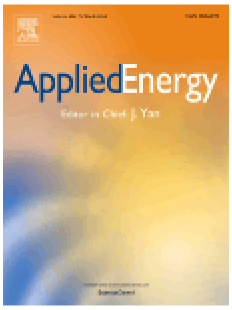
Journal Accepted Version



Opportunities and risks of implementing zero-carbon building policy for cities: Hong Kong case

Wei Pan, Mi Pan

DOI: https://doi.org/10.1016/j.apenergy.2019.113835

To appear in: Applied Energy

Received 13 June 2018, Revised 22 August 2019, Accepted 1 September 2019, Available online 23 September 2019.

Please cite this article as: Pan, W., Pan, M. (2019). Opportunities and risks of implementing zero-carbon building policy for cities: Hong Kong case. Applied Energy, 256, 113835. https://doi.org/10.1016/j.apenergy.2019.113835

Opportunities and Risks of Implementing Zero-Carbon Building Policy for Cities: Hong Kong Case

Abstract

There is a worldwide policy agenda of reducing buildings' carbon emissions. Zero-carbon building has emerged as an advanced model with policy support, but high-rise remains a knowledge gap. This paper aims to contribute a better understanding of the opportunities and risks of formulating and implementing a zero-carbon building policy, and identify recommendations for maximising the opportunities and minimising the risks. Hong Kong as a typical high-rise high-density city was considered as the case for study. The research was conducted through the combination of a policy review, a questionnaire survey, interviews and focus group meetings with several hundred professionals and stakeholders carefully selected using stratified sampling. Wide opportunities were identified, with most important ones including raising public awareness of sustainable living, reducing buildings' energy use and carbon emissions, and promoting strategic urban planning. However, risks were found to co-exist, with most significant ones including geographical obstacles to domestic renewable energy generation, heavy reliance on fossil fuels, and resistance of practitioners to the policy. Nevertheless, the opportunities were considered to outweigh the risks. Recommendations were identified to mitigate the risks, which are centred on policy guidance, business strategy, stakeholder partnership, and government and client leadership. The findings reveal the complex, interactive, interchangeable and context-specific features of the opportunities and risks, which alert to reconstruct a dialectical system framework of implementing zero-carbon building policy for Hong Kong. The yielding policy implications and recommendations should shape the reconstruction of that framework for high-rise high-density cities.

Keywords: zero-carbon building; building energy and carbon policy; carbon emission; high-rise building; Hong Kong.

1. Introduction

Climate change is a global issue [1], to address which low carbon development has been raised as a key strategy in the Paris Agreement [2]. In particular, buildings contribute over one third of the world's total carbon emissions [3]. Reducing the carbon emissions of buildings is an essential aspect of green building [4], and is highly significant to minimising environmental effects, safeguarding people's quality of life and ensuring energy security. These factors warrant building carbon emissions becoming a focal point of both practice and public policy. There is a worldwide trend to develop low-carbon or zero-carbon building (ZCB) in the fight against climate change [5] and to promote this as a most advanced model for green building [6] and transition of global energy system [7]. To invigorate such practices, policies on ZCB and the alike are being developed in many countries and regions, which include the regulation, code, standards, or other political or statutory acts [8]. Well formulated policies [9] and regulations [10] are deemed to guarantee the sustained development of ZCB. However, the successful formulation and implementation of a ZCB policy is faulted with difficulties and challenges, such as the cancellation of the early version policy in the UK [11]. Although the importance of zero carbon innovation in the building sector has been widely recognised, there is still limited policy support for ZCBs [12].

Hong Kong is located at the mouth of the Pearl River Delta in Southern China, with a total area of 1,106.3 square kilometres and a population of 7.39 million as of 2017. Actually, only less than 25% of the land is developable with the others protected (e.g. country parks and nature reserves), rendering the vast majority of the built urban areas of Hong Kong being most high-rise high-density. The total greenhouse gas emissions in Hong Kong amounted to 41.9 million tonnes of carbon dioxide equivalent in 2016, where electricity generation amounted to 27.9 million tonnes that accounted for 66.5 % of the total [13]. Hong Kong is a service-based economy with no energy-intensive industries, where the contribution of buildings to electricity consumption and carbon emissions is around 90% and 60%, respectively [14], well above the world averages. In Hong Kong, building energy policies, codes and regulations have evolved over the past two decades towards increasingly stringent standards of energy efficiency, which are coupled with recently released policy initiatives for carbon reductions [8]. Yet, there is no policy forum or consultation on the formulation of a ZCB policy for Hong Kong. Thus, the potential benefits, opportunities and risks of such a policy are mostly unknown. There are also practical challenges to reducing buildings' carbon emissions in the subtropical high-rise high-density urban settings [15]. Given the sweeping global urbanisation and high-density developments, the knowledge gap in both policy and practice is significant. There is, therefore, a necessity for a clear understanding of the benefits and opportunities that a ZCB policy could bring to motivate accelerated reductions of carbon emissions in high-rise buildings, as well as of the potential risks.

The aim of this paper is to contribute a better understanding of the opportunities and risks of formulating and implementing a ZCB policy for high-rise high-density urban environments focused on Hong Kong, and identify recommendations for maximising the opportunities and minimising the risks. This paper is the first in its kind to examine the issues associated with the formulation and implementation of a ZCB policy for high-rise high-density cities. The findings provide insights into the interwoven opportunities and risks of introducing a ZCB policy in the dense city context. The contributed knowledge should greatly inform and shape the thinking and practices of policy makers and industry practitioners when dealing with carbon reductions. Following this introduction, the paper provides an overview of the building energy and carbon policies in Hong Kong and reviews the relevant literature. It then explains the research methodology, within which the ZCB policy concept and framework adopted for this study is outlined. The paper then examines the results about the opportunities from and risks of the formulation and implementation of a possible ZCB policy for Hong Kong. After that, the paper identifies recommendations in technical, regulatory, social and geographical aspects for mitigating the risks, discusses policy implications and finally draws conclusions.

2. Literature Review

2.1. An overview of zero-carbon building relevant policies in the world

There are proposed targets to achieve 'zero carbon', 'nearly zero energy' or 'net zero energy' from buildings in a number of countries and regions as part of their initiatives and policies regarding building energy, carbon and climate change [16]. For instances, the Mayor of London [17] has set the city-wide policy targets to achieve 'zero carbon' for new homes from 2016 in Policy 5.2 of the London Plan. The recast of the Energy Performance in Buildings Directive (EPBD) of 2010 [18] requests that the EU member states shall ensure that: 'a) by 31 December 2020, all new buildings are nearly zero-energy buildings; and b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero energy buildings.' In the US, the Energy Independence and Security Act of 2007 authorizes the Net-Zero Energy Commercial Building Initiative to support the goal of net zero energy for all new commercial buildings by 2030, and further specifies a zero-energy target for 50% of US commercial buildings by 2040 and net zero for all US commercial buildings by 2050 [19]. The Zero Emissions Residential Task Group of the Australian Sustainable Built Environment Council (ASBEC) has proposed the definition of and roadmaps to ZCB [20], and recommended the establishment of a consistent, long-term, regulated timeline towards zero carbon with industry-agreed targets.

In Asia, many cities are characterised as being high-rise high-density that challenges the global goal of decarbonising the building sector towards net-zero [5]. There have arisen increasing actions for exploring or delivering zero energy or zero carbon buildings in Asian countries. Japan's Strategic Energy Plan established the goals to realise zero energy building (ZEB) in 'newly constructed public buildings by 2020 and in average newly constructed public and private buildings by 2030' through a stepwise approach as 'ZEB-ready, nearly-ZEB and ZEB' [21]. The Building and Construction Authority (BCA) of Singapore has shared the country's long-term aspiration in 2016 to achieve 'positive energy low-rise, zero energy medium-rise and super low energy high-rise buildings (PE-ZE-SLEB) in the tropics', and has devoted great efforts to developing the technology roadmap [22]. While policies for buildings towards 'zero carbon' and 'zero energy' are highly relevant and both emphasise energy efficiency [23], zero energy buildings focus more on energy generation potential [24] and ZCBs highlight the use of clean energy to achieve net-zero carbon emission [8]. Ambiguous definitions exist in many policies containing net-zero targets [25]. Therefore, the key concepts such as net-zero energy, low energy, and low-carbon buildings should be clearly defined to support effective policy formulation and implementation [25].

Worldwide there is an increasing number of ZCB demonstration projects [6]. Cross-contextual learning of ZCB relevant policies, albeit being useful, would not be straightforward, as the nature and context of each country or city are unique and building carbon policies are highly value-laden and context-specific [8]. It is thus important to understand the intricate context specifics, should a possible ZCB policy be formulated.

2.2. An overview of building energy and carbon policies in Hong Kong

Although there is yet no ZCB policy in Hong Kong, building energy and carbon policies have for long embraced building energy and carbon reductions.

In terms of building energy policies, the government has endeavoured to raise public awareness of climate change and has introduced many energy-saving measures at different levels. There have been a series of building energy codes (BECs) and regulations in Hong Kong, from the first Building (Energy Efficiency) Regulation Cap.123 implemented in July 1995 to the Buildings Energy Efficiency Ordinance that came into full operation in September 2012 and the follow-up revisions to the BEC and Energy Audit Code (EAC) in 2013 and 2014. As an Asia-Pacific Economic Co-operation (APEC) member, Hong Kong is pledged to fully support APEC's target in energy intensity reduction by 45% by 2035 with 2005 as the base year [26]. In May 2015, the government published "Energy Saving Plan for Hong Kong's Built Environment 2015~2025+" [27], which further raises the target to reduce energy intensity by 40% by 2025 using 2005 as the base year, as well as achieving green building targets for government buildings and public housing. To achieve the target, the Plan combines educational, social, economic and regulatory means.

