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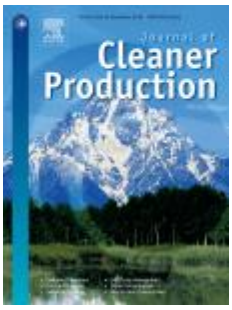

A dialectical system framework of zero carbon emission building policy for high-rise high-density cities: Perspectives from Hong Kong

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A Dialectical System Framework of Zero Carbon Emission Building Policy for High-rise High-density Cities: Perspectives from Hong Kong

Abstract

Several countries and cities have developed policies on zero carbon emission building or the alike as a driver for achieving sustainable development, which however mainly target houses and low-rise buildings. High-rise buildings in high-density urban built areas are generally perceived impossible to achieve zero carbon emission, and remain as a gap in policy study. Nevertheless, given the continuous rapid urbanisation, building higher and denser becomes the norm for many cities due to scarce developable land resources. This paper aims to develop and verify a dialectical system framework of zero carbon emission building policy for high-rise high-density cities focused on Hong Kong which is a typical high-density metropolis with the largest number of high-rise buildings in the world. The research was conducted through a questionnaire survey, follow-up interviews and focus group meetings, which together engaged over one thousand professionals and stakeholders selected using clustered and random sampling. The developed framework emphasises the interdependency between the technical elements of the policy within their complex and interactive socio-economic, geographical, and regulatory and political boundaries. For the technical elements, the zero carbon emission targets and timelines for Hong Kong were perceived very ambitious but can prioritise new public non-residential buildings. User behaviour and energy efficiency were considered critical given the limited renewables in the city. The boundaries of the policy should be clearly defined to address different contexts and stakeholders. A strong need was identified for formulating zero carbon emission building policy for Hong Kong, which however was perceived difficult to implement. The identified strategies should inform the practice of reducing high-rise buildings' carbon emissions and thus achieving urban sustainability. The findings verify zero carbon emission building policy as complex dialectical systems and provide useful learning for such policy development in high-density cities.

Keywords: zero carbon emission building; dialectical system; building energy and carbon policy; carbon emission; Hong Kong.

1 Introduction

Reducing carbon emissions and energy consumption of buildings is an important aspect of sustainable development, as buildings typically account for 30-40% of primary energy globally (Duić et al. 2013) and resultant huge carbon dioxide, and is highly significant to minimising environmental effects and safeguarding people's quality of life. To address anthropogenic climate change, zero carbon emission building (ZCB) has emerged as a most advanced and innovative model (Zhao et al. 2018). This concept has been described manifold regarding different extents, periods and contexts (Zhao et al. 2018), such as nearly-zero and net-zero energy building, whereas this paper adopts 'zero carbon emission building' (ZCB) as a collective representation of these terms.

Well-formulated policy systems (Zhang et al., 2017) and regulations (PukŠec et al., 2013) are believed to guarantee the successful development of ZCB for a sustainable future. A number of countries and regions have proposed targets to achieve 'zero carbon', 'nearly zero energy' or 'net zero energy' as part of their building energy, carbon and/or climate change policies (Pan and Ning, 2015), such as EU (European Commission, 2010) and US (Crawley et al., 2009). Nevertheless, such policies primarily target single-family houses and low-rise buildings in cold and temperate climates (Pan and Li, 2016) with feasibility widely demonstrated by ZCB initiatives. For example, PukŠec et al. (2013) reported the great potentials of energy saving and emission reduction from new and renovated ZCBs in Croatian; Heiskanen et al. (2015) showcased several zero-energy buildings in Finland with the focus on solar technology applications; Li et al. (2018) examined the actual energy performance of six low-rise net zero energy homes in Canada, and revealed that most reached the net-zero target. However, high-rise buildings in high-density urban built areas are generally perceived impossible to achieve zero carbon emission (Pan and Li, 2016), and remain as a gap in ZCB policy study. Given the continuous rapid urbanisation, building higher and denser becomes the norm for many cities due to scarce developable land resources. Policy instruments are necessitated to guide and spur sustainable development of buildings in those cities, but whether or not should follow the similar practice as in low-rise low-density areas towards zero carbon remains largely unknown.

However, the severity of carbon and energy issues from buildings in high-rise high-density cities illustrates the importance of policy instruments in place to invigorate proper ZCB development. Hong Kong is a typical such case with a population of 7.39 million as of 2017. The city's total area is of 1,106.3 square kilometres, but only less than 25% of the land is developable with the others being country parks, nature reserves, etc., and thus the vast majority of the built urban areas are of the highest density. Hong Kong has the largest number of high-rise buildings in the world for a city. Also, Hong Kong is a service-based economy with no energy-intensive industries, where the contribution of buildings to electricity consumption and carbon emissions is well above the world average, being around 90% and 60% respectively (EPD and EMSD, 2010). Therefore, the city faces a particularly severe challenge to achieving substantial reductions of carbon emissions in buildings towards developing into a sustainable metropolis. Furthermore, in Hong Kong, although building energy policies, codes and regulations have evolved over the past two decades towards increasingly stringent standards of energy efficiency, yet there is no ZCB policy. Perspectives on such a policy for Hong Kong are limited and fragmented.

High-rise high-density cities like Hong Kong have the immediate need to reduce building-related carbon emissions to foster a sustainable future, where ZCB policies could have an important role to play as in other areas. However, these are insufficiently studied. There is thus an urgent and significant need to understand the perspectives on and implications for a ZCB policy, should it be formulated and implemented in high-rise high-density cities such as Hong Kong.

The aim of this paper is to develop and verify a dialectical system framework of ZCB policy for high-rise high-density cities focused on Hong Kong. The study should contribute to a dialectical understanding of the ZCB policy formulation and implementation in high-rise high-density cities, where ZCBs are deemed as ideal for achieving sustainability but as problematic in practice. Following this introduction the paper reviews the literature, presents a dialectical system framework of ZCB policy and explains the research methodology. It then examines the perspectives of professionals and stakeholders on the technical systems of the policy and strategies for achieving zero carbon emission. After that, the paper discusses the perspectives and draws conclusions.

2 A Snapshot of ZCB Policies Worldwide

Policies on achieving 'zero carbon', 'nearly zero energy' or 'net zero energy' for buildings have been formulated in a number of countries and regions. The first ever ZCB policy was brought forward by the UK Government to achieve 'zero carbon' for new homes from 2016 (DCLG, 2006) and for non-domestic new buildings from 2019 (HM Treasury, 2008). However, this UK ZCB policy has been scrapped (Environmental Audit Committee, 2016). Nevertheless, this national ZCB policy still remains for London as a city-wide policy as shown in the London Plan (Mayor of London, 2016) for new homes built from 2016 to be zero-carbon. Also, the UK as a country is still under governance of the recast of the Energy Performance in Buildings Directive (EPBD) of 2010 (European Commission, 2010) that 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 (Crawley et al., 2009). The Zero Emissions Residential Task Group of the Australian Sustainable Built Environment Council (ASBEC) has proposed the definition of and roadmaps to ZCB (ASBEC, 2012), and recommended that a consistent long-term, regulated timeline towards zero carbon with industry-agreed targets should be built. In Asia, Townshend et al. (2013) reported that Japan is discussing plans to adopt a goal for zero energy buildings by 2030. Zhang et al. (2017) discussed the imperfect development of low-carbon buildings in China and outlined the critical needs for improving the policy system and promoting the execution.

Previous research reviewed these policies and highlighted the fundamentals of the definition. Crawley et al. (2009) criticised that a common language in defining and measuring ZCBs is lacking, which contributes to significant ambiguity when setting targets and procedures to achieve carbon reduction. Marszal et al. (2011) also argued that a clear and consistent definition combined with a commonly agreed measurement on ZCB concept is the prerequisite for the effective implementation of policies and standards. Golubchikov and Deda (2012) discussed an integrated policy framework that encompasses three dimensions, i.e. governance and finance, technological advancement, and access and affordability, which albeit being useful for enlightening as to institutional barriers, is constrained to low-carbon housing. Kibert and Fard (2012) investigated the difference and similarities among various net-zero strategies for buildings and suggested the resolution of priorities and definitions for better policy formulation and international collaboration. Panagiotidou and Fuller (2013) argued that the concept of zero-energy for buildings still has no internationally-agreed definition or pathway to achieve it, while established policies in different countries do not effectively drive the implementation of the concept. Pan and Ning (2015) developed a socio-technical transition framework drawing on an examination of ZCB policies and the supporting literature, and argued that reliance on only technical solutions constrains the achievement of the zero-carbon target, yet human behaviours are poorly addressed in the policies. Thus, it is significant to fill the gap that exists between policy intentions and actual practices.

The existing ZCB policies worldwide provide useful cross-contextual learning, which however is not straightforward because the nature and context of each country or city is unique and building carbon policies are highly value-laden and context-specific (Pan and Garmston, 2012). The ZCB policy frameworks established in previous research set a good foundation on which to further address the complex system of ZCB policy within high-rise high-density urban environments.

3 Building Carbon Policies in Hong Kong

The reduction of building energy consumption and carbon emissions has long been a focus of the Hong Kong Government Policy Address and building energy codes and regulations. In the 2007-2008 Policy Address, the Chief Executive (2007) of the Hong Kong Government stated that, as an Asia-Pacific Economic Co-operation (APEC) member, Hong Kong subscribed to the Sydney Declaration on Climate Change and pledged to seek a reduction in energy intensity of at least 25% by 2030, with 2005 as the base year. The 2013 Policy Address (Chief Executive, 2013) further envisaged turning Hong Kong into a low-carbon metropolis. The 2014 Policy Address (Chief Executive, 2014) stated that the Steering Committee on the Promotion of Green Building, set up in 2013, would formulate strategies to further promote green buildings, of which energy use is a major aspect of assessment.

