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BENEFITS AND POTENTIAL APPLICATIONS OF GREEN ROOF SYSTEMS IN HONG KONG

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Green roof systems are living vegetation installed on the roofs and could contribute positively to the mitigation of urban heat island and enhancement of building thermal and environmental performance. Research study has been carried out to investigate the green roof technology and research in the world, with the aim to develop practical information for its applications in Hong Kong and other similar urban cities. The important factors for assessing the performance and designing the systems have been evaluated. This research paper highlights the key findings of the evaluation and discusses the benefits and potential applications of the green roof systems.

1. Introduction

Green roof systems are living vegetation installed on the roofs and could contribute positively to the mitigation of urban heat island and enhancement of building thermal and environmental performance [1-3]. They could range from a spontaneously occurring moss and lichen covered roof to a full-scale roof garden that includes trees, shrubs and hard landscaping features. In recent years, green roof application and development are becoming increasingly popular in many countries [4-12] and have also attracted much attention in Hong Kong [13, 14].

1.1. *The Purpose of This Research*

Research study has been carried out since 2002 to investigate the green roof technology and research in the world, with the aim to develop practical information for its applications in Hong Kong and other similar urban cities. The important factors for assessing the performance and designing the systems have been evaluated. This research paper highlights the key findings of the evaluation and discusses the benefits and potential applications of the green roof systems.

1.2. *Urban Heat Island*

Urban heat islands are created by warming of the air over urban areas, due to meteorological and urban factors. Their thermal effects are related to the urban energy and mass exchanges [15]. In general, urban heat island in summer increases cooling-energy use and accelerates the formation of urban smog. This summer heat island is created mainly by the lack of vegetation and by the high solar radiation absorptance by urban surfaces [16]. Therefore, people believe that green roof systems can be a useful tool for reducing the adverse effects of urban heat islands.

2. Green Roof Systems

Table 1 shows three major types of green roofs and their characteristics.

- Extensive green roof
- Semi-intensive green roof
- Intensive green roof

Table 1. Major types of green roofs and their characteristics.

Characteristics	Extensive	Semi-intensive	Intensive
Depth of material	150 mm or less	Above and below 150 mm	More than 150 mm
Accessibility	Often inaccessible	May be partially accessible	Usually accessible
Fully saturated weight	Low (70-170 kg/m^2)	Varies (170-290 kg/m^2)	High (290-970 kg/m^2)
Plant diversity	Low	Greater	Greatest
Plant communities	Moss-sedum-herbs and grasses	Grass-herbs and shrubs	Lawn or perennials, shrubs and trees
Use	Ecological protection layer	Designed green roof	Park like garden
Cost	Low	Varies	Highest
Maintenance	Minimal	Varies	Highest

2.1. *Types of Green Roofs*

Extensive green roofs are suitable for lightweight buildings; the plants adopted are species of sedum, shrubs and bushes that need low maintenance and can be self-generative. Usually, the costs are lower than semi-intensive or intensive green roofs.

Semi-intensive green roofs fall in between extensive and intensive green roof systems. More maintenance, higher costs and more weight are expected. A deeper substrate level allows more possibilities for the design; various grasses, herbaceous perennials and shrubs such as lavender can be planted while tall growing bushes and trees are still missing.

The intensive green roof or landscape, suitable for underground garages and heavy buildings, is a common roof garden, with bushes, ornamental plants and also trees, and needs regular garden maintenance. Walkways, benches, playgrounds or even ponds can be established as additional features on the roof.

2.2. *Extensive Green Roof*

To reduce structural loading and maintenance burden, extensive green roofs are applied in many countries for both new and existing buildings. Figure 1 shows a typical structure of extensive green roof. The various layers of the green roof perform different functions in the system: giving the nutritional elements, storing water, allowing transpiration and drainage.

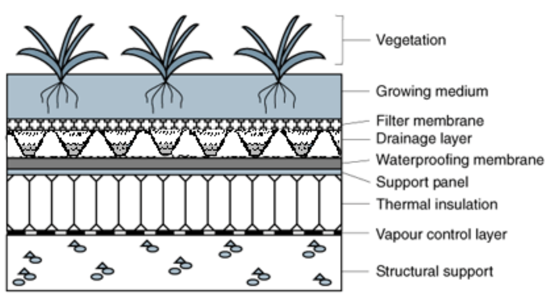

Figure 1. Typical structure of extensive green roof.