Building carbon policies in Hong Kong are typically integrated with those on energy. The government launched Buildings Energy Efficiency Funding Schemes (BEEFS) in 2009, which provided HK$450 million over three years to promote building energy efficiency by subsidising building owners to conduct energy-cum-carbon audits and energy efficiency projects. The government published "Guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for Buildings (Commercial, Residential or Institutional Purposes) in Hong Kong" [14] as a systematic and scientific approach to assist the building users and managers to improve their awareness of carbon emissions, measure building carbon emission performance and actively participate in actions to combat climate change. The Council for Sustainable Development (SDC) submitted its report on the public engagement on "Combating Climate Change: Energy Saving and Carbon Emission Reduction in Buildings" to the government in 2012 [28]. In the same year, the government supported the Hong Kong's first ZCB, developed and completed by the Construction Industry Council (CIC), which is of 3 storeys and serves the purpose to share knowledge in low or zero carbon building design and latest technologies, as well as raise community awareness of sustainable and low carbon living [29]. This project has well demonstrated the possibilities for achieving ZCBs in Hong Kong and initiated active communication among stakeholders on ZCBs. Meanwhile, the government also commenced a 3-year programme to conduct energy-cum-carbon audits at 120 government buildings. The 2013 Policy Address envisaged turning Hong Kong into a low-carbon metropolis [30]. The Environment Bureau published new energy saving plan in 2015 to encourage all sectors of the community to save energy and adopt a low carbon lifestyle to contribute to the sustainable development of Hong Kong [27]. For the future, the government devised Hong Kong's Climate Action Plan 2030+ in 2017 to push ahead of the carbon emission, set an ambitious target to lower the carbon intensity by 65%-70% from the 2005 level by 2030, and specified the critical needs for energy and carbon efficiency in buildings [31]. The 2018 Policy Address further highlighted that energy saving in buildings is an essential means for Hong Kong to continuously reduce carbon emissions, since buildings account for over 90% of the total electricity consumption in Hong Kong [32].

Building energy and carbon policies in Hong Kong cover building energy efficiency, building products and systems, energy supply (renewable energy and decarbonised electricity generation), as well as building energy and carbon audit and reporting. All these policies and codes together cover the political, social, technical, economic aspects, reflecting building carbon policy as a complex system. The motivating impacts of these policies have been recognised on the green building market in Hong Kong [4].

2.3. *Previous research on opportunities and risks of formulating and implementing ZCB policy*

Previous research on the opportunities and risks associated with ZCB policy in Hong Kong and elsewhere has been limited. Relevant studies have examined the policies on green buildings, energy or carbon reduction schemes with a broader scope than ZCBs. The SDC [28] in Hong Kong launched a public engagement process on energy saving and carbon emission reduction in buildings, and provided recommendations of 'systemic enhancement' and 'facilitation of behaviour change' to help engage the community, but did not explore the opportunities and risks of possible strategic movement towards zero carbon. As observed by Crawley et al. [19], a common language in defining and measuring ZCBs is lacking, which contributes to significant ambiguity when setting targets and procedures to achieve carbon reduction in forming policy.

Some researchers discussed the opportunities of formulation and implementing a relevant policy for the green building market. For example, Gou [4] identified legislation as one most effective method for promoting green buildings and relevant business in Hong Kong. Zhang [9] highlighted the potential of well-formulated policies to provide guarantees for low-carbon buildings development in China. The US Green Building Council (USGBC) [33] reported that a comprehensive policy has been proven to help reduce energy usage, achieve emission targets, foster innovation, create a sophisticated green building industry, and promote community sustainability.

The potential of policies to drive the carbon reduction practice in construction has also been argued to be dependent on organisational culture to changes [34]. The studies on real and perceived barriers of achieving low or zero carbon or green buildings informed the risks of policy by reflecting feasibilities of policy targets. Chan et al. [35] suggested that the barriers in Hong Kong include higher upfront costs, lack of education, lack of fiscal incentives and lack of awareness. Pan et al. [36] examined the technical feasibility of delivering low or zero carbon public residential building (of 40 storeys) and private office building (of 26 storeys) in Hong Kong, and revealed that it is technically feasible to reduce the buildings' carbon emission intensity by 60% but still not to achieve net-zero. Häkkinen and Belloni [37] argued that organisational and procedural difficulties in achieving green buildings can be more challenging than the technical aspects; despite the potential benefits of green buildings, the 'externality' of green buildings (i.e. benefits to those other than the developers) may significantly decrease developer enthusiasm to deliver green buildings, thereby leading to market failure.

2.4. *A zero-carbon building policy framework adopted for this study*

Drawing on the contexts of the international policies on ZCB (and the alike) and of Hong Kong's evolution of building energy and carbon policies and codes, a ZCB policy framework is constructed for this study. This framework adopts the 'socio-technical framework of ZCB policy' developed by Pan and Ning [8], and refers to the 'socio-technical transitional approaches' elaborated by Geels [38] and Coenen et al. [39] for the multiple perspectives on innovation and transition. The framework emphasises the need to address innovative ZCB and its policy within the social, economic, regulatory and geographical contexts. The technical system of the ZCB policy consists of four components, which are elaborated below.

1) ZCB definition and energy use scope, e.g. whether or not the scope covers buildings' life cycle carbon/energy and energy use from appliances. The generic form of the definition of a ZCB proposed for this study is "*a building within its defined system boundaries with*

net-zero carbon emissions on an annual basis during the operational stage of this building". The system boundaries should be defined in terms of the technical components of the definition within relevant contexts (see Pan [40] for the elaboration of the system boundaries of ZCB).

2) Carbon reduction targets and timelines. Considering three variables, namely, building type (e.g. residential and commercial), building sector (public and private) and building status (new-build and retrofit), a number of combinations of policy targets were considered for proposing the preliminary timelines of achieving zero carbon.
3) Measures and indicators of energy use and carbon emissions, which are numerical indicators of energy production (of on- and off-site renewable energy) and energy use and their associated carbon emissions (offset and positive) of the building. Measures were suggested to be in kWh/m^2/year (energy use intensity – EUI) and kgCO_2e/m^2/year (carbon emission intensity - CEI), respectively, as they are commonly used.
4) Use of renewable energy to enable a possible net zero. Given the limited use of renewable energies in Hong Kong, it was proposed that the required renewable energy for a ZCB may be generated on-site, off-site but directly connected with the building, and/or off-site and indirectly connected with the building.

The technical system of the ZCB policy, its regulatory, economic, social and geographical contexts, and the mechanism of stakeholder engagement, together form the nutshell of the possible ZCB policy framework for Hong Kong for study.

3. Research Methodology

The research reported in this paper was carried out through the combination of a policy review, a questionnaire survey, follow-up interviews and focus group meetings with professionals carefully selected in the Hong Kong building industry. Interviews and focus group meetings served as supplements to the questionnaire survey and explored in depth and verified the results of the survey as a methodological 'triangulation' of the results.

3.1. Research methods

The questionnaire survey aimed to examine the opportunities and risks associated with formulating a possible ZCB policy for Hong Kong. The focus of the paper is on the policy itself where opportunities are deemed as benefits from the formulation and implementation of the policy while risks are defined as obstacles and problems in the successful formulation and implementation of the policy. The questionnaire included a number of questions in the following sections (also see Appendix):

- Information on the participant, which included educational background; profession; work experience with low or zero carbon building; and type of affiliation.
- Perceived opportunities and risks associated with the formulation and implementation of the possible ZCB policy for Hong Kong. Using a 5-point Likert scale, participants were asked to evaluate a list of possible opportunities and a list of possible risks identified from the literature review.
- Recommendations for mitigating the identified risks for effective reduction of building energy consumption and carbon emissions in Hong Kong.

Space was provided in the questionnaire to allow provision of any additional comments in relation to the questions. The questionnaire was verified through a pilot study with relevant academics and researchers before being sent to the targeted participants.

The follow-up interviews complemented the questionnaire survey by enabling direct contact between the researchers and the survey participants. The follow-up interviews aimed to reveal insights into the stakeholders' perceptions and attitudes and verify the responses and results of the questionnaire survey. The interview questions were similar to those of the questionnaire, but were focused more on 'why' and 'how' to elicit insights. The proposed ZCB policy concept and framework was made to the awareness of the participants in the study for informed engagement and discussion.

The stakeholder focus group meetings aimed to further explore and verify the perceived opportunities and risks and develop recommendations for mitigating the risks. Four focus group meetings were conducted, which together covered the demand, supply, regulation and institution sides of stakeholders. During these meetings, the project team further explained to the participants the possible ZCB policy and the complex system framework, in addition to the opportunities and risks and initial recommendations identified from the questionnaire survey and interviews. In turn, the focus group participants raised enquiries and provided comments and suggestions.

3.2. Participant sampling

The questionnaire survey participants were selected through a process of classification, identification and selection. The participants were first classified using two-stage stratified sampling [41] in order to obtain a representative sample of the population affected by the possible ZCB policy. In doing so, professionals were targeted from four sides of buildings or ZCBs in Hong Kong, and further subdivided into eight key stakeholder groups [9].

- The demand side, with the key stakeholder groups:
    1) developers, clients and investors (critical to market uptake of ZCB);
    2) estate and facilities managers (critical to building operation and lifetime performance);
- The supply side, with the key stakeholder groups:
    3) contractors (critical to the delivery of buildings and ZCB implementation);
    4) professional advisors, including architects, designers, engineers, planners, surveyors (critical to ZCB design and innovation);
    5) manufacturers and suppliers from both the building and energy sectors (critical to ZCB market and supply chains);
- The regulation side, with the key stakeholder groups:
    6) government and its departments and agencies (critical to the regulation and motivation of the market and industry);
- The institutional side, with the key stakeholder groups:
    7) financers, bankers and mortgage lenders (critical to insurance and long-term investment in buildings);
    8) universities and professional bodies (critical to professional development and training).

Next, potential survey participants were identified under the eight key stakeholder groups using publicly available databases supplemented by the networks of the researchers and their affiliated institutions. Examples of the relevant publicly available databases of stakeholders used include: the Hong Kong Real Estate Developers Association's list of directors and committee members for developers [42]; the Development Bureau's list of approved contractors for public works [43] and the Hong Kong Trade Development Council's (HKTDC) database of architectural & civil engineering works at construction site for contractors [44]; the Hong Kong Green Building Council's (HKGBC) BEAM Professional Directory [45] and the Hong Kong Institute of Surveyors' (HKIS) directory for professional advisors [46]. Finally, the survey participants were selected in each stakeholder group using random sampling [41] to minimise bias in the sampling process. The overall process yielded a sample of 1000 professionals for the survey.

The interview participants were identified and selected from the survey participants who were willing to participate in a follow-up interview. Nevertheless, stratified sampling was adopted in the selection of interviewees to ensure that the interviews covered the eight identified key stakeholder groups. The focus group participants were selected from the targeted survey participants. Each focus group meeting was organised to encourage engagement and allow focused and detailed discussion.