There have been a series of building energy codes (BEC) 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 2015 (EMSD, 2015). The Government devised Hong Kong's Climate Change Strategy and Action Agenda and proposed a target to reduce Hong Kong's carbon intensity by 50–60% by 2020 relative to 2005 levels (Environment Bureau, 2010). The Government published "Energy Saving Plan for Hong Kong's Built Environment 2015~2025+" in May 2015 (Environment Bureau, 2015), which raises the target to reduce energy intensity by 40% by 2025 using 2005 as the base. To achieve the target this Plan combines educational, social, economic and regulatory means. In 2011 the Council for Sustainable Development (SDC, 2012) 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 propose a possible strategic movement towards zero carbon emission.

Hong Kong policies on building energy and carbon emissions cover building energy efficiency, building products and systems, energy supply (renewable energy and decarbonised electricity generation), and building energy and carbon audit and reporting (Pan and Ning, 2015). These aspects together cover different stages in the life cycle of buildings to reduce building energy use and carbon emissions in Hong Kong.

4 A Dialectical System Framework of ZCB Policy

Previous research on socio-technical systems and ZCB policies provides a useful theoretical basis on which to develop a system framework of ZCB policy. Scott (1995) referred a policy to the formal rules, standards and procedures that are coercive to the stakeholders. Taking that, the ZCB policy is co-existent with other regulations regarding carbon emissions in the building sector. Geels (2004) and Coenen et al. (2012) developed the socio-technical transitional approaches to understand the interactions among technology development and broader socio-technical systems towards sustainability transition. Thus, ZCB policies should be considered to co-evolve with their relevant regulatory, social and geographic contexts. The conceptual model of ZCB policies developed by Pan and Ning (2015) is adapted to this present study to construct a dialectical system framework of ZCB policy for Hong Kong. The dialectical system framework (illustrated in **Fig. 1**) emphasises the interdependency between the technical elements of ZCB policy within complex and interactive socio-economic, geographical, and regulatory and political boundaries. The construction of this framework also takes into consideration the contexts of ZCB policies, initiatives and demonstrations internationally and of the evolution of building energy and carbon policies in Hong Kong.

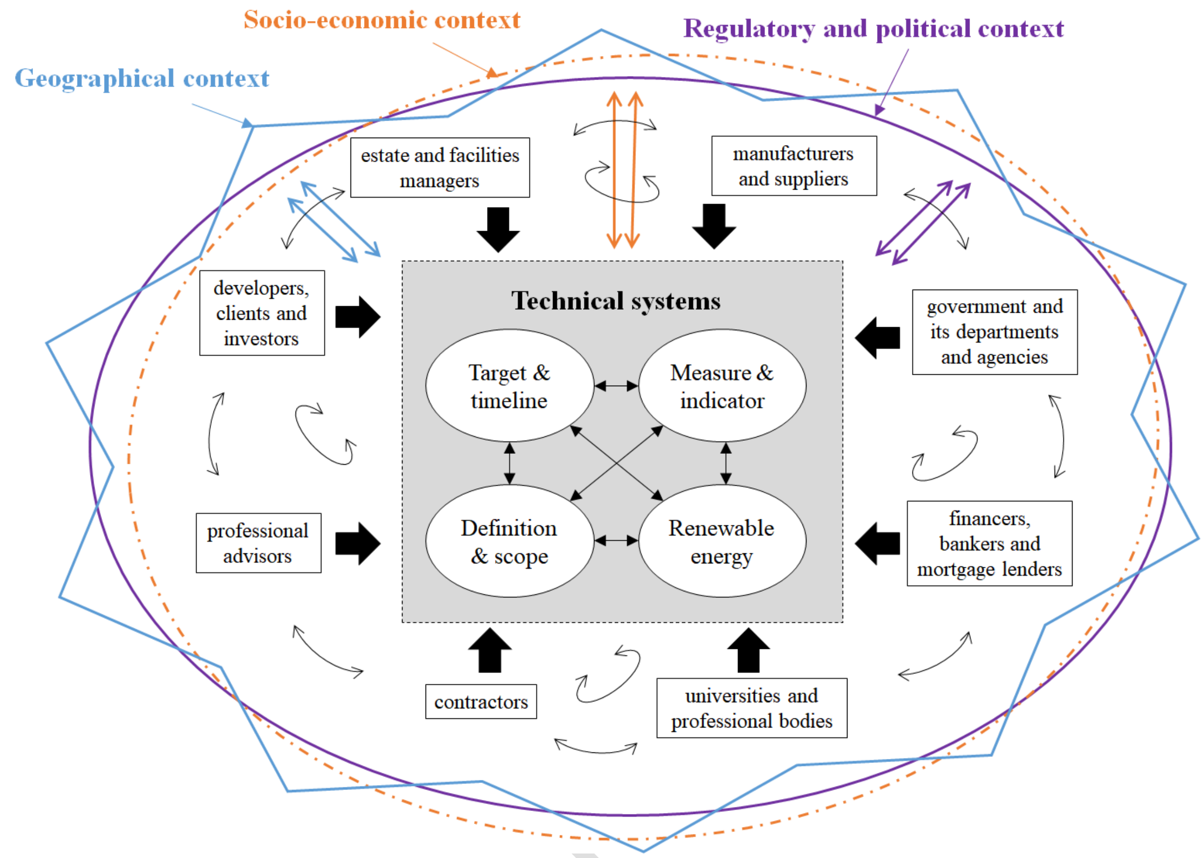


Fig. 1 A dialectical system framework of ZCB policy

This dialectical system framework of ZCB policy (**Fig. 1**) has the following key features:

- The framework addresses the ZCB policy as complex dialectical systems, with the technical system of the policy embedded in its socio-economic, geographical, and regulatory and political contexts (Pan, 2014).
- The technical system sets relevant rules, standards and procedures for achieving the target, and consists of four components:

  1) ZCB definition and energy use scope, e.g. whether or not the scope covers all operational energy use and energy use from appliances;

  2) carbon reduction targets and timelines, which should be specific to different types of buildings;

3) measures and indicators of energy use and carbon emissions, which are numerical indicators of energy production and use and its associated carbon emissions of the building, e.g. expressed as $kWh/m^2/year$ and $kgCO_{2-e}/m^2/year$, respectively; and
4) reliance on renewable energy that on-site and off-site renewables are integrated and the building is grid connected to enable possible achievement of net zero.

- The social embedment complements the technical system by enhancing industry learning and skill development and enabling behavioural change and stakeholder engagement. Stakeholder engagement is an important mechanism for formulating and implementing a policy (Ng et al., 2013) as well as solving issues in complex policy arenas (Walker and Hills, 2012). It is even more important to the ZCB policy formulation and implementation in high-density urban environments given the stakeholder complexity and severe challenges faced by decarbonising high-rise buildings.
- The economic embedment denotes that the technical components should be practically achievable for the economic systems.
- The geographical embedment requires that the technical components should well address the geographical and climatic conditions of the location of buildings of concern.
- The regulatory and political embedment denotes that the technical components, albeit setting challenging targets, should align with the existing policies, codes and regulations.
- The technical system of ZCB policy may not fully address the socio-economic, geographical, and regulatory and political contexts altogether at one time. In many cases the implementation of the technical system of ZCB policy may require trade-off between addressing the different contexts. Even within one specific context, e.g. in the economic context, the implementation of ZCB policy may irrigate different interpretations of different stakeholders, e.g. that clients may favour the operational stage of carbon performance while contractors may focus on the construction stage of carbon emissions.

The complexity of, and the interactions between, the technical components, the stakeholders and the contexts feature the dialectics of ZCB policy.

5 Methodology

The study was conducted through a careful research design combining the use of a questionnaire survey, follow-up interviews and focus group meetings, which together engaged over one thousand informed professionals selected from eight key stakeholder groups in Hong Kong.

5.1 Research design

The questionnaire survey aimed to reveal the perspectives of professionals and stakeholders on the dialectical system framework of ZCB policy. The questionnaire included a number of questions in the sections including: information on the participant; perspectives on the four technical components of the policy and on the need for ZCB policy for Hong Kong; and strategies for achieving net zero carbon emission in the policy.

The follow-up interviews aimed to reveal insights into the stakeholders' perceptions and attitudes and verified the responses to, and results of, the questionnaire survey. The interview questions were similar to those of the questionnaire, but focused more on 'why' and 'how'.

The stakeholder focus group meetings aimed to further explore and verify the perceptions and strategies. 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 policy framework, and the participants put forward enquiries, comments and suggestions.

5.2 Research sampling

The questionnaire survey participants were selected through a three-stage process that consisted of classification, identification and selection. The participants were first classified using clustered sampling (Fellows and Liu, 2008). In doing so, professionals were targeted from 8 key stakeholder groups covering 4 sides of buildings or ZCBs in Hong Kong (i.e. the 'demand, supply, regulation and institution' sides as suggested by Pan, 2014).

This clustered sampling aimed to address ZCB policies as complex dialectical systems (Pan and Ning, 2015). This focus also helped to maximise the insights with available resources. Next, potential survey participants were identified under key stakeholder groups using publicly available databases supplemented by the networks of the researchers and their affiliated institutions. Examples of the accessed publicly available databases of stakeholders included: Hong Kong Real Estate Developers Association's (REDA, 2014) list of developers; Development Bureau's (2014) list of approved contractors and Hong Kong Trade Development Council's (HKTDC, 2014) database of contractors; Hong Kong Green Building Council's (HKGBC, 2014) BEAM Professional Directory and Hong Kong Institute of Surveyors' (HKIS, 2014) directory for professional advisors. Finally, the survey participants were selected using random sampling (Fellows and Liu, 2008) 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, clustered 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 organized to encourage engagement and allow focused and detailed discussion.

