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# Green Retrofit of Aged Residential Buildings in Hong Kong: A Preliminary Study

## Abstract

Green retrofit of aged residential buildings offers an alternative solution to reduce global energy consumption and greenhouse gas emissions. The promotion of green retrofit and the performance of retrofitted buildings depend on applicable technologies and policies. A wide range of retrofit technologies and retrofit policies have been applied throughout the world. However, little attention has been paid to identify feasible retrofit technologies and retrofit policies for particular regions, for example Hong Kong. In this study, both of technologies and policies of refurbishment were reviewed and examined with aiming to develop a framework for implementing suitable green retrofit technologies and green retrofit policies in Hong Kong. The particular characteristics of Hong Kong residential buildings were extracted based on the investigation of 100 public buildings. Taking the typical situations (building feature, climate environment and policy circumstance) as the selection criteria, 28 green retrofit technologies and 18 green retrofit policies were recommended. By analysing their attributes, these technologies and policies were integrated into a framework based on the three development stages of green retrofit (namely, pilot stage, promotion stage and full implementation stage). The findings in this study are useful for local government setting up green retrofit strategies for Hong Kong and also provide good references for other countries and regions.

## Keywords:

Green retrofit; Technology; Policy; Residential building; Hong Kong



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# 1. Introduction

Over the past two decades, sustainable development has been challenged by the issues of greenhouse gas (GHG) emissions and energy consumption (Seneviratne, Donat, Pitman, Knutti, & Wilby, 2016). One of the major contributors of greenhouse gas emissions and energy consumption is the building and construction sector (Jagarajan et al., 2017). Previous studies, such as Li, Ng, and Skitmore (2017), showed that buildings are responsible for over 30% of global anthropogenic greenhouse gas emissions and 40% of the primary energy consumption. Meanwhile, building sector also consumes 72% of electricity, produces 67% of solid waste, depletes 13% of potable water (U.S. Environmental Protection Agency, 2009). Considering the high ratio of existing buildings to new constructions (Durmus-Pedini & Ashuri, 2010; Zhou et al., 2016), one reasonable solution to reduce global GHG emission and energy consumption is green retrofit of existing buildings (Hwang, Zhao, See, & Zhong, 2015; Jagarajan et al., 2017; Onat, Egilmez, & Tatari, 2014).

Compared to the demolition of existing buildings and rebuilding, building green retrofit to some extent is more beneficial (Langston, Wong, Hui, & Shen, 2008). These benefits are generalized as the triple structure (namely, environment, society, and economy) of green retrofit underpinning sustainability (Langston, 2010; Wilkinson, 2012). As demonstrated that green retrofit of existing buildings can improve their energy efficiency, which is essential for the promotion of environmental sustainability (Ciulla, Galatioto, & Ricciu, 2016; Ma, Cooper, Daly, & Ledo, 2012). At the social level, green retrofit is deemed to preserve cultural, aesthetic, and heritage value of aged buildings (Bromley, Tallon, & Thomas, 2005; Bullen, 2007; Wilkinson, James, & Reed, 2009). In addition, retrofitted buildings are more livable and comfortable for dwellers (Sweatman & Managan, 2010). The economic advantages of green retrofit can be found in project flexibility, low financing cost, and increased building value (Wilkinson, 2012; Wilkinson et al., 2009). For example, Chau, Wong, Leung, and Yiu (2003) found that retrofitted buildings have 9 percent enhancement of their property values in comparison with un-retrofitted buildings in the same area.

By virtue of these advantages, green retrofit in existing building has been carried out in many countries. For example, the federal government of the United States has conducted the refurbishment plan to improve energy productivity by 2030 (Chung, Kumaraswamy, & Palaneeswaran, 2009). In Germany, over 900 pre-1978 built residential buildings were renovated with installing energy efficient heating and cooling systems (Power, 2008). In Switzerland, policies, such as tax incentives and financial assistance, were launched to support existing building retrofit (Amstalden, Kost, Nathani, & Imboden, 2007; Azizi, Fassman, & Wilkinson, 2011). Mandatory policies were adopted by Australian government to require the owners of large commercial office buildings to provide energy efficiency information to potential buyers or lessees. Similarly, there are a number of schemes to help home owners to make energy saving improvements, such as Green Deal, Energy Company Obligation, Feed-in Tariffs, Renewable Heat Incentive in UK (International Energy Association, IEA). In Singapore, Building Retrofit Energy

Efficiency Financing (BREEF) scheme provides financing to building owners for energy retrofit. These efforts indicate the importance of green retrofit of existing buildings.

In a typical developed and densely populated metropolis like Hong Kong, the proportion of aged buildings, especially the residential buildings, to the total number of buildings is large and continues to increase, whereas the rate of retrofit is low (Chiang, Li, Zhou, Wong, & Lam, 2015; Langston et al., 2008). According to the Hong Kong Energy End-use Data 2016 published by EMSD, the energy consumption of residential buildings accounted for 22% of the total energy use, and there is also an increasing trend. Of these residential buildings, over 89% were built before 1998. Most buildings are not regularly maintained with low performance, accessibility, safety and security, poor indoor air quality etc. This situation indicates that the number of aged buildings in Hong Kong is increasing, and these buildings will have to be maintained or retrofitted due to poor performance. Relevant studies on improving buildings' energy efficiency have been done by local researchers (Chan and Yeung, 2005; Ng, Skitmore, and Cheung, 2013; Li, Ng, and Skitmore, 2017). In 2012, two mandatory schemes, Mandatory Building Inspection Scheme (MBIS) and Mandatory Window Inspection Scheme (MWIS), were implemented in Hong Kong. This provides a good opportunity to promote green retrofit of aged buildings in Hong Kong.

The existing experience of building retrofit accumulated throughout the world can be used as references for decision-makers when implementing green retrofit of existing buildings. However, the distinctive climatic features, architectural characteristics, and construction standards may lead to such experience unsuitable or unfeasible for application in Hong Kong (Lam, 2000; Li et al., 2017). It is important to identify the technologies and policies which are in line with the local situation. Therefore, this study aims to identify appropriate green retrofit technologies and policies for aged residential buildings in Hong Kong, and establish a framework for guiding the future development of building green retrofit in Hong Kong.

