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Towards the next generation of green building for urban heat island mitigation: Zero UHI impact building

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ABSTRACT

At present, cities are under the threats of global warming and urban heat island (UHI) phenomenon, where buildings are an important cause and also the sufferer of urban overheating. Therefore, building, especially the green building (GB), is predominantly provisioned to address the increasing energy consumption and carbon emissions in response to climate change, while to our best knowledge, it has been scarcely requested for UHI mitigation (UHIM). Therefore, this paper proposes the concept of GB-based UHIM system, or 'zero UHI impact building', or 'zero-heat building' or 'microclimate neutral building', aiming to achieve the zero-heat impact on surrounding environments through reasonably designing and operating buildings, or depending on innovative techniques to eliminate the excessive heats, on the basis of GB's goals. In specific, this paper defines the boundary of the GB-based UHIM system, analyzes the interactions between building and urban heat fluxes, and the factors that may affect the use of UHIM techniques on building components. The potentials to establish the GB-based UHIM system are further analyzed in aspects of the UHI impacts on the GB benefits and the principle for heat mitigation. Moreover, the pathway to GB-based UHIM system implementation is further elaborated and suggestions for future direction and work are given. Overall, this paper presents the theoretical and practical foundation for the establishment of GB-based UHIM system and it is a significant move of building sector in response to the temperature increase.

1. Introduction

Because of anthropogenic activities, particularly in recent years, the earth has been undergoing unprecedented climate change and environmental deterioration. The most evidenced global warming and energy shortage have successfully driven human beings to take stringent actions and reshaped people's awareness and behaviors. In the building sector, an important culprit of the energy consumption and greenhouse gas emission, a variety of measures and practices have taken shapes to improve energy efficiency and reduce carbon emission. One of the most advanced practice lies in the green building (GB) that pursues the creation of healthy and comfortable living spaces for human beings, whilst it guards against environmental deterioration and global warming.

However, when the international collaborations are dedicated to constraining global warming to 1.5 °C, the temperature of many cities has already been 2–5 °C, even 12 °C under extreme conditions, higher than that of the surrounding rural or suburban areas, which is known as the urban heat island (UHI) phenomenon (Zinzi & Agnoli, 2012). The UHI phenomenon can be interactive with the heat wave, one of the most common behaviors of the climate change, making the local urban warming more lasting and devastating. Consequently, not only has the outdoor thermal comfort been worsened, but also the indoor environment has been significantly undermined. This results in the increase in energy and water demand, and improved risks in mortality and morbidity among vulnerable groups. Moreover, the low-income families are under much severer threats, as they are incapable of paying for air-conditioning equipment and spend longer time in overheating spaces (Santamouris & Kolokotsa, 2016).

Active responses, as a result, to the UHI phenomenon are highly and urgently required. Existing studies have verified several causes of the UHI phenomenon such as the anthropogenic heat, huge thermal mass of building and paved materials, low evapotranspiration, low wind condition and air pollution. Accordingly, a consortium of strategies and techniques, including urban greenery, water bodies and cool materials, have been advocated for UHI mitigation (UHIM) (Hathway & Sharples, 2012; Santamouris, 2014; Zinzi & Agnoli, 2012). Ideally, they are effective to limit ambient or surface temperature (Oke, 1988; Qi, He, Wang, Zhu, & Fu, 2019; Santamouris et al., 2017). However, these techniques are not always robust because of the restrictions of elevating city skylines, limited urban spaces and already well-structured urban tissues. For instance, both green and cool roof will make no difference

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to the temperature at the street bottom, if the buildings are higher than ten storeys (Santamouris et al., 2017). The increasingly densified cities leave inadequate large patches of spaces for vegetation and water bodies (Qi et al., 2019). Redesigning and altering already existing urban tissues may also be unachievable in the short run (Qi et al., 2019). As population growth and continuous urbanization, the implementation of above-mentioned UHIM techniques will face more significant challenges along with the urban consolidation.

Therefore, apart from the urban greenery, water bodies, agricultural lands and roads, from the perspective of land use/land cover, buildings should be criticized as the main sector for the UHIM, because they cover the highest proportion of urban land and they are the main causation of the higher localtemperature (He, Zhao, Shen, Wang, & Li, 2019; Stewart & Oke, 2012; Zhao, He, Li, Wang, & Darko, 2017). In the future, the impact of building on UHI phenomenon will further be aggravated as the increase of building density. Therefore, the responses of buildings to UHI phenomenon should be concerned, buildings should be modified as the barriers rather than drivers to urban warming, offering opportunities to UHIM. Until now, however, the GB has been predominantly provisioned to solve the problems of energy consumption and carbon emissions in addressing climate change, while to our best knowledge, it has been scarcely requested for microclimate regulation. Only Shin, Kim, Gu and Kim (2017) reported the cooling effects of LEED-certified buildings compared with conventional buildings, where GBs with a higher certification level resulted in a lower UHI intensity by 0.48 °C, while with a lower certification level had a weakened cooling effect. Therefore, this study aims to examine the probabilities to establish a GB-based UHIM system, and to unleash the capabilities of the GB system to mitigate UHI effects. In specific, this study is requested to respond to the following questions: Is there any theoretical and practical foundation for the establishment of a GB-based UHIM system? If so, what are the drivers to promoting and the barriers to constricting the formation of the GB-based UHIM system? And what kinds of work should be carried out to enhance the above drivers and to overcome corresponding barriers in the next move? GB practice has been widely implemented, so that the GB-based UHIM system can provide pragmatic opportunities to make UHIM achievable. Moreover, the GB-based UHIM system, is a move towards the holistic heat-mitigation building from conventional building.