5.3 Data collection and analyses

The questionnaire survey was carried out through the combination of (1) postage of a printed version, (2) an editable PDF file attached to a cover email and (3) an electronic version to be filled in on-line, 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 give their views based on a 5-point Likert scale, or to select or rank provided items. The means were calculated to rank variables. The standard deviations were calculated to illustrate the degree of difference among the respondents. One-way Analysis of Variance (ANOVA) was used to test the difference of means in the results obtained from the eight different stakeholder groups. The Pearson correlation coefficient (r) is used to analyse the strength of linear relationship between two different items, where $-1 \leq r \leq 1$. A higher absolute value of r manifests the stronger positive or negative correlation.

The interviews, each for about 45 minutes, were conducted in person or over the telephone. Each of the four focus group meetings lasted two to three hours. The interviews and the focus group meetings were audio-recorded with permission from the participants, and then transcribed. Transcriptions and notes were logged and analysed using Nvivo software to identify key codes, themes and patterns in the responses.

6 Results and Analyses

The questionnaire survey approached 1000 informed professionals and stakeholders in Hong Kong building industry and society. In total 260 questionnaires were returned, of which 235 were properly completed, yielding an overall effective response rate of 23.5%. Semi-structured interviews were conducted with 30 selected professionals. The focus group meetings together engaged 106 selected professionals and stakeholders.

6.1 Profile of research participants

6.1.1 Participants in the questionnaire survey

The participants in the questionnaire survey, through their primary organisational affiliations, effectively covered the defined eight stakeholder groups in the Hong Kong construction industry and society (Fig. 2). The 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%).

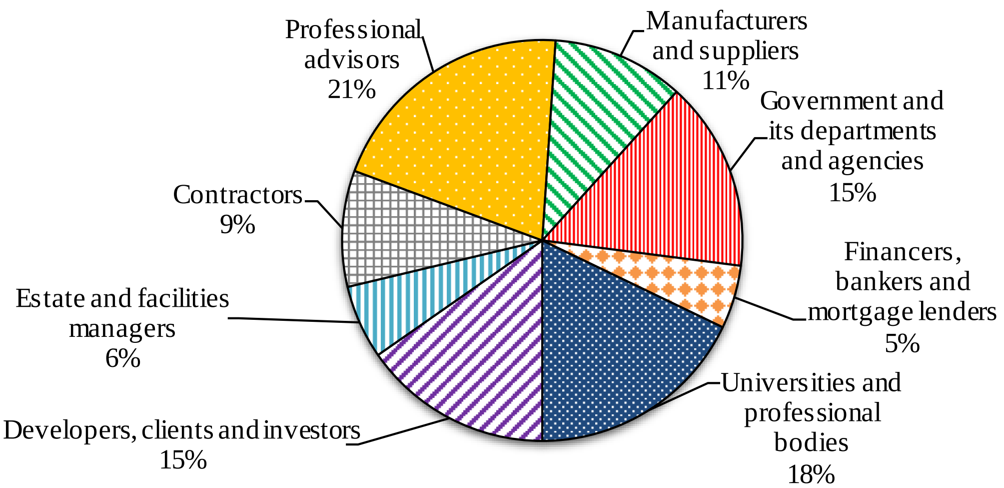


Fig. 2 Types of primary organisation of questionnaire survey participants (n=235)

Nearly 60% of participants had more than 10 years of working experience in the Hong Kong building industry (**Table 1**). However, their experience with low or zero carbon emission building was quite limited, with 76% having less than 5 years of such experience, although over one third were certified green building professionals. Their participant profiles well fitted the general profile of building and construction professionals and reflected the fact that the ZCB concept was relatively new in Hong Kong. According to Pearson's coefficient results, there is no statistically significant correlation between participants' experience and their perspectives on ZCB policy.

Table 1 Questionnaire survey participants' experience

Category	Percentage
Years of experience in the Hong Kong building sector (n=233)	
0-5	27.9%
6-9	9.9%
10-19	21.5%
20+	36.5%
Not applicable (e.g. software engineer, banker)	4.3%
Years of experience with low or zero carbon emission building (n=233)	
0-5	76.0%
6-9	12.9%
10-19	8.2%
20+	3.0%
Certified green building professional (n=233)	
Beam Pro	27.5%
Lead AP	3.4%
Other certificates	5.2%
Nil	65.7%

6.1.2 Interviewees

Semi-structured interviews were conducted with 30 informed professionals, who together covered all the eight stakeholder groups specified above (Table 2).

Table 2 Types of primary organisation of interviewees

Organisation Type	Number
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
Government and its departments and agencies	5
Total	30

6.1.3 Participants in the focus group meetings

Four focus group meetings were conducted. The participants collectively covered all the eight stakeholder groups specified above (**Table 3**).

Table 3 Profile of participants in the focus group meetings

Focus group	Number of participants	Covered stakeholders
1	60	All stakeholder groups as a kick-off session
2	16	Manufacturers and suppliers Professional advisors Contractors Universities, professional bodies and institutions
3	15	Universities, professional bodies and institutions Financers, bankers and mortgage lenders
4	15	Government and its departments and agencies Developers, clients and investors Manufacturers and suppliers Universities, professional bodies and institutions

6.2 Perspectives on the technical system of ZCB policy

6.2.1 ZCB definition and energy use scope

Over two thirds (67%) of questionnaire survey respondents either agreed (57%) or strongly agreed (10%) with the proposed ZCB definition that *"A zero carbon emission building is a building with net zero energy consumption or net zero carbon emissions on an annual basis within its defined system boundaries during its operational stage".*

Nevertheless, 23% of the respondents held a neutral attitude to the definition and the other 10% were in disagreement (**Fig. 3**).

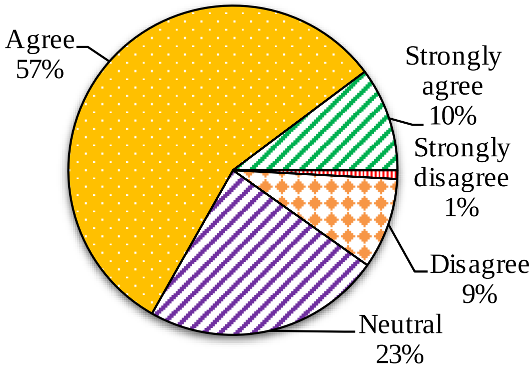


Fig. 3 Appraisal of the proposed ZCB definition (n=235)

Through the follow-up interviews and focus group discussion several reasons for the neutral and disagreement views were identified as: (1) the uncertainty about a true definition; (2) the lack of clarity about the system boundaries in the definition; (3) whether or not embodied energy should also be considered; and (4) the need for different ZCB considerations for different types of buildings.

Among the provided nine elements of energy use to be covered in the scope of the ZCB definition, lighting was identified by most questionnaire survey respondents (90.6%), followed by air conditioning (87.7%), lifts & escalators (83%), and others (**Table 4**). About one in ten respondents (9.4%) also suggested other energy use elements to be covered in the scope of the ZCB definition, including household appliances, energy used during construction and maintenance, energy embodied in building materials and structures, emergency generators, computer energy use and IT server centre power, wastewater reuse, and energy used in transportation to the building. One respondent to the questionnaire also suggested that different types of buildings should have different energy use scope in their affiliated ZCB definition.

Table 4 Scope of energy use to be covered in the ZCB definition (n=235)

Scope of energy use	Percentage
Lighting	90.6%
Space conditioning	87.7%
Lift & escalator	83.0%
Hot water	72.3%
Water pump	72.0%
Refrigeration	68.5%
Communal area	66.8%
Office equipment	60.9%
Cooking	38.3%
Others (e.g. appliances, embodied energy)	9.4%

From the follow-up interview and focus group discussion several patterns were revealed of the comments on the definition and energy use scope of the proposed ZCB policy.

First, the system boundaries of ZCB policy should be defined context-specifically in order to address the diverse environment of Hong Kong. Different policies and energy use scopes were required for different types of buildings, and even at a more detailed level for different building heights, locations, usages, and tenant styles, because different building typologies have different energy use structures and patterns. Also, different energy use scopes should be adaptable and adjustable, set in alignment with the progressive policy targets of carbon reductions towards net zero in order to ensure the effectiveness and practicability of the ZCB policy.

Second, the energy use scope should also consider the key stakeholders of energy use, typically the energy use in communal areas controlled by facility managers and tenant energy use controlled by tenants. Energy use in these areas differs in pattern and requires different strategies and incentives for effective reductions. Therefore, they are both key to the implementation of the ZCB policy. However, it is difficult to obtain tenant energy use data. It was suggested that architects and engineers produce end-user focused design, that architects, facility managers and energy consultants enable more communication and engagement with end-users to achieve a better understanding of end-use energy, and that a share portal of energy use be developed to allow tenants to monitor and benchmark their energy use and review their behaviours.

Third, the definition and energy use scope should address not only the building but related building products and materials and appliances that contribute to the life cycle carbon emissions of the building. Embodied energy and carbon in the production and construction process is higher in the importing-dominated and high-density urban settings of Hong Kong than many other places. It was considered strategically important to promote the use of low carbon products and materials for achieving life cycle ZCBs and effective carbon reductions in the long run.

6.2.2 Policy targets and timelines for carbon reductions

Most questionnaire survey respondents either agreed (49%) or strongly agreed (12%) that the ZCB policy timeline should first target the public sector and then the private one, 17% held neutral view and 22% disagreed (**Fig. 4**). Through the interviews and focus group meetings, the reasons for the neutral and disagreement views were identified to be: (1) that public buildings are mainly target for general public and the budget for building construction and operation is relatively lower, while private buildings normally have a larger budget for higher quality of the buildings and the clients and customers in theory could invest more to achieve more carbon reductions; (2) that new-build public residential buildings in Hong Kong are nowadays typically of 40-storeys which set technical challenges to the achievement of zero carbon emission, while some private buildings are still medium-rise in Hong Kong.

