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Sustainable refurbishment methods for uplifting the energy performance of high-rise residential buildings in Hong Kong

S. Thomas Ng^{a,*}, Wei Gong^a, D. L. Loveday^b

^aDepartment of Civil Engineering, The University of Hong Kong, Pokfulam, Hong Kong

^bSchool of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, United Kingdom

Abstract

Improving the energy performance of existing building refurbishment has been identified as one of the key measures to reduce greenhouse gases (GHGs) emissions and combat climate change. However, little has been done to uncover how human behaviours would affect the selection of refurbishment solutions selection. The problem is particularly obvious for high-rise residential buildings as they are owned and/or occupied by different peoples with idiosyncratic behaviour and preference. In this research, 46 potential methods commonly used for major sustainable building refurbishment in high-rise residential buildings located in cities with sub-tropical climate like Hong Kong were identified through literature review. These sustainable building refurbishment methods are classified under five groups namely energy user pattern, domestic, high-rise building, climate feature and other building characteristics. A questionnaire survey was conducted to examine the feasibility of the identified refurbishment methods based on the perception of owners and occupants. The results show that those methods classified under building services category such as lighting, appliance, ventilation and lift received greater support from owners and occupants. It is interesting to note that owners and occupants did not favour those sustainable refurbishment options which are related to the building envelop when it comes to major building refurbishment. As for the renewable energy refurbishment methods, their acceptability was moderate indicating that there is huge potential for being incorporated into the major building refurbishment. This paper should help improve our understanding on what factors contribute to the satisfaction of owners and occupants of high-rise residential building in a major sustainable refurbishment scheme.

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* Corresponding author. Tel.: +852-2857-8556; fax: +852-2559-5337
E-mail address: tsng@hku.hk

1. Introduction

As the effect of climate change is exacerbating, reducing the greenhouse gases (GHGs) emissions is an imminent task for the years to come. To achieve a significant reduction in GHGs necessitates the joint effort of various sectors with no exception to the construction industry. According to EMSD [1], buildings in Hong Kong take up almost 90% of electricity consumption in the city. Building facilities, therefore, provides an immense opportunity for GHG reduction, and a practical approach is by improving the energy performance of existing buildings through sustainable refurbishment schemes.

Sustainable building refurbishment has attracted serious attention in the research community and the industry in recent years. A thorough review of literatures has revealed that there are numerous sustainable refurbishment solutions which can be applied to improve energy efficiency. However, as the climatic condition, building design, ownership pattern and energy consumption behaviour vary between different countries [2], not all the sustainable building refurbishment methods are applicable or relevant to the Hong Kong context. Applying the sustainable refurbishment concepts to high-rise residential buildings in Hong Kong, therefore, remains extremely challenging.

To successfully introduce sustainable refurbishment in high-rise residential buildings necessitates not only a better understanding of the technical merits and feasibility of sustainable refurbishment options but also the perception of owners and/or occupants towards those measures. By revealing the social and human issues, policy and decision-makers can decide how to promote the application of various sustainable refurbishment solutions to maximum the GHG reduction potential. Until now, there are research gaps between (i) which sustainable refurbishment solutions are more suitable for high-rise residential buildings in HK; and (ii) the relationship between the human behaviours and sustainable refurbishment. This paper, therefore, aims to establish a list of sustainable refurbishment solutions that would suit a major overhaul initiative in Hong Kong and would also maximise occupants' satisfaction.

2. Literature review

According to the theory of reasoned action, the performing behaviour is determined by the intention which can be predicted by one's attitude and subjective norm [3]. It is not uncommon for owners and occupants of the sustainable residential refurbishment projects to stay in their property while work is carried out. Therefore, it is sensible to get the owners and occupants involved in the decision making process [4]. Occupants' norm, attitude and intention towards residential energy consumption would inevitably affect the success of any sustainable building refurbishment scheme. A small change in occupant behaviours, e.g. by lowering the indoor temperatures, using energy efficient light bulbs, turning off the lights when leaving a room, changing the hours of occupation, adjusting the ventilation rates, using various Energy Usage Systems (EUS) for cooking, switching off unused electrical appliances, etc. could lead to a sizeable reduction in energy consumption [5]. On the other hand, the use of innovative technologies and/or materials as well as advance building services systems may also help cut down on energy consumption [6].