3.3. Data collection and analysis

The questionnaire survey was carried out through post, email, and online form, to achieve an effective response rate and maximise stakeholder engagement. The data collected were logged onto a Microsoft Excel Spreadsheet. The quantitative data were then converted using SPSS software for descriptive and statistical analyses. The participants were asked to judge the importance or significance of the identified factors in opportunities, risks and recommendations based on a 5-point Likert scale with weighting from 1 to 5. The Cronbach's alpha coefficient (α) was applied to test the reliability of the questionnaire [47]. The calculated α of factors in opportunities, risks and recommendations were 0.922, 0.870 and 0.925, demonstrating a high level of internal consistency of the scale ($\alpha > 0.7$). The ranking of factors was based on the calculation of means. A higher mean was considered to be with a higher level of importance or significance. The standard deviation of each factor was calculated to illustrate the degree of difference among the respondents. The Pearson correlation coefficient (r) is used for the correlation analysis on perceptions and experiences. The coefficient r represents the strength of the linear relationship between two different items, where $-1 \leq r \leq 1$ [48]. A higher absolute value of r manifests the stronger correlation, and the correlation is considered indiscernible when the value is less than 0.1.

The interviews were conducted in person or over the telephone, each for around 45 minutes, so that a reasonably rich amount of data and information could be collected in relation to the interview questions. Each of the four focus group meetings lasted two to three hours during a working day for maximum participation. The interviews and the focus group meetings were audio-recorded with permission from the participant, and then transcribed. Transcriptions and notes taken during the interviews and focus groups were logged onto Microsoft Word documents using the headings set in the interview script and focus group agenda respectively. The data were analysed using Nvivo software to identify key codes, themes and patterns in the responses. The research procedures were approved by the Human Research Ethics Committee of the researchers' affiliated institution.

4. Results and Analyses

4.1. Participants in the research

The questionnaire survey attracted 235 effective responses out of 1000 approached informed professionals and stakeholders in Hong Kong building industry and society, yielding an overall effective response rate of 23.5% for analysis. The sampling size and the response rate were considered reasonable compared to other relevant L/ZCB studies, such as Lam et al. [49] (652 distributed, 15% response rate), Wong et al. [34] (300 distributed, 34% response rate) and Zhao et al. [50] (1910 distributed, 6.9% response rate). The semi-structured interviews were conducted with 30 selected professionals. The four focus group meetings together engaged 106 selected professionals and stakeholders.

4.1.1. Participants in the questionnaire survey

By primary organisational affiliation, the participants in the questionnaire survey effectively covered the eight defined stakeholder groups in Hong Kong building industry and society. These groups were (1) developers, clients and investors (15%), (2) estate and facilities managers (6%), (3) contractors (9%), (4) professional advisors (21%), (5) manufacturers and suppliers (11%), (6) government and its departments and agencies (15%), (7) financers, bankers and mortgage lenders (5%), and (8) universities and professional bodies (18%) (Figure 1).

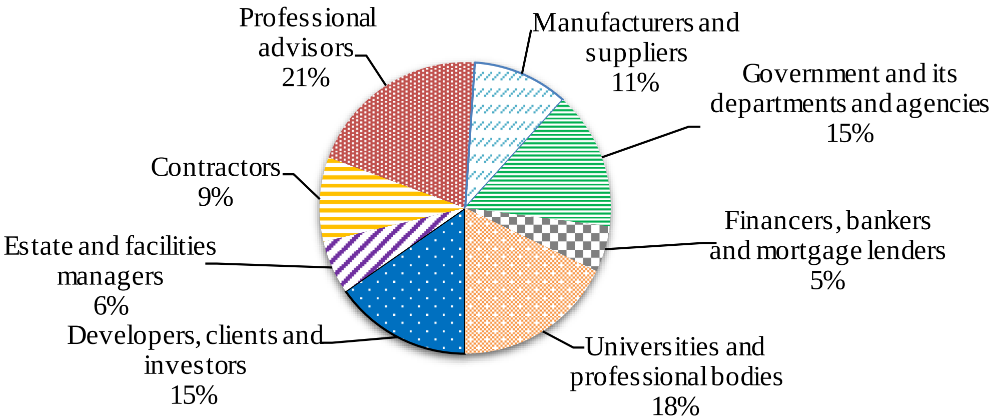


Figure 1 Questionnaire survey participants by type of primary organisation (n=235)

By green building certificate, 27.5% of the effective respondents (n=233) were certified BEAM Professionals, 3.4% were LEED Accredited Professionals and 5.2% held other green building certificates, but the majority (65.7%) held no such certificate.

By the number of years of experience, 58% of the participants had 10 years or more of work experience in the Hong Kong building industry. However, the experience of the participants with low or zero carbon building was quite limited, with 76% having no more than 5 years of such experience at the time of the survey (Figure 2).

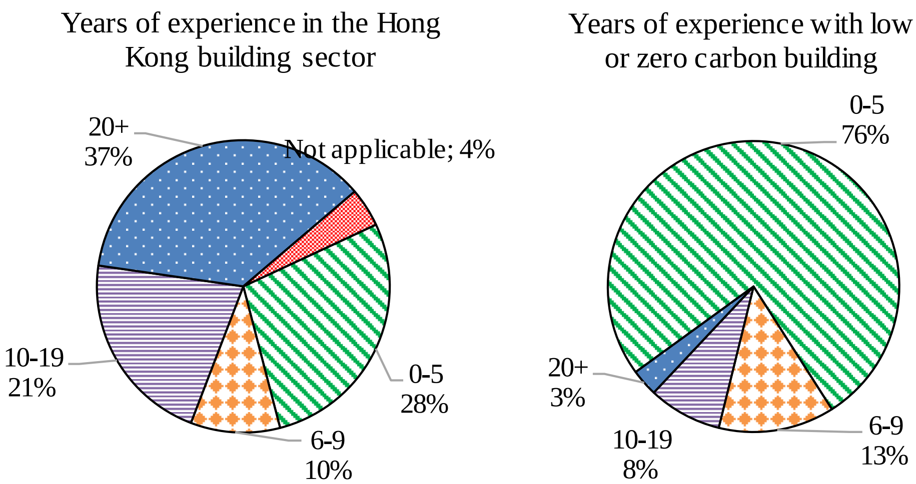


Figure 2 Questionnaire survey participants by experience (n=233)

Overall, the profile of the survey participants well represented the key stakeholder groups of the Hong Kong building sector and reflected the general feature of building and construction professionals. While green buildings had been reasonably promoted, the ZCB concept was still relatively new in Hong Kong.

4.1.2. Participants in the interviews

Semi-structured interviews were conducted with 30 informed professionals, who together covered all the eight specified stakeholder groups, namely, universities and professional bodies (6), developers, clients and investors (3), manufacturers and suppliers (3), professional advisors (3), contractors (4), financers, bankers and mortgage lenders (3), estate and facilities managers (3), and government and its departments and agencies (5).

4.1.3. Participants in the focus group meetings

Four focus group meetings were conducted. The first acted as a kick-off session with participants from all the identified eight stakeholder groups, the other three followed up with focuses on specific stakeholder groups for in-depth discussion (Table 1). The focus groups together engaged 106 professionals and stakeholders and collectively covered all key stakeholder groups.

Table 1 Profile of participants in the focus group meetings

Stakeholder group	Focus group			
	1	2	3	4
Manufacturers and suppliers	√	√		√
Professional advisors	√	√		√
Contractors	√	√		
Financers, bankers and mortgage lenders	√		√	
Estate and facilities managers	√			√
Government and its departments and agencies	√		√	√
Developers, clients and investors	√			√
Universities, professional bodies and institutions	√	√	√	√
Number of participants	60*	16	15	15

**This focus group meeting was carried out as a discussion workshop divided into six groups. The discussion was first conducted in groups by six moderators, followed by group summary and open discussion.*

4.2. Opportunities from formulating and implementing a ZCB policy for Hong Kong

Taking sustainable development as an overarching principle for pursuing the future, more than half (57%) of the questionnaire survey respondents believed a proposed ZCB policy would strongly affect sustainable development in Hong Kong (Figure 3). Through the interviews and focus group discussion, the neutral (23%) and (very) weak (20%) perceptions were attributed to the views of the uncertainty of the ZCB policy for Hong Kong and the difficulty with implementing the policy in a high-rise high-density city, respectively. For example, one interviewee commented, "*I have the reservation as Hong Kong has too many policies at the moment. I am concerned whether this ZCB policy can be established and how the Government and other organizations will encourage this policy?*"

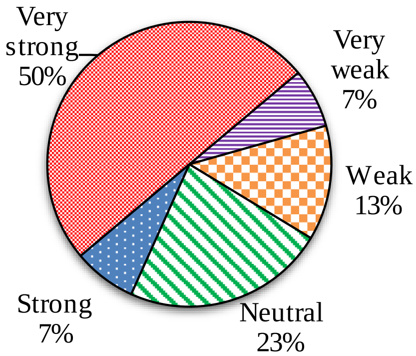


Figure 3 Perceived influence of the proposed ZCB policy on sustainable development in Hong Kong (n=230)

The level of importance of possible opportunities from formulating and implementing the proposed ZCB policy in Hong Kong was examined using a 5-point Likert scale as part of the questionnaire survey (Table 2). Examined were 12 possible opportunities identified from the literature review and grouped in the technical, regulatory, social and geographical aspects. Judged by the mean values (listwise n=229) all of the 12 identified opportunities were considered 'very important' (all mean values falling in the range 3.5-4.5). The opportunity 'raising public awareness of sustainable living' was considered the most important (*m*=4.12), followed by others (listed in Table 2).