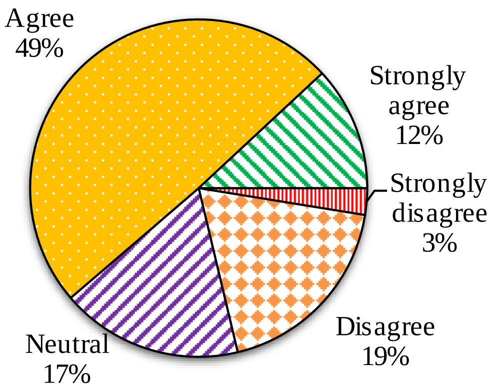


Fig. 4 Appraisal of ZCB policy target: public buildings first and then private ones (n=235)

More than half of the questionnaire survey respondents either disagreed (44%) or strongly disagreed (8%) that the ZCB policy timeline should first target the residential buildings and then the non-residential ones, 35% held neutral view and 13% agreed (Fig. 5). Through the interviews and focus group meetings, the reasons for the neutral and disagreement views were identified to be: (1) that although many other countries or cities prioritise residential buildings over non-residential in their ZCB policy, this may be unsuitable for Hong Kong due to the high-rise, high-density characteristics of residential buildings; (2) that the user behaviour factor of residential occupants (generally perceived as being reluctant to change) may make it more difficult to achieve zero carbon emission in residential buildings.

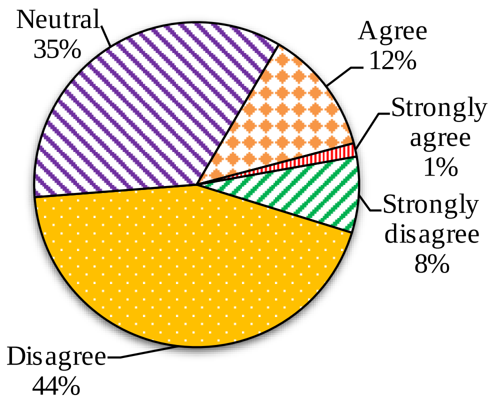


Fig. 5 Appraisal of the ZCB policy target: residential buildings first and then non-residential ones (n=225)

Eight scenarios of the ZCB policy targets and timelines were provided to the research participants, which configured the three pairs of policy variables, namely, (1) public vs. private; (2) residential vs. non-residential; and (3) new-build vs. existing. The level of achievability of these provided scenarios of ZCB policy targets and timelines in Hong Kong was examined using a 5-point Likert scale (**Fig. 6**).

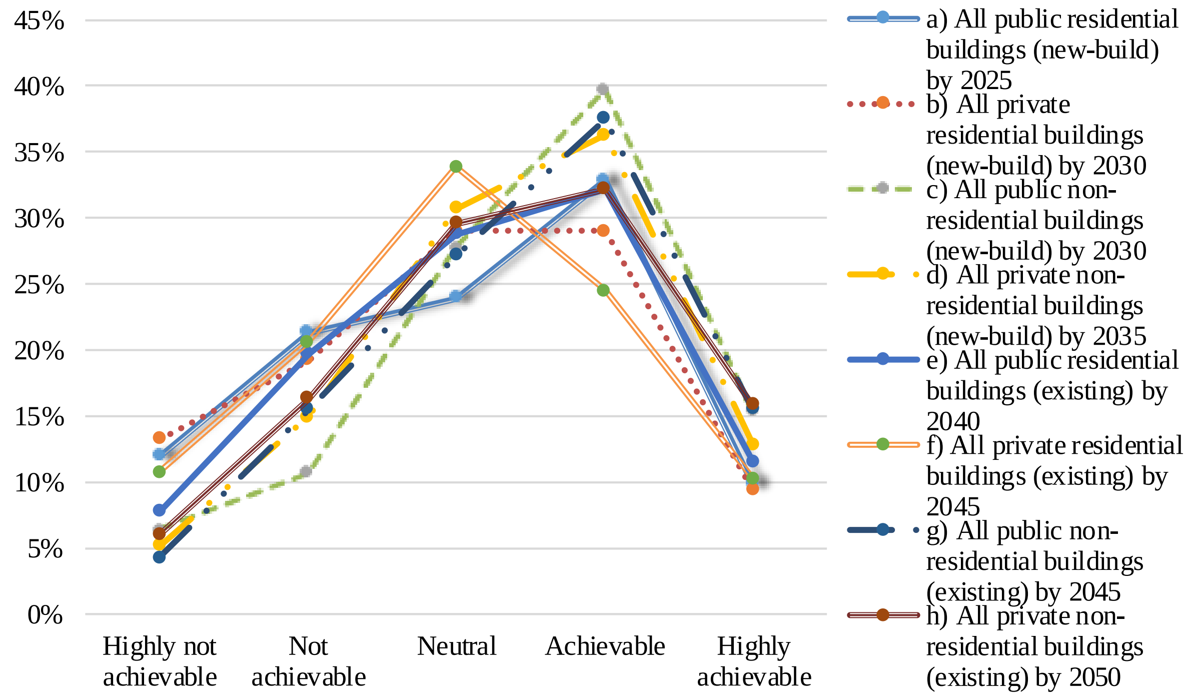


Fig. 6 Achievability of the proposed ZCB policy targets and timelines

Judged by the mean values (listwise n=232) all eight proposed ZCB policy targets and timelines were considered 'neutral' for their achievability (all mean values falling in the range 3-3.5; **Table 5**). The ZCB policy target of "all public non-residential buildings (new-build) by 2030" received the highest mean value of achievability (3.47). The targets of "all private residential buildings (existing) by 2045" (3.03) and "all private residential buildings (new-build) by 2030" (3.02) were considered to be the most difficult to achieve (**Table 5**).

Table 5 Achievability of the proposed ZCB policy targets and timelines

ZCB policy target and timeline	Valid n	*m*	SD	Ranking
a) All public residential buildings (new-build) by 2025	234	3.07	1.1897	6
b) All private residential buildings (new-build) by 2030	234	3.02	1.1808	8
c) All public non-residential buildings (new-build) by 2030	234	3.47	1.0771	1
d) All private non-residential buildings (new-build) by 2035	234	3.37	1.0490	3
e) All public residential buildings (existing) by 2040	233	3.20	1.1210	5
f) All private residential buildings (existing) by 2045	233	3.03	1.1386	7
g) All public non-residential buildings (existing) by 2045	232	3.44	1.0635	2
h) All private non-residential buildings (existing) by 2050	233	3.36	1.1131	4

Note: Calculations are based on a 5-point Likert scale consisting of 'Highly unachievable' as 1, 'Not achievable' as 2, 'Neutral' as 3, 'Achievable' as 4 and 'Highly achievable' as 5.

From the follow-up interview and focus group discussion two patterns were revealed of the comments on the policy targets and timelines.

One the one hand, many participants, although agreeing that the policy targets and timelines should set the same or similar pace to the international approach, argued that the proposed policy targets were too ambitious and difficult to achieve by the proposed timelines. This perceived low achievability was attributed to the factors including the high-rise, high-density features of buildings, difficulties with utilising renewable energy, political uncertainty on energy planning, and lack of industry and public willingness of zero carbon emission in Hong Kong. Several suggestions were provided for enhancing the achievability of the ZCB policy in Hong Kong. First, it would be more feasible to set progressive step-by-step targets combined with compulsory and optional parts or a portfolio of smaller shorter-term targets and milestones instead of a single one. Nevertheless, risks were also identified that people tend to pick up the easiest target if several are provided. Second, the ZCB policy targets should be differentiated by region, e.g. newly developed areas and longstanding downtown areas, and by building type, e.g. commercial prioritised to residential, public prioritised to private, and new-build prioritised to existing. To adopt this suggestion, the variables must be clearly defined, as for examples 'new' buildings will become 'existing' after completion and many buildings integrate 'residential' and 'commercial' usages.

One the other hand, some participants believed that the pace of achieving the policy targets and timelines could be achieved or even be accelerated by utilising available and emerging technologies and changing current building regulations and ordinances. Developers should take up the initiative of ZCB rather than waiting for the government to lead, and universities should offer relevant courses to educate students and upskill professionals.

6.2.3 Measures and indicators of energy use and carbon emissions

Nearly two-thirds of the questionnaire survey respondents either agreed (54%) or strongly agreed (8%) on the use of $kgCO_2/m^2/year$ and $kWh/m^2/year$ as measures and indicators of carbon emissions and energy use respectively, while 36% of the respondents held neutral view and only 2% disagreed.

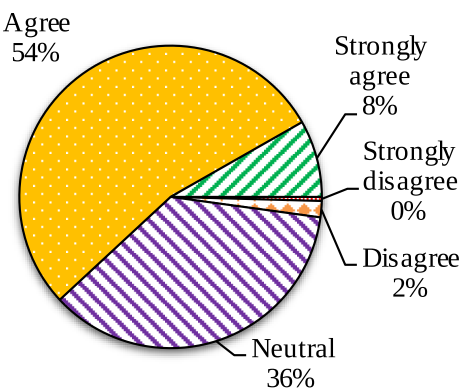


Fig 7 Views on use of '$kgCO_2/m^2/year$' and '$kWh/m^2/year$' as measures and indicators (n=231)

Some respondents considered that the measures and indicators should also include per person, cost, and how m^2 was specified (GFA, CFA, etc.). Other measures and indicators proposed included $kgCO_2/m^3$/year, $kgCO_2/ft^2$/year, $kgCO_2e/m^2$/year, kWh/m^2/capita and kWh/occupant/year. The provided additional measures and indicators through the survey were verified through the follow-up interviews and focus group meetings. Most interviewees and meeting participants agreed on the proposed measures and indicators. In addition, some suggested considering an economic indicator, primary energy, and GHG emissions potential as supplements.