## 2. Literature review of green retrofit

According to Tryson (2016), retrofit is the "change" of elements or components of a building. Wherein, the "change" for green retrofit is limited to the "upgrade", which aims to improve a building's environmental performance. In this sense, the scope of "retrofit" covers the scope of "upgrade". The "retrofit" also refers to other terms in literature as well, such as refurbishment, rehabilitation, renovation, improvements, adaptation, repairs and renewal on existing buildings (Liang, Peng, & Shen, 2016). Further, green retrofit is defined by Brown, Swan, and Chahal (2014) as "the upgrading of the building fabric, systems or controls to improve the energy performance of the property". In more detail, the U.S. Green Building Council (USGBC) defines green retrofit as "any kind of upgrade at an existing building that is wholly or partially occupied to improve energy and environmental performance, reduce water use, and improve the comfort and quality of the space in terms of natural light, air quality, and noise - all done in a way that it is financially beneficial to the owner". From these definitions, it can be seen that green retrofit can improve energy performance, satisfactory service level and indoor environmental quality of existing buildings (Kumar, Chani, & Deoliya, 2014).

In this sense, green retrofit offers an alternative solution for greenhouse gas emissions and energy consumption issues (Liang et al., 2016). In both developed and developing countries, extensive studies on green retrofit have been carried out from various aspects. Examples of these include studies of stakeholders' perceptions of green retrofit (Hwang, Shan, Xie, & Chi, 2017; Miller & Buys, 2008), evaluation (Liang et al., 2017; Ruparathna, Hewage, & Sadiq, 2017), refurbishment measures (e.g., envelope renovation technologies, air conditioning system refurbishment solutions, green roofs) (Castleton, Stovin, Beck, & Davison, 2010; Rakhshan & Friess, 2017; Wilkinson & Reed, 2009), and the policies (Baek & Park, 2012; Zhang & Wang, 2013). Stakeholders' perceptions of green retrofit are different. For example, homeowners prefer to pay for a heat pump, whereas tenants prefer floor insulation (Phillips, 2012). Some owners or tenants are reluctant to retrofit because of the uncertainty in energy saving, lack of understanding of green retrofit, and long payback time (Liang, Peng, and Shen, 2016). In a nutshell, these studies can be summarized as "2W1H", wherein "2W" represent "What is green retrofit" and "Why need green retrofit"; "1H" refers to "How to conduct green retrofit" (Jagarajan et al., 2017). The aforementioned contents have explained the definiton (what) and the necessity (Pugh, Mackenzie, Whyatt, & Hewitt, 2012) of green retrofit. However, there is no a standard answer for the question "how to conduct green retrofit". In fact, the implementation of green retrofit is the key to achieve sustainbility.

The success of green retrofit depends on many factors, such as retrofit awareness (Liang et al., 2016) and green willingness of owners (Jagarajan et al., 2017), retrofit cost (Ruparathna et al., 2017), avaliable technologies (Durmus-Pedini & Ashuri, 2010), and policy support (Li & Shui, 2015). Among these factors, public awareness and participation in green retrofit can be improved through government policy guidance and support (Arif, Bendi, Toma-Sabbagh, & Sutrisna, 2012; Darko, Zhang, & Chan, 2017). This opinion is supported by Hwang et al. (2017). They pointed out that government policies, such as retrofit guide and retrofit incentive for dwellers, are helpful for implementing retrofit work easily and effectively. By assessing China' building retrofit policies, Li and Shui (2015) claimed that the government makes a significant contribution to promote green retrofit by the provision of adequate financial support, appropriate oversight and monitoring. For the issues of retrofit cost, fiscal policies such as tax deduction, loan discount, capital subsidy are successful in leveraging investment in green retrofit (Ciulla et al., 2016; Delmastro, Mutani, & Corgnati, 2016; Dineen & Gallachóir, 2017).

Moreover, the cost problem may be solved by selecting appropriate retrofit technologies (Amstalden et al., 2007; Wu, Wang, & Xia, 2016). For example, the Ground Coupled Heat Pump (GCHP) system can be used reduce the payback period in comparison with renewable energy (Zhou et al., 2016). Likewise, technology feasibility can help to reduce relevant risks of retrofitting, and increase the acceptance rate of stakeholders involved in retrofit projects (Brown et al., 2014). It is noteworthy that available technologies are considered by Tryson (2016) as the basement to improve building performance. Two reasons contribute to this argument. On one hand, the definition of retrofit stresses that the technical intervention is the main measures to improve building performance (Shaikh, Shaikh, Sahito, Uqaili, & Umrani, 2017); on the other hand, the innovation and adoption of advanced technologies determine the economic growth, customer satisfaction and environment effect (GhaffarianHoseini et al., 2013). In this sense, the availability of technology and its advancement are considered as key factors affecting green retrofit of buildings (Shaikh et al., 2017).

Based on above analysis, technology and policy are the two most improtant factors affecting the application of green retrofit to existing buildings. The retrofit technology and policy vary from the climate regions and the features of buildings (Lam, 2000; Li et al., 2017). For example, Ascione, Bianco, De Masi, de' Rossi, and Vanoli (2014) discovered the renovation technology of phase change materials wallboards is more appropriate for semi-arid climate than hot/subtropical Mediterranean climates. By applying technologies in different climate zones, Ciulla et al. (2016) found pay-back time vary for the same action, increasing from colder to warmer zones. In the light of construction characteristics, Kontokosta (2016) put forward that the selection of technologies and policies of green retrofit is impacted by the characteristics of buildings, such as a building's age, primary fuel type, or construction type. Additionaly, the studies of green retrofit were conducted based on different building types, covering residential buildings (Amstalden et al., 2007; Friedman, Becker, & Erell, 2014), commercial buildings (Bullen, 2007; Hou, Liu, Wu, Zhou, & Feng, 2016), hotel buildings (Xu, Chan, Visscher, Zhang, & Wu, 2015), industrial buildings (Gourlis & Kovacic, 2016), laboratory buildings (Kumar et al., 2014), historic buildings (Filippi, 2015). This implies that it is essential to identify suitable green retrofit technology and green retrofit policy based on the characteristics of buildings and their physical environment (Figure 1).

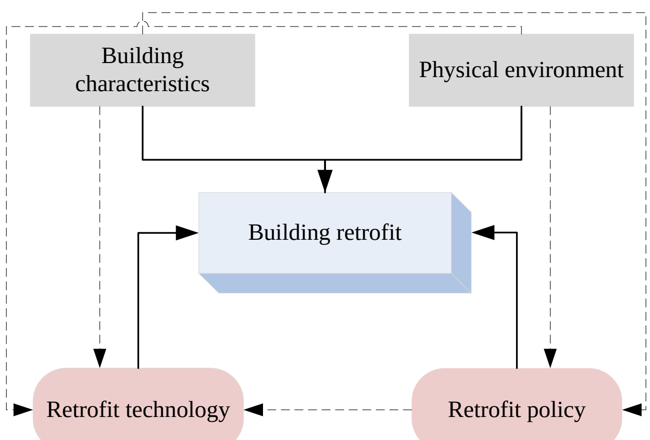

Figure 1 Key elements for building green retrofit

Among the multiple building categories, residential buildings account for 29% of the total building stock built after World War II and before 1975, therefore need attentions (Konstantinou & Knaack, 2011). However, few efforts have been made to retrofit those aged residential buildings (Li et al., 2017). Therefore, it becomes necessary to identify the suitable green retrofit technologies and develop relevant policies for residential buildings in line with particular environment (e.g., climate, characteristic of buildings).