Our research study indicates that Germany is technically most advanced and has done a lot of pioneering work in supporting roof greening with various innovations over the last 20 years. The Germany's guidelines and standards for planning and designing green roof systems [17, 18] are widely adopted and referred in many other countries.

Japan, Canada, USA, Singapore and Australia are also very active in promoting green roof applications that are suitable to their own climate and context [7, 10, 11, 12].

3. Evaluation of the Benefits

Wong, et al. [19] pointed out that green roofs provide a wide range of benefits from amenity to ecological, technical advantages to financial aspects. Table 2 gives a summary of the public and private benefits of green roof systems. It is believed that cities could benefit from green roofs both in visual, aesthetic and local human climatic amelioration [8].

Table 2. Public and private benefits of green roof systems.

Public benefits:	Private benefits:
- Mitigate urban heat island - Reduce dust and pollutant levels - Stormwater retention - Natural habitat for animals/plants - Cities and landscapes - Nature look	- Increase roof life expectancy - Reduce noise levels - Enhanced thermal insulation - Heat shield - Better use of space - Reduced risk of glare for surrounding buildings

3.1. *Benefits for the Community*

For the community at large, green roofs act as filters to particles, alleviate the problems of poor air quality [16], and attenuate the volume and quality of storm water [20]. Roof greenery also provides habitat for native plants and birds and possibilities for urban food production. In addition, extensive roof greening could enhance biodiversity and offer a valuable opportunity for urban people and students to learn from the nature.

3.2. *Benefits for Building Owners and Users*

For building owners and users, green roofs will reduce the cooling energy consumption of air-conditioned buildings by adding thermal insulation to the roof structure, preventing excessive solar heat through transpiration and photosynthesis of the vegetation, and modifying microclimate via evaporation and air filtration. Indoor thermal comfort can also be enhanced since the green roof can contribute to the modulation of indoor air temperature [3]. If rooftop spaces are turned into roof gardens, they can offer residents doorstep green oasis in high-rise buildings [21] and an opportunity for innovative design for rainwater harvesting.

In hospitals and infirmaries, it is believed that patients' recovery rate is faster where they have a view to a landscaped green roof – also known as horticultural therapy. In schools and educational facilities, students are better motivated by greenery.

4. Analysis of System Performance

Green roofs contribute positively to the improvement of the thermal performance of a building because they can reduce solar radiation, daily temperature variations and annual thermal fluctuations [5]. In order to analyse the system performance of green roofs under the Hong Kong climate, theoretical models have been developed and a pilot study was carried out.

4.1. *Theories and Models*

A mathematical model for analysis of the thermal and cooling effects of green roof systems was developed by studying the theories and principles in the relevant research from other countries [2, 22].

It is found from the analysis that the mechanism of evapotranspiration plays an important role in the thermal performance. For the biological functions of green roofs such as photosynthesis, respiration, transpiration and evaporation, the foliage materials absorb a significant proportion of the solar radiation. This result is consistent with the research findings from Lazzarin, Castellotti and Busato [23]. To ensure the thermal protection of green roofs, it is important to maintain healthy plants and enough moisture in the substrate or soil.

Besides theoretical models, the experimental studies in other research were also examined [2, 9, 11, 23] so as to extract useful information and experience for the pilot study in Hong Kong.

4.2. *Pilot Study in Hong Kong*

A pilot study was carried out to evaluate the design and performance of an innovative green roof system installed on a 'green construction site office' [13, 24]. Figure 2 shows the extensive green roof system installed on the two-storey green site office building. To allow the components and materials to be re-usable, the green roof system was modular by design (about 8 m by 2.5 m) and was constructed on the ground before putting and fixing onto the roof. Figure 3 shows the construction process of the modular green roof. To enable comparison of thermal performance, a typical site office adjacent to the green site office was selected as the baseline. Figure 4 shows the green site office and the typical site office located side-by-side.

Figure 2. Green roof system installed on a construction site office.

Figure 3. Modular design of the green roof system.

Figure 4. Green site office and typical site office.

