Title	Sustainable refurbishment solutions for high-rise residential buildings in subtropical areas
Author(s)	Ng, TST; Li, J; Lomas, K; Zou, W
Citation	The 2014 International Conference on Zero Energy Mass Custom Homes (ZEMCH 2014), Londrina, PR., Brazil, 4-6 June 2014. In Mass Customisation and Sustainability in Housing, 2014, p. 266-275
Issued Date	2014
URL	http://hdl.handle.net/10722/201471
Rights	Creative Commons: Attribution 3.0 Hong Kong License

SUSTAINABLE REFURBISHMENT SOLUTIONS FOR HIGH-RISE RESIDENTIAL BUILDINGS IN SUBTROPICAL AREAS

S. Thomas Ng
Department of Civil Engineering,
The University of Hong Kong, Hong Kong,
tstng@hku.hk

Jun Li
Department of Civil Engineering,
The University of Hong Kong, Hong Kong,
h1085008@hku.hk

Kevin Lomas
School of Civil and Building Engineering,
Loughborough University, United Kingdom,
k.j.lomas@lboro.ac.uk

Weiwu Zou
Department of Civil Engineering,
The University of Hong Kong, Hong Kong,
zwwsky@hku.hk

SUSTAINABLE REFURBISHMENT SOLUTIONS FOR HIGH-RISE RESIDENTIAL BUILDINGS IN SUBTROPICAL AREAS

S. Thomas Ng[1], Jun Li[2], Kevin Lomas[3] & Weiwu Zou[4]

[1]Department of Civil Engineering, The University of Hong Kong, Hong Kong, tstng@hku.hk
[2]Department of Civil Engineering, The University of Hong Kong, Hong Kong, h1085008@hku.hk
[3]School of Civil and Building Engineering, Loughborough University, United Kingdom, k.j.lomas@lboro.ac.uk
[4]Department of Civil Engineering, The University of Hong Kong, Hong Kong, zwwsky@hku.hk

Abstract
Building maintenance and refurbishment has become a particular concern in developed economies, as there are many old buildings in urban areas. While various refurbishment methods have been developed for the purpose of sustainable development, these refurbishment approaches are designed for specific climatic condition and building characteristic. Until now, there is not much suggestion on which sustainable refurbishment methods are more suitable for subtropical areas like Hong Kong. This paper aims to bridge this gap by developing a set of sustainable refurbishment methods applicable to high-rise residential buildings in Hong Kong. The research begins by a comprehensive literature review of the existing sustainable refurbishment methods. The results of literature review form the basis of a preliminary screening according to the local climate and buildings feature. Interviews with experienced industry experts are conducted in order to confirm the applicability of the proposed methods. Through the above studies, a list of sustainable refurbishment methods for subtropical regions as well as a set of principles for selecting refurbishment methods are identified. The results of this study should help owners and design team members identify sustainable refurbishment to maximise the chance of success.

Keywords: *Sustainable refurbishment, residential buildings, subtropical areas.*

Introduction
The building sector in Hong Kong consumes a significant amount of electricity (Environmental Protection Department 2010) and is therefore one of the key contributors to greenhouse gas (GHG) emissions (Environmental Protection Department 2010). According to HKGBC (Hong Kong Green Building Council 2012a), the existence of a huge stock of inefficient existing buildings may compound the energy demand of a city, and any improvement to uplift the energy efficiency of existing buildings would be indispensable. However, it is never easy for owners and occupants to identify a set of suitable sustainable refurbishment solutions for their property as there are so many different options available and their effectiveness may vary substantially.

Until now, much research effort has been directed to improve the energy performance of offices and commercial buildings. Examples of these include the improvement in thermal insulation (Bojic, Yik and Leung 2002), introduction of switchable glazing (Yik and Bojic 2006) and other glazing systems (Bojic, Yik and Sat 2002), combination of space cooling and water heating system (Chen and Lee 2010), application of water cooled air-conditioner (Chen, Lee and Yik 2008), etc. Identifying suitable strategies to lower the energy consumption of residential buildings remains relatively sparse (e.g. Gao, Lee and Chen 2009) and this is especially the case in Hong Kong despite a large proportion of private and public apartments in the city.

