Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), and Green Star [2, 3]; as summarised in Table 1.

There are similarities between these three schemes. They assess the building against multiple criteria in different categories including Land Use & Ecology, Water, Energy, Materials, Health & Wellbeing, Waste & Pollution, Management and Innovation [4-6]. Secondly, all these schemes are based on credit collecting systems that determine the level of sustainability and hence the building's rating classification [7]. Thirdly, all three rating tools have been developed into a series aimed at rating of a wide range of building types, both newly constructed and existing buildings [8]. All three rating methods are compared in Table 1. It demonstrates that the building rating methods have differences in their methodologies, evaluation scopes, weighting in credits and certification processes.

Among these worldwide building rating tools, a common acceptance should be noted that the weight of the Energy category has the most significant importance, accounting for nearly 25% of the total weightings. However, this may not be sufficient for buildings aiming for ultimate energy neutral or fully self-sustained. Under these circumstances, a recast of the Energy Performance of Buildings Directive (EPBD) will take force on 31 December 2018 by the European Parliament and the Council of the European Union in order to strengthen the energy performance requirements. The EPBD states that the nearly zero or very low amount of energy required should to a very significant level be covered by energy from renewable source, including renewable energy produced on-site or nearby [9].

According to the agreements among the building ratings, energy savings in the operating stage are believed to be the most substantial benefits of green buildings. A detailed review of 60 LEED rated buildings demonstrates that green buildings are on an average 25-30% more energy efficient compared to conventional buildings [10]. Energy savings in green building are achieved primarily by reducing electricity purchases from the power grid and secondly by reducing the peak energy demand. The reduced energy demand from power grids contributes to simultaneous reduction in greenhouse gas emissions. Li et al. [11] confirmed the energy saving potential by studying one of the most common green technologies, the photovoltaics panels in office buildings. They found that when semi-transparent PV panels are used together with dimming controls, a peak cooling load reduction of 450 kW was achieved. This was equivalent to annual building electricity saving of 1203 MWh, which contributed a reduction of 12% of the annual building electricity expenditure.

This evidence has indicated that the level of sustainability a building achieves is strongly coupled with the degree that renewable energy is integrated and utilised. The application of on-site renewable energy production provides possibility to reduce dependence on fossil fuel and mitigates emissions.

II. OUTDOOR ENERGY SOURCES FOR BUILDINGS

Renewable energy resources and their utilisation in buildings are key components of sustainable development [12]. In this context, the renewable energy resources and technologies applicable for integration into the green buildings are divided here into those that can generate energy from outdoor sources and indoor energy sources. One of the most important outdoor energy sources is solar radiation.

A. *Solar-Electrical and Building Integrated Photovoltaic*

Solar energy is the most abundant and inexhaustible of all the renewable energy resources [13]. The amount of solar energy incident on the overall land area far exceeds the total world energy demand. Aside from the access and abundance of the solar resource, there are other positive features that make solar energy the ideal source of alternative energy. First, solar energy has the potential to provide electricity during peak demand times, due to the correlation between solar radiation and daytime peak electricity demand. Second, solar energy technologies have high compatibility and can be easily operated within other hybrid systems [14]. Third, solar technologies can offer distribution utilities ancillary services, such as grid support [15].

Photovoltaic (PV) is a technology used for generating electrical power by converting sunlight into direct current electricity using semiconductor materials. The PV system converts solar radiation into electricity that can be directly applied to power electronic appliances. Moreover, PV panels have no mechanically moving parts, hence are very easy to install and require very little maintenance. The overall cost-benefits analysis of applying PV in buildings were studied through Life Cycle Assessment (LCA) and the results were encouraging [16]. The carbon footprint of PV electricity is found to be favourable compared to the carbon footprint of electricity from fossil fuel based electricity and the energy payback time is significantly shorter than the expected lifetime of 30 years.

The traditional way of installing PV panels on to buildings is named Building Adopted Photovoltaic (BAPV), by mounting PV modules to a separate metal support structure on the roof. In contrast to the BAPV, Building Integrated Photovoltaic (BIPV) is defined as an architecturally integrated building component: the electricity producing modules are both a functional unit of the building and also part of the exterior building envelope, since these modules replace conventional building materials [17]. The fields of BIPV application are the roof areas of the building as well as facades, such as vertical walls, skylights, windows and external shading devices depending to the particular features of the photovoltaic materials.