Table 2 Opportunities from formulating and implementing the ZCB policy in Hong Kong

Possible opportunities	Valid n	*m*	SD	Rank
Technical aspect				
a) cut building energy consumption	230	3.97	0.874	3
b) reduce building carbon emissions	229	3.93	0.772	5
c) promote uptake of green building and inform BEAM Plus revisions	229	3.61	0.855	12
d) stimulate the market to innovate and adopt low carbon technologies	230	3.87	0.887	8
Regulatory aspect				
e) support achievement of HK Energy Saving Plan 2015-2025+	230	3.77	0.902	9
f) support implementation of Building Energy Codes & Buildings Energy Efficiency Ordinance	230	3.90	0.863	7
g) support achievement of sustainable development in the city	230	3.95	0.766	4
Social aspect				
h) promote skills and employment	230	3.75	0.923	10
i) raise public awareness of sustainable living	230	4.12	0.825	1
j) create new development opportunities for young generations	229	3.92	0.929	6
Geographical aspect				
k) promote development of renewable energy in HK	229	3.72	0.919	11
l) promote strategic urban planning for long-term city development	230	3.99	0.828	2

Note: Calculations are based on a 5-point Likert scale consisting of 'Not important' as 1, 'Somewhat important' as 2, 'Important' as 3, 'Very important' as 4 and 'Extremely important' as 5.

In addition to the 12 opportunities listed in the questionnaire, the participants in the questionnaire survey and interviews suggested some other important ones that are summarised below:

- Promoting benchmarking and competition in the construction industry to improve the whole industry.

- Encouraging more innovation in the construction industry such as green products and technology.
- Stimulating green business opportunities (e.g. green design) and relevant markets (e.g. green materials, technology and products).
- Showcasing Hong Kong as a green city and attract foreign investment.
- Complementing the Mainland China's strategic planning emphasis on a low-carbon economy to strengthen Hong Kong's international profile.
- Formulating better and more comprehensive energy strategies to enable greater energy independence and resilience for Hong Kong.
- Supporting the implementation of relevant carbon trading policies in Hong Kong.

These additional opportunities together cover all the four aspects provided in the questionnaire (i.e. technical, regulatory, social and geographical). Also, the economic aspect was embedded in the four aspects and raised in the additional opportunities. However, some survey respondents and interviewees suggested that the economic aspect should be made explicit, considering that promoting the green industry as economically beneficial was a great opportunity from formulating a ZCB policy.

From the focus group discussion, several patterns of comments were identified. The participants agreed that the policy could assist in promoting strategic urban planning for long-term city development. For example, district cooling systems and combined cooling, heating and power (CCHP) plants are more achievable and cost-effective if established from the beginning of city planning. Also, it is beneficial to raise public awareness of sustainable living, which was considered by most participants to be the most important opportunity. Raised awareness should contribute to behavioural changes and stakeholder engagement. Furthermore, the participants suggested, "*economic factors are most critical*" and "*it is important to demonstrate the potential economic benefits of ZCBs in order to gain public acceptance of the policy*". There would also be opportunities of shifting from pure economic evaluation towards socio-economic appraisal of carbon reductions, as raised by one participant, "*the implementation of such policy can promote the culture of corporate social responsibility in the building sector*". For demonstrating benefits carbon trading and carbon credits were suggested, as well as instruments such as smart meters to show tenants monetary benefits from reducing energy use and carbon emissions. The use of smart meters should also facilitate energy use data sharing and improve information transparency. In addition, the ZCB policy was considered to be able to encourage innovation in low or zero carbon technologies.

4.3. Risks of formulating and implementing a ZCB policy for Hong Kong

The level of significance of possible risks of formulating and implementing the possible ZCB policy for Hong Kong was also surveyed using a 5-point Likert scale (Table 3). Examined were 14 possible risks identified from the literature review and grouped in the technical, regulatory, social and geographical aspects. Judged by the mean values (list-wise n=221) 4 of the 14 identified risks were considered 'very significant' (with mean values falling in the range 3.5-4.5), namely, 'geographical obstacles to domestic renewable energy' (*m*=3.69) being the most significant risk, followed by 'heavy reliance on fossil fuels' (*m*=3.66), 'resistance of practitioners due to unsure benefits' (*m*=3.6), and then 'difficulties due to the high-rise, high-density urban environment' (*m*=3.52). The other 10 possible risks were considered still relevant but at a lower level of significance (Table 3).

Table 3 Risks of formulating and implementing the ZCB policy in Hong Kong

Possible risks	Valid n	*m*	SD	Rank

Technical aspect				
a) lack of industrial experience/skilled labour to fulfil the policy	230	3.21	0.945	7
b) poor understanding of low or zero carbon systems and technology	230	3.31	0.996	6
c) resistance of practitioners due to unsure benefits	229	3.60	0.953	3
d) misunderstanding of the policy	229	3.13	0.932	8
Regulatory aspect				
e) potential conflict with other sustainability objectives	230	2.59	1.040	13
f) potential conflict with other aspects of building codes/regulations	229	2.90	1.076	10
g) potential conflict with existing Building Energy Codes and Regulations	229	2.76	1.064	12
h) non-compliance	229	2.89	1.005	11
Social aspect				
i) effect on the old generations in industry	229	3.08	1.103	9
j) slowing effect on economic growth	230	2.53	1.136	14
k) institutional barriers through poor data access and sharing	230	3.33	1.018	5
Geographical aspect				
l) difficulties due to the high-rise, high-density urban environment	230	3.52	1.144	4
m) heavy reliance on fossil fuels	228	3.66	0.978	2
n) geographical obstacles to domestic renewable energy	230	3.69	0.998	1

Note: Calculations are based on a 5-point Likert scale consisting of 'Not significant' as 1, 'Somewhat significant' as 2, 'Significant' as 3, 'Very significant' as 4 and 'Extremely significant' as 5.

In addition to the 14 risks listed in the questionnaire, the participants suggested some additional ones that are summarised below:

- The technical feasibility of achieving zero carbon may be low in Hong Kong where most of the buildings are high-rise, particularly for existing buildings in the private sector.
- Public acceptance of the ZCB policy may also be low due to unsure benefits from adopting ZCB and lack of incentives.
- Obtaining financial resources to support the high capital cost of ZCB is difficult.
- Power supply companies may not be fully supportive.
- It may be problematic to justify the business case for renewable energy in Hong Kong due to geographical constraints and perceived less established supply chain.
- It may also be challenging to find resources for renewable energy in Hong Kong.

These additional risks suggested together cover all the aspects and also the economic one. One interviewee recommended, "*The implementation of such a policy will mostly involve risks from the unclear feasibility of achieving the policy objectives within the timeframe, where to get the resources of renewable energy, and where to obtain investment*".

From the focus group discussion, several patterns of comments were identified. A serious risk was considered to be the low awareness and acceptance of low carbon materials, products and buildings. One participant criticised, "*The construction industry is generally reluctant and slow-responsive to changes, where residential tenants are even more difficult to change than commercial tenants.*" The reluctance and perception were coupled with a lack of low or zero carbon technologies and products for residential buildings, even less developed than for commercial buildings. The public and end-users therefore hardly see demonstrable benefits from carbon reductions and may not support a ZCB policy. Besides, one participant particularly commented, "*old habit and user behaviour will hinder the achievement of building energy reduction targets and the realisation of such policy*". Another significant risk was revealed to be the lack of financial case and support. Renewable energy in Hong Kong was recognised to require a long payback period, e.g. around 20–30 years without government incentive, and issues with applications. For examples, although the cost of PV panels has dropped significantly, their construction and maintenance costs in Hong Kong have increased significantly; although CCHP seems a promising technology, the high cost of land has reduced the incentive of developers for its take-up. The fluctuating government investments in construction with a perceived decline in economy also weaken the financial case of ZCB. The lack of financial case and support was viewed to be coupled with the insufficient use of lifecycle analysis in evaluating the economic and social effects of ZCB. It has also been argued, "*The focus on zero carbon with great policy support may slow down the economic growth*". A further risk was agreed to be the performance gap between actual metered energy use performance and as-designed targets for energy and carbon reductions, and the subsequent uncertainty of target achievement to industry. An additional risk was pointed as the difficulty with decarbonising existed buildings. Due to the dominant portion of existing buildings in Hong Kong and the lack of an established supply chain for energy retrofit the ZCB policy target for building stock appeared to be quite challenging.

4.4. The opportunities vs. the risks

While the important opportunities were found to exist in all of the technical, regulatory, social, geographical and economic aspects, the significant risks mainly resided in the geographical, technical and economic aspects. When compared the opportunities and risks as a whole, over half (51%) of the questionnaire survey respondents believed that the opportunities outweighed the risks (Figure 4), with 40% remained neutral and only 9% disagreed.

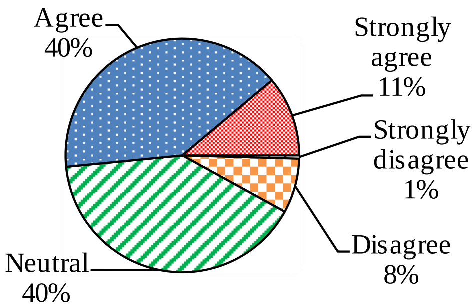


Figure 4 Perception on if the opportunities outweigh the risks (n = 225)

The survey participants' positive perception that the opportunities outweigh the risks was in agreement with their rating of the overall feasibility of formulating and implementing the proposed ZCB policy in Hong Kong. Nearly half (47%) of the survey respondents considered the ZCB policy possible or highly possible for Hong Kong, 41% were neutral, and the remaining 12% regarded that as impossible (Figure 5). The correlation analysis (Table 4) indicates that the perceptions on opportunities outweighing the risks has a moderate correlation with the perceived feasibility of formulating and implementing the ZCB policy ($r = 0.503$, $p < 0.01$). Besides, participants' working experience does not affect their perceptions of feasibility ($r = -0.048$), while their experience with ZCB is weakly negatively related to their perceived feasibility ($r = -0.174$, $p < 0.01$). Besides, all the perceived opportunities are weakly positively correlated to perceived feasibility, while perceived risks are weakly negatively correlated. There is no single opportunity or risk has a high correlation to the perceived feasibility.

