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Thermal insulation and cost effectiveness of green-roof systems: An empirical study in Hong Kong

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A R T I C L E I N F O

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A B S T R A C T

Hong Kong is a densely populated city with high density of skyscrapers and the population is typically concentrated on 30% of the land. The adoption of skyscrapers is therefore common to maximize its capacity. As a result, the need of open space and greenery in our built environment is thus often neglected. In recent years, many building professionals promote green-roof systems to increase green space. This paper investigates the effectiveness of using green-roof systems. Questionnaire surveys and interview discussions are conducted. It is found that the questionnaire respondents are interested in implementing green-roof systems and understanding their environmental, economical and social benefits. Three case studies are also conducted to show the effectiveness of green roofs thermal insulation. The results show that green roofs can reduce the inside temperature by up to 3.4 °C. However, the respondents were not willing to invest a large amount of money for green-roof systems. It is suggested that governments should take leading positions to promote green-roof systems. This paper can provide insights on the use of green roofs in Hong Kong and around the world focusing on cost effectiveness and thermal insulation effectiveness.

1. Introduction

In Hong Kong, high pollution and lack of greenery have become serious problems to our built environment and communities [1–5]. Majority of buildings are high-rises and their roof areas are typically very limited. As built environments are commonly very densely concentrated, putting greenery on some intermediate roofs and man-made structures such as podia, sky gardens and covered walkways could significantly enhance the surrounding built environment [6–13].

Although green-roof research is comparatively new, its publication rate has dramatically increased in the last 20 years [14]. Green roofs suffer from water stress during long dry periods. Periodically, irrigation is usually required to maintain the health of green roofs [15]. Net shortwave radiation of the canopy is also one of the key parts for green-roof energy balance [16]. Hydroponic green roofs can also reduce rooftop's temperatures and heat amplitude in subtropical climates such as Taiwan [17]. The implementation of green roofs may also relieve heat-island effect problems [12,13]. However, its economy and environmental protection have not been clearly identified [18–26]. Thirty-three green roofs in southern Ontario were surveyed and samples of planting media were recovered for hydrological analyses [27]. Different vegetation types and covers were also studied and found to be important for roof cooling [28]. Green roofs' temperatures have initially been found to be close to the air temperature and green roofs may also provide thermal insulation, runoff reduction, and carbon uptake, but might require irrigation during dry periods [29]. Despite their rising popularity, studies on green roofs thermal insulation performance are however limited. A study in a Central New York climate found that a green roof dampens the extreme responses often observed on urban roofs. Vegetation and substrate layers may be used as insulation, but they are not recommended in lieu of insulation [30]. Energy balance analysis indicates that evapotranspiration and long-wave radiation dissipate most of heat gain for green roofs, and soil water content has a significant impact on energy balance [31]. It is difficult to find out the intangible benefits, i.e. visual aesthetic improvement, health and therapeutic value and ecological value [32–35].

According to the direction announced by the Hong Kong Special

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Administration Region in 2000 to green-up Hong Kong by planning more planting in the urban areas, the Steering Committee on Green established in December 2002 formulated related strategies and supervised the implementation of major programmes. However, no short-term measures or long-term programmes have been set up because of different opinions from bureaux and departments, lack of public consulted opinion and professional knowledge. This paper thus investigates the effectiveness of green-roof applications in Hong Kong. Thermal insulation, capital and maintenance cost, and tangible and intangible benefits are also examined to provide short-term and long-term recommendations for green-roof applications in Hong Kong.

2. Green-roof systems

A green roof is a conventional roof that is covered with a layer of vegetation [36]. Green roofs serve several purposes for a building, such as absorbing rainwater, providing insulation, creating a habitat for wildlife, lowering urban air temperatures and combating heat-island effects [36]. A green-roof system should include a waterproofing layer, a root barrier, a moisture mat, a drainage grill, a filter layer, vegetation soil and vegetation. The purpose of the root barrier is to prevent plant roots damaging waterproofing materials. The moisture mat is to absorb surplus water overflow from the drainage grill. Excessive moisture will be absorbed by vegetation soil during a dry period through evaporation processes. The drainage grill is used to keep a certain amount of water so that the vegetation soil can remain moist during dry period.

