Transition from Low-rise to High-rise Zero Carbon Buildings: The Potential of Socio-Technical Systems

Wei PAN[1] and Yan NING[2]

[1] Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, email: wpan@hku.hk
[2] Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, email: ningyan@hku.hk

ABSTRACT

Most Zero Carbon Buildings (ZCBs) to date are of low-rise, with high-rise often considered impossible to achieve zero carbon due to enormous difficulties in socio-technical perspectives. This paper aims to explore the future of high-rise towards zero carbon drawing on the theory of socio-technical systems. Grounded on this theory, ZCBs are examined as social-technical systems and the technologies and key stakeholders are embedded in the social, cultural and political environments. The research was carried out through a case study of the first ZCB of three stories in Hong Kong and a workshop with the key stakeholders of buildings. It was found that the delivery solution of the case ZCB was considered to be technically infeasible for new buildings in Hong Kong of typical 40 stories due to geographic constraints. The use of emerging technologies must be explored for enhanced technical feasibility. The split among contributions of end-users, the building industry and the energy sector to carbon emission reductions was considered crucial to developing a practical ZCB definition for Hong Kong. Approaches based on socio-technical systems should help influence end-users' attitudes towards reducing energy consumption, and enable integrated project delivery of high-rise buildings towards zero carbon.

INTRODUCTION

The Hong Kong Green Building Council (HKGBC, 2012) has proposed a 'HK3030' campaign aiming to reduce 30% of the absolute amount of electricity used in buildings by 2030, as compared to 2005 levels, which equals to a reduction of 60% when taking into account the growth in demand under 'business-as-usual' scenario. The total proposed reduction of 60% will comprise 48% from technology advancement and uptake and 12% from behavioral changes. The approach of Zero Carbon Building (ZCB) has emerged as an innovative model of green building, with recognized advantages in reducing energy consumption and carbon emissions. Pan and Ning (2013) reviewed a number of project case studies worldwide and suggested that designs for ZCB should be technically feasible with rational design strategies embracing passive design and energy efficiency coupled with the use of on- and off-site renewable technologies. Zuo et al. (2013) studied a small scale commercial building in Australia and revealed that construction techniques are not required to change drastically to meet the carbon neutrality target. Such technical feasibility, however, is largely observable in low-rise buildings, e.g. the 6-storey residential building in Demark studied by Marszal and Heiselberg (2011) and the 3-storey ZCB in Hong Kong built by the Construction Industry Council (CIC, 2012). Hitherto, it remains unknown if high-rise ZCBs are achievable given the technologies currently available.

Apart from the technical aspect, the delivery of green buildings requires intense interdisciplinary collaboration, highly complex design analysis and careful material and system selection (Magent et al. 2009). As buildings become more complex, the need for the integration of different kinds of expertise increases further (Berker and Bharathi, 2012). Häkkinen and Belloni (2011) found that organizational and procedural difficulties associated with the adoption of new methods and technologies often impede the success to deliver green buildings. This might be because team members in delivering green buildings face a steep learning curve (Chong et al., 2009) or exhibit strong resistance to new technologies. Besides, the current delivery processes are also criticized about their shortfalls to meet the requirements of delivering green buildings (Lapinski et al. 2005). Horman et al.'s (2006) study, for instance, reveals that the current project processes used to deliver green buildings often suffer from wasteful rework, delays, changes and overproduction. The research background outlined above indicates that the technical challenges in delivering ZCBs are interwoven with the organizational impediments, which echoes Strijbos' (2006:365) observation "the use of technology of all sorts is embedded in a socio-technical context". Therefore, it is imperative to examine the social and technical aspects in a systems integrated manner. This paper aims to contribute to knowledge by exploring the transition from low-rise to high-rise ZCBs drawing on the theory of socio-technical systems.