With the development of Thin-Film (TF) technology, several types of TF modules with varied photovoltaic materials, such as amorphous (a-Si), micromorph (µm-Si), copper indium gallium selenide (CIGS), organic photovoltaics (OPV) and dye-sensitized cells (DSC) are accepted by the market due to their advanced features. For instance, by adding an encapsulating polymer of any colour or interferential coating, the TF modules can be tailor-made into any size and shape to satisfy the specific architectural requirements [18]. The coating and printing techniques which are known as the roll-to-roll printing technology, employed for the manufacture of the TF PV products, the manufacturing costs are expected to be much lower than the crystalline silicon solar cells in the next few years [19]. Furthermore, a prototype transparent photovoltaic cell with an ultrahigh visible transmission has been produced in the laboratory [20, 21]. By absorbing only infrared and ultraviolet light, letting visible light pass through the cells, the cell is able to reach a transmission of >55%±2%, which is sufficiently transparent for incorporation on architectural glass [20].

BIPV systems significantly extend the solar collecting area from roof only to the whole building skin, converting the largest vertical areas such as exterior walls and windows into electricity generators. They provide a vast vertical area directly exposed to the bright morning and early evening sunlight and hence the total electricity yield will be significantly increased [22].

B. *Building Suitable Small-Scale Wind Turbines*

Wind energy is an established and mature renewable energy alternative as it is clean, safe and available. However, the adaptability of mid-scale wind turbines in urban environment faces severe challenges because of the turbulence of the wind profile, noise pollution, limited size and space. In the past few years, many efforts have been made to harness wind energy and optimise the small-scale wind turbine performance. Until now, two main classified types of wind turbines, horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT) are developed for the turbulent urban wind profile [23].

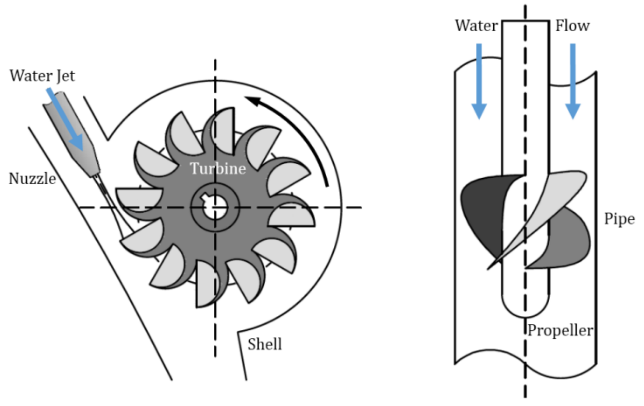
HAWTs dominate the majority of the wind industry in urban environment [24], due to its extreme high efficiency in constant wind conditions. But because their axis of rotation of the blades is in a horizontal position, which needs to be pointed into the wind, the turbines are very sensitive for the wind direction changes. Moreover, the maximum size of HAWTs is strictly limited to 1.5-5 m in diameter, regarding the safety of wildlife and aircraft, esthetics and maintenance [25]. On the other hand, their counterparts VAWTs do not necessarily need to point in any particular wind direction. Since the main rotor shaft is arranged vertically, the vertical wind turbines can handle much higher turbulence and varied wind speeds and thus makes them much suitable in building mounting to overcome the turbulent nature of the wind in the urban environment. According to the size of building mounted wind turbines, the energy generating potential is reported from 100 W to 30 kW in the wind speed range from 10-20 m/s [25].

III. INDOOR RENEWABLE ENERGY ALTERNATIVES

A number of indoor renewable energies, such as waste heat, flowing water in internal drainage systems, electromagnetic waves and vibration, may also become important energy sources for buildings.