Green-roof can be classified as extensive and intensive systems. An extensive green roof is characterised by thin soil, limited or no irrigation requirement, low water retention and poor nutrient conditions can be classified as either extensive or intensive green roofs. An extensive green roof is characterised by thin soil, limited or no irrigation requirement, low water retention and poor nutrient conditions for plants [37]. An intensive green roof is characterised with deep soil, irrigation requirements, high water retention and fertile conditions for plants [37]. A summary of the characteristics of extensive and intensive green roofs is shown in Table 1.

The top three critical barriers encountered in implementing green roofs were highlighted as ‘Lack of promotion from the government and social communities among the public and private sectors’, “lack of incentive from the government towards the owners of the existing buildings” and “increase in maintenance cost” [38]. Barriers exist in the whole building life cycle process, including plan and design, construction and operation and management stages. It was also argued that the current gap in the life-cycle analyses on green roofs is due to weak focusing on the substrate [39]. These major problems are practically because of fertilizer usage during a disposal phase. Various types of green roofs, components of a green roof, economic revenues and technical attributes have been reviewed [40]. The use of indigenous vegetations for reducing water consumption and increasing energy efficiency for different geographical regions was recommended as possible solutions. Optimal green-roof areas being kept within the cost of a conventional home over a specific life time, such as 50 years have also been discussed [5].

3. Research methodologies

To explore the effectiveness of green-roof systems in Hong Kong, a questionnaire survey was conducted. The aim of the questionnaire survey is to assess tangible and intangible benefits of green roofs, to identify particular concerns from professionals, owners and end-users when proposing green roofs, and to examine priorities among capital costs, technical and design considerations as well as maintenance costs. 1000 questionnaires were sent out to professionals, including architects, engineers, surveyors, landscape architects, property management staff, contractors, environmental protection officers and educationists. 357 responses were received, with the response rate of about 35.7%.

After conducting the questionnaire survey, face-to-face interviews were also conducted with seven professionals, including two environmental protection officers, three architects and two educationists, to further elaborate the questionnaire results.

To investigate the thermal insulation and cost effectiveness of green-roof systems, three case studies: (i) Lady Shaw Building, Chinese University of Hong Kong; (ii) Runme Shaw Building, University of Hong Kong; and (iii) Effort Industrial Building, Hong Kong Greenlink Kusters Company Limited, were conducted. These three projects have different green-roof systems, species of plants and environmental conditions so that different resultant performance can be measured. The temperature difference between green rooftop and ceiling beneath the rooftop are measured and analyzed to reflect thermal insulation performance of green roofs. Measuring points are located at the green–roof's surface, soil substrate and at the ceiling immediately beneath the rooftop. The measurement locations are shown in Fig. 1, which is undertaken in the middle of the room to avoid the effects from windows and doors. The temperature is measured using an infrared thermometer and a digital

Table 1
Comparisons between extensive and intensive green-roofs [37].

	An extensive green-roof	An intensive green-roof
Brief description	Thin soil (50 mm-150 mm thick) Limited or no irrigation Low maintenance (HK$0.8 to $2.25/m^2/year) Extensive application over large area for optimal environmental benefits	Deep soil (200 mm-2000 mm thick) Irrigation Normal maintenance (HK$6.5 to $44/m^2/year) Intensive capital and maintenance input for optimal benefits
Advantages	Lightweight (80–150 kg/m^2) Low maintenance Suitable for retrofit projects Relatively inexpensive (HK$400 to 1000/m^2) Suitable for large areas Suitable for roofs with 0-30° slope Can leave vegetation to develop spontaneously	Diverse utilization of roof (i.e. for recreation, growing food, as open space) with direct benefit to owner Greater diversity of plants and habitats Good insulation properties Can simulate a wildlife garden on the ground Can be made very attractive Often visually accessible
Disadvantages	Limited choice of plants Usually no access for recreation or other uses May be visually unattractive to some, especially in dry season	Relatively high cost (HK$1000 to 5000/m^2) Not usually suitable for green roof retrofit projects Greater weight loading (300–1000 kg/m^2) Need for irrigation and drainage systems hence, greater need for energy, water material, etc.