Being a densely populated city, virtually all residential buildings in Hong Kong are of multi-storey multi-occupant form. With the diverse property rights, refurbishments are

usually carried out in an *ad-hoc* manner unless a major overhaul is commissioned, for example, under the Mandatory Building Inspection Scheme as required by the local law. Therefore, relevant sustainable strategies shall be adopted to commensurate different scales of refurbishment.

Despite much experience has been accumulated in overseas countries, the distinctive climatic condition and building characteristics render them unsuitable for being applied in the Hong Kong scenario (Lam 2000). There is a need to identify a set of sustainable refurbishment strategies which can be applied to the multi-storey residential buildings in Hong Kong. The aim of this paper is to develop a list of feasible options to help owners and occupants of residential buildings in Hong Kong selecting the most appropriate sustainable refurbishment solutions.

The paper begins by outlining the methods used in this research. A list of sustainable refurbishment methods as identified from the literature is reported. The applicability of the identified sustainable refurbishment methods to the Hong Kong scenario is then examined. Finally, the suitable sustainable refurbishment solutions for multi-storey residential building in Hong Kong are highlighted.

Research Methods

With extensive existing body of knowledge in sustainable refurbishment around the world, a literature review should be carried out to identify all the possible sustainable refurbishment solutions. The literature review was not restricted to research papers and relevant reports, but it also covered information in the website. With a comprehensive list of sustainable refurbishment options, the authors can then narrow them down by eliminating those which are not corresponding to the climatic condition and building characteristics of Hong Kong.

As sustainable refurbishment is a rather new concept to the residential sector of Hong Kong, the opinions from construction professional would be extremely useful. Therefore, a series of semi-structured interviews was carried out with experienced industry experts to first confirm the applicability of the identified sustainable refurbishment options and then unveil the determining factor when selecting the sustainable refurbishment strategies.

Table 1 shows the profile of the participants. The samples were randomly chosen from the relevant telephone directories. Seven face to face interviews were conducted with a total of 13 experienced experts agreeing to take part in the interview. All of these 13 experts are holding senior positions in their organisations.

Table 1: Information of the participants

Interview No.	Organisation	Title	Number of participants
1	Government	Chief Manager	2
2	Consultant	Executive Director	1
3	Consultant	Development Director	2
4	Private developer	Project Manager	1
5	Academic	Associate Professor	2
6	Government	Senior Building Services Engineer	2
7	Government & Consultant	Chief Architect, Sustainable Engineer	3

With the consent from the interviewees, the interviews were recorded. The interview transcripts were analysed subsequently. The responses from the interviews concerning the following information were coded, categorized, and summarized: whether and why a method was applicable, and the principles of selecting sustainable refurbishment method.

Sustainable Refurbishment Methods

In the absence of a comprehensive study on sustainable refurbishment solutions for Hong Kong, a literature review was conducted to identify all potential sustainable refurbishment solutions. With increasing attention to the importance of the residential sector, some pilot studies have already been conducted researchers, e.g. EST (Energy Saving Trust 2007), CPA (Construction Product Association 2010), Thrope (2010), Burton (2012) and Hakkinen *et al*. (2012). Sustainable refurbishment measures for the non-residential, however, remain an area of interest to research scientists (e.g. Baker 2009; Gelfand and Duncan 2012). Others such as Clark (1997) and Xing, Hewitt and Griffiths (2011) examined the sustainable refurbishment methods for both the residential and non-residential sectors. This together with the useful findings *viz*. an introduction of sustainable refurbishment (Shah 2012), relevant guidelines (Hong Kong Green Building Council 2010, 2012b) and the tools/frameworks for sustainable decision making (Prupim Developments 2009, Konstantinou and Knaack 2013) provide a solid foundation for the authors to compile a list of sustainable refurbishment methods.