A. *Water flow energy harvesting*

Water flow is known as a useful source of mechanical energy which is essentially constant over extended period of time [26]. Water flow energy sources in the outdoor environment are widespread and used on the macro scale for electrical power generation as in hydroelectric plants. The streams of water found in the indoor environments also offer a great potential for energy harvesting. For instance, the grey and black water in the water pipes of a building drain system, as well as the rain water collected by the rain harvesting system which is installed on the building roof, have also been considered for smaller scale harvesting application. The hydro turbines that suit for small scale energy harvesting are designed and constructed according to the widely used large scale hydro turbines, Pelton (Figure 1a) and propeller (Figure 1b) turbines respectively [27]. The Pelton turbine is rotated by a jet of water discharged from a nozzle and is connected to a shaft. The water stream from an upper tank or high gravitational potential area sluiced out through the nozzle pushing the shaft and hence the energy is harvested in the form of electricity. It has been confirmed that the required power from a sensor node, 160 mW was obtained for HQ=0.14 ml/s with an efficiency of 11.3%. The energy harvest system using propeller turbine has a simple configuration. The turbine directly installed in the middle of the water pipeline could be pushed rotating by the down flowing water. Based on the test result, the turbine produced 900 mW of average power in a home irrigation system. In [28], a radial-flux energy harvester incorporating a three-phase generation principle is proposed for converting energy from water flow in domestic water pipelines. The energy harvester is able to generate from 15 mW at a flow rate of 5 l/min to 720 mW at 20 l/min. Therefore, it is possible to generate enough energy using very low water stream, without the need for energy storage.



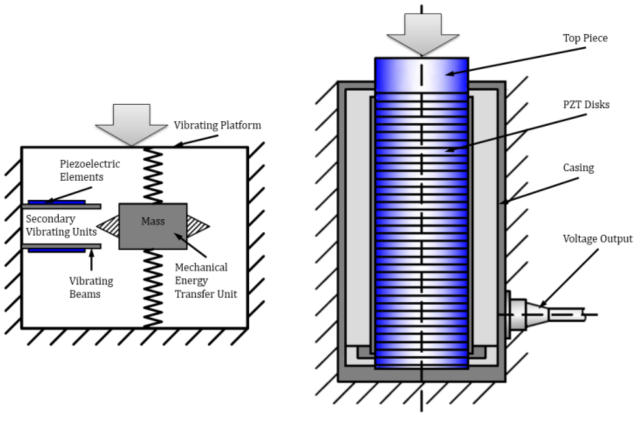
a) b)

Figure 1. Hydro turbines: a) Pelton system; b) Propeller system.

B. Kinetic Energy Harvesting

The vibration-based energy harvesting, termed as piezoelectric energy generation, has received the most attention due to its ability to capture the surrounding ambient energy and then directly convert the applied strain energy into usable electrical energy and the ease at which they can be integrated into a system [29]. By connecting the energy harvester with a remote sensor, the harvest can be seen as an eternal energy source to replace the conventional battery, therefore eliminating the need for long term maintenance.

At present, a cantilever type vibration energy harvester is the most commonly used design due to its simple structure and the feature that can produce a large deformation under vibration [30]. For this type of design, the majority of the cantilever beam piezoelectric harvesters are used in micro-electro-mechanical system (MEMS) applications [31], aiming for vibration resources with high frequency and small mechanical stress. In order to extend receiving range of vibration frequency and to improve power conversion efficiency, a two-stage energy harvester design was suggested for the very low frequency vibration environment in the 0.2–0.5 Hz range [22], as shown in Figure 2a. This design contains two main components, a mechanical energy transfer unit linked with a vibration platform and secondary vibrating units composed of additional piezoelectric elements and vibrating beams fixed on one side. Ideally, when the initial impact effects on the platform, the mass attached on the mechanical energy transfer unit starts to vibrate in low frequency. The low vibration energy is then transferred to a much higher natural frequency vibration in the piezoelectric elements as the mass passes over and excites the piezoelectric beams.



a) b)

Figure 2. Two designs of the piezoelectric system: a) a two-stage energy harvesting approach based on the cantilever system [32]; b) a stack type piezoelectric harvester [33].

A stack type piezoelectric harvester is produced by stacking multiple layers of piezoelectric materials, as shown in Figure 2b. This results in a high mechanical stiffness in the stack configuration. Compared to the cantilever configuration, the stack type possesses a large capacitance and a higher capability of energy harvesting. It is suitable for a high force environment, such as a heavy manufacturing facility or in areas of large operating machinery [34]. With these features, the stack type piezoelectric harvester breaks the limitation from micro-scale energy harvesting in MEMS to macro-scale energy generation. In Israel, Innowattech has tested this type of energy harvester on highway to collect kinetic energy from passing cars as well as railways [35]. In the ideal conditions, the system is able to generate up to 200 kWh in every kilometre, which is enough to satisfy the energy demands from more than 800 families.