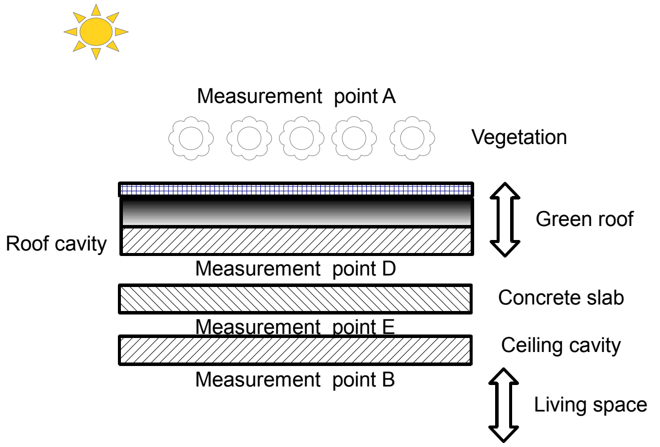

Fig. 1. Schematic diagram of measurement.

thermometer with a metal stick sensor. The infrared thermometer is used to measure surface temperatures of plants and the top floor ceiling beneath the green roofs. The digital thermometer is used to measure the temperatures in the soil substrate. The temperature measurements for the case studies are all conducted at a similar time of the day of around 12 noon in similar weather patterns to avoid disturbances to the measurements by the surroundings. In-depth interviews were carried out to understand background information of the buildings and the green-roof systems, particularly capital and maintenance costs. Cost-benefit analysis studies of their green-roof systems are then examined.

4. Results and discussions

The survey respondents are categorized as architects (about 10%), engineers (about 20%), surveyors (about 23%), landscape architects (about 2%), property management staff (about 15%), contractors (about 15%), environmental protection officers (about 3%), educationists (about 3%) and others (about 9%). From the survey results, about 38% of the respondents have been involved in green-roof projects; while about 62% of the respondents did not. The results indicate that majorities of the respondents have no actual involvement in green-roof projects. This shows that green-roof applications are not widely adopted in Hong Kong.

From the survey results on the suitable building types for the implementation of green-roof systems in Hong Kong, about 74%, 61%, 32%, 69%, 57%, 79%, 70% and 7% considered that residential, offices, industrials, shopping centres, hotels, education institutions, community centres and others are suitable for the implementation. The above respondents' involvement in green-roof project is higher than 100% as each respondent is allowed to select up to 5 choices. The results reveal that green roofs can be applied to different types of building. Educational institutions, residentials, community centres, shopping centres and offices are densely populated and green roofs can be effectively used. The roof areas in industrial centres are mostly possibly be used for the placement of building service plants and other facilities. Therefore they are less suitable comparing with other types of buildings, noted by the interviewees.

Over half of the respondents prefer a green roof with area about 51 m^2–100 m^2 (about 34%) and about 101 m^2–200 m^2 (about 21%). This may be due to higher efficiency from larger green roofs. There are about 26% of the respondents prefer a green roof with at least 200 m^2. The others prefer about 10 m^2–50 m^2 (about 8%) and 151 m^2–200 m^2 (about 11%) from the survey results.

Table 2 summarizes the benefits from the implementation of green-roof systems. The results show that green-roof applications would bring many benefits to the buildings, our community and the environment. All interviewees agreed that green-roof systems can improve our built environment such as air quality, thermal and sound insulation and mitigation of urban heat-island effect.

The respondents agreed that green roofs can improve visual aesthetic value of buildings which is ranked as the first benefit from the survey results because its attractiveness, noted by the interviewees.

Improving air quality and reducing urban heat-island effect are ranked as the second and third benefits respectively in the implementation of green roofs from the survey results. The interviewees explained that climate change has already made significant changes to the environment. It is therefore very necessary to implement green roofs to green-up buildings.

The respondents are doubtful that whether greening roofs can increase their life, which is ranked as the least benefit from the survey results. One possible reason is that green roofs may lead to leakage problems and blockage. The weight of the green roof is also one of the major issues affecting the roof life, noted by the interviewees.

There are five major considerations for the implementation of green roofs in the buildings, including: i) construction costs; ii) repair and maintenance costs; iii) cost on accommodating roof areas and removing existing facilities; iv) financial subsidy grants towards capital costs; and v) rate reduction. There are very similar results among these five issues from the survey results (see Table 3). It is revealed that each factor weighs similar importance to the respondent's decision. Most interviewees agreed that capital and maintenance costs are the major considerations in most green-roof applications. Government financial incentives thus become an essential consideration to promote green-roof applications. Funding for the development of urban greenery should be established among governments, developers and the public. Besides, technical problems such as loading capacity, leakage and drainage are other issues that the interviewees were concerned. A successful development of green roofs is usually relied on efforts from different professions such as landscape architects, surveyors and engineers. Establishing an organization for urban greenery can assist in the coordination of different professions and knowledge sharing. Moreover, government policies and requirements on green features encourage developers to spare greening areas for new developments. The concept of urban planting could also be promoted to the public for long-term benefit with sufficient guidelines and support from different professions and governments. All interviewees agreed that green-roof applications are cost-effective ways to further develop green buildings. The interviewees also revealed that increasing soil depth and developing other renewable energy components can typically bring significant economic benefit and shorten the payback period.