According to Hong Kong Environment Bureau (2017), many existing buildings, including old buildings, have great potentials to perform better through retro-commissioning and retrofitting. To retrofit these buildings, a series of policy initiatives on greening and energy efficiency in existing buildings have been introduced by the Hong Kong government, including Building Energy Codes, Reporting and Benchmarking of Energy Performance Data, Mandatory Auditing and Retro-commissioning, Financial Incentives and the like (Environment Bureau, 2017). It can be derived that the government has put a lot efforts on energy saving in existing buildings. However, a guiding framework on the development of green retrofit is yet to be established. It is, therefore, important to review existing policies and technologies of green retrofit to develop a guiding framework for promoting green retrofit of existing aged residential buildings in Hong Kong.

## 3. Green retrofit technology and policy

### *3.1. Technologies of green retrofit*

Retrofit technologies are energy conservation measures used to promote building energy efficiency and sustainability (Ma et al., 2012). A variety of measures have been developed to upgrade building heating-ventilation/air conditioning (HVAC), lighting, water heating, transportation (lift and escalator) and other systems (Pan, Yin, & Huang, 2008; Sharma, Chani, & Kulkarni, 2013). The technologies adopted include building-integrated photovoltaics, green roof/garden/podium, smart meter, green material, low-energy lighting and LED lighting, grey water collection and re-use. In particular, green roofs/walls have been considered as an efficient method for building green retrofit (Charlesworth, Perales-Momparler, Lashford, & Warwick, 2013; Wilkinson & Feitosa, 2015; Wong & Lau, 2013). This can be attributed to the environmental benefits of green roofs, including improving urban biodiversity, storm water retention, air quality improvement, temperature reduction and mitigation of the heat island effect (Francis & Lorimer, 2011; Gago, Roldan, Pacheco-Torres, & Ordóñez, 2013; Pugh et al., 2012; Santamouris, 2014). Solar energy is another widely-used renewable energy technique, which can be used to generate electricity for the daily demand, heat water for the bathing purpose, cook steam to replace the fossil fuel, and reduce the energy demand in buildings. In addition, the daylight sensor for light (Wacyk, 2002), variable-voltage, variable-frequency drive system for lift (Hutt, Vollrath, & Carey, 2004) and water-flow window (Chow, Li, & Lin, 2010) are also considered as effective renovation approaches for existing buildings.

To identify the retrofit technologies adopted in green retrofit, a systematic review was conducted based on related literatures. Finally, 117 technical methods for building retrofit were collected. With reference to Li et al. (2017), these technologies are grouped into three categories, namely, building service, building envelope and renewable energy, and further grouped into sub-categories. The detailed classification and their distribution are shown in Figure 2.

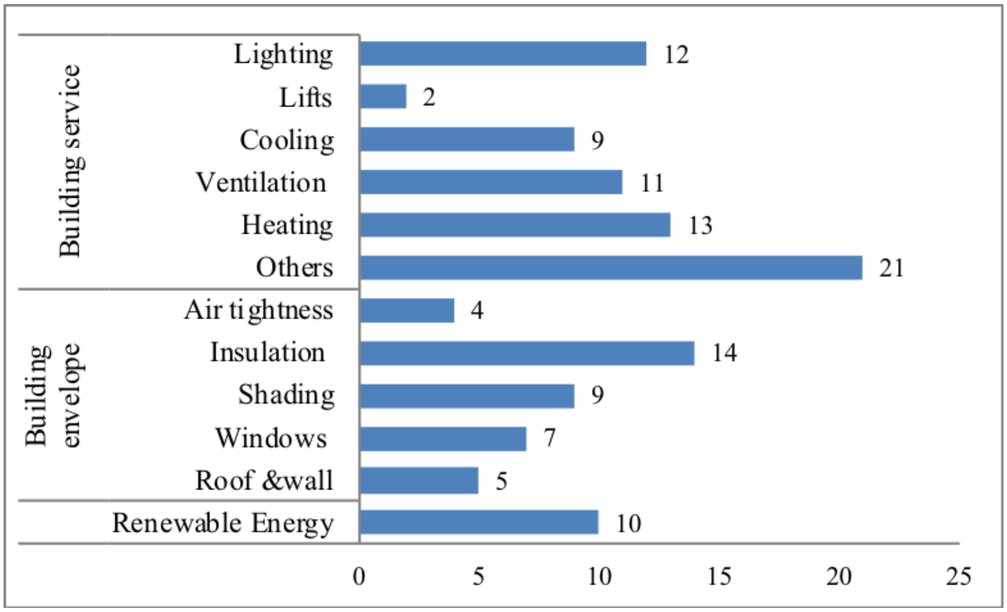


Figure 2 Distribution of existing retrofit technologies under different categories

### *3.2. Policies of green retrofit*

Policies are essential for promoting green retrofit. In this study, the policy refers to the government policy, such as standards or regulations, which influences, encourages and supports the process of building green retrofit (Lindén, Carlsson-Kanyama, & Eriksson, 2006; Wilson, Crane, & Chryssochoidis, 2015).There are great potentials for energy saving and carbon reduction by implementing efficient energy policies (Lester, 2013). Wong and Lau (2013) conducted a preliminary investigation into the potential of retrofitting green roofs in Mongkok district of Hong Kong and argued that incentive programs by the government are helpful for the success of the green roof implementation. Delmastro, Mutani, and Corgnati (2016) reckoned that interest rate is a powerful way for motivating building energy renovation. Lester (2013) supposed the real estate transfer taxes to encourage home buyers to undertake significant retrofit projects at the time of sale. To understand the status quo of refurbishment policies, more than 500 policies in over 29 countries and regions were collected mainly based on International Energy Agency (IEA). The collected green retrofit policies were grouped into six categories: direction-based policies, regulation-based policies, evaluation-based policies, financial support policies, organization & professional training policies and knowledge & information policies. The distribution of collected policies is shown in Figure 3.