LITERATURE REVIEW

Socio-Technical Systems (STS)

STS assumes that an organization or organizational work system can be described as a socio-technical system. A work system is made up of a social and a technical system. It is assumed that these two systems are independent but correlatively interacting and outputs of the work system are the result of joint interactions between these two systems (Bostrom and Heinen, 1977). Specifically, the technical system is concerned with the processes, tasks and technology needed to transform inputs to outputs. The social system is concerned with the attributes of people (e.g. attitudes, skills and values), the relationships among people, reward systems and authority structures (Bostrom and Heinen, 1977).

Strategies to achieve zero carbon in high-rise buildings

Grounded on the socio-technical systems, a four-tier strategy for delivering high-rise towards zero carbon is proposed. This strategy consists of: 1) reducing demand; 2) improving energy efficiency; 3) on- and off-site renewable solutions; and 4) carbon offsetting (Table 1). A1: associated with energy demand by user behavior changes; A2: associated with energy loss through building fabric; A3: associated with energy for M&E systems; A4: associated with energy for white goods; A5: associated with energy loss in transmission; A6: associated with energy production and supply; B1: on-site renewable energy generation; B2: off-site renewable energy generation direct; B3: accredited renewable energy; and C: carbon captured and storage.

Table 1. A four-tier ZCB strategy

Strategy	Composition/target	Solutions
Reducing demand	X% carbon emission reductions (A1)	Technical: low carbon products, technologies/devices

		Social: networking, information sharing, peer pressure, historical data comparison
Improving energy efficiency	Y% carbon emission reductions (A2-A6)	Technical: passive design, energy efficient system Social: diffusion, adoption and maintenance of energy efficient system, construability of passive design
On- and off-site renewable	Z% carbon emission reductions (B1+B2)	Technical: renewable energy Social: innovation, public acceptance, diffusion of renewable energy technology, installation, maintenance of renewable energy technology
Carbon offsetting	K% carbon emission reductions (B3+C)	Technical: offsetting projects Social: willingness to pay

Reducing demand

Glad (2012) summarized that any demand reduction approach should consider end-users and their interfacing with the technology. The technical solutions for reducing demand comprise the adoption of low carbon products and technology in end-users' daily life. Since these low carbon products and processes should be integrated into end-users' lifestyle, behavioral changes would be made accordingly (Ellegård and Palm, 2011). While it is perceived that energy saving through end-user behavioral changes may have larger potentials than generally assumed (Sunikka-Blank and Galvin, 2012), pervasive changes in end-users' energy behaviors are found tremendously difficult (Axsen and Kurani, 2012) due to the inertia (Jensen, 2005) and possible risks (Thollander and Palm, 2013). These barriers would be furthermore accentuated by the information and communication gaps between end-users and other stakeholders, e.g. construction professionals (Newsham et al., 2009), manufacturers and suppliers (Thollander and Palm, 2013) and government agencies (Ellegård and Palm, 2011). Moreover, due to a high degree of heterogeneity across end-users (Ma et al., 2013), the effects of the practical on behavioral changes vary considerably (Ellegård and Palm, 2011), which often renders the technical solutions less effective.

Nevertheless, past studies have identified that the social approaches have a significant role to play in influencing end-users' energy consumption behaviors. Several studies have quantified this impact. For example, Allcott (2011) noted that non-price interventions can substantially and cost effectively change consumer behaviors: the effect is equivalent to that of a short-run electricity price increase of 11 to 20%. Carrico and Riemer's (2011) study identifies that feedback and peer education could result in a 7% and 4% reduction in energy use, respectively. Xu et al. (2012) found that eco-feedback systems that leverage place-based social networks lead to improved energy efficiency at the inter-building level that are comparable to efficiencies gained through typical building retrofits.

Jain et al.'s (2012) study reveals that historical comparison and incentives could motivate higher end-user engagement and thus help to reduce energy consumptions. Besides the historical comparison, peer comparisons of end-users' home electricity are also found helpful in reduce energy consumptions at a low cost (Peschiera and Taylor, 2012). Furthermore, the comparison could be carried out in a social network environment. Gulbinas et al. (2013) presented an eco-feedback system, *Watt's Watts*, to leverage the impacts of individual and social feedback. This eco-feedback system integrates individual level, near real-time energy consumption feedback within a social network environment. Compared to the end-users who received feedback in direct energy units, Jain et al. (2013) observed that users receiving eco-feedback as an environmental externality reduced their consumption more.