From the survey results, about 35%, 45%, 12%, 3%, 1% and 4% of the respondents accept less than HK$1,000, between HK$1000 and HK$2,000, between HK$2000 and HK$3,000, between HK$3000 and HK$4,000, between HK$4000 and HK$5,000, and more than HK$5000 respectively per meter square for the capital costs for a green roof. In general, the respondents are not willing to invest a large amount of money in green-roof systems. The green-roof concept is still new in Hong Kong, the advantages of applying them may not be understood by the public and therefore what they are willing to pay on this aspect is lower than other household expenditures.

About 26%, 23%, 21%, 15%, 6%, 3% and 6% of the respondents accept less than HK$0.5, between HK$0.5 and HK$1.0, between HK$1.0 and HK$2.0, between HK$2.0 and HK$3.0, between HK$3.0 and HK$4.0, between HK$4.0 and HK$5.0, and more than HK$5.0

Table 2
Benefits from the implementation of green-roof systems.

Benefits	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Mean	Ranking
Amenity and aesthetic benefits							
Leisure and open space	0	3	6	54	37	4.25	4
Visual aesthetic value	0	1	7	47	45	4.36	1
Health and therapeutic value	0	2	32	44	22	3.86	7
Environmental benefits							
Improving air quality	0	1	5	54	40	4.33	2
Reduce urban heat-island effect	0	1	8	49	42	4.32	3
Ecological and wildlife value	1	3	45	37	14	3.60	8
Stormwater management	0	10	47	30	13	3.46	9
Economic benefits							
Building insulation and energy efficiency	0	0	11	60	29	4.18	5
Increase roof life	0	18	47	27	8	3.25	10
Green building assessment and public relations	0	2	26	51	21	3.91	6

Table 3
Major consideration for implementing green-roof systems.

Consideration areas	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Mean	Ranking
Construction costs	0	2	13	51	34	4.17	2
Repair and maintenance costs	1	3	4	54	38	4.25	1
Cost on accommodated roof area and remove existing facility	0	2	11	60	27	4.12	4
Financial subsidy grants towards capital costs	1	2	9	57	31	4.15	3
Rate reduction	0	4	15	48	33	4.10	5

respectively per meter square for the maintenance costs of a green roof. The possible reason for this result is that there are different types of consumers having different objectives on their green roofs. For example, an interviewee of the Case Study I merely uses the green as additional open space for students and staff from the university, he is only willing to pay low maintenance costs for the green roofs. On the contrary, another interviewee noted that they are willing to pay high maintenance costs to upgrade their corporate image and improve competitiveness of the properties and thus obtain a leading role in the construction industry. Therefore, there are different consumption levels in the market.

From the survey results, different degrees of thermal insulation performance can be achieved from green roofs: 1-2 °C (about 9%), 2-3 °C (about 39%), 3-4 °C (about 28%), 4-5 °C (about 14%) and more than 5 °C (about 10%). The majority of the respondents (about 41%) believed that about 10–15% of the electricity costs can be saved using air conditioning from green roofs. The other respondents considered that less than 5% (about 15%), 5–10% (about 25%), 15–20% (about 12%) and more than 20% (about 7%) of the electricity costs can be saved.

About 82%, 69%, 39%, 38% and 30% of the respondents considered that governments, private sectors, building profession, environmental protection and all citizens respectively should be responsible for the promotion of green roofs. The total sum of the above involvement is higher than 100% as each respondent is allowed to select up to three choices. It can obviously be seen that the government plays an important role to promote green-roof applications in Hong Kong. In fact, the government should play a leading role for the implementation of green roofs on all new developments, and to review retro-fitting of green roofs for the existing buildings. More importantly, provision of financial and technical assistance is indispensable to drive private developers and public for applying green roof systems. However, the respondents also thought that the responsibilities should not be solely on the government, private sectors should also share the responsibilities.