Sustainable refurbishment methods can be classified according to different building components [7], building functions [8], technical or non-technical aspects [4], etc. As discussed in the preceding section, not all sustainable refurbishment methods are applicable to Hong Kong. To determine which sustainable refurbishment methods are relevant to the local context, it is necessary to identify suitable criteria to assess the suitability of those methods. Amongst other aspects, the climatic condition [9] and seasonal variations [10] were considered influential. Besides, the building usage as well as owners and occupants' behaviour could also lead to a variation in energy demand. Therefore, five factors were used to determine the suitability of sustainable refurbishment methods and they include: climatic condition, user pattern in energy consumption, relevancy to residential building, suitability for being applied in high-rise construction, and other building characteristics.

While high-rise buildings in Hong Kong are owned and occupied by different people, it is never easy to have a consensus in sustainable refurbishment decisions except for retrofitting, i.e. one of a comprehensive nature and large scale [11]. However, individual owner and occupant could also initiate sustainable refurbishment initiatives at different times. According to Shah [6], refurbishment can be divided into light touch or refresh, medium intervention, extensive intervention, comprehensive refurbishment and demolition. Thorpe, on the other hand, opined that sustainable refurbishment can be in form of a whole dwelling approach or an element by element regime to minimise the disturbance brought by refurbishment [2]. In this research, sustainable refurbishment is divided into three types, namely: minor upgrading, medium scale improvement and major refurbishment.

In order to examine as many possible sustainable refurbishment methods as possible, major refurbishment was chosen as the subject of study. In Hong Kong, major refurbishment is mandated for those buildings which are over 30 years old, and the purpose is to uplift the building condition and maintain a safe living environment. It would be the best opportunity to integrate the sustainability measures in the major refurbishment scheme. As a result, a total of 46 potential sustainable refurbishment methods were selected for further analysis. These sustainable refurbishment methods were grouped under: (i) building services; (ii) building envelop; (iii) building layout; and (iv) renewable energy.

3. Methodology

In order to uncover the feasibility of various sustainable refurbishment methods in Hong Kong, a questionnaire survey was carried out to collect the data. Meanwhile, according to the age of building, refurbishment scale and refurbishment difficulty, building refurbishment were divided into three levels: minor upgrading, medium scale improvement and major refurbishment. This questionnaire focused on major refurbishment for buildings of 30 years or more. For this type of refurbishment, the scale is supposed to be much larger and the difficulty should be higher too. The samples are the residents in Hong Kong who aged 18 or above at the time the survey was conducted.

The questionnaire consists of two parts. The first part is to collect personal background of respondents including the personal background of respondents, age, type of building living in and educational background. The second part of the questionnaire, however, aims to capture respondents' perception on the feasibility of sustainable building refurbishment methods by indicating the degree of acceptability of each building refurbishment methods assuming the degree of acceptability is a close proxy to the feasibility of those sustainable refurbishment methods. A 6-point Likert scale is used to represent the respondents' '5' being extremely acceptable while '0' denoting not unacceptable at all.

The reliability of the data collected from this questionnaire survey was tested through Cronbach's coefficient alpha. Cronbach's alpha [12] is one of the most popular reliability statistics which determines the internal consistency or average correlation of items in a survey to measure its reliability [13]. A mean score ranking technique is used to rank the relative importance of each variable. In this study, the rankings of various sustainable refurbishment methods were achieved by calculating the means for the whole sample. If there were two or more variables with the same mean value, the one with a lower standard deviation would be given a higher ranking [14]. While distinguishing the variations between different groups of respondents was considered beneficial, Levene's Test [15] was adopted to decide whether equal variances between the two groups should be assumed. If $\text{Sig.} > 0.1$, then an equal variance can be assumed. Otherwise, an equal variance should not be assumed. An independent sample t-test was then adopted to test the significance of the mean difference between the two groups. The Statistical Package for the Social Sciences (SPSS) 19.0 software was used to analyse the data and measure the indicators as mentioned above.