6.2.4 Appraisal on the use of renewable energy

Nine possible types of renewable energy were provided to the research participants, which configured two sets of variables, namely, (1) solar, wind, bio energy or hydropower; (2) on or off site (**Table 6**). The level of achievability of these provided types of renewable energy in Hong Kong was examined. Judged by the mean values (listwise n=228), only 'on-site solar energy (e.g. BIPV)' (m=3.73) was considered an achievable source of renewable energy for achieving ZCB in Hong Kong. All other types of renewable energy were considered either neutral or not achievable (with their associated mean values less than 3.50). Nevertheless, the other highly rated renewable energies included off-site biogas and biodiesel (e.g. district CCHP), off-site solar energy (e.g. solar farm) (**Table 6**). Hydropower and on-site wind energy were considered the least achievable (m<3.0; ranked number 9 and 8 respectively). These results suggest that the feasibility of applying many renewable energy technologies in Hong Kong has been largely limited, which explains the early resultant hesitation with formulating a ZCB policy in Hong Kong as renewable energy is a most important strategy for achieving ZCB.

Table 6 Appraisal of the use of renewable energy for ZCB in Hong Kong

Renewable energy	Valid n	*m*	SD	Ranking
a) solar energy (onsite), e.g. building-integrated PV	230	3.73	0.980	1
b) solar energy (offsite), e.g. solar farm	230	3.42	0.920	4
c) wind energy (onsite), e.g. small wind turbine	230	2.95	1.079	8
d) wind energy (offsite), e.g. wind farm	229	3.31	0.920	6
e) biogas (onsite), e.g. site-based combined cooling, heat and power (CCHP) plant	231	3.34	0.913	5
f) biogas (offsite), e.g. district CCHP	231	3.49	0.818	2
g) biodiesel (onsite), e.g. site CCHP	231	3.26	0.881	7
h) biodiesel (offsite), e.g. district CCHP	231	3.44	0.887	3
i) hydropower	231	2.80	1.015	9

Note: Calculations are based on a 5-point Likert scale consisting of 'Highly unachievable' as 1, 'Not achievable' as 2, 'Neutral' as 3, 'Achievable' as 4 and 'Highly achievable' as 5.

From the follow-up interview and focus group discussion several patterns were revealed of the comments on the use of renewable energy in Hong Kong.

First, the use of renewable energy has been considered largely constrained and very difficult to increase in Hong Kong. A number of reasons were identified. The average wind speed in Hong Kong, particularly those downtown areas, is low and renders the use of wind power impossible as a major power generator. There is also a risk of turbine being damaged by storm in Hong Kong. The use of solar energy is also limited in Hong Kong, as in most cases only roofs can be equipped with solar panels and their contribution to offsetting energy use in high-rise buildings is marginal. BIPV was considered highly potential, but its efficiency is significantly impaired due to shadowing of high-rises, coupled with effects on views through glazing. Despite the limited choices, energy from waste was considered promising in Hong Kong with government support. Furthermore, economic factors are still most crucial to the use of renewable energy. However, the low-level use of renewables and lack of an established market for that hamper the improvement of cost-effectiveness of renewables in Hong Kong.

Second, the use of onsite renewable energies (e.g. onsite CCHP) was considered difficult in Hong Kong due to the shortage of developable land (hence limited space to home the plant) and the discrepancy in different policies and regulations on onsite energy generation. Offsite renewable energies (e.g. from Pearl River Delta) could make very useful contribution to decarbonised energy supply, but perceptions existed that extensive energy importing might impose risks of energy security and cause conflicts with power companies within Hong Kong.

Third, the use of renewable energy was nevertheless suggested to be a longer-term strategy for implementing the ZCB policy in Hong Kong. The concepts of "renewable energy ready" and "zero carbon ready" were suggested, meaning that buildings and infrastructures not being installed with low or zero carbon technology should be designed with real options so that they will be capable to receive such installations in the future when the technologies become more practical and affordable. Incentives should be provided to developers and power suppliers for use of renewables.

6.3 Perspectives on formulating and implementing ZCB policy

6.3.1 Perceptions on the lack of a strategic policy on zero carbon emission

The majority of the questionnaire survey respondents either agreed (48%) or strongly agreed (23%) that Hong Kong lacks a strategic policy leading to zero carbon emission, nearly one in five (19%) held neutral perception and 10% either disagreed (3%) or strongly disagreed (**Fig. 7**). Through the interviews and focus group discussion, the neutral and disagreed appraisals were found to attribute to several perceptions: (1) that the existing building energy policies and ordinances were capable of reducing building energy use and carbon emissions in Hong Kong; and (2) that achieving zero carbon emission in Hong Kong lacked technical feasibility due to the high-rise, high-density features of most buildings in the city. Some participants suggested that steps would be required for achieving zero carbon emission and thus a low-carbon or low-energy (rather than net zero) building policy might be more practicable.

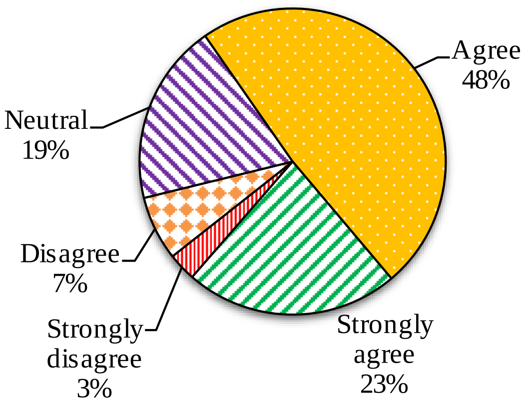
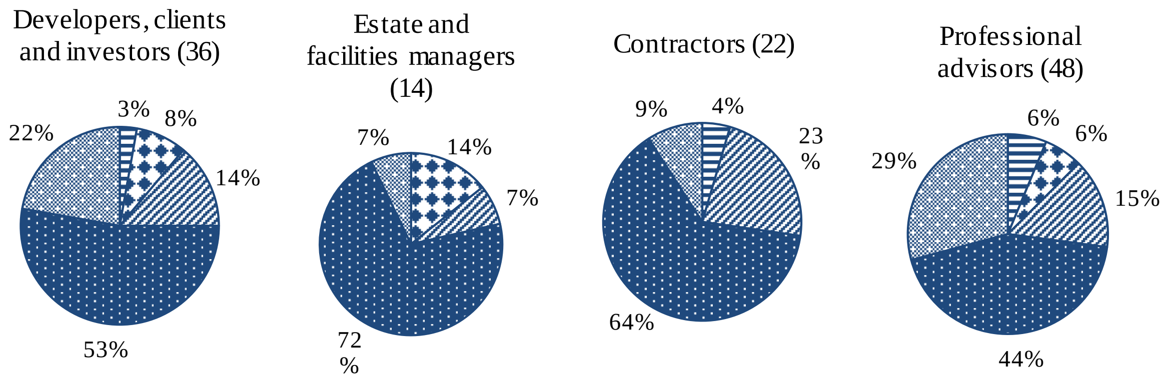


Fig. 7 Appraisal of the lack of strategic policy leading to zero carbon emission in HK (n=235)

Breaking down the responses into the eight identified key stakeholder groups, variations in their perceptions were discovered among the groups (**Fig. 8**).



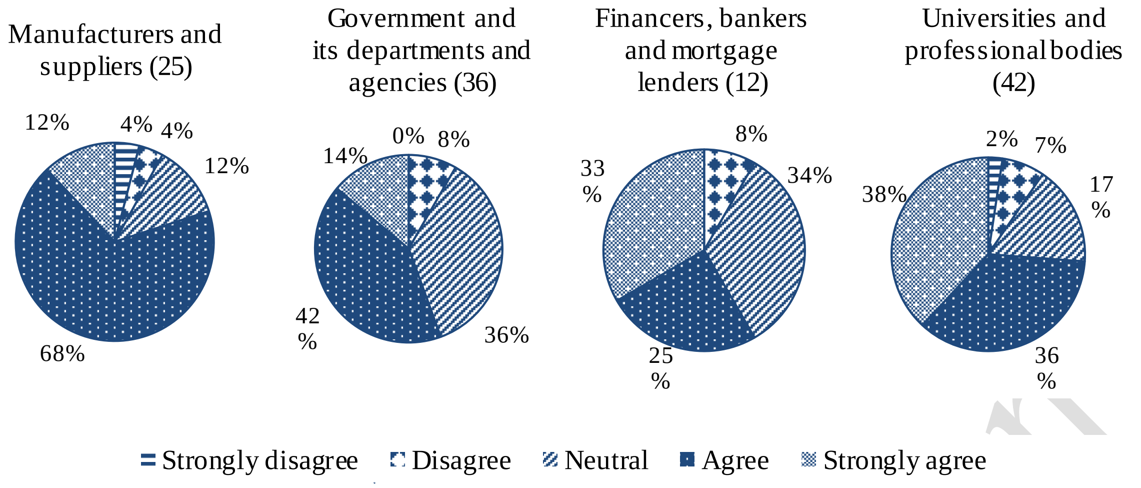


Fig. 8 Appraisal of the lack of strategic policy leading to zero carbon emission in HK by different stakeholder groups

From the breakdown analyses, the stakeholder group 'universities and professional bodies' held a strongest perception that there was a lack of strategic policy leading to zero carbon emission in Hong Kong, followed by the other groups (**Table 7**). The stakeholder group 'Government and its departments and agencies' had a relatively weaker perception. Nevertheless, the differences between the groups' perceptions were not statistically significant (F=0.498, p=0.835). All these results together suggest that the wide stakeholders held a consistent perception that there is a lack of strategic policy leading to zero carbon emission in Hong Kong.