All interviewees agreed to engage with stakeholders including building professionals, construction developers and contractors as well as buildings owners to encourage green-roof developments with direct and indirect incentives including cash grants towards capital costs to building users, provision of additional gross floor area exemption and bonuses to private developers and revision of the existing requirements and policies on the green features. From the views of all interviewees, a continuous benefit from green roof is worth the efforts and expenses.

5. Case studies

Three cases studies are carried out: (i) Lady Shaw Building, Chinese University of Hong Kong; (ii) Runme Shaw Building, University of Hong Kong; and (iii) Effort Industrial Building, Hong Kong Greenlink Kusters Company Limited, to investigate thermal insulation, and capital and maintenance costs of green-roof systems.

Table 4 summarizes the details of the case studies. Figs. 2–6 show the building plans for these case studies.

From the measured temperatures from the three case studies (see Tables 5–7), the great effectiveness in thermal insulation of both intensive and extensive green roofs is evident. With the aid of green roofs, temperatures can practically be lowered by up to 3.4 °C.

From Fig. 7, it is clear that deeper soil has greater thermal insulation performance. The deeper soil may have high efficiency in moisture retention, leading to high evaporation efficiency for plants, resulting in high thermal insulation performance. Duranta repens L. has the highest foliage density whose shadow can effectively reduce heat to the ceiling beneath the green roof to additionally increase the roof's thermal insulation performance.

Table 8 compares the thermal insulation and cost effectiveness for the case studies. The calculated thermal insulation effectiveness for the case studies is found to be similar. This can be explained with the geological conditions in Hong Kong which is mostly 95% humidity for the whole year. This can enhance plants' development and their thermal insulation effectiveness on green-roof systems. It is revealed that the capital costs spend on the green roof proportionally enhance the performance of thermal insulation. Case Study One uses an intensive green-roof system and therefore the capital

Table 4
Details of the case studies.

	Case Study I	Case Study II	Case Study III
Background	Lady Shaw Building was built in 1988 and commissioned with a large 2,700m^2 flat roof with only around 10% area used as planters for shrubs. In 2004, taking the opportunity to repair the roof waterproofing, it was intensively modified to a green roof with more than 82% of floor slabs covered by plants vegetations, along with addition of solar panels for lighting and water circulation in fountain.	The top roof of Runme Shaw building has been undertaken as a research project since July 2007 to examine the effectiveness of a green roof in different soil depths and quantify the benefits of green roofs.	The green roof building aims to improve the corporate image and competitiveness.
Year of completion	1988	1983	1982
Number of floors	5	4	13
Building height (m)	16.34	17.13	47.45
Roof area (m^2)	2700	1140	1270
Green-roof area (m^2)	2214	192 [64 × 3 zones]	75 [25 × 3 zones]
Plant covered	82%	16.8%	5.9%
Initiate green roof	2004	2006	2006
Green-roof type	Intensive green roof	Extensive green roof	Extensive green roof
Soil depth	300 mm	Zone A – 150 mm Zone B – 100 mm Zone C – 50 mm	50 mm
Plant types	Zoysia matrella Rangoon creeper Golden dewdrop Baragina tree Paper flower Port wine magnolia Bamboo White sandalwood	Zone A: Duranta repens L. Zone B: Arachis pintoi Zone C: Zoysia grass amarillo	Sedium
Other incorporated features	Solar panels for lighting; and Water circulation in fountain	The professional climate instrument; and The automatic sprinkler with timer control	Growing medium in Zone A: Recycled clay tiles; Growing medium in Zone B: Palm-Fibref; and Growing medium in Zone C: Recycled brick

costs sharply increases comparing with those of Case Studies II and III. The interviewee explained that the intensive green roof conversion work is a pilot program of the university and accumulated spending expenditures on different types of shrubs and tall trees irrigation and drainage systems incorporated with many reusable energy equipment such as solar panels for lighting and water circulation in fountain, eventually increase the total capital costs.