To date, several piezoelectric power generating products have been released to the market by different companies [32], such as Pavegen, Waynergy and Powerleap. The Pavegen piezoelectric harvester, Pavegen Tile, was demonstrated at the London 2012 Olympic Games. Twelve tiles were installed on a temporary walkway connecting the Station to the Greenway walking route at the Olympic Park. It was estimated that these tiles would receive more than 12 million impressions from footfalls, generating 72 million joules of energy, which equals to 21 kWh of electricity. This amount of electricity was enough to illuminate the walkway for eight hours at full power during the night, and 16 daylight hours at half power [36]. A similar test was conducted at the University of Beira Interior. The Waynergy People prototype was deployed in the pavement at the main entrance of the Engineering Faculty. It was confirmed that 525 Joules or 0.15 Watt-hours of electric energy was harvested from 675 human steps by the Waynergy system during a peak hour, between 9 am and 10 am [37].

IV. ENERGY PRODUCTION FROM WASTES

Activities within the buildings contribute to considerable generation of organic waste that can be considered as a biomass and used for conversion into useful forms of energy. The main technologies for biomass processing can be classified into three categories: thermo-chemical, bio-chemical and mechanical extraction. There are three optional processes included in the method of thermochemical conversion: combustion, gasification and pyrolysis; while under the biochemical conversion category, there are two technologies available, which are digestion and fermentation. In the following, thermochemical pyrolysis and biochemical anaerobic digestion are introduced as two promising indoor renewable energy generating technologies.

A. *Pyrolysis - A Thermo-Chemical Conversion*

Pyrolysis is a method that converts biomass to more useful fuel products [38]. Under pyrolytic conditions biomass is heated to maximum temperatures of 450–500□C in the absence of oxygen to produce a hydrocarbon rich gas mixture (biogas), an oil-like liquid (bio-oil) and a carbon rich solid residue (bio-char) [39].

Bio-char is a light black residue of the biomass material with very high surface area structure, which can retain soil-water and nutrients for plant growth. Recently, with the growing realisation of the importance of constructing human shelters that better conserve energy and water through appropriate insulation and architectural designs, bio-char is used as a substrate material for green roofs due to its positive influences on both plants and roof heat insulation [40]. The bio-oil is the dark brown liquid fraction of biomass generated during the pyrolysis process. It is expected to play a dominant role as a substitute for crude oil because of its CO_2 neutral and low sulphur content properties, because of a potential to improve fuel oil security and reduction in GHG emissions from fossil oil use. There are several options for bio-oil applications as fuel materials, which including combusting in boilers, diesel engines, gas turbines, and Stirling engines or being upgraded to higher energy density fuel before it can be economically used for energy production in standard equipment [41]. Biogas produced by pyrolysis is a mixture of volatile gases that consist primarily of CO_2, CO, methane and higher hydrocarbon compounds. Due to the combustable components in the biogas, biogas can be used as a fuel. Raveendran and Ganesh [42] compared biogas with fossil fuels. They found that the heating value of biomass pyrolysis gases are much lower than those of natural gas, but are comparable with those of blast furnace gas and producer gas. Although pyrolysis has gained much interest in the field of waste to energy conversion, the commercial proven pyrolysis plant in industrial scale remains limited.

B. *Anaerobic Digestion – A Bio-Chemical Conversion*

Anaerobic Digestion (AD) is a chain of interconnected biological reactions, where the organic matter is transformed into biogas, which is a gaseous mixture of methane, carbon dioxide and small quantities of other gases such as hydrogen sulphides, in an oxygen-free environment [43]. During the process, the biomass is converted by bacteria in an anaerobic environment, producing a gas with an energy content of about 20–40% of the lower heating value of the feedstock [44].

The methane component in the biogas produced from the AD process can be combusted in internal combustion engines or micro turbines for the production of electricity. Meester et al. [45] compared electricity production from domestic organic waste and energy crop digestion with reference to electricity. They highlighted an effect of vaporisation brought about by the AD technology, as it is able to convert almost all sources of biomass, including different types of organic wastes, slurry and manure to a high calorific value biogas. Komatsu et al. [46] proposed a mesophilic-thermophilic hybrid flow scheme which further enhanced the electricity production from municipal sludge, resulting in electricity production at a cost of 0.05 USD/kWh, lower than the market price of 0.009 USD/kWh. In relation to individual building heating, Esen and Yuksel [47] designed a hybrid system which integrated an AD reactor into a greenhouse. During a winter period the system maintained a constant self-sustained temperature of 27°C within the reactor, while the greenhouse temperature was able to be maintained at about 23°C. Recently, an on-site prototype anaerobic digester for high-rise building was proposed [48]. It demonstrated that the AD of sewage sludge and food waste from canteen has great potential to be used as an alternative renewable energy source.