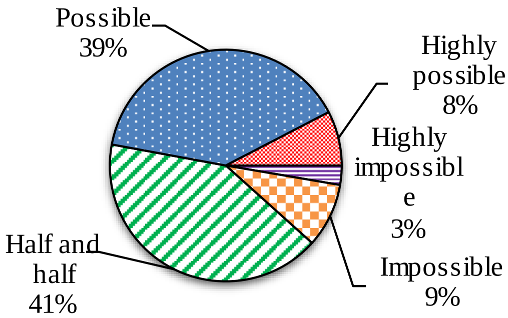


Figure 5 Perceived feasibility of formulating and implementing the ZCB policy (n = 223)

Table 4 Result of correlation analysis on perceived feasibility

Correlation with perceived feasibility of formulating and implementing the ZCB policy	Pearson correlation *r*	Sig. (2-tailed)
Perception on if the opportunities outweigh the risks	0.503	<0.01
Years of experience in the Hong Kong building sector	-0.048	0.481
Years of experience with low or zero carbon building	-0.174	0.009

Through the interviews and focus group meetings, two patterns of considerations were identified for the perceived impossibility. One was that a low carbon policy rather than zero carbon was perceived to be more feasible and practicable for Hong Kong given the high-rise high-density urban features and geographical conditions. The other was that the feasibility of formulating and implementing a ZCB policy in Hong Kong would depend on how different stakeholders cooperate and support the policy.

4.5. Recommendations for mitigating the identified risks

The level of importance of possible recommendations for mitigating the identified risks was examined using a 5-point Likert scale as part of the questionnaire survey (Table 5). Examined were 13 possible recommendations identified from the literature review and grouped in the technical, regulatory, social and geographical aspects. Judged by the mean values (list-wise n=226) all of the 13 possible recommendations were considered 'very important' (all mean values falling in the range 3.5-4.5). The recommendations 'encourage energy/carbon reduction through urban planning' was considered the most important (*m*=4.03), followed by others (listed in Table 5).

Table 5 Recommendations for mitigating the identified risks

Possible recommendations	Valid n	*m*	SD	Rank
Technical aspect				
a) improve knowledge base and industry skills by education and training in ZCB and relevant technology	228	3.83	0.825	8
b) motivate industry using successful examples	228	3.86	0.883	7
c) include zero carbon/energy targets in public project procurement	228	3.99	0.780	2
d) develop guidance on not only technical aspects but economic and business models of ZCB	227	3.96	0.864	6
Regulatory aspect				
e) revise Building Energy Code to raise carbon reduction requirements	228	3.78	0.878	10
f) allocate more credits for carbon reductions in BEAM Plus	228	3.65	0.979	12
g) encourage ZCB uptake in private sector by penalties and subsidies	228	3.81	0.956	9
Social aspect				

h) raise public awareness of ZCB and sustainable living	228	3.97	0.852	4
i) demonstrate life cycle economies and cost benefits of ZCB	228	3.99	0.920	2
j) install smart meters in buildings to improve understanding of building energy use and performance	228	3.79	0.918	11
k) conduct occupant surveys to better understand occupant behaviour	228	3.64	0.930	13
Geographical aspect				
l) provide business opportunities in renewable energy	227	3.97	0.820	4
m) encourage energy/carbon reduction through urban planning	228	4.03	0.826	1

Note: Calculations are based on a 5-point Likert scale consisting of 'Not important' as 1, 'Somewhat important' as 2, 'Important' as 3, 'Very important' as 4 and 'Extremely important' as 5.

In addition to the 13 recommendations listed in the questionnaire, the participants in the questionnaire survey and follow-up interviewees suggested some other important ones that are more relevant to the government:

- Government or relevant institutions may engage celebrities to promote zero carbon behaviour. Celebrity charm could be an effective way to raise public awareness and influence behaviour. This may help to address the concern about low public acceptance.
- Government should provide funding for new technologies and relevant innovative research and engage with the Innovation and Technology Bureau of the government to promote relevant innovation in the construction industry and mitigate potential technological and financial risks. Subsidising manufacturers and suppliers of green products was also suggested.
- Establish a platform for cross border collaboration on renewable energy. This should address the difficulty with the development of renewable energy within Hong Kong.
- An ambitious climate policy is needed before setting up the ZCB policy and should help to formulate the ZCB policy in a progressive manner with targets for different building types and sectors.

These suggested additional recommendations expand the four provided aspects to cover the political side. The focus group meetings also supplemented that zero carbon policy is different from zero carbon building. One participant recommended, "*It would be better to differentiate the policy or even zero carbon target against different types of buildings in different locations in Hong Kong*." The successful formulation of such a policy is also leveraging on renewable energy that however is restricted by the limited developable land availability in Hong Kong. It was also raised that if renewable energy is imported from Mainland China or other places, there will be conflicting issues with Hong Kong power companies. One interviewee proposed that the concepts like "Renewable energy ready" or "Zero carbon ready" could be considered in the policy, which mean that buildings not installed with ZCB technologies now can have designs capable to allow installation in the future. In such circumstance, when systems and technologies become more affordable, buildings will be easier to achieve low or zero carbon.

The survey participants were asked to select three most important stakeholder groups for the mitigation of the risks. The 'government and its departments and agencies' and the 'developers, clients and investors' were selected as two most important stakeholder groups (with 86.6% and 86.2% of the responses respectively), followed by 'general public' (36.2%), 'professional advisors' (21.4%), 'estate and facilities managers' (20.5%) and others at a lower level of responses (Figure 6). There was no significant difference among the responses from different participating stakeholder groups in the survey, which helps to verify the robustness of the results. Some respondents also proposed some specific organisations for risk mitigation such as power companies, technology supporters and experienced practitioners; such responses however were at a marginal level.

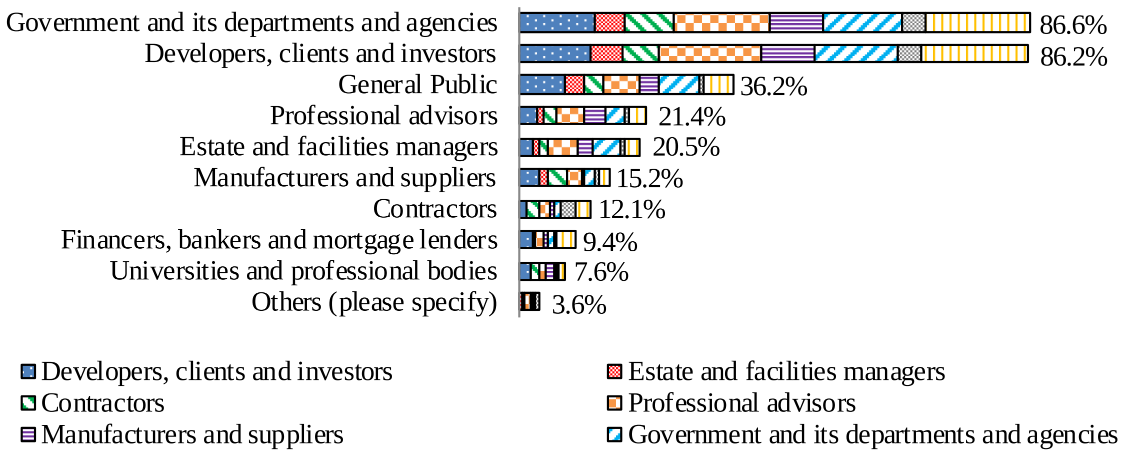


Figure 6 Most important stakeholder groups to mitigating the risks (n=225)

5. Discussion

The results have manifested that there would be wide valuable opportunities from formulating a ZCB policy for Hong Kong, which were considered to fairly evenly arise among the technical, social, regulatory, geographical and economic aspects. Risks were revealed to co-exist and to be also wide-ranging but with significant ones mainly residing in the geographical aspect. The multifaceted features of the identified opportunities, risks and recommendations verify the approach of regarding ZCB policy as a complex system [8] to tackle the complexities of the ZCB concept [12]. Drawing on the findings, a system framework is constructed to illustrate the co-existing complex opportunities and risks and relevant risk-mitigating recommendations for formulating a ZCB policy (Figure 7).

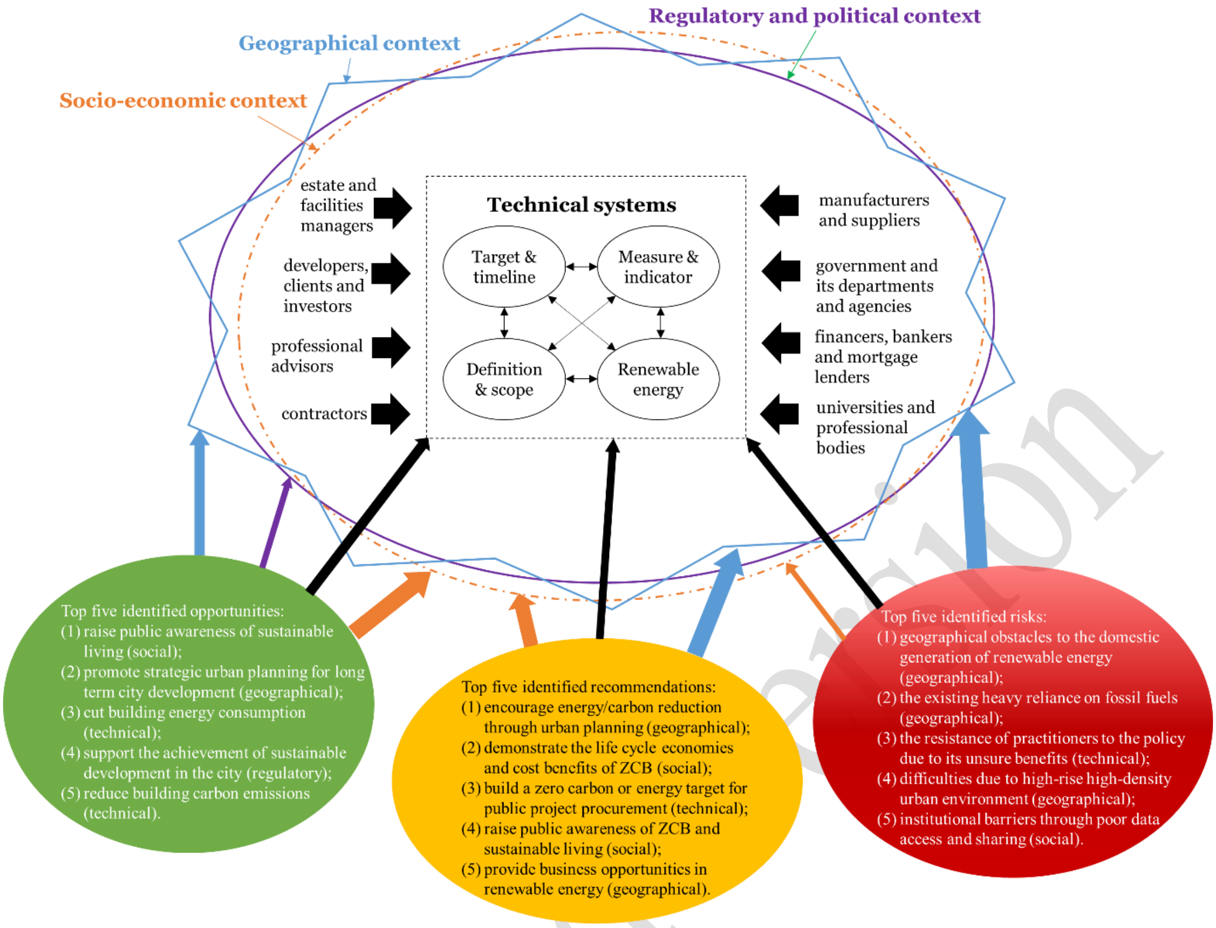


Figure 7 A system framework of opportunities, risks and recommendations on formulating a ZCB policy for Hong Kong

Notes:
1) The listed top five risks, opportunities and recommendations were results from the questionnaire survey under the technical, regulatory, social and geographical aspects, in which the economic aspect was embedded.
2) The interaction between the three circles illustrated by dotted line, solid line and zig-zag line denotes the complex interaction between the contexts.
3) The width of the arrows linking the opportunities, risks and recommendations represent the extent of relevance to the types of context.