A total of 88 sustainable refurbishment methods were identified, and these methods can be classified into four broad categories namely:

a) building services;
b) building envelope and layout;
c) renewable energy; and
d) user-initiated approaches.

It is worth noting that the sustainable refurbishment methods identified have not been screened for the local relevancy at this stage to prevent some potential solutions being eliminated at this stage unnecessarily.

Preliminary Screening

A preliminary screening was conducted in order to better understand the suitability of the identified sustainable refurbishment methods. To minimize the risk of prejudice in the screening, the identification of criteria should be based on the possibility of applying those methods, instead of the cost, outcome, or any other external influence. At the end, three criteria were identified according to the context of high-rise residential buildings in Hong Kong, namely: pattern of energy consumption, suitability to domestic usage, and relevancy to high-rise building.

Pattern of energy consumption

Energy audits and field surveys conducted by researchers showed that air-conditioning dominate the electricity consumption in subtropical regions as summer season in these areas is hot and humid (Tso and Yau 2003 and Wan and Yik 2004). In contrast, the reliance on space heating is extremely sparse in Hong Kong, and not too many households in the city have installed with appliances for heating up the interior space. It is, therefore, reasonable to eliminate those sustainable refurbishment methods which are related to space heating, such as radiant heating, cogeneration, under floor heating, district or block heating system, mechanical ventilation with heat recovery, heat-recovery chiller system, thermostat for heating or cooling, solar heat intake air, ground source or air source heat pumps, etc. Moreover, as green energy procurement and biomass heating

are not common in Hong Kong, these methods were not considered applicable at least in the near future.

Suitability to domestic usage
Compared with commercial buildings, multi-storey residential apartment have several distinctive characteristics. Except for very luxurious or service apartments, residential towers seldom have centralised heating, ventilation and air-conditioning systems making it impossible to introduce those concepts like the displacement systems, upgrade heat rejection of cooling towers, high efficiency air-cool oil-free magnetic chillers, thermal wheels to pre-cool fresh air, under floor air distribution, evaporative cooling, chilled beams or under floors supply, mixed mode ventilation, multiple-level switching, power-factor correction, etc. Other approaches being proposed by researchers including individual switches, operable windows, mechanical extract ventilation, internal roller blinds, desk fan or locally controlled fan, louvers, etc. should have already exist in most of the families. On the other hand, initiatives like appropriate zoning, shallow plans, and smaller sizes of framing elements are difficult to be implemented in an existing multi-storey building. In Hong Kong, most family members would have left home in the day time for work or school leaving those approaches such as light shelves, daylight and task lighting backup and automatic blinds impracticable.

Relevancy to high-rise building
In Hong Kong, over 90% of the population are living in high-rise residential buildings (Lam 2000). With different statutory, design and practical considerations, it is not easy to introduce any new components to the external envelopes of a building, such as green walls, canopy, dynamic insulation, and double skin façade external blinds, etc. Other initiatives such as roof pond, rafter insulation, loft insulation, integrated balconies in the thermal envelope, passive stack ventilation and basement insulation are not relevant to Hong Kong's multi-storey building perspective.

Applying these three criteria to the preliminary screening, a number of initiatives found in the literature are not applicable to the multi-storey residential buildings in Hong Kong. In the end, only 38 sustainable refurbishment methods are considered more relevant for further study.

Applicability
To better understand the suitability of the 38 identified sustainable refurbishment methods, semi-structured interviews were carried out with experienced industry experts. These experts were invited to express their views on the applicability of each proposed method based on the situation of Hong Kong.

Building services
The interviewees confirmed that low energy lamps such as T8 and T5 fluorescent tubes and electronic ballast are becoming increasingly popular in Hong Kong nowadays. Many refurbishment projects have applied these measures to increase the energy efficiency. While LED lighting is another possible solution, its cost is still rather high and it is doubted if the saving in energy bill can offset the initial cost. Besides, LED lighting works better in the indoor environment with a more stable temperature.