Table 7 Appraisal of the lack of strategic policy leading to zero carbon emission in HK

Stakeholder group	Valid n	*m*	SD	Ranking
Developers, clients and investors	36	3.83	.9710	2
Estate and facilities managers	14	3.71	.8254	7
Contractors	22	3.73	.8270	6
Professional advisors	48	3.83	1.1172	2
Manufacturers and suppliers	25	3.80	.8660	5
Government and its departments and agencies	36	3.61	.8376	8
Financers, bankers and mortgage lenders	12	3.83	1.0299	2
Universities and professional bodies	42	4.00	1.0359	1
Total	235	3.81	.9616	-

Note: Calculations are based on a 5-point Likert scale consisting of 'Strongly disagree' as 1, 'Disagree' as 2, 'Neutral' as 3, 'Agree' as 4 and 'Strongly agree' as 5.

6.3.2 Views on the need for a ZCB policy

The vast majority of the questionnaire survey respondents viewed the need for a ZCB policy for Hong Kong to be either important (50%) or very important (30%), 16% held neutral perception and only 4% considered that need not important (**Fig. 9**). These results echo the identified general perception on the lack of strategic policy leading to zero carbon emission in Hong Kong. It is verified that there is a strong need to develop a ZCB policy for Hong Kong. Through the focus group discussion those survey participants who disagreed on the lack of policy leading to zero carbon emission or considered the need for a ZCB policy for Hong Kong not important may not fully understand the definition of the proposed ZCB policy or have confused the ZCB policy with current environmental policies.

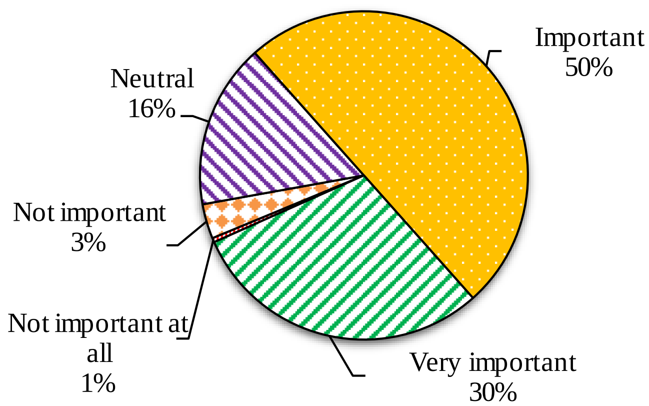


Fig. 9 Views on importance of the need for ZCB policy for HK (n=234)

Breaking down the responses into the eight identified key stakeholder groups, variations in their perceptions were discovered among the groups (**Fig. 10**).

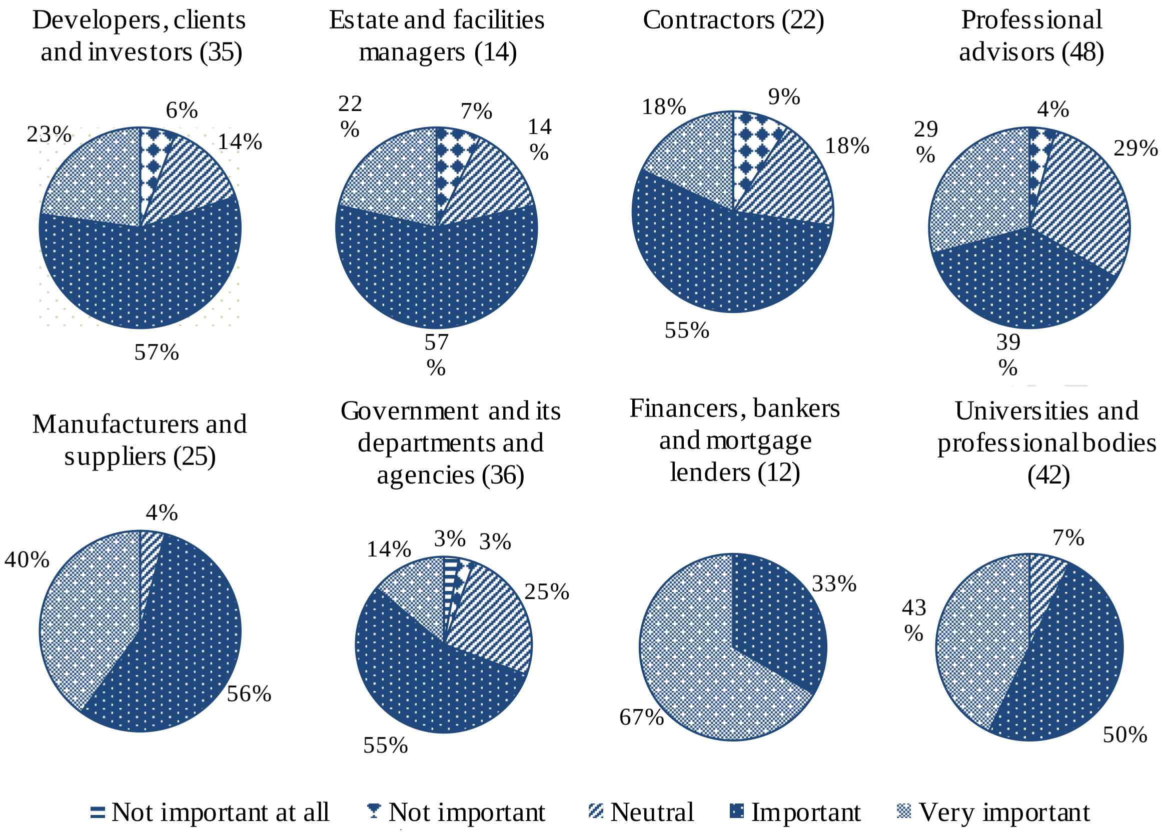


Fig. 10 Views on importance of the need for ZCB policy for HK by different stakeholder groups

From the breakdown analyses, the stakeholder group 'financers, bankers and mortgage lenders' held the most positive attitude towards the importance of a ZCB policy for Hong Kong, while the stakeholder group 'Government and its departments and agencies' had the least positive attitude. The differences among the eight groups were statistically significant ($F=4.075$, $p<0.01$). From the results distribution indicated in **Fig. 10** and means in **Table 8**, there were two slightly different attitudes. The stakeholder groups 'manufacturers and suppliers', 'financers, bankers and mortgage lenders' and 'universities and professional bodies' held a more positive attitude, and the differences among them were not statistically significant ($F=1.412$, $p=0.25$). In contrast, the remaining five stakeholder groups had a relatively less positive view, and the differences among them were also not statistically significant (F=0.384, p=0.82). Nevertheless, despite the two patterns of attitudes revealed, the overall view from all stakeholder groups as a whole on the need of a ZCB policy for Hong Kong was considered 'important' (all mean values falling in the range 3.5-5). All these results together suggest that the wide stakeholders held a consistent view that there is a strong need to develop a ZCB policy for Hong Kong.

Table 8 Views on importance of the need for ZCB policy for HK

Stakeholder group	Valid n	*m*	SD	Ranking
Developers, clients and investors	35	3.97	.7854	4
Estate and facilities managers	14	3.93	.8287	5
Contractors	22	3.82	.8528	7
Professional advisors	48	3.92	.8711	6
Manufacturers and suppliers	25	4.36	.5686	2
Government and its departments and agencies	36	3.75	.8409	8
Financers, bankers and mortgage lenders	12	4.67	.4924	1
Universities and professional bodies	42	4.36	.6177	2
Total	234	4.06	.7977	-

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

The revealed perspective on the need for a ZCB policy for Hong Kong was verified through the interviews and focus group meetings that Hong Kong should initiate a ZCB policy. Most participants agreed that the proposed ZCB policy should take good reference to and critical learning from relevant policies and practices in other countries. The participants also suggested that the ZCB policy for Hong Kong should align with, but also differentiate from, the Energy Saving Plan and the energy intensity reduction target.

6.3.3 General attitudes to implementing ZCB policy

Three quarters of the questionnaire survey respondents considered that the implementation of the possible ZCB policy in Hong Kong would be difficult (56%) or very difficult (19%), 17% held neutral evaluation and only 8% considered the implementation not difficult (**Fig. 11**). Through the follow-up interviews and focus group discussion, a main explanation was suggested to be that the difficulty results from the industry not trying hard enough with carbon reductions because no ZCB policy is yet in place in Hong Kong.

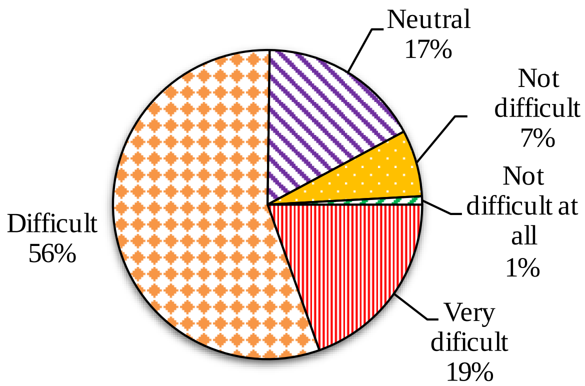


Fig. 11 Evaluation of the difficulty with implementing ZCB policy in Hong Kong (n=230)

Over half of the survey respondents thought that the willingness of the building industry in Hong Kong to support the ZCB policy was weak (41%) or very weak (10%), 36% respondents held a neutral perception and only 13% considered the building industry's willingness being strong or very strong (**Fig. 12**).