This framework illustrates that the technical systems of the ZCB policy reside in the social, economic, geographical, regulatory, and political contexts, which are interactive with each other. Despite the identified wide-ranging opportunities and risks that echo previous research, the results also yield some Hong Kong specific findings that are further discussed below.

5.1. Distinctive importance of the geographical context of Hong Kong

The geographical context was highlighted distinctive for the identified opportunities, risks as well as recommendations. One major opportunity was identified to be "promoting strategic urban planning for long-term city development". This finding reflects the particular need of Hong Kong to optimise its land utilisation and to seek a solution for sustainable city planning. Risks in the geographical context were reckoned as the most significant ones. Consequently, the recommendation "encouraging energy/carbon reduction through urban planning" was deemed as the most important one for mitigating the risks. Although Hong Kong is a well-developed city, there are still many schemes/projects related to redevelopment (e.g. urban renewal), new development (e.g. new housing supply), and various new development areas under planning and implementation that cover about 540 hectares of brownfield sites in total [32]. These findings discover that the unique geographical features of high-rise, high-density, hot-and-humid urban environment in Hong Kong impose more severe challenges to the achievement of ZCBs than in many other countries and regions, where efforts for delivering net zero mainly reside with low-rise buildings in temperate or cold climates [6]. Thus, a context-specific approach is needed for ZCB policy formulation and implementation in Hong Kong, which has also been proposed by research in other regions [13]. The research and development on innovative renewable technologies are significant to support the feasibility of policy targets. ZCB policies that are adopted predominantly for low-rise in temperate or cold climates should not be directly copied, but be reconstructed to address the high-rise high-density urban settings in subtropical climates of Hong Kong. Besides, Singapore as a tropical city could serve as a counterpart, which has successfully developed the first retrofitted zero energy building in South-east Asia [22].

5.2. Difficulty with residential buildings and importance of behavioural changes

The residential buildings in Hong Kong were perceived to be more difficult with achieving net zero carbon compared with commercial, due to their extremely small-sized multi-occupancy features and energy use patterns. Considering the large amount of existing residential buildings, retrofitting technologies for lowering energy use should be learned from worldwide [22]. Occupant behaviour is an essential part in achieving zero carbon or zero energy considering unregulated energy [24]. In European countries, residential buildings that generally exist as low-rise with fewer occupants in one building, where the occupancy profiles and occupant dynamics are relatively easy to model and control [24]. In Hong Kong, however, the large number of units in the same building with different habitants engenders uncontrollable complexity of energy use patterns, and thereby it is more difficult to achieve effective substantial carbon reductions. Therefore, for high-rise buildings in high-density cities, the ZCB policy target should be prioritised to non-residential buildings over residential ones. This differs from the ZCB policy priority for low-rise buildings in low-density regions which is evidenced in the large number of low-rise ZCBs worldwide in general. Besides, it is necessary and vital to educate the public to change their energy use behaviours. This point tallies with the findings that the top opportunity from the proposed possible ZCB policy was considered to be "raising public awareness of sustainable living", and one main recommendation was suggested to be "raising public awareness and demonstrating life cycle economies and cost benefits of ZCB".

5.3. Economic impact of ZCB policy embedded in other contexts

The economic impact of the ZCB policy for Hong Kong was not particularly highlighted but embedded in other contexts. The potential risk "slowing effect on economic growth" was recognised as the least significant one. During the follow-up interviews and focus group meetings, although the need for incentives and guaranteed benefits was emphasised to underpin the ZCB policy, additional costs of achieving ZCB and economic concerns of the policy were not specifically mentioned. It has been found that the cost issue does not play a key role in many existing zero carbon or zero energy buildings, as most are demonstration projects [16]. However, experience from the UK shows that substantial economic investment and economic inefficiency of ZCBs is the primary consideration for the cancellation of its ZCB policy [11]. Hong Kong is still in the preliminary stage of a possible ZCB policy development, and economic concern, overseas experience such as of the UK case should be drawn on to value the economic impact and additional costs of ZCB in the policy setting, and jointly discussed with the impact on mass housing supply [11].

5.4. Fundamental importance of producing technical standards and guidance

The opportunities associated with the possible ZCB policy were found to outweigh the risks, which suggests a generally favourable attitude of the professionals and stakeholders in Hong Kong towards exploring a zero carbon future of buildings. However, ZCB practices were considered to hardly exist in the mainstream building sector of Hong Kong, with no public technical standards and guidance, while such standards and guidance were suggested as the necessity in the interviews and focus group meetings to provide the fundamental base of the ZCB policy formulation and implementation. Golubchikov and Deda [51] pointed out that zero carbon targets require new technological performance standard and incur the risks of affordability, accessibility and distributive justice in the policy set-up. Also, Goodchild and Walshaw [52] argued that formulating and implementing the zero-carbon policy might have risks in conflicts between different institutional actors, lack of compliance, and increased difficulties for the industry. Hong Kong is probably having a worse situation than in many other places in lacking technical standards and guidance for ZCB delivery for a couple of reasons. First, there has yet been only one ZCB demonstration project in Hong Kong with governmental support [29]. It would be useful to establish more demonstration projects for different building types with cost-effective solutions for achieving low or zero carbon. Second, the norm of buildings in Hong Kong is high-rise, which has been a recognised gap in the body of knowledge of ZCB [6], which contributes to the lack of commitment to the ZCB policy. The development of green specifications (e.g. materials, principles, technologies) [49] is highly needed to support the successful formulation and implementation of such a policy.

5.5. Strategic importance of stakeholder engagement and partnership

The identified recommendations highlight the strategic importance of policy guidance and business strategy. The two stakeholder groups, i.e. 'government and its departments and agencies' and 'developers, clients and investors', were recognised as the key stakeholders to mitigate the risks. Stakeholder engagement is an effective mechanism for the formulation and implementation of a ZCB policy. Previous studies also emphasised that such policy activities require a wide range of stakeholders to engage in order to incorporate various stakeholder interests [49] and to better understand the policy network [53]. Besides, the experience of the first ZCB in Hong Kong [29] suggests that stakeholder partnership can help to integrate market knowledge and expertise in developing ZCB and to share the benefits and risks. The Singapore's achievement of higher energy efficiency standards in the retrofit of existing buildings, supported by the local Green Mark Scheme, was also reported as being enabled by extensive industry and stakeholder engagement [22]. The government or institutions should establish relevant platforms or partnerships to facilitate continuous communications and collaborations among stakeholder groups to support ZCB development and inform policies.

5.6. Policy implications

The findings and the discussion above impose four policy implications for achieving ZCB in high-rise high-density cities, which lead to the provision of 16 policy strategies. The policy implications and strategies and their key stakeholders of concern are outlined in Table 6 and elaborated hereinafter.

Table 6 Policy implications and strategies for achieving ZCB and key stakeholders

Policy implications	Policy strategies	Key stakeholders
There is a huge challenge to achieve high-rise ZCB.	1. Formulate a ZCB policy with progressive targets and timelines for different building sectors and types 2. Clearly define the targets, timelines, systems boundaries and energy use scope for different policy scenarios 3. Adopt the identified recommendations 4. Publish ZCB policy consultation to raise awareness and encourage engagement of industry, society and communities	• Government and its departments and agencies
A dual approach is needed: i.e. policy guidance with incentives, and business strategy with demonstrated benefits.	5. Publish ZCB policy guidance with technical solution to substantial energy and carbon reductions 6. Provide incentives for substantial carbon reductions 7. Disseminate the potential benefits of achieving ZCB 8. Set up training and skills programme on ZCB covering planning, design, construction, operation and maintenance 9. Develop a building energy and carbon performance database and portal to enable benchmarking and transparency 10. Promote critical international learning on the state-of-the-art ZCB policies and practices	• Government and its departments and agencies • Developers, clients and investors • Universities, professional bodies and institutions
Carbon reduction targets should be raised in policies and codes.	11. Raise the profile of energy saving and carbon reductions in building codes and regulations 12. Keep pace to post-COP21 in climate change policy consultation. 13. Raise energy and carbon aspects in green building assessment and award	• Government and its departments and agencies • Professional advisors and institutions
ZCB policy should be addressed as a dialectical system.	14. Disseminate the identified opportunities and risks for informing awareness and practices 15. Adopt systems approach in policy formulation and implementation 16. Promote collaboration cross government, industry, universities and institutions	• Government and its departments and agencies • Universities, professional bodies and institutions

The first policy implication is that there is a considerable challenge to achieve high-rise ZCB. A key reason was the geographical obstacles to reducing buildings' energy consumption and increasing renewable energy generation in Hong Kong. To address that, the government should formulate a Hong Kong ZCB policy with progressive carbon reduction targets and timelines for different building types (e.g. residential and commercial) and sectors (public and private, and new-build and retrofit), rather than merely adopting a unified net-zero target and time point for all. The government should then take the lead in clearly defining the different targets and timelines, and also the systems boundaries and energy use scope within the Hong Kong context. As international learning is not straightforward due to the fact that available policies and practices on ZCB are mostly for low-rise buildings [8], the government should publish a ZCB policy consultation to further raise the awareness of Hong Kong industry, society and communities of the proposed policy and to encourage stakeholder engagement in its formulation.