From the aspect on maintenance costs, Case Study II has spent the most maintenance costs but it cannot obtain the highest thermal insulation performance. One possible reason is that the

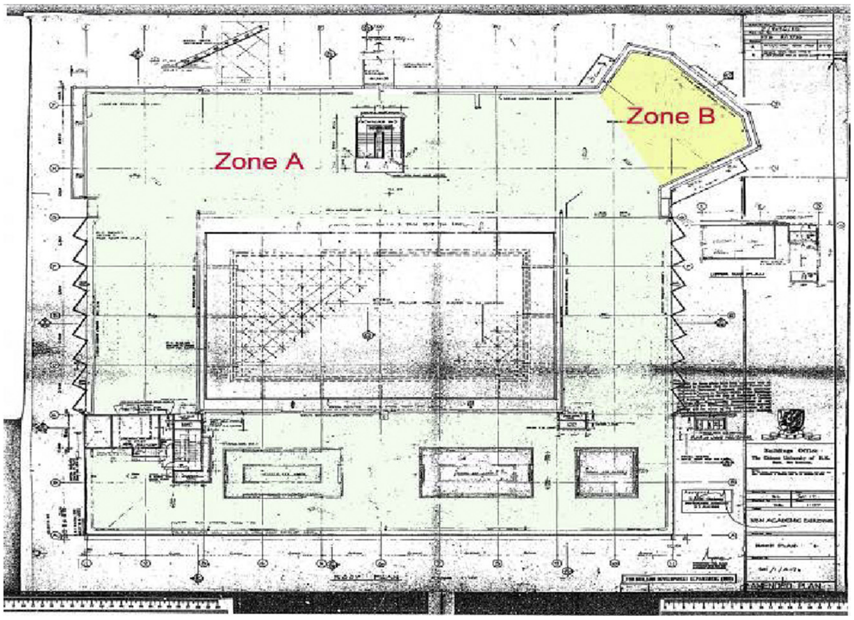

Fig. 2. Building plan for the Case Study I.

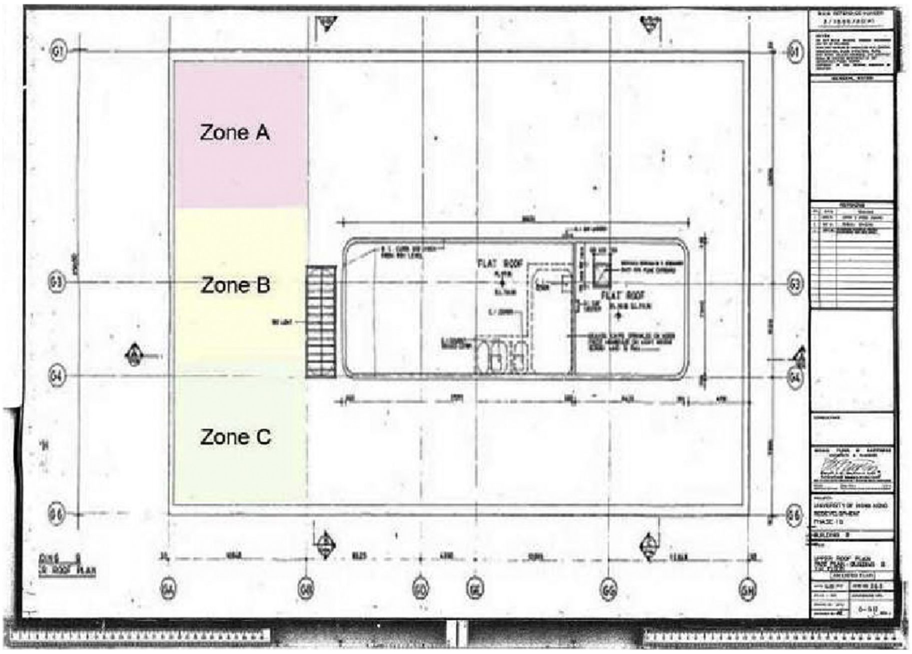

Fig. 3. Building plan for the Case Study II.

Fig. 4. Building plan for the Case Study II.