Daylight sensors and motion sensors can also be used to cut off the artificial lighting when the luminance is sufficient or when there is no human activity. In Hong Kong, the public buildings with open corridors would provide a greater opportunity for the installation of daylight sensors. Motion sensor is also restricted by the local fire safety codes, which stipulate that all the staircases must have the lights on throughout the night (Fire Service

Department 2012). Although the Hong Kong Housing Authority has developed and used a two-level lighting system with motion sensors in staircases for new buildings, applying this technology to existing buildings is yet to gain popularity. Time switches could enhance the energy efficiency by reducing the daily operational time of building services equipment. For example, some of the lifts for high-rise residential buildings could be switched off after midnight to reduce the energy consumption.

Power regeneration system and variable voltage variable frequency lift drive has almost become a standard design of new lifts. However, it is a major initiative for existing buildings and would only be justified when a major refurbishment scheme is carried out.

Building envelope and layout
Replacing clear windows with low-emissivity glass, tinted glazing, reflective glazing or multiple glazing can reduce the sunlight and heat from outside and thus cut down the thermal load of air-conditioners. However, the disruption caused by window replacement can be very high especially when the property is still occupied. Besides, some residents would prefer a better visual comfort by not having a heavily tinted glazing system. As for inter-pane glazing, the cost is too high to warrant a widespread usage in Hong Kong.

Although insulations play an important role in energy conservation, interviewees opined that it is almost impossible to upgrade the insulation property of the external envelop in residential buildings unless the external wall covering is completely replaced by one with better thermal insulation property. The chance for substantially improving the thermal insulation of the roof system is also quite low. Despite green roof can be installed to some buildings, the roof area is normally sold with the penthouse property. Furthermore, the effectiveness of the green roof depends on how well it is maintained and this can be rather expensive. As for the vertical fins and overhangs, they are effective means to shade off the sunlight provide they satisfy the statutory requirements and would not affect the structural stability.

All in all, refurbishing the building envelope is less effective than enhancing the building services system not only because of the difficulty and cost of installation but also due to the high maintenance cost. These measures are indeed more applicable to large scale of sustainable refurbishment schemes in order to achieve an ambitious goal of energy conservation.

Renewable energy
By installing phase change materials, the envelope could store heat during the daytime and warm the rooms at night. In subtropical regions like Hong Kong, however, residential buildings consume most of the energy at night as a result of space cooling. Using phase change materials would result in a higher thermal load, and thus adversely increase the energy consumption.

Solar water heating and photovoltaic panels should generate a certain proportion of energy provide there is sufficient sunlight in subtropical regions. However, the limited roof area in the high-rise buildings has restricted their capacity. When solar power is used for water heating, a lack of central hot water supply system for multi-storey residential buildings would restrict its application. Even of superfluous power can be generated by the photovoltaic panels, it cannot be fed back to the existing power grid under the existing regulation. As for wind turbine, none of the interviewees considered it feasible due to high investment cost, lack of space in the urban area and the noise generated. Therefore, renewable energy is not the most practical sustainable refurbishment option for Hong Kong.

User-initiated approaches
Apart from refurbishing the common areas, this study has identified six ways to conserve energy inside the units including reducing the storage temperature of electronic water heater, installing low-flow aerated showerheads, reconfiguring air conditioner's temperature, selecting energy efficiency appliances, stopping the draught, and using induction cooker. The interviewees have confirmed their applicability. However, the uptaking of these measures depends on the residents' awareness of sustainability rather than the technical concerns.

According to the above findings, a list of sustainable refurbishment methods applicable to the multi-storey residential buildings in Hong Kong is identified (Tab. 2).

Selection of Sustainable Refurbishment Methods
The interviewees suggested several principles for selecting sustainable refurbishment methods. Firstly, the condition of a building determines the opportunity of sustainable refurbishment as some measures like the installation of vertical fin, overhang, green roof, photovoltaic panel, and so on would depend on the structural soundness. It is absolutely indispensable to conduct a careful analysis of building condition before any drastic sustainable refurbishment initiative is introduced. On the other hand, policy makers should consider relaxing the regulations so that additional sustainable features can be added to the external envelop if the structure is sound enough.

