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Low-Carbon Buildings: Renewable Energy Systems, Materials and Assessment Methods

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ABSTRACT

Buildings are one of the main sources of carbon emission. Minimization of carbon emission from new and existing buildings is vital for the abatement of climate change. Recent research on buildings has shown great interest in the development of strategies and technologies to lower the carbon emission of buildings. Buildings that are designed and engineered to have low levels of carbon emission are called low-carbon buildings. This paper reviews the current state and trend of published research on low-carbon buildings with focus on installation of renewable energy systems, development and selection of low-carbon building materials and development of new design and assessment methods. Gaps are highlighted and recommendations for future research are proposed.

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INTRODUCTION

Research has proven that climate change does occur and that efforts to mitigate it are urgently required (Stern, 2006). High level of carbon emission is one of the major factors that contribute to climate change and buildings are one of the major sources of carbon emission. For instance, the domestic building sector in the UK contributes around 23% of the national greenhouse gas emissions (Allen *et al.*, 2008). Elsewhere, Byggsektorns Kretsloppråd (BYKR) (2001) and Organisation for Economic Co-operation and Development (OECD) (2003) reported that buildings contribute up to 40% of the use of energy and materials in Sweden (BYKR, 2001; OECD, 2003). In China, buildings consume about 28% of the national energy consumption (Chen *et al.*, 2012), with 95% of the existing buildings are categorized as high-energy buildings (Xu and Chan, 2013). It has been estimated that buildings provide the greatest potential for climate change mitigation (Pachauri and Reisinger, 2007; McKinsey & Company, 2009). Researchers have reacted to this by investigating different approaches to overcome this issue, which include enhancing building energy-efficiency (Farhan *et al.*, 2012b; Farhan *et al.*, 2012c; Al Yacouby *et al.*, 2012) and creating awareness of its importance (Farhan *et al.*, 2012a; Al Yacouby *et al.*, 2011). Therefore, minimizing carbon emission from new and existing buildings is vital for the abatement of climate change. Buildings that are designed and engineered to have low levels of carbon emission over their lifetimes are called low-carbon buildings (Sartori and Hestnes, 2007; Williams, 2010). Development of new buildings and retrofit of existing buildings to become low-carbon buildings can significantly contribute towards the mitigation of climate change (Chen *et al.*, 2011; Heinonen *et al.*, 2011). Researchers and practitioners have recently shown great interest in developing solutions to tackle challenges associated with the development of low- carbon buildings and cities (Zhu *et al.*, 2013). This paper reviews the current state and trend of published research on low-carbon buildings and suggests future directions.

Firstly, the literature search process is explained. Then, the review is presented based on three (3) strategies adopted for low-carbon buildings, which are installation of renewable energy systems, development and selection of low-carbon building materials and development of new design and assessment methods. Lastly, the conclusion is stated and recommendations are proposed.

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Literature Search:

Research papers relevant to low-carbon buildings were searched and acquired from Scopus, which is presently the largest abstract and citation database of peer-reviewed literature online (Scopus Facts & Figures, 2013). Keyword entries "low carbon building*" is used to conduct the search and the fields selected for the placement of the keywords are "Title", "Abstract" and "Keywords". Papers searched are those that were published from 2008 to 2013. The author also refers to a number of other articles obtained from citations in the articles that initially appeared in the search results.

Renewable Energy Systems:

Installation of renewable energy systems in buildings makes them low-carbon by reducing the use of electricity or generating them. Allen *et al.* (2008) investigated the performances of a micro wind turbine, mono-crystalline solar photovoltaic (PV) array and a solar hot water (SHW) system for adoption in houses in the UK. Findings suggested that the micro wind turbine and solar PV array can supply 25 – 49% of the average electricity demand for households in the UK while the SHW system can provide 28% of the annual hot water demand. Glass and Levermore (2011) evaluated the performances of 1-kW rated 3-blade and 0.4-kW rated 5-blade micro wind turbines fixed on the roof of experimental houses in the EcoSmart Show Village in Lancashire, UK. Theoretical carbon offsets were 203 and 100 kg CO2 for the 3-blade and 5-blade micro wind turbines respectively. However, the measured carbon offsets were negative values with errors that occur due to the lateral turbulence and inefficient inverter. Dahlstrøm *et al.* (2012) investigated the impact of adopting wood, solar heat collector and air-water heat pump in combination with electric as heating systems on cumulative energy demands of wooden houses. Findings revealed that the heat pump system reduced energy demands of the house by 40%. Chen *et al.* (2012) analyzed the impact of a solar ground-source heat pump (GSHP), collector panels and a SHW system in a new office-factory building. Findings revealed that energy consumed in the GSHP system is 34.1% less than the air-source system. The solar collectors achieved savings of approximately 156.11 kWh per day, which is equivalent to a reduction of 142.37 kg of CO2 per day. The SHW system achieved power savings of 47%. Bristow *et al.* (2011) analyzed the effects of a GSHP, a wind turbine and a PV system on the carbon footprint of a condominium in Ontario, Canada. Hammond *et al.* (2012) studied the impact of a building-integrated PV system with several analysis methods that cover energy, environment and economic aspects. Carvalho *et al.* (2013) investigated the operation of wood-burning stoves in modern single-family houses. Table 1 summarizes the renewable energy technologies reviewed.