Energy efficiency measures and on-site and off-site renewable solutions

Various energy efficiency measures and on- and off-site renewable solutions are to date available to reduce carbon emissions. For example, Li et al. (2013) classified energy efficiency measures into three categories: 1) building envelopes thermal insulation, thermal mass, windows/glazing (including daylighting) and reflective/green roofs; 2) internal conditions indoor design conditions and internal heat loads (due to electric lighting and equipment/appliances); and 3) building services systems HVAC (heating, ventilation and air conditioning), electrical services (including lighting) and vertical transportation (lifts and escalators). Enhanced energy efficiency could also be achievable in residential buildings by highlighting the critical design parameters, which are building orientation, shape, envelope system, passive heating and cooling mechanisms, shading, and glazing (Pacheco et al., 2012).

Torcellini et al. (2006) provided a zero energy building renewable energy supply option hierarchy, following the order that: 1) reducing site energy use through low-energy building technologies; 2) using renewable energy sources available within the building’s footprint; 3) using renewable energy sources available at the site; and 4) using renewable energy sources available off site to generate energy on site; and 5) using off-site renewable energy sources.

However, outputs of energy efficiency and on- and off-site renewable solutions are often found inconsistent with planned; there existing significant gaps between the design and the built products. For example, Newsham et al. (2009) identified four gaps: 1) the occupancy hours differ from those in the initial design assumptions; 2) the final as-built building differs from the initial design; 3) experimental technologies do not perform as predicted; and 4) plug loads are different than assumed. These gaps are probably attributed to the diverse understanding of and attitudes to sustainability, a lack of a shared vocabulary gaps (Mukherjee and Muga, 2010), existing traditional sequential design process, the lack of integrated approaches and insufficient socio-technical knowledge (Li and Yao, 2012). To close these gaps, the STS approach seems to offer a good potential by shading light on forging design competence, improving project delivery efficiency and disseminating information across projects. The development of designers’ competence could contribute to higher green/low carbon performance (Häkkinen and Belloni, 2011). Necessary skills for managing the design of a green building project consist of awareness, communication, comprehension, experience, lateral thinking, leadership, negotiation, passion and technical knowledge (Mills and Glass, 2009).

Mukherjee and Muga (2010) suggested a life cycle approach by which the design solutions should take the situation and temporal context into account. With such approach, greater attention should be paid to the assessment of how stakeholders value an alternative design, the dynamics and uncertainties arising from the social contexts. Information technologies also have a significant role to play in coping with the uncertainties. Häkkinen and Belloni (2011) noted that building information modeling could assist in making the life cycle information available through open interfaces. Unlikely the IT supported solutions, Cole et al. (2013) addressed the dynamics and uncertainties in the life cycle by employing regenerative design approaches. The regenerative design could respond to the changes over time through a combined human/technical systems of the building process. One important attribute of regenerative design is the co-evolutionary and partnering relationship between socio-cultural and ecological systems and the engagement with the consequences of future design decisions (Cole et al., 2013).

Mollaoglu-Korkmaz et al. (2011) conducted a case study of 12 projects and suggested that the level of integration in the delivery process also affects energy performance. Swarup et al. (2011) found that green projects delivered by 'construction management at risk' (CMR) and 'design-build' (DB) have a higher chance of producing better outcomes than 'design-bid-build' (DBB) projects. Lee et al. (2013) pointed out that the application of integrated project delivery (IPD) is helpful in achieving target life cycle values while reducing system complexity and overdesign. Understanding the energy related risks in the delivery process is also conducive to energy reductions and project performance (Zou and Couani, 2012). To manage energy related risks effectively, Lee et al. (2013) suggested that a high level of collaboration among team members is essential. Collaboration among team members might be further achieved by: 1) early inclusion of the green concept in the project; 2) early involvement of contractors; 3) owner commitment toward green/energy reduction targets (Swarup et al., 2011); 4) project team member's compatibility (Mollaoglu-Korkmaz et al., 2011); 5) fluent cooperation and networking (Häkkinen and Belloni, 2011); and 6) project managers' competency (Hwang and Ng, 2013).