V. CONCLUSION

In accordance with trends in building development where modern buildings are becoming complex and multi-functional, the green technologies can either be integrated into pre-standing urban buildings or designed into new buildings as part of a shift toward a more renewable, sustainable future. While the ideas and approaches are highly promising, they remain as components of a concept that is yet to be fully demonstrated in practice, due to investment costs and very small energy generated. These technologies are expected to contribute in the future exploitation and with further reduction in cost, because of the rapid break-through on material developments, design innovations as well as the manufacturing revelations. Further research needs to address their adaptability and their capabilities when integrated into buildings. Assessment of the sustainability of buildings beyond the green ratings should be considered by the energy diversification approaches to minimise energy consumption and GHG emissions.

REFERENCES

[1] A. Sev, “A comparative analysis of building environmental assessment tools and suggestions for regional adaptations,” Civil Engineering and Environmental Systems, 28(3), 2011, pp. 231-245.

[2] W. L. Lee and J. Burnett, “Benchmarking energy use assessment of HK-BEAM, BREEAM and LEED,” Building and Environment, 43(11), 2008, pp. 1882-1891.

[3] Y. Roderick, D. McEwan, C. Wheatley, and C. Alonso, “Comparison of energy performance assessment between LEED, BREEAM and Green Star” Eleventh International IBPSA Conference, Integrated Environmental Solutions Limited. Glasgow, Scotland, 27-30 July 2009.

[4] BREEAM. BREEAM “International New Construction (NC)” 2013 Available from: http://www.breeam.org/ (accessed 22/01/2014).

[5] LEED. “Projects earn points to satisfy green building requirements” 2013 Available from: http://www.usgbc.org/leed/rating-systems/credit-categories (accessed 22/01/2014).

[6] GBCA, The dollars and sense of green buildings: building the business case for green commercial buildings in Australia Green Building Council of Australia, 2008, pp. 143.

[7] R. Reed, A. Bilos, S. Wilkinson, and K.-W. Schulte, “International comparison of sustainable rating tools,” The Journal of Sustainable Real Estate, 1(1), 2009, pp. 1-22.

[8] L. Perez-Lombard, J. Ortiz, R. Gonzalez, and I. R. Maestre, “A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes,” Energy and Buildings, 41(3), 2009, pp. 272-278.

[9] EPU. EU Directive on the Energy Performance of Buildings. 2010 Available from: http://www.dfpni.gov.uk/content_-_energy_performance_of_buildings-pubs-directive (accessed 14/08/2014).

[10] S. W. Tsang, and C. Y. Jim, “Game-theory approach for resident coalitions to allocate green-roof benefits,” Environment and Planning A, 43(2), 2011, pp. 363-377.

[11] D. H. W. Li, T. N. T. Lam, W. W. H. Chan, and A. H. L. Mak, “Energy and cost analysis of semi-transparent photovoltaic in office buildings,” Applied Energy, 86(5), 2009, pp. 722-729.

[12] I. Dincer, “Renewable energy and sustainable development: a crucial review,” Renewable & Sustainable Energy Reviews, 4(2), 2000, pp. 157-175.

[13] F. Dincer, “The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy,” Renewable & Sustainable Energy Reviews, 15(1), 2011, pp. 713-720.

[14] T. T. Chow, “A review on photovoltaic/thermal hybrid solar technology,” Applied Energy, 87(2), 2010, pp. 365-379.

[15] J. Urbanetz, C. D. Zomer, and R. Ruther, “Compromises between form and function in grid-connected, building-integrated photovoltaics (BIPV) at low-latitude sites,” Building and Environment, 46(10), 2011, pp. 2107-2113.

[16] M.J. de Wild-Scholten, "Energy payback time and carbon footprint of commercial photovoltaic systems," Solar Energy Materials and Solar Cells, 119, 2013, pp. 296-305.