4. Results and discussion

The questionnaire survey was carried out in most of different districts in Hong Kong to ensure a wider coverage and hence a better reliability. The questionnaire survey was administered from June to July 2013. A total of 154 questionnaires were distributed. While it is a street survey, a response rate of 100% was achieved. Table 1 shows the classification of the responds. By referring to the personal background of the respondents, 3 questionnaires from those living in Public House and 3 completed by students living in the dormitory were eliminated. As a result, a total of 148 valid questionnaires were used for the data analyses. With the Cronbach's Alpha of 0.934, which was higher than 0.7 and closer to 0.9, the 6-points scale measurement used in the questionnaire survey was considered reliable.

Table 1. The classification of the responds.

Age	Frequency	Type of housing	Frequency	Educational Degree	Frequency
<20	5	Private housing (Tenant)	64	High school or below	75
20-40	65	Private housing (Owner)	74	Undergraduate	50
40-60	48	Others	10	Postgraduate	23
>60	30				

4.1. Ranking of refurbishment methods

Table 2 indicates the mean score ranking results of 46 sustainable refurbishment methods identified. The top ten sustainable refurbishment methods as perceived by the respondents included: energy efficiency appliance selection (S13), low energy lamps (T5 fluorescent) (S1), time switches (S12), motion sensors (S4), LED lighting (S2), enhance metering to audit energy performance (S14), photovoltaic (PV) panels (R3), solar water heating (R2), window frames with thermal break (E6), and mechanical extract ventilation (S8). All these 10 sustainable refurbishment methods had the mean scores of more than 4 or close to 4.5. As for the least feasible sustainable refurbishment methods, they were inter-pane glazing (E3), tinted glazing (E2), light shelves (E12), locating room air-conditioner at floor level (L3), and reflective glazing (E4). The degree of acceptance as perceived by the respondents was low with the mean scores of less than 3. The mean scores of all the identified sustainable refurbishment methods are highlighted in Table 2.

Table 2. Mean score ranking of refurbishment methods.

Code	Refurbishment methods	Mean	Rank	Code	Refurbishment methods	Mean	Rank
S13	Energy efficiency appliance selection	4.52	1	S16	Lifts with permanent magnet motor	4.08	19
S1	Low energy lamps (T5 fluorescent)	4.49	2	E17	Double/multiple glazing	4.07	20
S12	Time switches	4.48	3	S15	External wall insulation	4.06	21
S4	Motion sensors	4.44	4	E16	Internal wall insulation	4.06	22
S2	LED lighting	4.38	5	E20	Replace motors and pumps with higher energy efficiency	3.97	23
S14	Enhance metering to audit energy performance	4.34	6	S19	Roof insulation	3.97	24
R3	Photovoltaic (PV) panels	4.33	7	S9	Ductwork and pipework insulation	3.85	25
R2	Solar water heating	4.32	8	E15	Revising air conditioning set-points	3.83	26
E6	Window frames with thermal break	4.24	9	S10	Evaporative cooling	3.72	27
S17	Mechanical extract ventilation	4.17	10	E18	Check and repair duck work leakage	3.69	29
R1	Modernise lifts with advanced VVV-F control system	4.17	11	E13	Floor or ceiling insulation	3.67	30
S8	Phase change materials	4.16	12	E13	Floor or ceiling insulation	3.67	30

E9	Automatic blinds	4.15	13	R4	Install showers with low-flow aerated showerheads	3.65	31
S3	Reflective surface (cool roofs or walls)	4.13	14	S7	Wind turbine	3.62	32
E7	Green roof	4.13	15	L2	Remote source solar lighting (light pipes)	3.58	33
L1	Daylight sensors	4.12	16	S11	Chilled beams or under floors supply	3.48	34
E8	Optimise lighting circuits to fully utilise daylight corridors	4.11	17	S18	Building management system	3.46	35
E5	Lift power regeneration system	4.09	18	S5	Induction cooking	3.34	36
Code	Refurbishment methods	Mean	Rank	Code	Refurbishment methods	Mean	Rank
S6	Reduce hot-water storage temperature	3.33	37	E4	Reflective glazing	2.78	42
E11	Overhangs	3.12	38	L3	Locating room air-conditioner at floor level	2.69	43
E19	Door insulation	3.12	39	E12	Light shelves	2.64	44
E10	Simple coating	3.04	40	E2	Tinted glazing	2.55	45
E1	Vertical fins	3.04	41	E3	Inter-pane glazing	2.03	46

4.2. Most acceptable sustainable refurbishment methods

Energy efficiency appliance selection (S13) was ranked as the utmost acceptable method. Burton [4] indicated the use of electricity by appliances involves huge amount of energy and selecting energy efficiency electrical appliances will help reduce energy consumption. Consumers can easily select energy efficiency appliances by making reference to various energy efficiency labelling schemes, e.g. Green Seal, Scientific Certification Systems, Energy Guide, Energy Star, Green-e, etc. [16]. Respondents found this very acceptable when making decisions on purchasing the electrical appliances as it would lead to energy and cost savings in their daily life. Although this is more essential to minor upgrading and medium scale improvement, respondents strongly believed that it is equally applicable to major refurbishment.