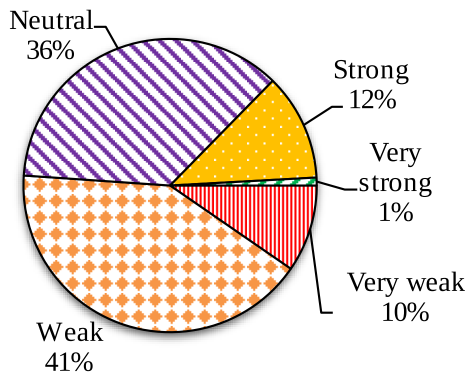


Fig. 12 Perceived willingness of the building industry in HK to support ZCB policy (n=229)

Over a third of the survey respondents thought the willingness of the public in Hong Kong to support the ZCB policy was weak (32%) or very weak (7%), 37% respondents held neutral perception and 24% considered the Hong Kong public willingness being strong or very strong (**Fig. 13**).

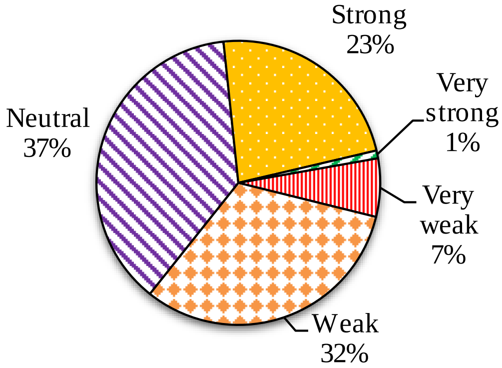


Fig. 13 Perceived willingness of the public in HK to support ZCB policy (n=226)

These results echo each other, indicating that it is difficult to implement a ZCB policy in Hong Kong. Also, there is in general a weak or uncertain willingness of both the building industry and the public to support the policy; nevertheless, the level of willingness of the public was revealed to be higher than that of the building industry. The correlation analysis indicates that the perceptions on the difficulty with policy implementation has a moderate correlation with the perceived unwillingness from the building industry (r=0.339, $p<0.01$) and the public (r=0.319, $p<0.01$).

6.4 Strategies for achieving net zero carbon emission in the ZCB policy

Six strategies (with one additional category denoting 'others') for achieving net zero carbon emission in the ZCB policy were provided to the research participants for ranking within the context of Hong Kong (**Table 9**). Weightings are defined based on a 7-point scale to calculate means and standard deviations. The strategy 'Building envelope energy efficiency' was ranked the most important (with the mean value of 5.49), followed by 'HVAC energy efficiency' (m=5.26) and 'user behaviour' (m=5.22). Other strategies suggested included carbon trading, demand-side control, community planning, building geometry, government incentives and policies, a passive design strategy.

Table 9 Ranking of strategies for achieving net zero in ZCB policy for HK

Strategy	Valid n	*m*	SD	Ranking
User behaviour	208	5.22	1.8274	3
Building envelope energy efficiency	208	5.49	1.3297	1
HVAC energy efficiency	210	5.26	1.3871	2
Office equipment efficiency	207	3.55	1.3886	5
Onsite renewable energy	210	3.90	1.5388	4
Offsite renewable energy	210	3.53	1.5656	6
Others (e.g. carbon trading, incentives)	38	2.18	1.8285	7

Note: Calculations are based on the sorted results with weighting as 'Rank 1' as 7, 'Rank 2' as 6, 'Rank 3' as 5, 'Rank 4' as 4, 'Rank 5' as 3, 'Rank 6' as 2 and 'Rank 7' as 1.

Through the interviews and focus groups, several patterns were revealed of the comments on the ranked strategies for achieving zero carbon emission in Hong Kong. First, all the strategies should be adopted in tandem for achieving net zero carbon emission in order to address the challenges imposed by the high-rise high-density subtropical characteristics of buildings in Hong Kong. Second, the rankings should not be rigid but change for different building types and sectors. For example, building envelope and HVAC energy efficiency should take priority for residential and commercial buildings, respectively. Third, behaviour change was emphasised as a key fundamental strategy for building energy use and carbon emission reductions. Encouraging energy-saving behaviours should be supported by financial incentives. Fourth, the strategies of adopting renewable energy technologies, although ranked lower (that was probably attributed to the low use and constraints to their take-up), suggesting a strategic potential of future development.

7 Discussion and Conclusions

High-density metropolises face severe challenges to substantial carbon reductions in buildings to facilitate the transformation towards sustainability. The difficulties are even more severe in Hong Kong give the high-rise norm of buildings. To achieve very low or zero carbon emission buildings requires not only technological advances but socio-economic, regulatory and political measures. This unavoidably introduces different values of wide-ranging stakeholder groups on the ZCB policy. It is therefore critical to address the policy on ZCB in a dialectical system approach. This paper has examined the perspectives of wide-ranging professionals and stakeholders on a dialectical system framework of ZCB policy for Hong Kong.

The identified perspectives on the ZCB definition and energy use scope indicate the uncertainty of the definition and the lack of clarity about the system boundaries. The different views on the energy use scope to be covered in the ZCB definition reflect and take further the debate in the literature. On the scope in relation to the items included in energy use, the findings indicate different items that cross regulated energy use (e.g. lighting, space conditioning under BEC, see EMSD, 2015; and refrigeration under MEELS in Hong Kong, see EMSD, 2018) and unregulated energy use (e.g. hot water and office equipment). This profile is more complicated than others that differentiate energy use purely by regulated and unregulated items such as in the UK (HM Treasury, 2011). Also, the items of cooking and appliances were only suggested by minority participants. On the scope in relation to the building life cycle stages, the findings indicate a predominant focus of views on operational energy use with embodied energy only being raised by minority participants. This profile can be explained by the dominant contribution of buildings' operational energy use to carbon emissions in Hong Kong (EPD and EMSD, 2010) which renders the embodied energy of marginal attention. Also, the identified perspectives lead to another interesting finding that different ZCB definitions and energy use scopes were required for different types of buildings, and such energy use scopes should be adaptable and adjustable to the progressive policy targets of carbon reductions towards net zero in order to ensure the effectiveness of the ZCB policy. This dialectics offers an approach to addressing the rigidness in setting a ZCB policy, for example in the UK where the government had revised the definition and scope for ZCB several times (for a detailed account see Pan and Ning 2015) and more recently scrapped their proposed 2016 'zero carbon' target for the nation (HM Treasury, 2015). The ZCB definition and scope has a significant impact on the solutions to delivering ZCBs (Voss et al., 2012). *Therefore, the first conclusion is that the boundaries of ZCB policy should be clearly defined to reflect different contexts and stakeholders in a dialectical systems manner, which can serve as the foundation for ZCB policy formulation and implementation in cities*.

The uncovered perspectives on the carbon reduction policy targets and timelines verify the patterns reported in the literature that public buildings should be targeted with priority over private ones and that new buildings should be targeted with priority over existing ones such as the cases in the US (Federal Office, 2009) and EU (European Commission, 2010). However, the results are in disagreement with the reported pattern that residential buildings should be prioritised over non-residential ones such as the case in the UK (HM Government, 2011). It was found that user behaviours of residential occupants are generally reluctant to change, although has perceived great energy reduction potential (Marszal et al., 2011), which in high-rise buildings makes it difficult to achieve substantial carbon reductions. Nevertheless, all studied scenarios of the ZCB policy targets and timelines in Hong Kong were perceived challenging to achieve, addressing which requires more advanced renewable technologies, policy motivation, industry and public awareness and support, and education and training. *Therefore, the second conclusion is that ZCB policy targets and timelines are* *very ambitious for subtropical high-rise high-density settings but can prioritise new public non-residential buildings as leading examples, which provides exemplar initiatives for more practical ZCB policy formulation and implementation*.

The disclosed perspectives on the use of renewable energy in Hong Kong indicate a largely constrained usage which is also very difficult to increase due to geographical limitations, climatic conditions and lack of government incentives and an established market. This worsens the already perceived low level of achievability of net zero carbon emission for high-rise buildings in Hong Kong, as it has been a norm to integrate the use of cleaner renewables in designing ZCBs or the alike worldwide (Pan and Li, 2016). Nevertheless, the strategy of adopting emerging and innovative renewable technologies suggests a strategic potential for future development, as also theoretically verified in the literature (Fong and Lee, 2014). Thus, behavioural changes and energy efficiency measures are fundamental strategies for effective reductions of buildings' energy use and carbon emissions. Behavioural changes are being further explored and addressed by, e.g. the IEA-EBC Annex 66 'Definition and Simulation of Occupant Behavior in Buildings' (Yan et al., 2017); efforts such as that are however hampered by the issues including privacy and large data analysis. How to obtain occupants' energy use data with accuracy and consistency and analyse them in correlation with building parameters warrants future research. *Therefore, the third conclusion is that user behaviour and energy efficiency are critical given the limited use of renewable energies in high-rise high-density developments while emerging technologies for both renewables and large data collection and analysis are strategically important, which suggests practical means and technological solutions for the successful implementation of ZCB policies*.

The revealed perspectives on the need for a ZCB policy for Hong Kong appeared to be conflicting. On the one hand, identified was a statistically consistent appraisal of the lack of strategic policy leading to zero carbon emission in Hong Kong, which was echoed by the captured views on the importance of formulating a ZCB policy for accelerating a more sustainable future of the city. On the other hand, revealed was the questioned technical feasibility of achieving ZCB due to the high-rise high-density features of most buildings in the city. Underlying this conflict was the absence of a clearly defined ZCB policy for Hong Kong. This finding highlights a gap in both knowledge and policy on ZCB or the alike, which has been focused on low-rise buildings in cold and temperate climates (see Pan and Li 2016). *Therefore, the fourth conclusion is that there is a strong need for ZCB policy for Hong Kong but such policy is difficult to implement mainly because of the challenging feasibility of neutralising carbon emissions in high-rise buildings, which emphasises the need for future feasibility study*.