Table 2: Sustainable refurbishment methods for high-rise residential buildings in Hong Kong

Category		Refurbishment methods
Building services	Lighting	Low energy lamps (T5 fluorescent)
		LED lighting
		Daylight sensors
		Motion sensors
		Electronic ballast
	Lifts	Lift with power regeneration system
		Lifts with advanced VVV-F control system
	Others	Time switches
		Replace water pumps with higher efficiency one
Envelopes and layouts	Windows	Simple coating
		Tinted glazing
		Reflective glazing
		Double / multiple glazing
	Roof and walls	Reflective surface (cool roofs or walls)
		Green roof
	Shadings	Vertical fins
		Overhangs
	Layouts	Rearrangement of lighting circuits to fully utilise daylight corridors
Renewable energy		Solar water heating
		Photovoltaic panels
		Wind turbine
User-initiated approaches		Reducing storage temperature of electronic water heater
		Installing low-flow aerated showerhead
		Reconfiguring air conditioner's temperature
		Selecting energy efficiency appliance
		Stopping the draught
		Using induction cooker

Of various considerations, cost-effectiveness is a key factor when selecting sustainable refurbishment methods. As a result, the life cycle cost as well as the payback period of various feasible sustainable refurbishment options should be thoroughly identified. Preference should be given to those methods with short payback period. In addition, the disruption during and after the sustainable refurbishment measures are introduced should not be underestimated. Any potential disturbance should be eliminated by careful planning and implementation.

While building environmental assessment schemes like the Leadership in Energy and Environmental Design (LEED) and the Hong Kong Building Environmental Assessment Method (BEAM-Plus) can stimulate owners and occupants' desire to adopt sustainable refurbishment measures, suitable policies should be introduced to reward those existing properties with outstanding energy performance. Subsidising owners and occupants to refurbish in a sustainable way can expedite the sustainable refurbishment programme in Hong Kong. A residential property with better energy performance may also result in a more attractive resale or rental value.

Conclusion

This research has identified a list of 88 sustainable refurbishment approaches. Of which, 50 have been considered irrelevant to the Hong Kong climatic condition and building characteristics. Another 10 sustainable refurbishment methods have been eliminated after interviewing the industry experts. Finally, 28 sustainable refurbishment methods are considered as appropriate for the high-rise residential buildings in Hong Kong, and these include measures pertinent to building services equipment, building envelop and layout, renewal energy and user-initiated approaches. The selection of suitable sustainable refurbishment solutions, however, depends on the cost. Government's subsidies would help realise some expensive sustainable refurbishment approaches which could lead to substantial reduction in energy consumption in existing buildings in Hong Kong.

Acknowledgement

The authors would like to thank the Research Grants Council of the Government of Hong Kong Special Administrative Region for their financial support through the General Research Fund (Grant No.: 7160/11). The support of The University of Hong Kong through the CRCG Seed Funding for Basic Research (Grant No.: 201111159093) should also be gratefully acknowledged.

References

BAKER, N.V., 2009, The Handbook of Sustainable Refurbishment: Non-Domestic Buildings, Earthscan, London.

BOJIC, M., YIK, F. and LEUNG, W., 2002, 'Thermal Insulation of Cooled spaces in High Rise Residential Buildings in Hong Kong,' Energy Conversion and Management, 43(2), pp. 165-183.

BOJIC, M., YIK, F. and SAT, P, 2002, 'Energy Performance of Windows In High-Rise Residential Buildings in Hong Kong,' Energy and buildings, 34(1), pp. 71-82.

BURTON, S., 2012, The Handbook of Sustainable Refurbishment: Housing, Earthscan, London.

CHEN, H., LEE, W.L. and YIK, F.W.H., 2008, 'Applying Water Cooled Air Conditioners in Residential Buildings in Hong Kong,' Energy Conversion and Management, 49(6), pp. 1416-1423.

CHEN, H. and LEE, W.L., 2010, 'Combined Space Cooling and Water Heating System for Hong Kong residences,' Energy and Buildings, 42(2), pp. 243-250.