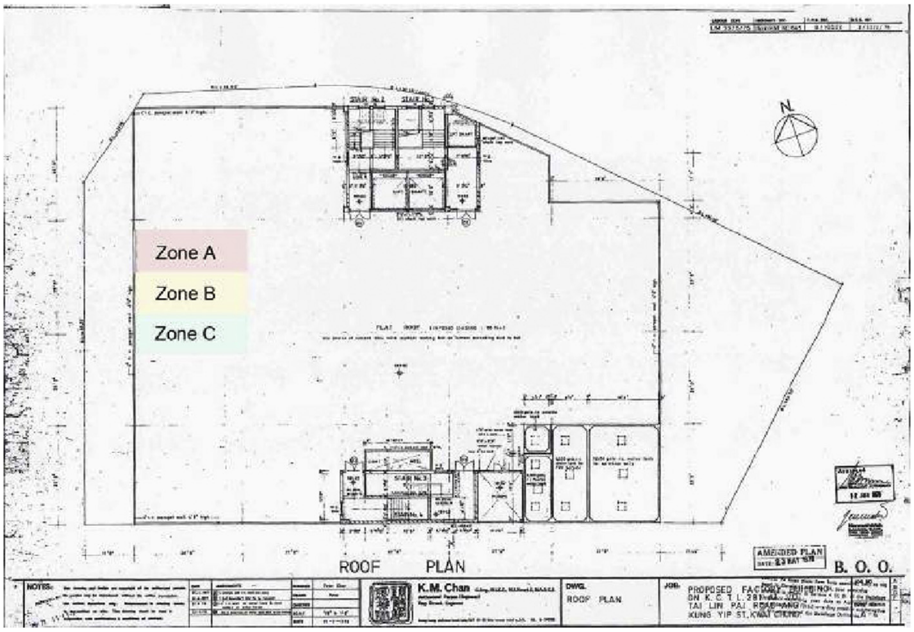

Fig. 5. Building plan for the Case Study III.

Fig. 6. Building plan for the Case Study III.

objective of the research project is to obtain accurate measurements and therefore there are lots of required professional measurement equipment and professional appointments to maintain the green roof. The maintenance costs thus dramatically increase.

In Case Study I, it is clear that the intensive green roof can effectively reduce heat gain from the roof. The sole disadvantages of an intensive green roof are high capital costs and loading capacity. Therefore, an intensive green roof has not widely been adopted. In comparing Case Studies II and III on extensive green-roof systems, a greater green roof may improve thermal insulation performance for the building. This may result from a larger thermal mass accumulated from a larger quantity of plants and substrates, which store energy and delay the transfer of heat to or from building fabric.

The results can also reveal that soil depth and plant types are particularly significant to thermal insulation performance. Palm-fibre adopted in Zone B from the Case Study III has high thermal insulation performance. An optimum growing medium may have the following characteristic including moisture retention, maximum water capacity, hydraulic conductivity, porosity, absorption, sedimentation and filtration, light dead weight and drainage efficiency, noted by interviewees. Sedium is practically adopted in the three case studies and is widely used in many countries. The interviewees highlighted that sedium is one of the most successful green-roof plants for slow-growing, shallow-rooted perennial plants with heat, cold, sun, wind, drought, salt,

Table 5
Measured temperature for the Case Study I.

Test point	Zone A				Zone B	Average value
	1	2	3	4		
Air temperature	19.5 °C					
Green roof surface temperature (°C) (A)	22.2	22.2	22.5	22.4	21.4	22.14
The top floor ceiling temperature beneath the green roof (°C) (B)	18.4	18	18.5	18.8	16.6	18.06
Temperature difference between green roof surface and the top floor ceiling (°C) (C = A-B)	3.8	4.2	4	3.6	4.8	4.08
Concrete slab surface temperature (°C) (D)	28.4	28.4	28.2	28.6	26.2	27.96
The top floor ceiling temperature beneath the concrete slab (°C) (E)	27.3	27	27	27.8	24.8	26.78
Temperature difference between concrete slab surface and the top floor ceiling temperature (°C) (F = D-E)	1.1	1.4	1.2	0.8	1.4	1.18
Thermal insulation from the green roof without the effect from concrete slab (°C) (C–F)	2.7	2.8	2.8	2.8	3.4	2.9

Table 6
Measured temperature for the Case Study II.

Test point	Zone A	Zone B	Zone C	Average value
Air temperature	20.5 °C			
Green roof surface temperature (°C) (A)	22.5	22.8	22.8	22.7
The top floor ceiling temperature beneath the green roof (°C) (B)	19.2	20.8	21.1	20.4
Temperature difference between green roof surface and the top floor ceiling (°C) (C = A-B)	3.3	2	1.7	2.3
Concrete slab surface temperature (°C) (D)	24.3	24.6	24.4	24.4
The top floor ceiling temperature beneath the concrete slab (°C) (E)	23.1	23.5	23.6	23.4
Temperature difference between concrete slab surface and the top floor ceiling temperature (°C) (F = D-E)	1.2	1.1	0.8	1.03
Thermal insulation from the green roof without the effect from concrete slab (°C) (C–F)	2.1	0.9	0.9	1.27

Table 7
Measured temperature for the Case Study III.