The second is that a dual approach is needed for promoting the ZCB policy in high-rise high-density contexts, i.e. policy guidance with incentives, and business strategy with demonstrated benefits. The stakeholder groups of 'government and its departments and agencies', and 'developers, clients and investors' play indispensable roles in adopting this approach. The provision of incentives for adopting ZCB coupled with demonstrable benefits from such practice should motivate the industry to reassess the risks associated with innovation. Universities, professional bodies and institutions also essential, as they should help to set up training and skills programme on ZCB covering planning, design, construction, operation and maintenance, develop a building energy and carbon performance database and portal, and promote critical international learning on the state-of-the-art policies and practices.

The third is that government policies and codes should raise carbon reduction targets. Also, the government should lead climate change policy consultation in keeping pace to post-COP21 agenda, which has explicitly specified low greenhouse gas development as a key strategy for addressing climate change [2]. Progressive but challenging milestones should be established to strategically evolve the Hong Kong path of building energy and carbon policies, codes and regulations towards net zero energy and carbon neutrality. Carbon reduction targets should also be raised in green building assessment schemes, e.g. BEAM Plus in Hong Kong.

The fourth is that ZCB policy should be addressed as a dialectical system. The dialectical system was brought forward by Pan and Ning [54] to denote the interdependency between elements of a complex system of sustainable buildings. The identified opportunities, risks and recommendations of implementing ZCB policy in this present study all demonstrate complex, interactive, interchangeable and context-specific features. Thus, the dialectical system approach can be adopted for not only formulating the ZCB policy in its four technical components, but implementing the policy by taking account of relevant social, economic, geographical and regulatory contexts (Fig. 8). All key stakeholder groups should be engaged in formulating and implementing the ZCB policy, with government and client leadership, to satisfy the requirements and needs from different stakeholders, as well as to grasp the opportunities and mitigate the risks.

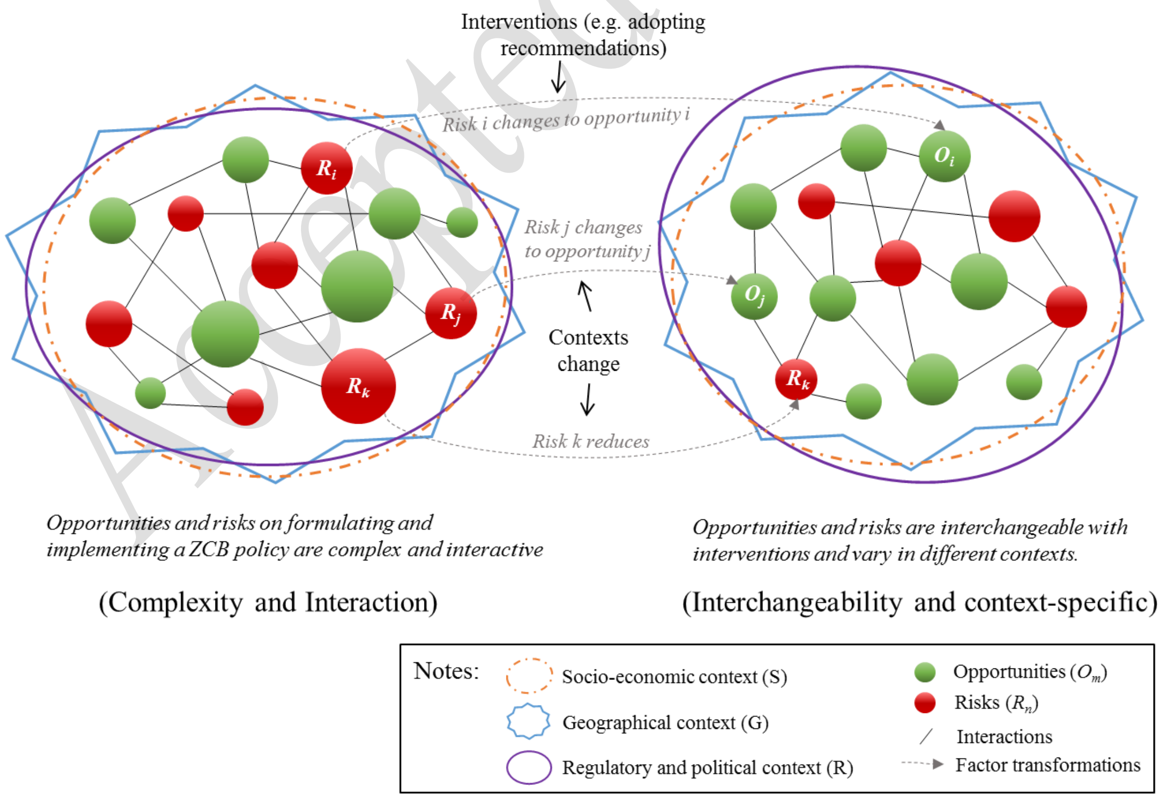


Figure 8 A dialectical system approach to implementing ZCB policy

Furthermore, Opportunity-to-Risk Ratio (ORR) could be used as a key indicator to support decision making in the implementation of the formulated ZCB policy and in the adoption of the provided recommendations. The ORR can also be used as a visual add for policy consultation with stakeholders. Mathematically, the calculation of ORR could be described as follows.

$$ORR = \sum_{i=1}^{m} \alpha_i \times O_i \Big/ \sum_{i=1}^{n} \beta_i \times R_i \tag{3}$$

$$O_i = f_{Oi}(S, G, R, I),\ \ i = 1, 2, \ldots, n \tag{4}$$

$$R_i = f_{Ri}(S, G, R, I),\ \ i = 1, 2, \ldots, m \tag{5}$$

where O_i (i=1, …, n) are opportunity parameters, R_i (i=1, …, n) are risk parameters, α_i and β_i are the coefficients, S represents socio-economic context parameters, G represents geographical context parameters, R represents regulatory and political context parameters, and I are parameters of possible inventions and recommendations for maximising the opportunities and mitigating the risks. The model could be validated or substantiated using regression analysis, which is recommended for future research. The mathematical description provides a conceptual basis on which to understand the dialectical system approach to implementing ZCB policy. Future research should specify the formulas through quantifying the parameters and their relationships, and therefore enable the quantitative calculations of the ORR to support policy evaluation.

6. Conclusions

This paper has identified interwoven opportunities from and risks of formulating and implementing a zero-carbon building policy for high-rise high-density urban environments, and developed recommendations for maximising the opportunities and mitigating the risks. The research was carried out with Hong Kong as a typical case of high-rise high-density metropolises through a questionnaire survey, follow-up interviews and focus group meetings with several hundred professionals and stakeholders carefully selected in Hong Kong building industry and society.

The paper concludes that there would be important opportunities from formulating a zero-carbon building policy for Hong Kong, and the opportunities were considered to fairly evenly arise among all the technical, social, regulatory, geographical and economic aspects. The top five important opportunities were identified as:

1) raising public awareness of sustainable living;
2) promoting strategic urban planning for long term city development towards a low-carbon metropolis;
3) cutting buildings' energy consumption;
4) supporting the achievement of sustainable development in the city; and
5) reducing buildings' carbon emissions.

Another conclusion is that risks co-exist with the opportunities. The top five significant risks were revealed as:

1) geographical obstacles to the domestic generation of renewable energy in high-rise buildings;
2) the existing heavy reliance on fossil fuels due to marginal renewable energy supply and uncertain policy on decarbonised electricity generation;
3) the resistance of practitioners to the policy due to its unsure benefits;

4) difficulties due to high-rise high-density features of urban environment, particularly with retrofit in the private sector; and
5) institutional barriers owe to poor building energy use data access and sharing.

Nevertheless, the opportunities were perceived to outweigh the risks. The identified opportunities and risks demonstrate complex, interactive, interchangeable and context-specific features, which calls for the adoption of the dialectical system approach for effectively implementing ZCB policy.

A further conclusion is that recommendations for mitigating the risks vary and highlight policy and business strategy. The top five important recommendations were identified as:
1) encourage energy/carbon reduction through urban planning;
2) demonstrate the life cycle economies and cost benefits of ZCB;
3) building a very low or net zero carbon or energy target for public project procurement;
4) raise public awareness of ZCB and sustainable living; and
5) provide business opportunities in renewable energy.

While the identified opportunities exist in all aspects, the revealed risks and recommendations align well with each other with a particular focus on the geographic and technical aspects. These findings well demonstrate the significance of the subtropical high-rise high-density features of the urban environment of Hong Kong to the zero-carbon building policy formulation. These features explain the difficulties with the successful policy implementation and emphasise the importance of occupant behavioural changes. While it is found fundamental to produce technical standards and guidance for zero-carbon building, the findings alert the potential economic impact and additional costs that should be well embedded in the policy formulation. The resultant opportunities, risks and recommendations form a system framework on formulating a zero-carbon building policy, which can be a point of reference for other high-density built environments and contribute to cross-country learning and discussion.

The research reported in this paper is innovative in examining the issues associated with the formulation and implementation of ZCB policy for high-rise high-density cities. The findings impose four important implications to shape future thinking and practices: (i) that there is a huge challenge to achieve high-rise zero-carbon building; (ii) that a dual approach is needed integrating policy guidance with incentives and business strategy with demonstrated benefits; (iii) that government policies and codes should further raise carbon reduction targets; and (iv) that zero-carbon building policy should be addressed as a dialectical system. For effectively achieving zero-carbon building, partnership is needed between government, industry, universities and communities to enable an institutional paradigm shift with behavioural changes. To this paradigm shift government and client leadership is critical. Given the long evolution of Hong Kong's building energy policies and codes towards stringent standards of energy efficiency, the findings should lead the Hong Kong path towards a more strategic future of carbon neutrality. The resultant policy implications and strategies should also inform robust zero-carbon building policy development in other high-density urban settings.

Acknowledgements

This work was supported by the Public Policy Research Funding Scheme from the Central Policy Unit of the Hong Kong Special Administrative Region Government (Project Number: 2014.A8.020.14E). Also acknowledged are the many professionals and stakeholders who participated in the survey, interviews and focus groups and Jeffrey Lam for assistance for the study.