Knowledge dissemination across projects is also gaining increased prominence. Chong et al. (2009) suggested that American Society of Civil Engineers (ASCE) and other professional agencies should play a major role in promoting sustainable construction by acting as a platform for knowledge sharing, transfer, education, and dissemination of sustainability-related information. Zuo et al.'s (2013) case study of the Pixel Project in Australia reveals that extensive knowledge of overseas standards was called upon in the design and overseas knowledge of low-carbon building could help the progress of the carbon-neutral building concept in Australia.

Carbon offsetting solutions

It has been acknowledged that the use of renewable solutions is often constrained by geographical conditions. For instance, the use of solar panels is limited by roof space and orientation, positioning, overhang and shadowing, and the application of ground source heat pumps is subject to the topography of the development. Therefore, possible carbon offsetting solutions are desirable to achieve zero carbon. DCLG (2013) proposed that allowable solutions are a possible choice to offset carbon emissions. It could be made by contracting with a third party allowable solutions provider to deliver carbon abatement measures, which are sufficient to meet the builders' obligations (DCLG, 2013). However, care is needed when designing carbon offsetting solutions, as solutions developed for a country may not be applicable to others due to the distinctions in the social, economic and political contexts.

RESEARCH METHOD

The literature review confirms that approaches grounded on STS theories help achieve the zero carbon target. However, the research question stands what the potential of such approaches is in the transition of ZCBs from low-rise to high-rise. The research was designed to include two components: 1) a case study of the first ZCB in Hong Kong with the purpose to examine the delivery solutions; and 2) a workshop to explore the future of high-rise ZCBs in Hong Kong and the potential of STS in the transition from low to high rise.

The case ZCB studied was developed by the Construction Industry Council (CIC) in partnership with the Hong Kong SAR government, and was opened in 2012. According to CIC (2012), this ZCB is a signature project to showcase the state-of-the-art eco-building design and technologies to the construction industry internationally and locally and to raise community awareness of sustainable living in Hong Kong. It is a 3-storey building, with a total site area of 14,700 square meters, comprising exhibition and education areas, an eco-office and a multipurpose hall in the building, eco-plaza, outdoor exhibition areas, HK's first urban native woodland and eco-café in the landscape area (CIC, 2012).

The workshop was of half a day, conducted at the researchers' university with ten selected senior practitioners and academics in the area of low/zero carbon buildings. The participants in the workshop were selected using a purposive sampling strategy to ensure an as-comprehensive-as-possible coverage of roles of stakeholders in the discussion while controlling the size of participants to allow detailed and focused discussion and debate. As a result, the participants covered the roles of developer, contractor, consultant, institution, academic and the public. All participants had significant experience with low/zero carbon building practice and/or research, and four were involved in the design and construction of the case ZCB, i.e. the first ZCB in Hong Kong.

CASE STUDY RESULTS

The ZCB was designed to achieve net zero carbon and energy plus (Table 2). The low energy use mainly results from the energy efficiency design solutions that comprise passive design strategies and green active systems with contributions to energy use reductions by 20% and 25%, respectively. The passive design was enabled by: 1) the use of tapered and linear build form; 2) cross-ventilated layout; and 3) high performance building envelope and glazing with external shading. The green active systems include high-volume-low-speed ceiling fans, desiccant dehumidification, under-floor displacement cooling and radiant cooling by chilled beams. Solar thermal panels were also installed to generate hot water for the eco-café area. Furthermore, the design was made flexible to cater for the fast-evolving low carbon and eco-building technologies and changing needs.