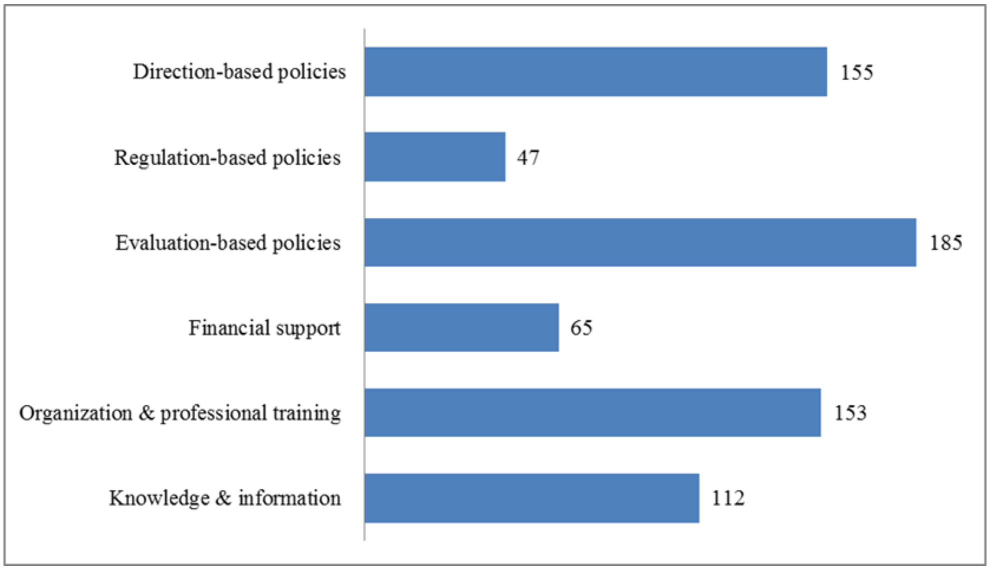

Figure 3 Distribution of existing retrofit policies under different categories

# 4. Applicable green retrofit technologies and policies for residential buildings in Hong Kong

## *4.1. Characteristics of residential buildings in Hong Kong*

Hong Kong is located in a typical sub-tropical region and is one of the most densely populated developed cities in the world (Ma & Wang, 2009). Its overall density is 6540 people/square kilometers. Due to the limited amount of development land (accounting for 24% of the total land area), the high-rise is one of main characteristics of Hong Kong' buildings. In addition, the climate of Hong Kong is hot and humid. In summer, the average temperature is 31 ℃ at daytime and 26 ℃ at night. In this situation, the buildings in Hong Kong are subjected to low heating demands throughout most of the year (Ma & Wang, 2009).

In order to identify the features of residential buildings in Hong Kong, a survey was carried out to collect relevant information. An investigation form was designed for the survey, which consisted of five aspects, including basic information, structure, facilities, services and policies. At the beginning of the survey, residential buildings including private and public buildings were selected. During the survey, private building owners were unwilling to participate, and even rejected the team's request. After discussion, the research team decided to conduct the survey on public housing. There are two reasons to support this decision. The first one is that the relevant information of public housing can be collected with the help of the estate management units. The second reason is that it is easy to promote green retrofit in public housing because they are administrated by the government. Although there is difference between public buildings and private buildings, the investigation on public buildings can represent a profile of residential buildings. In addition, refurbishment technology and policy in public buildings can also be applied to private buildings. Finally, 100 public residential buildings in 12 public housing estates, with building aged 30-39, were surveyed with the help of the Hong Kong Housing Authority. Of these, 10 percent are in Hong Kong Island, 28 percent in Kowloon and 62 percent in New Territories. Most of the items in the form were completed after field research and consultation with the Hong Kong Housing Authority. The collected main information was summarized in Figure 4.

Three main features of public housing in Hong Kong were identified as follows.

1) High rise buildings: 99 percent of the surveyed buildings are over 10 storeys, wherein the buildings with 21-30 storeys account for 64%. According to the investigation, the average height of each storey is 2.6m. Reference to this data, the height of 64 percent of the survived buildings is more than 54.6 metres.

2) Low adoption rate of energy-saving device: for high-rise buildings, lift is a must for transportation. However, 70 percent of the surveyed buildings are not equipped with energy-saving lifts. In addition, only 15 percent of the surveyed buildings are installed with LED; 27 percent are equipped with sensors. It is notable that the window material is ordinary, which may result in high heat gains (in summer) and loss (in winter).

3) Big difference in energy consumption: the average annual electricity consumption of the public area is from 35470.0 to 582454.7 kW·h. It shows a big difference in energy consumption of different estates.