CLARK, W.H., 1997, Retrofitting for Energy Conservation, McGraw-Hill, New York.

CONSTRUCTION PRODUCT ASSOCIATION, 2010, An Introduction to Low Carbon Domestic Refurbishment, Construction Product Association, London.

ENVIRONMENTAL PROTECTION DEPARTMENT, 2010, Greenhouse Gas Emissions in Hong Kong by Sector, Environmental Protection Department, Government of HKSAR, Hong Kong.

ENERGY SAVING TRUST, 2007, Energy-efficient Refurbishment of Existing Housing, Energy Saving Trust, London.

FIRE SERVICE DEPARTMENT, 2012, Codes of Practice for Minimum Fire Service Installations and Equipment and Inspection, Testing and Maintenance of Installation and Equipment, Fire Service Department, Government of HKSAR, Hong Kong.

GAO, C.F., LEE, W.L. and CHEN, H., 2009, 'Locating Room Air-Conditioners at Floor Level For Energy Saving in Residential Buildings,' Energy Conversion and Management, 50(8), pp. 2009-2019.

GELFAND, L. and DUNCAN, C., 2012, Sustainable Renovation: Strategies for Commercial Building Systems and Envelope, Vol. 19, John Wiley and Sons, Hoboken, N.J.

HAKKINEN, T., RUUSKA, A., VARES, S., PULAKKA, S., KOUHIA, I. and HOLOPAINEN, R., 2012, Methods and Concepts for Sustainable Renovation of Buildings, VTT Technical Research Centre of Finland, Espoo, Finland.

HONG KONG GREEN BUILDING COUNCIL, 2010, Green building award 2010, Hong Kong Green Building Council (HKGBC) <http://www.hkgbc.org.hk/gba/pdf/GBA_FinalBrochure.pdf> retrieved on March 13, 2014.

HONG KONG GREEN BUILDING COUNCIL, 2012a, HK 3030: A Vision for a Low Carbon Sustainable Built Environment in Hong Kong by 2030, Hong Kong Green Building Council (HKGBC), Hong Kong.

HONG KONG GREEN BUILDING COUNCIL, 2012b, Green building award 2012, Hong Kong Green Building Council (HKGBC), <http://www.hkgbc.org.hk/ebook/HKGBC_HKGBA2012/index.html>, accessed on 13 March 2014.

KONSTANTINOU, T. and KNAACK, U., 2013, 'An approach to integrate energy efficiency upgrade into refurbishment design process, applied in two case-study buildings in Northern European climate,' Energy and Buildings, 59, pp. 301-309.

LAM, J.C., 2000, 'Residential Sector Air Conditioning Loads and Electricity Use in Hong Kong,' Energy Conversion and Management, 41(16), pp. 1757-1768.

PRUPIM DEVELOPMENTS, 2009, Sustainable Refurbishment: A Framework for Decision Making, Prupim Developments, London.

SHAH, S., 2012, Sustainable Refurbishment, John Wiley and Sons, Sussex, UK.

THROPE, D., 2010, Sustainable Home Refurbishment: The Earthscan Expert Guide to Retrofitting Homes for Efficiency, Earthscan, London.

TSO, G.K. and YAU, K.K., 2003, 'A Study of Domestic Energy Usage Patterns in Hong Kong,' Energy, 28(15), pp. 1671-1682.

WAN, K.S.Y. and YIK, F.W.H., 2004, 'Building Design and Energy End-Use Characteristics of High-Rise Residential Buildings in Hong Kong,' Applied Energy, 78(1), pp. 19-36.

XING, Y., HEWITT, N., and GRIFFITHS, P., 2011, 'Zero Carbon Buildings Refurbishment? A Hierarchical pathway,' Renewable and Sustainable Energy Reviews, 15(6), pp. 3229-3236.

YIK, F., and BOJIĆ, M., 2006, 'Application of Switchable Glazing to High-Rise Residential Buildings in Hong Kong,' Energy and Buildings, 38(5), pp. 463-471.