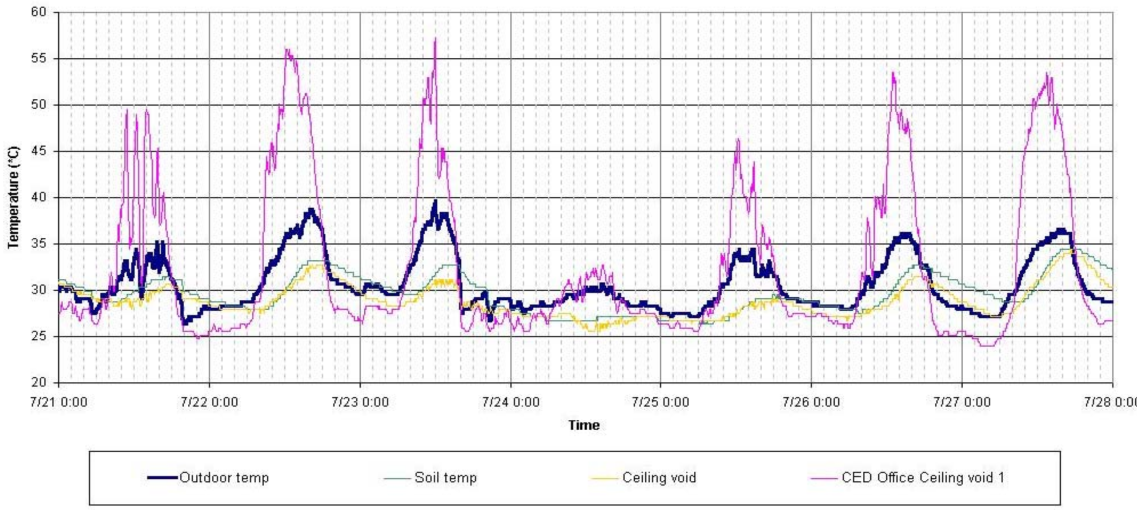

Figure 5. Results of the temperature measurements.

4.3. *Temperature and Thermal Effects*

After the green site office and typical site office were completed in 2002, measurements and monitoring were carried out to assess the thermal performance of these two buildings. Figure 5 shows the results of the temperature measurements during hot summer days.

It can be seen from Figure 5 that during the daytime the temperatures in the soil and ceiling void of the green site office is much lower than the temperature of the ceiling void in the typical site office. Thus, the green roof can reduce the air-conditioning energy consumption and maintain thermally comfort indoor environment.

During the nighttime and cloudy days, the green roof actually stored a significant amount of thermal energy and reduced the temperature fluctuations of the ceiling void and indoor space.

Figures 6 and 7 show the infrared thermographs of the green roof and the conventional roof, respectively, under a sunny day. It can be seen that the green roof is effective in reducing the roof surface temperature and limiting the indoor heat gain. Measurement of the attic temperatures in the two office buildings indicates a significant difference: 30 °C for green roof office and 40-60 °C for typical site office. The attic is the non-air-conditioned space between the roof and the false ceiling.

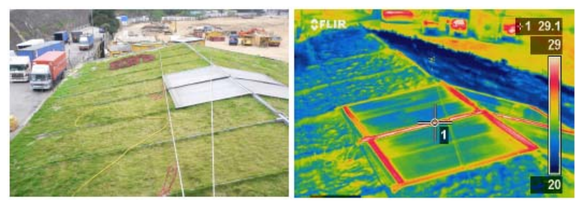

Figure 6. Infrared thermograph of the green roof.

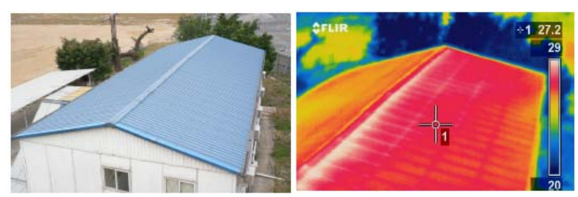

Figure 7. Infrared thermograph of a conventional roof.

4.4. *Sound Insulation and Water Issues*

It was surprising to the end-users that the green roof could act as a noise barrier to enhance the acoustic effects inside the green site office. Especially during the rainy days, the rain drops falling onto the metallic roof of the typical site office would create much noise. It was acoustically more comfortable to work in the green site office because of the sound insulation and protection.