The large-scale use of biodiesel made from waste cooking oil and utilizing 70% of the source energy as compared to the normal level of 40%. Three types of photovoltaic panels (i.e. ploy-crystalline, building integrated thin-film and cylindrical CIGS) together are expected to generate 87 MWh per year (Table 2). The main building roof is inclined to maximize solar irradiance on the PV panels. During the operation stage, real-time control and monitoring through a building management system with smart controls with over 2,800 sensing points are being carried out to evaluate the operation performance of the building.

Table 2. Energy performance of the CIC ZCB

Parameters estimated	Capacity
Energy use	116MWh/year
Energy use of the landscape area and others	15MWh/year
Output from biodiesel tri-generation system	143MWh/year
Output from PV panels	87MWh/year
Net energy export	99MWh/year

WORKSHOP RESULTS

Technical aspects

All participants highlighted that the first ZCB in Hong Kong is of three storeys only, and delivering high-rise ZCBs in dense urban environments would be extremely challenging due to geographical constraints. The participants also suggested that high-rise ZCBs would not be technically feasible in Hong Kong, given the technologies currently available to the market. More advanced emerging technologies are needed to reduce building energy consumption and carbon emissions dramatically. The take-up of energy efficiency measures and renewable energies is highly desirable. A participating developer shared their experience with reducing energy consumption by 60% of a LEED platinum-certified new hotel building in Hong Kong, drawing on a wide range of technological innovations. However, this participant commented that the remaining 40% (towards net zero) would be tremendously difficult to be reduced or offset. All participants concurred that it is urgent and important to conduct a study of the feasibility of delivering high-rise ZCBs in Kong Hong, as the majority of ZCBs to date are of low-rise, mainly located in the western countries with cold or mild weather conditions.

Social aspects

All participants suggested that developing a Hong Kong based definition of ZCB should be on top of the agenda of delivering high-rise buildings towards zero carbon. Such definition should addresses the high-density high-rise features of buildings in Hong Kong which is associated with hot and humid subtropical weather, and also take into consideration the availability of renewable energy sources and their connection with grid. A participant from a green building institution commented that a split of contribution to carbon reductions between the building and energy sectors should be provided along with the definition. A participating academic added that decarbonized energy production, e.g. via carbon storage and capture, and energy supply, e.g. with higher levels of transmission efficiency, contributes to the achievement of ZCBs particularly in high-density urban areas where space for on-site renewables is limited. The participants also recognized that the ZCB definition would vary from different types of buildings, e.g. residential and commercial buildings in the public and private sectors.

Building on the definition, the participants also shared the view that industry standards and guidance for ZCB design and construction should be developed, with best practices to be disseminated. Such standards and guidance could also inform the formulation of green building policies towards zero carbon, thereby regulating and facilitating the industry-wide take-up. Nevertheless, the participants pointed that the development of such standards and guidance should base on the current green building assessment schemes (i.e. ‘BEAM Plus’) for maximized continuity of learning in industry.

The participants agreed that the use of procurement methods might have a significant impact on achieving ZCBs. When following a traditional procurement route, the contractor (even those specialized in green building) is largely guided by the aspiration of the client/developer, and might not be powered enough to influence a client/developer who are less enthusiastic or knowledgeable about ZCB. The participants also realized that energy efficiency measures or renewable energy technologies are often not fully present in the early design stage; it is therefore important for the client/developer to engage with the specialist contractor or consultant early in the design stage so that innovative technologies can be integrated into the design rather than simply bolted on in the later procurement stages. The participants noted that the client would have greater enthusiasm with ZCB strategies when they bear longer term energy costs. Therefore, changing the attitudes of the public and stakeholders towards low or zero carbon would be crucial to reducing energy consumption of buildings.