Appendix: Key questionnaire survey questions

OPPORTUNITIES FROM AND RISKS OF FORMULATING AND IMPLEMENTING ZCB POLICY FOR HONG KONG

1. How would you evaluate the influence of the proposed ZCB policy to the sustainable development of Hong Kong? (1=very weak to 5= very strong)
2. How important do you view the following opportunities from formulating and implementing the ZCB policy for Hong Kong? (1=not important to 5= extremely important) [*Note: this question is provided with 12 items for assessment in the technical, regulatory, social and geographical aspect as in Table 2*.]
3. How significant do you view the following risks of formulating and implementing the ZCB policy for Hong Kong? (1=not significant to 5= extremely significant) [*Note: this question is provided with 14 items for assessment in the technical, regulatory, social and geographical aspect as in Table 3*.]
4. How would you agree on Statement: "The opportunities from formulating and implementing the ZCB policy outperform the risks"? (1=strongly disagree to 5=strongly agree)

RECOMENTATIONS ON ZCB POLICY FOR HONG KONG

5. Who would you think are the key stakeholders to mitigate the possible risks? (Developers, clients and investors; Estate and facilities managers; Contractors; Professional advisors; Manufacturers and suppliers; Government and its departments and agencies; Financers, bankers and mortgage lenders; Universities and professional bodies; General public; Others, please specify)
6. How would you rate the overall feasibility to formulate and implement the proposed ZCB policy in Hong Kong? (1=highly impossible to 5=highly possible)
7. How important do you view the following recommendations for mitigating the identified risks? (1=not important to 5= extremely important) [*Note: this question is provided with 13 items for assessment in the technical, regulatory, social and geographical aspect as in Table 5*.]

References

[1] Stern, N. The economics of climate change: The stern review, HM Treasury, London, 2007.
[2] United Nations Framework Convention on Climate Change (UNFCCC). Adoption of the Paris Agreement. Report No. FCCC/CP/2015/L.9/ Rev.1, 2015.
[3] Pan, W., Garmston, H. Building regulations in energy efficiency: Compliance in England and Wales. Energy Policy, 2012, 45(6), 594–605.
[4] Gou, Z., Lau, S. S. Y., Prasad, D. Market readiness and policy implications for green buildings: case study from Hong Kong. Journal of Green Building, 2013, 8(2), 162-173.
[5] Pan, W., Li, K. Clusters and exemplars of buildings towards zero carbon. Building and Environment, 2016, 104, 92-101
[6] World Green Building Council. From Thousands to Billions - Coordinated Action towards 100% Net Zero Carbon Buildings By 2050, World Green Building Council, London, 2017.
[7] Wang, H., Chen, W., and Shi, J. Low carbon transition of global building sector under 2-and 1.5-degree targets. Applied Energy, 2018, 222, 148-157.
[8] Pan, W., Ning, Y. A socio-technical framework of zero-carbon building policies. Building Research & Information, 2015, 43(1), 94-110.
[9] Zhang, L., Li, Q., Zhou, J. Critical factors of low-carbon building development in China's urban area. Journal of Cleaner Production, 2017, 142, 3075-3082.

[10] Pukšec, T., Mathiesen, B. V., Duić, N. Potentials for energy savings and long term energy demand of Croatian households sector. Applied Energy, 2013, 101, 15-25.
[11] Environmental Audit Committee Sustainability and HM Treasury, Fifth Report of Session 2016–17, House of Commons, London, 2016.
[12] Martiskainen, M., Kivimaa, P. Creating innovative zero carbon homes in the United Kingdom—Intermediaries and champions in building projects. Environmental Innovation and Societal Transitions, 2018, 26, 15-31.
[13] Environment Bureau. Greenhouse Gas Emissions in Hong Kong, Environment Bureau, HKSAR, Hong Kong, 2018.
[14] Environmental Protection Department (EPD) and Electrical and Mechanical Services Department (EMSD). Guidelines to account for and report on greenhouse gas emissions and removals for buildings (commercial, residential or institutional purposes) in Hong Kong, 2010.
[15] Fong, K. F., Lee, C. K. Towards net zero energy design for low-rise residential buildings in subtropical Hong Kong. Applied Energy, 2012, 93, 686-694.
[16] Panagiotidou, M., Fuller, R.J. Progress in ZEBs – A review of definitions, policies and construction activity. Energy Policy, 2013, 62, 196–206.
[17] Mayor of London. The London Plan March 2016: Policy 5.2 minimising carbon dioxide emissions, 2016.
[18] European Commission. Directive 2010/31/EU of the European parliament and of the council of 19 May 2010. Official Journal of the European Union, 2010, 53, 13–34.
[19] Crawley, D., Pless, S., Torcellini, P. Getting to net zero. ASHRAE Journal, 2009, 18-25.
[20] Australian Sustainable Built Environment Council (ASBEC). Net zero emission homes: An industry roadmap, 2012.
[21] Energy Efficiency and Conservation Division. Definition of ZEB and future measures proposed by the ZEB Roadmap Examination Committee. Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry, 2015.
[22] The Building and Construction Authority (BCA). Healthier and greener buildings in next lap of Singapore's green building journey, 2017.
[23] Kibert, C.J., Fard, M.M. Differentiating among low energy, low-carbon and net-zero-energy building strategies for policy formulation. Building Research & Information, 2012, 40(5), 625-637.
[24] Reda, F., Fatima, Z. Northern European nearly zero energy building concepts for apartment buildings using integrated solar technologies and dynamic occupancy profile: Focus on Finland and other Northern European countries. Applied Energy, 2019, 237, 598-617.
[25] Koch, A., Girard, S., McKoen, K. Towards a neighbourhood scale for low- or zero-carbon building projects. Building Research & Information, 2012, 40(4), 527–537.
[26] Asia Pacific Energy Research Centre (APERC). APEC Energy Overview 2017. Japan, 2017
[27] Environment Bureau (ENVB), Development Bureau (DEVB) and Transport and Housing Bureau (THB). Energy saving plan for the built environment 2015~2025+, 2015.
[28] Council for Sustainable Development (SDC). Report on the public engagement process on "Combating climate change: energy saving and carbon emission reduction in buildings", Hong Kong, 2012.
[29] Construction Industry Council (CIC). ZCB Fact Sheet, Hong Kong, 2012.
[30] Chief Executive. The 2013 Policy Address - Seek change maintain stability serve the people with pragmatism, Hong Kong, 2013.
[31] Environment Bureau (ENVB). Hong Kong's Climate Action Plan 2030+, 2017.
[32] Chief Executive. The 2018 Policy Address: Striving Ahead, Rekindling Hope. HKSAR Government, Hong Kong, 2018.
[33] The U.S. Green Building Council (USGBC). California – Local – Top 10 Green Building Policies, 2012.
[34] Wong, P.S., Ng, S.T. and Shahidi, M. Towards understanding the contractor's response to carbon reduction policies in the construction projects. International Journal of Project Management, 2013, 31(7), 1042-1056.
[35] Chan, E.H.W., Qian, Q.K., Lam, P.T.I. The market for green building in developed Asian cities-the perspectives of building designers. Energy Policy, 2009, 37(8), 3061-3070.

[36] Pan, W., Qin, H. and Yu, C. Feasibility of delivering high-rise low or zero carbon buildings in Hong Kong, Construction Industry Council, HKSAR, Hong Kong, 2018
[37] Häkkinen, T., Belloni, K. Barriers and drivers for sustainable building. Building Research & Information, 2011, 39(3), 239-255.
[38] Geels, F.W. From sectoral systems of innovation to sociotechnical systems: Insights about dynamics and change from sociology and institutional theory. Research Policy, 2004, 33(6), 897–920.
[39] Coenen, L., Benneworth, P., Truffer, B. Toward a spatial perspective on sustainability transitions. Research Policy, 2012, 41(6), 968-979.
[40] Pan, W. System boundaries of zero carbon building. Renewable and Sustainable Energy Reviews, 2014, (37), 424-434.
[41] Fellows, R., Liu, A. Research methods for construction. 3rd ed. Chichester: Wiley-Blackwell. 2008.
[42] The Real Estate Developers Association of Hong Kong (REDA). List of directors and committee members, http://www.reda.hk/board, 2014 [accessed 30 March 2014].
[43] Development Bureau. List of approved contractors for public works, http://www.devb.gov.hk/Contractor.aspx?section=80&lang=1, 2014 [accessed 30 March 2014].
[44] Hong Kong Trade Development Council (HKTDC). Database of Architectural & Civil Engineering Works at Construction Site (358 registered), 2014.
[45] Hong Kong Green Building Council (HKGBC). BEAM Professional Directory, https://www.hkgbc.org.hk/eng/BeamProDirectory.aspx, 2014 [accessed 30 March 2014].
[46] The Hong Kong Institute of Surveyors (HKIS). Directory for professional advisors, http://www.hkis.org.hk/zh/company_list.php?division=BSD, 2014 [accessed 30 March 2014].
[47] Cronbach L.J. Coefficient alpha and the internal structure of tests. Psychometrika. 1951, 16 (3): 297–334.
[48] Lee, P., Lam, P.T.I., Lee, W.L., Chan, E.H.W. Analysis of an air-cooled chiller replacement project using a probabilistic approach for energy performance contracts. Applied Energy, 2016, 171, 415-428.
[49] Lam, P.T.I., Chan, E.H.W., Poon, C.S., Chau, C.K., Chun, K.P. Factors affecting the implementation of green specifications in construction. Journal of Environmental Management, 2010, 91 (3), 654–661.
[50] Zhao, X., Pan, W. and Chen, L. Disentangling the relationships between business model innovation for low or zero carbon buildings and its influencing factors using structural equation modelling. Journal of Cleaner Production, 2018, 178, 154-165.
[51] Golubchikov, O., Deda, P. Governance, technology, and equity: An integrated policy framework for energy efficient housing. Energy Policy, 2012, 41, 733-741.
[52] Goodchild, B., Walshaw, A. Towards zero carbon homes in England? From inception to partial implementation. Housing Studies, 2011, 26(6), 933-949.
[53] Rydin, Y. The issue network of zero-carbon built environments: a quantitative and qualitative analysis. Environmental Politics, 2013, 22(3), 496-517.
[54] Pan, W., Ning, Y. Dialectics of sustainable building: evidence from empirical studies 1987-2013. Building and Environment, 2014, 82, 666-674.