Need not to say, the green roof also acts a buffer to attenuate the stormwater and allows some rainwater to be harvested and recycled for other uses. For example, drainage gutters were installed at the edge of the roof of the green site office (see Figure 2) to collect rainwater, some of which was being used for watering of the green roof. To make the watering more convenient to do, a water sprinkler and pipework was installed on the green roof and the system can be controlled remotely on the ground level. Figure 8 shows a picture of the water sprinkler installed on the top of the roof.

Figure 8. Water sprinkler for the green roof system.

It was reported by the end-users that watering for the sloping green roof system is important to avoid the plants being 'burnt out' under the strong direct sunlight of the Hong Kong climate. On the other hand, by maintaining enough water in the soil and spreading water droplets on the vegetation, a larger latent cooling effect through evaporation can be achieved on the roof. This will enhance significantly the thermal performance of the green roof.

4.5. *Other Research Findings*

In terms of biodiversity, the green roof has attracted some inserts and birds which are not common in a normal roof system. Although the bugs and caterpillars are not always welcomed by the female workers in the green site office, it is believed that the built environment is positively affected by these living organisms.

During the operation of the green site office, the weeds problem did affect the growth of vegetation and the appearance of the green roof. In order to avoid weeds growing too fast and covering the whole roof, the original plant species (sedum) on one half of the green roof has been changed to keep weeds under control. But for the purpose of biodiversity study, we have allowed the other half of the roof area to have weeds. On Figure 8, the upper part (above the water sprinkler) is the roof area covered with weeds (called 'brown roof' or natural green roof) and the lower part is the new plant species introduced.

Because the surrounding environment of the green site office is quite open and no specific measurements have been done to assess the oxygen level and outdoor air quality, therefore, no conclusion can be drawn about the effect of the green roof on the surrounding air quality and oxygen release.

5. Applications in Hong Kong

Unlike other western countries, many buildings in Hong Kong are high-rise and their roof areas are very limited. Nevertheless, as our city is very densely populated, putting greenery on some intermediate roofs and man-made structures such as covered walkways could enhance the surrounding built environment and people's impression very much.

5.1. *Current Applications*

Investigation has been carried out to study the existing green roof projects in Hong Kong. It is found that in recent years some government departments in Hong Kong have implemented a few green roof systems for government premises and school buildings. Examples of them are:

- Hong Kong Wetland Park Phase II, Tin Shui Wai
- Veterinary Laboratory at Tai Lung, Sheung Shui
- Hong Kong Science Park Phase I, Shatin
- Castle Peak Hospital extension, Tuen Mun
- EMSD New Headquarters, Kowloon Bay
- Canossa Primary School, San Po Kwong

Figure 9 shows a picture of the green roof system at the Hong Kong Wetland Park. It is one of the largest green roof project completed in Hong Kong so far.

There are also some private residential and commercial projects in Hong Kong which tried to include green roofs, but the scope and scale of them are usually small and limited. Examples of them include:

- Entrance Pavilion of Kadoorie Farm, Tai Po
- International Finance Centre II, Central
- Pacific Place I and II, Admiralty

Figure 9. Green roof system at Hong Kong Wetland Park.

5.2. *Potential Applications*

In general, the existing applications of green roof systems in Hong Kong are very few and the development potential is large because our city has many buildings with exposed roof areas.

The experience in Singapore indicated that greenery on buildings in the forms of rooftop garden, podium garden, balcony planting, greenery on façades and multi-storey carparks would be useful for tropical cities [12, 25]. The potential of rooftop greening in high-rise, high-density city has been discussed by Yuen and Wong [21] and it is found that green roof could become one of the main strategies for urban greening.

Since extensive green roofs are lighter in weight and convenient to build, they can be installed on new buildings and also incorporated in the conversion and retrofitting of existing buildings and structures too. Figure 10 shows a potential application of green roof in an existing school building in Hong Kong.

Figure 10. Potential application of green roof in a school building.

In fact, Hong Kong and many modern cities have enormous areas of wall space much of which could be covered with plants. Allowing plants to grow on and up walls could extend the natural environment into urban areas taking up little space and bringing with it many benefits similar to green roofs [26]. Planting green roofs and living walls could be an effective strategy to increase roof and façade greening in the city. If needed, the approach can also be applied to industrial buildings [9] which usually have large roof areas.