CONCLUSIONS

The ZCB approach has emerged as an innovative model of green building. This paper has explored the transition from low to high-rise ZCBs and the potential of socio-technical systems in that process. ZCBs are examined as complex social-technical systems and the key stakeholders are embedded in their social, cultural and political environments. The examination is substantiated through the combination of a case study of the first ZCB in Hong Kong and a workshop with the key stakeholders of buildings. The findings indicate that the delivery solution of the first ZCB of three stories in Hong Kong was considered to be technically infeasible for high-rise buildings in the city due to geographic constraints. Emerging technologies must be explored for enhanced technical feasibility. The split of contributions from end-users, the building industry and the energy sector to carbon reductions was considered crucial to developing a practical ZCB definition for Hong Kong. The delivery of high-rise ZCBs should not be regarded solely as a technological challenge, but a socio-technical uphill battle. In this sense, to enable the transition from low to high-rise ZCBs we should maximize the potential of socio-technical systems, i.e. not only capitalizing on the technological innovations but stimulating and consequently benefiting from social and behavioral changes towards reducing energy demand and carbon emissions.

REFERENCES

Allcott, H. (2011). “Social norms and energy conservation.” Journal of Public Economics, 95(9), 1082-1095.

Axsen, J. and Kurani, K.S. (2012). “Social Influence, behavior, and low-carbon energy transitions.” Annual Rev. of Env. and Resources, 37(1). 312-340.

Berker, T. and Bharathi, K. (2012). “Energy and buildings research: challenges from the new production of knowledge.” Bdg. Res. & Info., 40(4), 473-80.

Bostrom, R. P. and Heinen, J. S. (1977). “MIS Problems and failures: a sociotechnical perspective part I: the cause.” MIS quarterly, 1(3), 17-32.

Carrico, A. R. and Riemer, M. (2011). “Motivating energy conservation in the workplace: An evaluation of the use of group-level feedback and peer education.” Journal of Environmental Psychology, 31(1), 1-13.

Chong, W. K., Kumar, S., Haas, C. T., Beheiry, S. M., Coplen, L. and Oey, M. (2009). "Understanding and interpreting baseline perceptions of sustainability in construction among civil engineers in the United States." Journal of Management in Engineering, 25(3), 143-154.

Cole, R.J., Oliver, A. and Robinson, J. (2013). "Regenerative design, socio-ecological systems and co-evolution." Bdg. Res. & Info., 41(2), 237-47.

Ellegård, K., Palm, J. (2011). "Visualizing energy consumption activities as a tool for making everyday life more sustainable." Appl. Energy, 88(5), 1920-26.

Gulbinas, R., Jain, R. K., Taylor, J. E., Peschiera, G., and Golparvar-Fard, M. (2013). "Network eco-Informatics: development of a social eco-feedback system to drive energy efficiency in residential buildings." Journal of Computing in Civil Engineering.

Häkkinen, T. and Belloni, K. (2011). "Barriers and drivers for sustainable building." Building Research & Information, 39(3), 239-55.

HKGBC (2012) "HK3030" a vision for a low carbon sustainable built environment in Hong Kong by 2030. HK Green Building Council, HK.

Horman, M. J., Riley, D. R., Lapinski, A. R., Korkmaz, S., Pulaski, M. H., Magent, C. S., et al. (2006). "Delivering green buildings: Process improvements for sustainable construction." Journal of Green Building, 1(1), 123-140.

Hwang, B. G. and Ng, W. J. (2013). "Project management knowledge and skills for green construction: Overcoming challenges." International J. Project Management, 31(2), 272-284.

Jain, R. K., Taylor, J. E. and Peschiera, G. (2012). "Assessing eco-feedback interface usage and design to drive energy efficiency in buildings." Energy and Buildings, 48, 8-17.

Jensen, O.M. (2005) "Consumer inertia to energy saving, in ECEEE 2005 summer study." Panel 6:1327–1334.

Lapinski, A. R., Horman, M. J. and Riley, D. R. (2006). "Lean processes for sustainable project delivery." J. Const. Eng. & Manag., 132(10), 1083-91.