[17] D. K. Prasad, and M. Snow, Designing with solar power: a source book for building integrated photovoltaics (BiPV), 2005, pp. 252.

[18] K. L. Chopra, P. D. Paulson, and V. Dutta, “Thin-film solar cells: An overview,” Progress in Photovoltaics, 12(2-3), 2004, pp. 69-92.

[19] F. C. Krebs, J. Fyenbo, and M. Jorgensen, “Product integration of compact roll-to-roll processed polymer solar cell modules: methods and manufacture using flexographic printing, slot-die coating and rotary screen printing,” Journal of Materials Chemistry, 20(41), 2010, pp. 8994-9001.

[20] R. R. Lunt and V. Bulovic, “Transparent, near-infrared organic photovoltaic solar cells for window and energy-scavenging applications,” Applied Physics Letters, 98(11), 2011.

[21] R. R. Lunt, T. P. Osedach, P. R. Brown, J. A. Rowehl, and V. Bulovic, “Practical Roadmap and Limits to Nanostructured Photovoltaics,” Advanced Materials, 23(48), 2011, pp. 5712-5727.

[22] C. H. Peng, Y. Huang, and Z. S. Wu, “Building-integrated photovoltaics (BIPV) in architectural design in China,” Energy and Buildings, 43(12), 2011, pp. 3592-3598.

[23] S. Eriksson, H. Bernhoff, M. Leijon, "Evaluation of different turbine concepts for wind power," Renewable and Sustainable Energy Reviews, 12(5), 2008, pp. 1419-1434.

[24] T.F. Ishugah, Y. Li, R.Z. Wang, and J.K. Kiplagat, "Advances in wind energy resource exploitation in urban environment: A review," Renewable and Sustainable Energy Reviews, 37, 2014, pp. 613-626.

[25] A. Dutton, J. Halliday, and M. Blanch, "The feasibility of building-mounted/integrated wind turbines (BUWTs): Achieving their potential for carbon emission reductions," Energy Research Unit, CCLRC, 2005, pp. 77-83.

[26] J. M. Gilbert, and F. Balouchi, “Comparison of energy harvesting systems for wireless sensor networks,” International Journal of Automation and Computing, 5(4), 2008, pp. 334-347.

[27] J. A. R. Azevedo and F. E. S. Santos, “Energy harvesting from wind and water for autonomous wireless sensor nodes,” Circuits, Devices & Systems, IET, 6(6), 2012, pp. 413-420.

[28] D. Hoffmann, A. Willmann, R. Göpfert, P. Becker, B. Folkmer and Y. Manoli, “Energy Harvesting from Fluid Flow in Water Pipelines for Smart Metering Applications,” Journal of Physics: Conference Series. IOP Publishing, 2013.

[29] A. Erturk and D. J. Inman, Introduction to Piezoelectric Energy Harvesting. Piezoelectric Energy Harvesting. John Wiley & Sons, Ltd., 2011, pp. 1-18.

[30] H. S. Kim, J. H. Kim, and J. Kim, “A Review of Piezoelectric Energy Harvesting Based on Vibration,” International Journal of Precision Engineering and Manufacturing, 12(6), 2011, pp. 1129-1141.

[31] G. Tang, J. Q. Liu, H. S. Liu, Y. G. Li, C. S. Yang, D. N. He, V. Dzung Dao, K. Tanaka, and S. Sugiyama, “Piezoelectric MEMS generator based on the bulk PZT/silicon wafer bonding technique,” Physica Status Solidi a-Applications and Materials Science, 208(12), 2011, pp. 2913-2919.

[32] X. Li and V. Strezov, “Modelling piezoelectric energy harvesting potential in an educational building,” Energy Conversion and Management, 85, 2014, pp. 435-442.

[33] Piezo-University. Basic Designs of Piezoelectric Positioning Drives/Systems. 2013 Available from: http://www.physikinstrumente.com/en/products/primages.php?sortnr=400800.00&picview=2 (accessed 24/02/2014)

[34] R. A. Steven and A. S. Henry, “A review of power harvesting using piezoelectric materials (2003–2006),” Smart Materials and Structures, 16, 2007.

[35] Innowattech. Innowattech IPEG PAD Harvests Energy From Passing Trains. 2010 Available from: http://www.innowattech.co.il/technology.aspx (accessed 03/01/2014).