6. Discussions

In the design and construction of green roof systems the prime objectives is that the established planted roof shall be aesthetically pleasing, environmentally beneficial and will not compromise the essential function of the roof, that is, to prevent water entering the building. To ensure the quality, the following criteria must be considered carefully: position of the building, orientation of the roof, height of the roof above ground, roof pitch, weight limitations of the building, preferred planting, sustainability of components, levels of maintenance, and performance required from the plant layer.

In order to effectively develop and apply green roof systems in Hong Kong and other urban cities, it is essential to study the technical issues, environmental impacts, local government policy and maintenance considerations. It is also important to study the horticultural factors and determine suitable plant species and their requirements for optimal performance.

6.1. *Plant Species*

Sedums which are commonly known as stonecrops are often the core species for green roof systems [5]. They are a versatile and attractive ground cover plant belonging to the Crassulacaea family. Sedums are evergreen, self-generating, drought resistant and capable of withstanding extremes of climate. Needing very little attention and no mowing or cutting back, they give excellent foliage colour and texture and are attractive to all kinds of insects and birds. Sedums are generally pest and disease free but like most plants, can suffer from aphids, mealy bugs, thrips or vine weevil which can be controlled by biological means. Sedum plants are very economical when it comes to fertilizer. A slow-release, low-nitrogen granular fertiliser applied once a year (preferably in spring) is all that is needed.

6.2. *Green Roof Policies*

Green roof policies are important for encouraging applications and promoting the fast expansion of the green roof market [8]. Direct financial incentives, reduced stormwater taxes, density relief and regulatory measures, are some of the green roof policies which have been used in other cities. In certain countries, such as Japan, greenery installation to flat-roof areas is a legal requirement on new-build development.

In Germany, an entire service industry has been formed around green roof installation, significantly reducing the first costs of a green roof. In the UK, there are no public policies now that relate directly to green roofs, however policies encompassing urban renewal, construction, open space, nature conservation and drainage all have relevance [7].

6.3. *Life Cycle Costs*

Nowadays, two important barriers affecting wider use of green roof systems are the initial cost and follow-up maintenance work. As compared with a conventional bare roof structure, an extensive green roof system would cost two to five times more for the initial investment [19]. However, if planned and designed properly, green roofs could be less expensive than tiled roofs in the long run because they last longer and provide many other tangible and non-tangible benefits to the building owners.

Wong et al. [19] believed that the economic benefits of green roofs can offset the initial costs in the long run. However, the most significant benefits of green roofs, such as a cooler microclimate in urban areas and stormwater retention, are hard to quantify or to put a dollar value. These benefits, combined with the improved roof longevity and thermal insulation of a green roof, can easily outweigh the increased first costs for most installations.

6.4. *Lessons Learned*

For our pilot study, putting up a green roof system is a very challenging task from the economic and financial point of view, because the site office will stand there for only 3-4 years [24]. This short building life cycle has limited the economic benefits of the green roof.

The design solution we adopted is to use a modular system which will allow disassembly and moving of the green roof structure and components to another building or location without too much trouble (see Figure 3). Hopefully, most of the components and materials of the green roof system can be re-used when the green site office is demolished or relocated. This is an innovative approach which partly contributes to an environmental design award of this green site office granted by the Skanska Group in Sweden in 2003. It is hoped that this green roof system could provide opportunities for basic green roof research, as well as challenges to building and landscape designers.

In fact, after its completion, the green site office has been visited by many people including secondary school and university students, building designers (such as architects and engineers) and contractors, local government departments and overseas delegates (from mainland China and other countries). The educational and promotion functions could be more meaningful and significant than the life cycle economics of the project.

7. Conclusions

The concept of green roofs is not new; they have been in existence since ancient times. There is growing evidence that visual and physical contact with greenery of the natural environment provides substantial mental health benefits and an overall feeling of well being. Living or green roofs could enhance the contact and allow better use of the roof space.

To promote and adopt green roofs in urban cities, it is important to set up government policies, develop educational programmes and design guidelines, and stimulate the local market. It is also crucial to carry out research studies to determine the type of roof required, the expected performance, and how to design them within the framework of structural limitations and prevailing environmental conditions.

A rooftop revolution is coming and hopefully it would lead us to a more sustainable living environment.

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