Lee, H. W., Tommelein, I. D. and Ballard, G. (2013). "Energy-related risk management in integrated project delivery." *J. Const. Eng. & Management*.

Li, D. H., Yang, L. and Lam, J. C. (2013). "Zero energy buildings and sustainable development implications–A review." *Energy*.

Li, B. andYao, R. (2012). "Building energy efficiency for sustainable development in China: challenges and opportunities." *Bdg. Res. & Info.*, 40(4), 417-31.

Magent, C. S., Korkmaz, S., Klotz, L. E. and Riley, D. R. (2009). "A design process evaluation method for sustainable buildings." *Architectural engineering and design management*, *5*(1-2), 62-74.

Marszal, A. J. and Heiselberg, P., (2011). "Life cycle cost analysis of a multi-storey residential Net Zero Energy Building in Denmark." *Energy*, 36(9), 5600-9.

Ma, G., Andrews-Speed, P. and Zhang, J. (2013). "Chinese consumer attitudes towards energy saving: The case of household electrical appliances in Chongqing." *Energy Policy*.

Mollaoglu-Korkmaz, S., Swarup, L. and Riley, D. (2011). "Delivering sustainable, high-performance buildings: influence of project delivery methods on integration and project outcomes." *J. Management in Eng.*, 29(1), 71-8.

Mukherjee, A. and Muga, H. (2010). "An integrative framework for studying sustainable practices and its adoption in the AEC industry: A case study." Journal of Engineering and Technology Management, 27(3), 197-214.

Newsham, G. R., Mancini, S. and Birt, B. J. (2009). "Do LEED-certified buildings save energy? Yes, but…." *Energy and Buildings*, 41(8), 897-905.

Pan, W. and Ning, Y. (2013.) Requisite holism of the feasibility of delivering zero carbon buildings. *Sustainable Building 2013 Hong Kong Regional Conference Urban Density & Sustainability.* 12 -13 Sept 2013, Hong Kong.

Peschiera, G. and Taylor, J. E. (2012). "The impact of peer network position on electricity consumption in building occupant networks utilizing energy feedback systems." Energy and Buildings, 49, 584-590.

Stijbos, S. (2006) A normative systems approach for managing technology and collective human action. In Verbeek P. P. and A. Slob (eds.) "*User Behaviour and Technology Development: Shaping Sustainable Relations Between Consumers and Technologies*", Springer.

Swarup, L., Korkmaz, S. and Riley, D. (2011). "Project delivery metrics for sustainable, high-performance buildings." Journal of Construction Engineering and Management, 137(12), 1043-1051.

Sunikka-Blank, M. and Galvin, R. (2012). "Introducing the prebound effect: the gap between performance and actual energy consumption." Building Research and Information, 40(3), 260-273.

Swarup, L., Korkmaz, S. and Riley, D. (2011). "Project delivery metrics for sustainable, high-performance buildings." *J. Const. Eng. and Management*, 137(12), 1043-1051.

Thollander, P. and Palm, J. (2013) Barriers to energy efficiency from a sociotechnical perspective. In Thollander, P. and Palm J (eds.). "*Improving Energy Efficiency in Industrial Energy Systems*" (pp. 73-83). Springer.

Torcellini, P., Pless, S., Deru, M. and Crawley, D. (2006). Zero energy buildings: A critical look at the definition. "*ACEEE Summer Study Pacific Grove. California," USA, August*, 14-18.

Xu, X., Taylor, J. E., Pisello, A. L. and Culligan, P. J. (2012). "The impact of place-based affiliation networks on energy conservation: An holistic model that integrates the influence of buildings, residents and the neighborhood context." Energy and Buildings, 55, 637-646.

Zou, P. X. W. and Couani, P. (2012). "Managing risks in green building supply chain." Architectural Engineering and Design Management, 8(2), 143-158.

Zuo, J., Read, B., Pullen, S. and Shi, Q. (2013) "Carbon-neutral commercial building development." Journal of Management in Engineering, 29(1), 95-102.