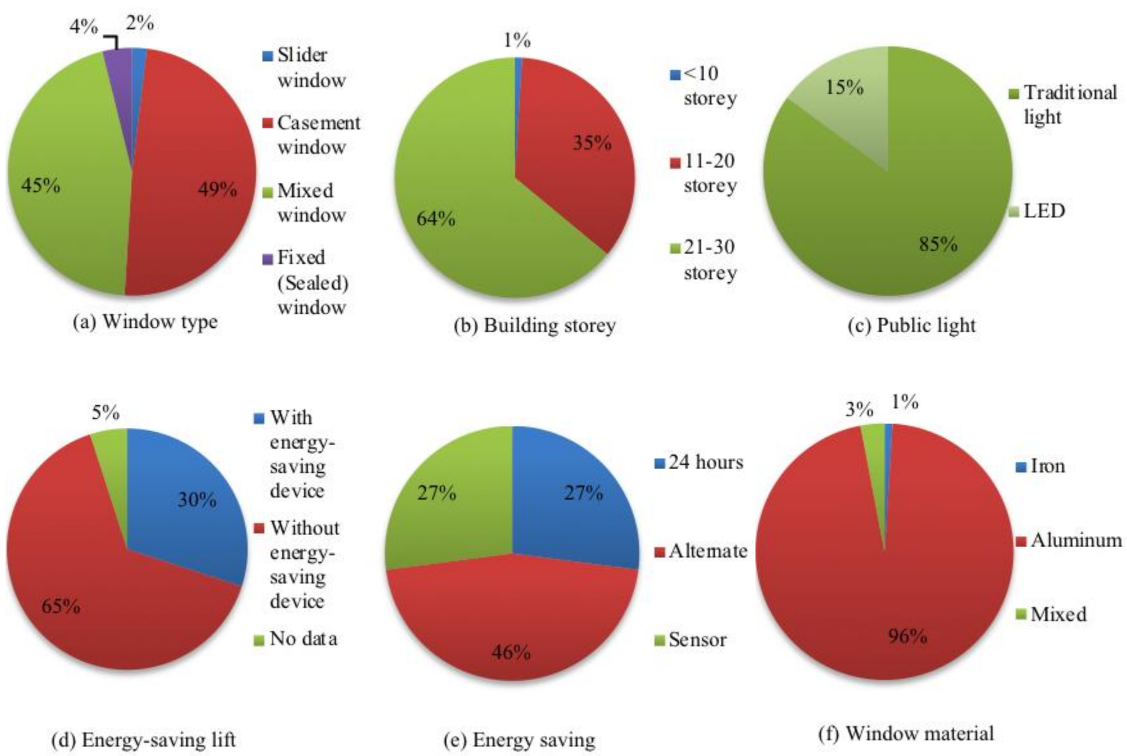


Figure 4 Features of public residential buildings in Hong Kong

*4.2. Policy instruments of retrofit in Hong Kong*

Many efforts have been made by the Hong Kong government to protect the environment. For example, the government has released mandatory policies (e.g., the Buildings Energy Efficiency Ordinance, Building Energy Code, and Energy Audit Code) and financial incentives (e.g., the Buildings Energy Efficiency Funding Scheme and Tax Deduction). At the same time, the Awareness Raising Programmes have been also carried out. To play an exemplary role, the government promulgated the "Energy Saving Plan for Hong Kong's Built Environment 2015~2025+" in 2015.

The Buildings Energy Efficiency Ordinance (BEEO), in effect since 1995, requires that the design and structure of exterior wall and roof of commercial and hotel buildings should be in compliance with the required total heat transfer value. The Buildings Energy Efficiency (Product Standard) Ordinance was launched in 2008, and implemented in two stages. The first stage was conducted in 2009 covering air conditioners, freezers and compact fluorescent lamp. The second stage was implemented in 2011 covering washer and dehumidifier. In 2012, the Hong Kong government implemented mandatory building inspection scheme (MBIS) and mandatory window inspection scheme (MWIS), requiring owners to regularly inspect and repair their buildings and windows. To supplement, relevant financial supports and voluntary schemes were introduced. For example, the Buildings Energy Efficiency Funding Scheme provided subsidies to building owners for conducting energy-cum-carbon audits and improving buildings energy efficiency. In collaboration with the Construction Industry Council (Gourlis & Kovacic, 2016), the government developed Hong Kong's first zero-carbon building to share knowledge and expertise in low/zero carbon building design and technologies, and to help raise community awareness about low carbon living.

These policies contribute to the improvement of energy performance. However, there are still some deficiencies, including the need for building retrofit policies, especially for green retrofit of aged residential buildings, as well as for the difficulties associated with enforcement of existing policies.

*4.3. Applicable green retrofit technologies in Hong Kong*

As aforementioned, suitability for specific use, characteristics, and environment of buildings plays an important role in identifying applicable refurbishment initiatives (Li et al., 2017; Ma et al., 2012). Moreover, Shen, He, Jiao, Song, and Zhang (2016) proposed that the different environments (e.g., political, environmental, economic situation) result in various policies, thus effective policies should fit the local development. To understand the suitability of technologies and policies identified above better, a desktop study was employed to eliminate those that are not applicable to Hong Kong's residential buildings. Based on the identified characteristics of residential buildings and the policy context in Hong Kong, the five criteria, namely, subtropical climate, pattern of energy consumption, suitability for residential building, high-rise buildings and high-density city, and development environment (e.g., political system, economic level and environment condition), are applied in the process of identifying the suitable green retrofit technologies and policies. For example, the technologies and policies on space heating were considered not applicable in Hong Kong. Based on these criteria, 28 technologies and 18 policies were identified, as shown in Table 1 and Table 2.

As shown in Table 1, the retrofit technologies for building service include lighting, lift, cooling and other building services. For lighting system, sensor installation is an alternative solution to save energy. For example, the daylight sensor and the motion sensor are the most popular devices to control lighting (Popat, 2000; Wacyk, 2002). It is also proved that the motion sensor (Webre et al., 2007), smoke sensor (Bukowski et al., 2003) and temperature sensor (Wood et al., 2008) are helpful to improve the energy performance of buildings. In addition, Mahlia, Razak, and Nursahida (2011) proposed that T5 fluorescent lamp is another efficient option for fluorescent lighting system. As shown in Figure 4, 85 percent of lighting is traditional type. It is, therefore, feasible to replace the traditional lighting by fluorescent lamp solutions in the first stage of green retrofit. Besides, a high-performance cooling system is very important for Hong Kong's typical hot and humid climate. The initiatives of cooling, such as installing the evaporative coolers with high energy efficiency, can accelerate the wind flow and reduce the indoor temperature and humidity (Chan, Riffat, & Zhu, 2010). Replacing old type air conditioners with new energy efficent ones is another option. With regard to the lift, the power regeneration system and Variable-voltage, variable-frequency drive system can be employed to improve the efficeincy of lift system (Hutt et al., 2004; Li et al., 2017; Tominaga et al., 2002) in Hong Kong. For example, lifts with power regeneration system can convert the energy generated from the lift motor driven by gravity into electricity, which may save 20% to 30% more energy than the traditional lifts (Tominaga et al., 2002).

Table 1 Recommended green retrofit technologies for Hong Kong

| | Categories | Recommendation | **N.** |
|---|---|---|---|
| Building service | Lighting(BS1) | Low energy lamps (T5 fluorescent) | BS1-1 |
| | | Light emitting diode (LED) lighting | BS1-2 |
| | | Daylight/Motion sensors | BS1-3 |
| | Lift (BS2) | Lifts with power regeneration system | BS2-1 |
| | | Modernize lifts with a VVV-F control system | BS2-2 |
| | | Lifts with permanent magnet motor | BS2-3 |
| | Cooling (BS3) | Evaporative cooling | BS3-1 |
| | | Use energy efficient room air conditioner | BS3-2 |
| | Others (BS4) | Time switches/sensors | BS4-1 |
| | | Use energy efficient appliances and equipment (e.g. appliances with green label, high efficiency pumps) | BS4-2 |
| | | Install meters for energy auditing | BS4-3 |
| | | Domestic water saving devices | BS4-4 |
| | | Grey water reuse and rainwater harvesting | BS4-5 |
| Building envelope | Roof & wall (BE1) | Reflective surface (cool roofs or walls) | BE1-1 |
| | | Green wall/roof | BE1-2 |
| | Windows (BE2) | Window frame with thermal break | BE2-1 |
| | | Reflective coating of window glass | BE2-2 |
| | | Double/multiple glazing | BE2-3 |

| | | | |
|---|---|---|---|
| | Shading (BE3) | Overhangs/Vertical fin | BE3-1 |
| | | Automatic blinds | BE3-2 |
| | Insulation (BE4) | External wall insulation | BE4-1 |
| | | Internal wall insulation | BE4-2 |
| | | Roof insulation | BE4-3 |
| | Air tightness (BE5) | Joint sealing | BE5-1 |
| | | Draught-proofing | BE5-2 |
| Renewable energy (RE) | | Solar water heating | RE1 |
| | | Building-integrated photovoltaics (BIPV) | RE2 |
| | | Building-integrated wind turbine (BIWT) | RE3 |