Table 1: Summary of renewable energy technologies reviewed.

Renewable Energy Technologies	References						
	Allen *et al.* (2008)	Bristow *et al.* (2011)	Glass and Levermore (2011)	Dahlstrøm *et al.* (2012)	Chen *et al.* (2012)	Hammond *et al.* (2012)	Carvalho *et al.* (2013)
Wind turbines	√	√	√				
PV	√	√				√	
SHW system	√				√		
Solar heat collector				√	√		
Air-water heat pump				√			
GSHP		√			√		
Wood heating system				√			√

Low-Carbon Building Materials:

Some researchers showed interest in the selection and development of building materials that have low embodied carbon (Farhan *et al.*, 2014) or can contribute towards reducing the operational carbon of the building. Venkatarama Reddy (2009) compared the embodied energies of two (2) load-bearing masonry buildings with conventional and alternative low-carbon systems. The conventional system consists of load-bearing brickwork, reinforced concrete solid slab floor and concrete tile floor, while the alternative low-carbon system adopted stabilized mud block (SMB) for the masonry, filler slab floor and roof with terracotta tile floor. Venkatarama Reddy and Prasanna Kumar (2011) investigated the compaction and physical characteristics of compacted cement stabilised soil mixtures and cement stabilised rammed earth (CSRE), which is a low-carbon building material. Kinuthia and Oti (2012) explored the potential of adopting lime or Portland cement activated ground-granulated blast-furnace slag (GGBS) mix to stabilize natural clay soil. Shea *et al.* (2012) investigated the effect of hemp-lime on the hygro-thermal performance of buildings and found that use of hemp-lime improves air tightness and minimizes thermal bridging that leads to low-carbon buildings. Table 2 summarizes the low-carbon building materials reviewed.

Table 2: Summary of the low-carbon building materials reviewed.

Low-Carbon Building Materials	References
SMB	Venkatarama Reddy (2009)
CSRE	Venkatarama Reddy and Prasanna Kumar (2011)
GGBS	Kinuthia and Oti (2012)
Hemp-lime	Shea *et al.* (2012)

New Design and Assessment Methods:

Some researchers developed new methods to design low-carbon buildings and assess their performances. Gupta and Chandiwala (2009) developed the Sustainability Appraisal Toolkit (SAT) to aid energy, carbon and cost feasibility evaluation of achieving Code Level 4 and above in the Code for Sustainable Homes, which is a guidance launched by the Communities and Local Government in the UK to assist the government to realize its goal of guaranteeing that new houses in England are zero-carbon by 2016. Gupta (2009) developed DECoRuM, which is a software that is based on the Geographical Information System that predicts and records baseline energy use and carbon emissions for every house, forecasts the prospect for reduction in carbon emission and oversees reductions achieved due to adoption of energy-efficiency measures and renewable energy technologies. Gupta (2009) also developed Oxford Climate Change Action Plan (OCCAP) to create an inventory of carbon emissions for the context of Oxford, UK for a baseline year, determine targets for carbon reduction and plan actions to achieve them. Chen *et al.* (2011) presented a method to calculate the carbon emission of the building life-cycle with consideration of the nine (9) stages of the life-cycle, which are 1) building construction, 2) fitment, 3) outdoor facility construction, 4) transportation, 5) operation, 6) waste treatment, 7) property management, 8) demolition and 9) disposal. Xu and Chan (2013) developed a model for sustainable Building Energy Efficiency Retrofit (BEER) of hotels in China to make them low-carbon. Zhu *et al.* (2013) proposed a new method to optimize the design of building envelopes to minimize operational carbon emissions with Orthogonal Experimental Design (OED). Table 3 summarizes new design and assessment methods reviewed.

Table 3: Summary of new design and assessment methods reviewed.

New Design and Assessment Methods	References
SAT	Gupta and Chandiwala (2009)
DECoRuM and OCCAP	Gupta (2009)
Method for calculation of carbon emission for the building life-cycle with consideration of the nine (9) stages of the life-cycle	Chen *et al.* (2011)
Model for sustainable BEER of hotel buildings	Xu and Chan (2013)
Method to optimize the design of building envelopes to minimize operational carbon emissions with OED	Zhu *et al.* (2013)

Conclusion:

Research on low-carbon buildings has been reviewed. The research area is reviewed according to three (3) categories, which are renewable energy systems, low-carbon building materials and design and assessment methods. It can be concluded that this area has started to gain interest among researchers but there is still lack of breadth and depth of knowledge in this research area. Based on the current state and trend of this research area, the following areas are highlighted as gaps to be filled in future research:

1) Investigation on the relationship between embodied and operational carbons for different types of buildings
2) Investigation on the impact of adopting selected low-carbon materials for different components of the building envelope
3) Development of integrated models to quantify the impact of various types of low-carbon strategies including installation of renewable energy systems and adoption of low-carbon building materials

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