The use of low energy lamps (T5 fluorescent) (S1) is the second most acceptable method. Upgrading existing fluorescent light fixtures become a backbone of commercial lighting upgrades according to Gelfand and Duncan [8], and this is also relevant to domestic lighting upgrades from the perceptions of the respondents. Low energy lamps (T5 fluorescent) can help reduce the energy bill, save energy, cut down on the frequency of bulb changes, and thus lower the carbon emissions. Most literatures pointed out that low energy lamps (T5 fluorescent) is a very important approach for sustainable building refurbishment [2,4,6,7,8,17,18,19,20,21,22,23]. With the government's supporting on low energy lamps like a strong subsidise in many provinces of China, low energy lamp has gain widespread usage by residents. Compared with LED lighting, low energy lamp is more acceptable due to the lower initial cost.

The third most acceptable refurbishment method is time switch (S12). As stated in Baidu Wikipedia, 'every morning when the sun rises, automatic curtain is slowly opened wake your sleeping; nightfall, curtains are automatically pulled together, an intelligent warm and wonderful home embrace you all the day'. This introduction indicates that timer switch plays an important role in people's lives which brings greater convenience to residents. That is why occupants tend to support this smart method.

Motion sensors (S4) come out to be the fourth most feasible sustainable refurbishment method. Fitting a motion sensor light switch to automatically turn off lights of an empty room is with very high potential in existing building refurbishment. Motion sensors can be easily installed to automate the lights and other applications in home [24]. Installing occupancy sensors in areas with intermittent usage should be strongly recommended despite putting an easy to understand label to remind users to turn off the lights when not in use can equally serve the purpose [6].

LED lighting (S2) is the other most acceptable refurbishment method of the same category with low energy lamps (T5 fluorescent). Majority of the literatures considered LED lighting as the preferred lighting sources for residential purpose [2,4,7,8,9,18,19,22,23,24]. LED lighting has a variety of colours and this could help create a stylish atmosphere [2] without generating excessive heat as secondary product when they are switched on [25]. However, a comparison between LED lighting and low energy lamps (T5 fluorescent) should be based on their performance, cost and electrical efficiency etc., and this could affect the ultimate decision.

4.3. Unfavourable sustainable refurbishment methods

From Table 6, inter-pane glazing (S22) was considered the most unacceptable refurbishment method due to the high initial cost. Besides, the inter-pane glazing system reduces the indoor temperature by automatically controlling the amount of sunlight penetration. For residential buildings, occupants like taking advantage of natural ventilation by opening the windows, and this may defeat the function of inter-pane glazing. The disruption caused by replacing the window should also be taken into account especially when the property is occupied. Therefore, inter-pane glazing system is seldom specified in residential building refurbishment in Hong Kong [7].

Interestingly, tinted glazing (S21) was also considered an unfavourable sustainable refurbishment method by the respondents. Tinted glazing is used to reduce the thermal transmittance and solar heat gain [26]. However, the China Glass Network reported in 2013 that tinted glazing in urban residential buildings can block off half of the solar radiation which plays the important roles as steriliser, disinfectant and deodorant. The low visible light transmittance of heavily tinted glazing would lead to a greater reliance on artificial lighting which would increase the demand for electricity in the day time [27].

Light shelf (S31) is an integrated approach to address the daylight distribution function and selective shading [7]. There are three common approaches to shade off the daylight, i.e.: external, internal and inter-pane [6]. While the suitability of the external approach depends on the structural soundness of the façade and safety considerations, the internal approach would affect the interior space which is particular precious for residential occupants as average apartments in Hong Kong are very small. Therefore, light shelf was considered a less popular method for sustainable refurbishment.