The green retrofit technologies in building envelope category consist of roof & wall, windows, shading, insulation and air tightness. Wherein, both of the roof & wall and windows have the attributes of the insulation and air tightness. Among the components of building envelope, the roof and wall are also the main structures of buildings with large area. Their performances (e.g., insulation) play important roles in building energy conservation (Nagy et al., 2014). For roof and wall refurbishment, green roof and green wall are advocated technologies (Van Renterghem, Hornikx, Forssen, & Botteldooren, 2013). This can be ascribed to the advantages of green roof and green wall in the reduction of the external noise, greenhouse gas emissions and the urban heat island effect (Wilkinson & Feitosa, 2015; Wilkinson & Reed, 2009). However, there are barriers to green roof and green wall uptake. The lack of awareness and high costs are highlighted by Wilkinson and Reed (2009) in hindering the implementation of green roofs. To tackle with this issue, policy instrument and guidance by the government are reckoned as efficient solutions (Irga et al., 2017). In addition, benefits from the economies of scale is another way to solve the high capital cost (Dowson, Poole, Harrison, & Susman, 2012). With regard to windows, the double glazing windows with high reflective glazing has the benefits of airtight seal, sound insulation and safety (Weir & Muneer, 1998). The other alternatives are the window frame with thermal break, which can reduce the thermal loss and save the air-conditioning electricity consumption. In Hong Kong, 96% of buildings are equipped with aluminum windows with ordinary glazing (see in Figure 4). Therefore, change of existing windows with reflective coating or double glazing in large scale will be cost effective.

The green retrofit technologies for renewable energy involve solar water heating, Building-integrated photovoltaics (BIPV) and Building-integrated wind turbine (BIWT). The application of renewable energy to green retrofit has been advocated by many scholars, such as Golubchikov and Deda (2012) and Darko et al. (2017). A study by Ng, Mithraratne, and Kua (2013) identified that building-integrated photovoltaic (BIPV) improves significant energy savings, and semi-transparent BIPV can be adopted in tropical countries. Chua, Chou, Yang, and Yan (2013) revealed that solar energy is a good heat source to operate chillers in hot and sunny climates. In practice, the use of 20% of renewable energy is set as a target for EU members by Renewable Energy Directive 2009/28/EU (Seghezzi & Masera, 2017). The importance of using renewable energy to achieve high performing buildings has been realized in many countries. However, climate applicability, high cost and long payback period are main challenges in implementing renewable energy (Ruparathna, Hewage, & Sadiq, 2016; Zhou et al., 2016). For example, Li et al. (2017) deemed that renewable energy is not suitable refurbishment initiative for Hong Kong due to high investment cost of renewable energy. In contrast, Shaikh et al. (2017) pointed out that it is feasible to select renewable energy in line with the local renewable energy supply to solve the issue of high cost. In addition, incentive policy is the impetus to encourage the use of renewable energy (Kong, Lu, & Wu, 2012). It can be derived that these barriers can be overcome through optimized incentive strategies. Bearing the long-term benefits of renewable energy and the abundant wind and solar source of Hong Kong in mind, building-integrated solar and wind energy are considered applicable in Hong Kong.

### *4.4. Recommended green retrofit policies for Hong Kong*

The effectiveness of retrofit policy on energy efficiency has been demonstrated in previous studies (Kerr, Gouldson, & Barrett, 2017). The collected green retrofit policies were grouped into six categories: direction-based policies, regulation-based policies, evaluation-based policies, financial support policies, organization & professional training policies, and knowledge & information policies. For these green retrofit policies types, 18 green retrofit policies are recommended to Hong Kong based on its building policies situation (see in Table 2).

Direction-based policies, such as plans, strategies, service as roadmaps to provide the direction in long term (Stieß & Dunkelberg, 2013). For example, with the guide of the direction-based policies, some building developers or the owners may understand what they can do in the future and the market will follow the macro trends. In this manner, direction-based policies have great impact on the development of green retrofit (Dowson et al., 2012). Considering this, the direction-based policies will have more effect on the initial stage, since it shows the future directions and can be adjusted according to real situations. The direction-based policies at the beginning stage are important for sustainable development of green retrofit.

Table 2 Recommended green retrofit policies for Hong Kong

| Categories | Recommended policies | N. |
|---|---|---|
| Direction-based policies (DP) | • Formulate strategy for building green retrofit | DP1 |
| | • Develop a building green retrofit action plan | DP2 |
| | • Develop a guideline on building green retrofit | DP3 |
| Regulation-based policies (RP) | • Incorporate green retrofit element in existing mandatory schemes (e.g., MBIS, MWIS) | RP1 |
| | • Formulate codes, standards and regulations (CSR) for building green retrofit | RP2 |
| | • Promotion programmes for green retrofit | RP3 |
| Evaluation-based policies (EP) | • Establish a new evaluation system for green retrofit or incorporate green retrofit element in existing evaluation systems ( e.g., BEAM-plus) | EP1 |
| | • Establish a labelling system for building green retrofit | EP2 |
| Financial support policies | • Research funds for building green retrofit (e.g. technology, policy) | FP1 |
| | • Low interest loans for green retrofit projects | FP2 |
| | • Tax reduction for building green retrofit companies | FP3 |

| | | |
|---|---|---|
| (FP) | • Initiate subsidy scheme for green retrofit projects | FP4 |
| Organization & professional training (OP) | • Establish an institution of green retrofit or create a green retrofit branch in existing institutions | OP1 |
| | • Provide relevant professional education and training | OP2 |
| | • Encourage specialist contractors in green retrofit | OP3 |
| Knowledge & information (KI) | • Promotion programmes for public awareness of green retrofit | KI1 |
| | • Provide a platform for knowledge & experience sharing (e.g., APP, website and conference) | KI2 |
| | • Encourage innovation in building green retrofit | KI3 |