[36] O.D Authority, Pedestrians to power walkway to London 2012 Olympic park. 2012 Available from: http://www.energyharvestingjournal.com/articles/pedestrians-to-power-walkway-to-london-2012-olympic-park-00004578.asp?sessionid=1 (accessed 05/01/2014).

[37] F. Duarte, F. Casimiro, D. Correia, R. Mendes, and A. Ferreira, “Waynergy people: a new pavement energy harvest system,” Proceedings of the ICE - Municipal Engineer, Vol. 166(4), June 2013.

[38] X. Li, V. Strezov, and T. Kan, “Energy Recovery Potential Analysis of Spent Coffee Grounds Pyrolysis Products,” Journal of Analytical and Applied Pyrolysis, 110, 2014, pp. 79-87.

[39] V. Strezov, T. J. Evans, and C. Hayman, “Thermal conversion of elephant grass (Pennisetum Purpureum Schum) to bio-gas, bio-oil and charcoal,” Bioresource Technology, 99(17), 2008, pp. 8394-8399.

[40] Y. J. Lin and H. T. Lin, “Thermal performance of different planting substrates and irrigation frequencies in extensive tropical rooftop greeneries,” Building and Environment, 46(2), 2011, pp. 345-355.

[41] A. Demirbas, “Competitive liquid biofuels from biomass,” Applied Energy, 88(1), 2011, pp. 17-28.

[42] K. Raveendran and A. Ganesh, “Heating value of biomass and biomass pyrolysis products,” Fuel, 75(15), 1996, pp.1715-1720.

[43] S. Yilmaz and H. Selim, “A review on the methods for biomass to energy conversion systems design,” Renewable & Sustainable Energy Reviews, 25, 2013, pp. 420-430.

[44] P. McKendry, “Energy production from biomass (part 2): conversion technologies,” Bioresource Technology, 83(1), , 2002, pp. 47-54.

[45] S. De Meester, J. Demeyer, F. Velghe, A. Peene, H. Van Langenhove and J. Dewulf, “The environmental sustainability of anaerobic digestion as a biomass valorization technology,” Bioresource Technology, 121, 2012, pp. 396-403.

[46] K. Komatsu, H. Yasui, R. Goel, Y. Y. Li and T. Noike, “Feasible Power Production from Municipal Sludge Using an Improved Anaerobic Digestion System,” Ozone-Science & Engineering, 33(2), 2011, pp. 164-170.

[47] M. Esen and T. Yuksel, “Experimental evaluation of using various renewable energy sources for heating a greenhouse,” Energy and Buildings, 65, 2013, pp. 340-351.

[48] C. Ratanatamskul, G. Onnum, and K. Yamamoto, "A prototype single-stage anaerobic digester for co-digestion of food waste and sewage sludge from high-rise building for on-site biogas production," International Biodeterioration & Biodegradation, 95, 2014, pp. 176-180.

TABLE I. COMPARISON OF THE BUILDING RATING METHODS

Feature	Rating Method Name		
	BREEAM	LEED	Green Star
Launch Date	1990	1998	2003
Ratings	Pass/Good/Very Good/Excellent/ Outstanding	Certified/Silver/Gold/Platinum	One –Six Star
Weightings	Applied to each criterion (consensus based on scientific/open consultation)	All credits equally weighted, although the number of credits related to each criterion is a de facto weighting	Applied to each criteria category (industry survey based)
Information Gathering	Design/management team or assessor	Design/management team or Accredited Professional	Design team
Third Party Valuation	BRE	N/A	GBCA
Update Process	Annual	As required	Annual
Assessment Collation Fee	$4000-20000	$75,000	$4002-8004
Cost of credit appeals	Free	$500	$800
Building Covered			
New	+	+	+
Interiors	-	+	+
Core & shell	-	+	+
Existing	+	+	+
Renovated	+	+	+
Mixed-use	+	+	-
Category Weightings			
Management	15%	8%	12%
Energy	25%	25%	24%
Transport	N/A	N/A	12%
Health	15%	N/A	12%
Well-being	N/A	12%	N/A
Water	5%	5%	14%
Materials	10%	18%	12%
Land use	15%	N/A	8%
Ecology	N/A	5%	N/A
Pollution	15%	11%	6%
Sustainable Site	N/A	16%	N/A