Usually, air-conditioners for domestic units in Hong Kong are located at high level. While research findings showed that there would be a 6.9% energy saving by installing the air-conditioner at the floor level (S42) [28], see Fig. 1, this would require a very substantial change to the façade. In Hong Kong, the façade is usually constructed by concrete, and any such change would inevitably result in the forming of a new opening in the external wall to house the air-conditioner. Even if the statutory bodies approve such alteration to the structure, the nuisance brought by the work could be very high. As a result, the respondents did not support the use of floor-level air-conditioner to improve the sustainability.

Reflective glazing (S23) was also ranked very low. The reflective glazing returns most of the solar radiation to the atmosphere [29]; however, reflective glazing is causing more and more concern in an urban environment especially from the perspective of light pollution. Some countries have already limited the daylight reflectance of glazing to minimise the social and environmental impacts. When applied to residential buildings, the effectiveness of reflective glazing may not be as optimal as being used in office premises as occupants would still prefer opening the windows to enjoy natural air.

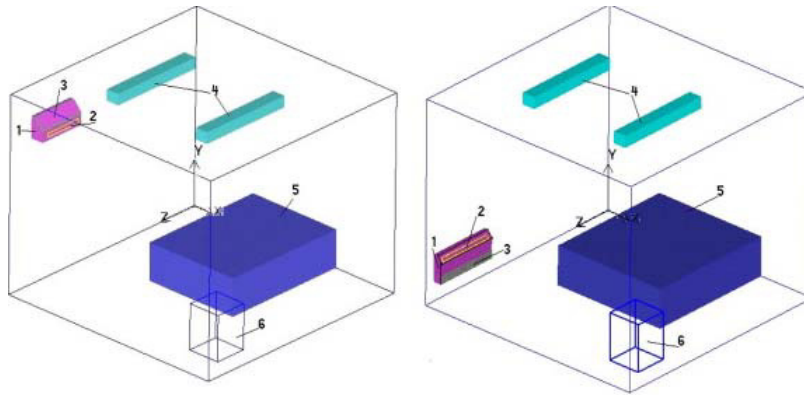


Fig. 1. (a) CAC Model; (b) FAC Model. Remarks: (1) air-conditioner; (2) outlet; (3) return; (4) lamps; (5) bed; and (6) heat generator [28].

4.4. Comparison between different residents type groups

T-test was used to test the significance of the mean difference between different resident type groups: the tenant group and owner group. Methods with significant difference between Tenant & Owner were identified under t-test which met the condition 2-tailed Sig. Should be less than 0.05. Reduce hot-water storage temperature (S6), Simple coating (E1), Tinted glazing (E2), Reflective glazing (E4), Door insulation (E19) were found to be more acceptable by tenants in private housing, while Automatic blinds (E9) was the only method with more preference by the private housing owners.

5. Conclusions

In this paper, various energy-efficiency measures which may be adopted during the sustainable refurbishment exercise have been examined. However, the selection of sustainable refurbishment strategy will depend more on the acceptability of owners and occupants. The results of the questionnaire survey should help decision-makers realise the most favourable and unfavourable sustainable refurbishment solutions for high-rise residential buildings in Hong Kong.

All in all, replacing the building services components and systems, especially for lighting, electrical appliance, ventilation, lifts, etc. have received much greater support from the owners and occupants surveyed. Improving the building envelopes such as windows and shading are not so acceptable. As for the solutions related to renewable energy, their acceptability are improving indicated there is huge potential for being incorporated into major sustainable residential refurbishment schemes. Factors affecting occupants' satisfaction to sustainable refurbishment include initial cost, operational cost, comfort, and service life. It is necessary to address the concerns of owners and occupants in order to maximise the chance of success of sustainable refurbishment schemes.

The research described in this paper is not without limitations. First, the sustainable refurbishment methods identified were mostly from foreign literature targeting different climatic condition, and some relevant methods could have been missed out in this study. Second, this paper only focuses on major refurbishment, and comparison with minor upgrading and medium scale improvement is inevitable to unveil the differences. Finally, the responses of the questionnaire survey are dominated by the private owners and occupants and this may affect the reliability of the findings. It is recommended further survey and comparative study shall be carried on to identify the factors influencing the success of a sustainable refurbishment project before, during and after renovation.

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