Regulation-based policies have great impact on promoting green retrofit, which include law, code, regulation and standard (Shen et al., 2016). For example, regulations set minimum energy efficiency requirements for retrofitting of existing buildings (Ma et al., 2012), being taken as a key driver for enhancing building performance (Darko et al., 2017). Other scholars, such as Wetherill, Swan, and Abbott (2014), have found that mandatory regulation policies accelerate the progress of the existing building refurbishment. To initiate energy related schemes, mandatory policies are adopted in many countries, such as China, Japan, Singapore, Germany, Britain, the US, New Zealand and Ireland etc., aiming to improve building energy efficiency. As an example, the enactment of energy regulations in Italian has contributed to the energy reduction of residential buildings (Galatioto, Ciulla, & Ricciu, 2016). Typically, the regulatory policy in China has been taken as the most efficient policy (Huang, Mauerhofer, & Geng, 2016). These regulation policies, to some extent, help the Chinese government enhance building energy efficiency. However, regulatory polices face many obstacles during their implementation. For instance, the scope of application (e.g., political environment, building type) is limited (Baek & Park, 2012). It is worth noting that the inefficient enforcement due to the costs and difficulties is another main barrier (Huang et al., 2016; Weiss, Dunkelberg, & Vogelpohl, 2012). Nevertheless, the efficiency of national legislation, regulation and code on building energy performance cannot be underestimated (Gourlis & Kovacic, 2016). One of the reasons is that if there are no code, standard and regulation for retrofitting, the incentive policies (e.g., financial fund) are difficult to implemented (Jagarajan et al., 2017). As a result, regulation-based policies are suggested in the mid- and long- term of green retrofit and other supporting policies should be adopted to overcome their implementation obstacles in Hong Kong.

Evaluation-based policies (e.g., label, rating, and star) play important roles in promoting the development of green buildings. There are many green building assessment tools, including the Green Star in Australia (Roderick, McEwan, Wheatley, & Alonso, 2009), Building Environmental Performance Assessment Criteria (BEPAC) in Canada (Cole, 1994), the Evaluation Standard for Green Building (ESGB) in China (Ye, Cheng, Wang, Lin, & Ren, 2013), the Eco-Management and Auditing Scheme (EMAS) in the European Union (Iraldo, Testa, & Frey, 2009), Building Environmental Assessment Method Plus (BEAM-Plus) in Hong Kong (Crawley & Aho, 1999), Comprehensive Assessment Scheme for Built Environment Efficiency (CASBEE) in Japan (Cole, 2005), Green Building Certification Criteria (GBCC) in Korea (Kim & Kim, 2013), Sustainable Building Assessment Tool (SBAT) in South Africa, and the Leadership in Energy and

Environmental Design (LEED) in the United States (Lee, 2013). These assessment methods not only help people to understand the green building assessment criteria, but also encourage both users and developers to fulfill the high energy efficiency level of buildings. However, there are also difficulties when implementing these policies, such as complex data collection, evaluation software development and lack of professional assessors, etc. For these reasons, evaluation-based policies are suggested to be conducted in mid- and long- term of green retrofit in Hong Kong.

Financial support policies are considered as one of alternatives for supplement to mandatory regulation policies (Weiss et al., 2012). Compared with the long effect of direction-based and regulation-based policies, these incentive policies are relatively effective in short term (Huang et al., 2016). Based on previous studies, the high refurbishment cost is a vital factor which hinders building refurbishment (Dowson et al., 2012; Hwang et al., 2015; Jagarajan et al., 2017). Due to this, stakeholder (e.g., owner, occupier, building contractor) are reluctant to retrofit their buildings due to high cost (Ruparathna et al., 2017). To enhance their willingness to green retrofit, relevant financial support policies are necessary to compensate the extra costs (Darko et al., 2017). A study by Mickaityte, Zavadskas, Kaklauskas, and Tupenaite (2008) indicates that subsidies, income tax deduction and carbon tax are driver of investments on energy-efficient retrofitting projects. Moreover, financial incentives can provide capital support for the development of new retrofit technologies (Zhou, Levine, & Price, 2010), which will enhance the effectiveness of retrofit and lead to successful rehabilitation (Tryson, 2016). In this manner, the financial support policy is a very important element in promoting green retrofit of buildings (Baek & Park, 2012). Therefore, the financial support policies are recommended in the whole process of implementing green retrofit of residential buildings in Hong Kong. However, there are several limitations associated with their application. For instance, this kind of policy raises fiscal burdens to governments (Baek & Park, 2012). Given this financial pressure, there are less such policies in developing countries in comparison with developed countries (Shen et al., 2016). For the similar reason, European countries have transferred to take advantages of market mechanisms to promote refurbishment (Baek & Park, 2012) in order to release the financial burden. As a result, the financial policies are suggested to focus on the research funds, tax reduction and low interest rate for new green retrofit technologies and building retrofit companies. In a long run, innovative financial policies should be developed in Hong Kong.

Organization & professional training policies, such as research & development (R & D) and association, can help to solve practical problems of green retrofit and to develop new retrofit technologies. For instance, the R & D policies can encourage researchers in universities and research institutes to develop new energy-saving technologies and find possible energy-saving solutions. Professional associations can help coordinate the various stakeholders and organize various activities for promoting green retrofit. Meanwhile, professional skill training and education provided by these associations are also essential for the development of green retrofit (Liang et al., 2016). For these advantages, it is proposed to have organization & professional training policies from the second stage of green retrofit.

Knowledge & information policies are alternative programmes for supplement to mandatory regulation-based policies and financial support policies. In comparison with regulation-based and financial policies, knowledge & information policies are less competent in promoting green retrofit, however, the policy flexibility is one of their prominent advantages (Shen et al., 2016). According to previous studies, information asymmetries, lack of awareness, lack of knowledge and expertise are barriers to improve building performance (Golubchikov & Deda, 2012). These barriers even offset the effectiveness of financial policies. Based on the questionnaires carried out by Huang et al. (2016), the majority of estate developers and households are lacking the relevant knowledge of refurbishement financing. This prevented owners and investors to implement buildings green retrofit because they did not know how to get financial support (Jagarajan et al., 2017). Therefore, the knowledge & information policies (e.g., green renovation propaganda, retrofit policies sharing) can improve the public awareness of green retrofit and related policies. Furthermore, a retrofit process is subject to many uncertain factors, such as uncertainty in savings estimation, energy use measurements, etc., leading to uncertain retrofit results (Weiss et al., 2012). For this phenomenon, the mandatory regulation implementation of green retrofit policies cannot enhance the enthusiasm of stakeholders involved in building refurbishment, and even evoke their discontent. In contrast, knowledge & information policies may overcome this dilemma through flexible retrofit options and experience sharing, etc. (Liang et al., 2016). As a response, it is suggested to implement knowledge & information policies in the whole process of green retrofit development in Hong Kong.