Test point	Zone A	Zone B	Zone C	Average value
Air temperature	23.5 °C			
Green roof surface temperature (°C) (A)	22.5	22.5	22.6	22.5
The top floor ceiling temperature beneath the green roof (°C) (B)	20.7	20.4	21.1	20.7
Temperature difference between green roof surface and the top floor ceiling (°C) (C = A-B)	1.8	2.1	1.5	1.8
Concrete slab surface temperature (°C) (D)	24.4	24.6	24.8	24.6
The top floor ceiling temperature beneath the concrete slab (°C) (E)	23.3	23.1	23.6	23.3
Temperature difference between concrete slab surface and the top floor ceiling temperature (°C) (F = D-E)	1.1	1.5	1.2	1.27
Thermal insulation from the green roof without the effect from concrete slab (°C) (C–F)	0.7	0.6	0.3	0.53

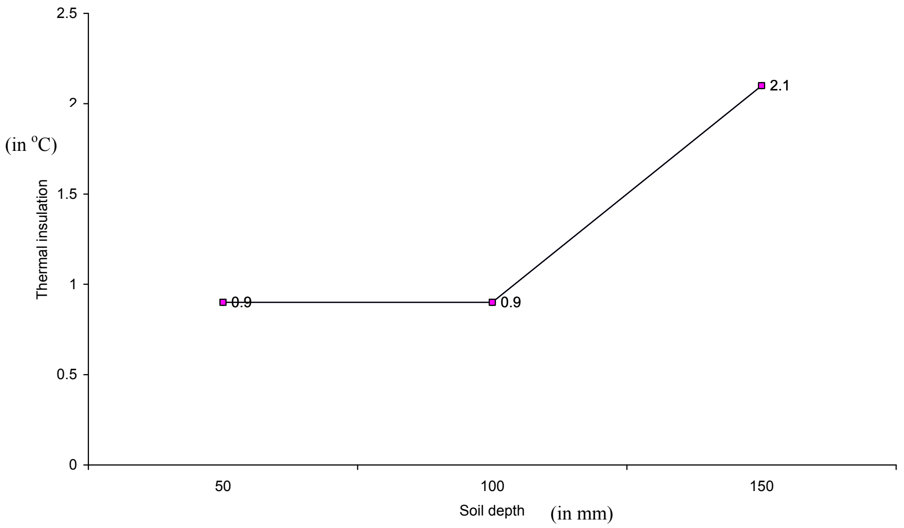

Fig. 7. The correlation between reducing heat gain from green-roof and soil depth from the Case Study II.

Table 8
Capital and maintenance costs for the case studies.

Factor	Case Study I	Case Study II	Case Study III
Capital costs (HK$)	1,500,000	65,000	20,000
Maintenance costs per month (HK$)	2500	500	100
Green roof area (m^2)	2214	192	75
Capital costs/green-roof area (HK$/$m^2$)	677.5	338.5	266.7
Maintenance costs/green-roof area (HK$/$m^2$)	1.12	2.6	1.3
Thermal insulation from the green-roof (°C)	2.7–3.4	0.9–2.1	0.3–0.7
Average value of thermal insulation (°C)	2.9	1.27	0.53

insect and disease tolerant.

6. Conclusion

This paper has examined thermal insulation and cost effectiveness of using green-roof systems in Hong Kong. Questionnaire surveys and interview discussions were conducted. It has been found that green-roof applications are not widely adopted in Hong Kong. Improve visual aesthetic value of the building is the major benefits gained on the green-roof implementation. From the implementation of green-roof systems, air quality can be improved and urban heat-island effect can be reduced. However, the respondents are not willing to invest for implementing green-roof systems. It was suggested that government should takes the leading position for the promotion of green-roof systems together with other stakeholders. The three case studies also proved that green-roof systems can improve thermal insulation by up to 3.4 °C. The results revealed that soil depth and plant types are particularly significant to the thermal insulation performance. The deeper soil may have a higher efficiency in moisture retention and lead to a higher evaporation efficiency from the plants that leads a higher thermal insulation performance. It was revealed that the capital costs spend on the green roof proportionally enhance the performance of thermal insulation. The calculated thermal insulation effectiveness for the case studies is found to be similar. This can be explained with the geological conditions in Hong Kong with mostly moisture of around 95% humidity level for the whole year. This can enhance plant development and its thermal insulation effectiveness on the green-roof systems.

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