Hong Kong's building energy and carbon policies are heading increasingly stringent standards of energy efficiency and carbon reduction, but yet there is no ZCB policy in place. The revealed perspectives will strategically take forward the over 20 years evolution of the city's building energy and carbon policies towards carbon neutrality. The developed strategies should inform the practice of reducing carbon emissions of high-rise buildings. The findings verify ZCB policy as complex dialectical systems and provide new light to tackle the challenges to achieving high-rise ZCBs by managing the dialectics, i.e. the complexity of and interdependence between the technical components, the stakeholders and the boundaries of ZCB policy. The findings also provide useful learning for ZCB policy development in other high-density cities. The developed research methodology for this study is robust and can be adapted for use for ZCB policy reviews in other cities. Future research should further address behavioural changes and develop technical solutions to delivering high-rise ZCBs, which will support the effective implementation of ZCB policy.

Acknowledgements

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References

ASBEC, 2012. Net Zero Emission Homes: An Industry Roadmap. Australian Sustainable Built Environment Council, Australian.

Chief Executive, 2007. The 2007-2008 Policy Address - A New Direction for Hong Kong. HKSAR Government, Hong Kong.

Chief Executive, 2013. The 2013 Policy Address - Seek Change Maintain Stability Serve the People with Pragmatism. HKSAR Government, Hong Kong.

Chief Executive, 2014. The 2014 Policy Address - Support the Needy Let Youth Flourish Unleash Hong Kong's Potential. HKSAR Government, Hong Kong.

Coenen, L., Benneworth, P., Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. Res. Policy. 41(6), 968-979. https://doi.org/10.1016/j.respol.2012.02.014.

Crawley, D., Pless, S., Torcellini, P., 2009. Getting to net zero. ASHRAE J. 18-25.

Development Bureau, 2014. List of Approved Contractors for Public Works. HKSAR Government, Hong Kong.

DCLG, 2006. Code for Sustainable Homes: A Step-Change in Sustainable Homebuilding Practice. Department for Communities and Local Government, London.

EMSD, 2015. Buildings Energy Efficiency Ordinance. Electrical and Mechanical Services Department, Hong Kong.

EMSD, 2018. Code of Practice on Energy Labelling of Products 2018. Electrical and Mechanical Services Department, Hong Kong.

Environment Bureau, 2010 Hong Kong's Climate Change Strategy and Action Agenda Consultation Document. HKSAR Government, Hong Kong.

Environment Bureau, 2015. Energy Saving Plan for the Built Environment 2015~2025+. HKSAR Government, Hong Kong.

Environmental Audit Committee, 2016. Sustainability and HM Treasury, Fifth Report of Session 2016–17. House of Commons, London.

EPD and EMSD, 2010. Guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for Buildings in Hong Kong. HKSAR Government, Hong Kong.

European Commission, 2010. Directive 2010/31/EU of the European parliament and of the council of 19 May 2010 on the energy performance of buildings (recast). Off. J. Eur. Union. 53, 13–34. https://doi.org/doi:10.3000/17252555.L_2010.153.eng.

Federal Office, 2009. Executive Order 13514: Federal Leadership in Environmental, Energy, and Economic Performance. http://www1.eere.energy.gov/femp/pdfs/eo13514.pdf (accessed 1 May 2015).

Fellows, R., Liu, A., 2008. Research Methods for Construction, third ed. Wiley-Blackwell, Chichester.

Fong, K.F., Lee, C.K., 2014. Investigation on zero grid-electricity design strategies of solid oxide fuel cell trigeneration system for high-rise building in hot and humid climate. Appl. Energy. 114, 426-433. https://doi.org/10.1016/j.apenergy.2013.10.001.

Geels, F.W., 2004. From sectoral systems of innovation to sociotechnical systems: Insights about dynamics and change from sociology and institutional theory. Res. Policy. 33(6), 897–920. https://doi.org/10.1016/j.respol.2004.01.015.

Golubchikov, O., Deda, P., 2012. Governance, technology, and equity: An integrated policy framework for energy efficient housing. Energy Policy. 41, 733-741. https://doi.org/10.1016/j.enpol.2011.11.039.

Heiskanen, E., Nissilä, H., Lovio, R., 2015. Demonstration buildings as protected spaces for clean energy solutions - The case of solar building integration in Finland. J. Clean. Prod. 109, 347-356. https://doi.org/10.1016/j.jclepro.2015.04.090.

HKGBC, 2014. BEAM Professional Directory. Hong Kong Green Building Council, Hong Kong.

HKIS, 2014. Directory for Professional Advisors. The Hong Kong Institute of Surveyors, Hong Kong.

HKTDC, 2014. Database of Architectural & Civil engineering works at construction site (358 registered). Hong Kong Trade Development Council, Hong Kong.

HM Government, 2011. Carbon Plan. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47621/1358-the-carbon-plan.pdf (accessed June 30, 2013).

HM Treasury, 2008. Budget 2008: Stability and opportunity: building a strong, sustainable future. The Stationery Office, London.

HM Treasury, 2011. The plan for growth. The Stationery Office, London.

HM Treasury, 2015. Fixing the foundations: Creating a more prosperous nation. The Stationery Office, London.

Kibert, C.J., Fard, M.M., 2012. Differentiating among low energy, low-carbon and net-zero-energy building strategies for policy formulation. Build. Res. Inf. 40(5), 625-637. https://doi.org/10.1080/09613218.2012.703489.

Li, H.X., Chen, Y., Gül, M., Yu, H., Al-Hussein, M., 2018. Energy performance and the discrepancy of multiple NetZero Energy Homes (NZEHs) in cold regions. J. Clean. Prod. 172, 106-118. https://doi.org/10.1016/j.jclepro.2017.10.157.

Marszal, A.J., Heiselberg, P., Bourrelle, J.S., Musall, E., Voss, K., Sartori, I., Napolitano, A., 2011. Zero-energy building – A review of definitions and calculation methodologies. Energy Build. 43(4), 971–979. https://doi.org/10.1016/j.enbuild.2010.12.022.

Mayor of London, 2016. The London Plan March 2016: Policy 5.2 minimising carbon dioxide emissions. Greater London Authority, London.

Duić, N., Guzović, Z., Kafarov, V., KlemeŠ, J.J., Mathiessen, B. vad, Yan, J., 2013. Sustainable development of energy, water and environment systems. Appl. Energy. 101, 3-5. https://doi.org/10.1016/j.apenergy.2012.08.002.

Ng, S.T., Wong, J.M.W., Wong, K.K.W., 2013. A public private people partnerships (P4) process framework for infrastructure development in Hong Kong, Cities, 31, 370-381. https://doi.org/10.1016/j.cities.2012.12.002.

Pan, W., 2014. System boundaries of zero carbon building. Renew. Sustain. Energy Rev. 37, 424-434. https://doi.org/10.1016/j.rser.2014.05.015.

Pan, W., Garmston, H., 2012. Building regulations in energy efficiency: Compliance in England and Wales. Energy Policy. 45(6), 594–605. https://doi.org/10.1016/j.enpol.2012.03.010.

Pan, W., Ning, Y., 2015. A socio-technical framework of zero-carbon building policies. Build. Res. Inf. 43(1), 94-110. https://doi.org/10.1080/09613218.2015.955759.

Pan, W., Li, K., 2016. Clusters and exemplars of buildings towards zero carbon. Build. Environ. 104, 92-101. https://doi.org/10.1016/j.buildenv.2016.04.027.

Panagiotidou, M., Fuller, R.J., 2013. Progress in ZEBs-A review of definitions, policies and construction activity. Energy Policy. 62, 196–206. https://doi.org/10.1016/j.enpol.2013.06.099.

PukŠec, T., Vad Mathiesen, B., Duić, N., 2013. Potentials for energy savings and long term energy demand of Croatian households sector. Appl. Energy. 101, 15-25, https://doi.org/10.1016/j.apenergy.2012.04.023.

REDA, 2014. List of directors and committee members. The Real Estate Developers Association of Hong Kong, Hong Kong.

Scott, W.R., 1995. Institutions and Organizations. Sage Publications, London/New Delhi.

SDC, 2012. Report on the public engagement process on "Combating climate change: energy saving and carbon emission reduction in buildings". Council for Sustainable Development, Hong Kong.

Townshend, T., Fankhauser, S., Aybar, R., Collins, M., Landesman, T., Nachmany, M., Pavese, C., 2013. The GLOBE climate legislation study a review of climate change legislation in 33 countries. www.forthpub.com (accessed 30 October 2013).

Voss, K., Sartori, I., Lollini, R., 2012. Nearly-zero, net zero and plus energy buildings: how definitions and regulations affect the solutions. REHVA J. 2, 23–27.

Walker R.M., Hills P., 2012. Partnership characteristics, network behavior, and publicness: evidence on the performance of sustainable development projects. Int. Public Manag. J. 15(4), 479-499. https://doi.org/10.1080/10967494.2012.761070.

Yan, D., Hong, T., Dong, B., Mahdavi, A., D'Oca, S., Gaetani, I., Feng, X., 2017. IEA EBC Annex 66: Definition and simulation of occupant behavior in buildings. Energy Build. 156 258-270. https://doi.org/10.1016/j.enbuild.2017.09.084.

Zhang, L., Li, Q., Zhou, J., 2017. Critical factors of low-carbon building development in China's urban area. J. Clean. Prod. 142, 3075-3082. https://doi.org/10.1016/j.jclepro.2016.10.160.

Zhao, X., Pan, W., Chen, L., 2018. Disentangling the relationships between business model innovation for low or zero carbon buildings and its influencing factors using structural equation modelling. J. Clean. Prod. 178, 154-165. https://doi.org/10.1016/j.jclepro.2018.01.010.