## 5. A framework of green retrofit development in Hong Kong

The above discussions of green retrofit technologies and green retrofit policies were further developed into a framework to guide the development of building green retrofit in Hong Kong, as shown in Figure 5. According to Kong et al. (2012), building energy efficiency can be divided into three stages: pilot demonstration stage, widespread promotion stage, and standard deepening stage. Similarly, the building performance stages are categorized as research preparation, pilot projects, system formation, and system improvement and implementation (Li & Shui, 2015). By referring to these classifications, the stages of building green retrofit are divided into three stages, namely pilot stage, promotion stage and full implementation stage in this study.

The pilot stage focuses on the demonstration of green retrofit pilot projects on small-scales to accumulate relevant experiences of building green retrofit. Due to the small-scales, relevant green retrofit technologies and policies can be easily implemented in pilot projects, whereas it will be a slowly developing period because of the lack of the experience and knowledge of building green retrofit (Kong et al., 2012). Therefore, this period should focus on identifying and solving technology and policy problems occurred in the process of building green retrofit. The promotion stage aims to promote green retrofit of residential buildings on medium scales. At this stage, the accumulated experience and knowledge at the first stage can be applied to more aged residential buildings. More importantly, the technologies and policies of green retrofit should be regulated to provide a guide of building green retrofit. At the full implementation stage, green retrofit of residential buildings will be implemented on large scales with mature technologies and effective policies. Standardization will be a prominent feature of this stage.

For each stage, any recommended green retrofit policies and technologies can be adopted by considering the characteristics of the existing buildings. However, it is suggested to implement different policies and technologies based on the targets of each stage. At the first stage, the guidance and incentive policies (e.g., DP1, KI1, FP4) and minor renovation technologies (e.g., BS1, BE2) related to lighting system and window are mainly suggested to encourage building stakeholders to accept and conduct green retrofit. The guidance policies provide the direction of building green retrofit in long-term, and provide supports to the application of various green retrofit technologies. The minor retrofit technologies with relatively low cost and easy application are selected, such as the reflective coating (BE2-2), double glazing (BE2-3), metering systems (e.g., BS4-3). These technologies are cost effective, easy to implement and have environmental benefits (Ma et al., 2012). At the second stage, some regulation-based and financial support policies can play essential roles in promoting green retrofit in a large scope. Meanwhile, with the increasing public awareness of green retrofit, retrofit technologies about building lift, shading and cooling are advocated. These technologies (e.g., BS2, BS3, and BE3) can be easily accepted by homeowners due to high energy efficiency. Meanwhile, government's financial support can help to solve the high investment cost problem. At the third stage, evaluation-based policies and organization & professional training are reckoned as key policies to regulate green reform market throughout the whole region. During this stage, some technologies with high retrofit cost (e.g., BE1-2) and high energy-efficiency (e.g., renewable technologies) are proposed for the majority of green retrofit projects. At this stage, the technologies may become mature with low capital cost and large scale implementation will also reduce the cost by the economies of scale. Moreover, there is a need to understand the interactive relationship between technology and policy. For example, the financial support policies can help the research and development of renewable energy related retrofit technologies, and the promotion of new technologies need the relevant supportive policies.

Figure 5 illustrates the main policies and technologies during the different stages of green retrofit. This framework provides a full picture of applicable technologies and policies in the development process of green retrofit in Hong Kong, and it also provides guidance for government departments and other stakeholders to develop their new policies or strategical plans for future green retrofit market.

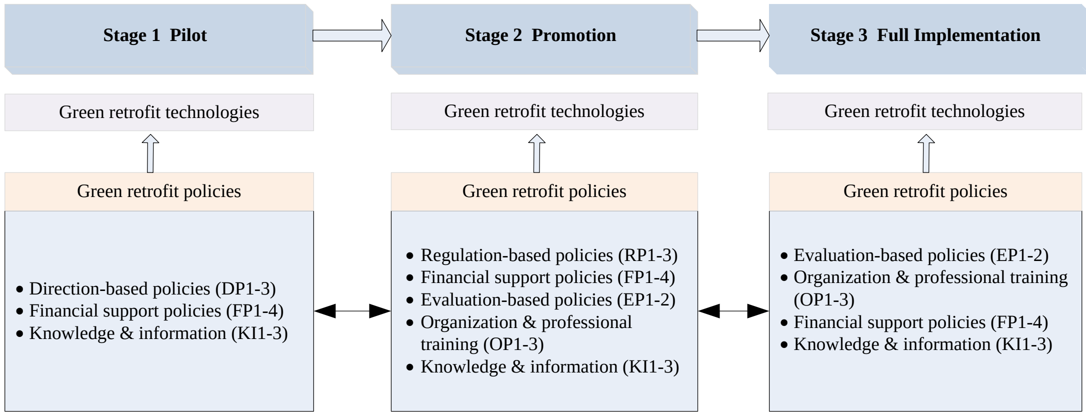


Figure 5 A framework for implementing green retrofit in Hong Kong

## 6. Conclusions

With the increasing number of aged buildings, green retrofit is considered important during the urban renew process. The significance of green retrofit has been studied by many researchers. It is necessary to identify the applicable green retrofit policies and technologies for particular regions by considering the local conditions, such as the climate, development stage, building feature. However, few studies have been done identifying both of applicable green retrofit policies and technologies for particular regions, such as Hong Kong. In this study, a comprehensive literature review on retrofit policies and retrofit technologies was conducted. By considering the local conditions and features of public residential buildings in Hong Kong, 28 technologies and 18 policies were recommended which are suitable for Hong Kong. These 28 technologies were grouped into three categories, namely building service, building envelope and renewable energy. Similarly, the 18 policies are grouped into six categories, including direction-based policies, regulation-based policies, evaluation-based policies, financial support policies, organization & professional training policies and knowledge & information policies. These recommended retrofit technologies and policies were further discussed for their application in Hong Kong.

Currently, most large cities are facing the aging problem, including aged buildings. There are less new constructed buildings in those well-developed large cities every year. Retrofit will dominate the construction market. Therefore, there is a need to study the green retrofit technologies and policies which are suitable for those large high-density cities. This study provides a full picture of applicable green retrofit technologies and policies for existing aged public residential buildings in the context of Hong Kong. Furthermore, a framework of green retrofit development in Hong Kong was developed to guide the future development of green retrofit in Hong Kong. The findings can help local government and other stakeholders to have a better understanding of building green retrofit and develop their future strategic plans for green retrofit, and also provide a good reference for directing the future research in green retrofit. For future study, the relationships between green retrofit technologies and green retrofit policies can be further explored.

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