2. Methodology

This study primarily elaborates the possibilities of GB-based UHIM system. In specific, this study first presents the reason why the UHIM should be included in the current GB system, from the perspectives of GB benefits and UHI impacts. The GB techniques are primarily advocated to reduce energy consumption and carbon emissions and to create comfortable and healthy indoor spaces. However, the UHI phenomenon is primarily against the goal of providing people with healthy and comfortable living spaces, through undermining the outdoor and indoor environment. The increase of outdoor temperature discourages people to use the outdoor activities and compels occupants to stay at indoor spaces. To create unrestrained indoor environment, the increasing demand for air-conditioning system results in higher electricity consumption and carbon emissions. Moreover, the physical and mental health, as well as the outdoor or indoor productivity can also be affected. Based on this, microclimate moderation should be included to foster, or at least be harmless to, the initial goals of GB in energy consumption reduction, carbon emission reduction and indoor environmental quality, as shown in Fig. 1.

There are numerous techniques, materials and equipment that have been developed to make GB goals achievable. However, their performances in reducing energy consumption and carbon emissions, as well as improving indoor environmental quality have been emphasized, while some techniques may underperform in microclimate moderation, or even aggravate UHI effects. Therefore, a review is required to screen what techniques can be adopted onto building components to moderate microclimates without negative impacts on the original goals or with positive benefits to alleviate environmental issues and improve the indoor quality. Moreover, the GB techniques that may have conflicts with outdoor thermal environment should be eliminated, as shown in Fig. 1. Otherwise, the undermined microclimate may further negatively influence indoor environmental quality in a loop. Before conducting the review, it is also essential to understand the definition and boundary of the GB and GB-based UHIM system, the mechanism of UHI formation, the building components for the inclusion of UHIM strategies, and the factors affecting the GB-based UHIM system.

2.1. Boundary of GB and GB-based UHIM system

GB refers to the structure and its operation process are environmental responsible and resource-efficient throughout the building lifecycle. As shown in Fig. 2, the GB boundary encloses the building and the building site. With the input of various energy, water and other resources, GB pursues better indoor environmental quality, the reduction of energy consumption and carbon emission, as well as the alleviation of waste, pollution and environmental degradation.

However, building is a significant driver to the UHI phenomenon, so that we propose the concept of GB-based UHIM system, or 'zero UHI impact building', or 'zero-heat building' or 'microclimate neutral building', aiming to achieve the zero-heat impact on surrounding environments through reasonably designing and operating buildings, or depending on innovative techniques to eliminate the excessive heats, on the basis of GB's original goals presented in Fig. 1. Compared with the GB boundary, the microclimate boundary is enlarged to the local scale, as shown in Fig. 2. Apart from energy, carbon, indoor environmental quality and other resources, heat input or temperature increase becomes another main concern of the GB-based UHIM system. Some inputs that are conducive to GB's original goals can be barriers to heat elimination.

2.2. Interactions between building and urban heat fluxes in cities

The mechanism of UHI formation has been well explained through the energy balance equation of the urban environment (Eq-1 and Eq-2) (Oke, 2002). As presented in Fig. 3, solar radiation Q^* is one of the most significant heat inputs of the built area. Akin to the natural landscape, the incoming short-wave radiation $K\downarrow$ and long-wave energy flux $L\downarrow$ are always the constant, while the short-wave radiation $K\uparrow$ reflected by the urban area is much less than the natural landscape. Although urban materials lead to higher urban surface long-wave radiation $L\uparrow$, a large proportion of the outgoing infrared is trapped by the street canyons (Roth, 2013). The anthropogenic heat flux generated by fuel combustion Q_F like traffic and HVAC operation, is increasingly becoming an important determinant whose impacts have been enhanced as the improvement of living quality (He, Yang, & Ye, 2014; Roth, 2013).

$$Q^* + Q_F = Q_H + Q_E + Q_S + \Delta Q_A \tag{1}$$

$$Q^* = K^* + L^* = K\downarrow - K\uparrow + L\downarrow - L\uparrow \tag{2}$$

where

Q^* represents solar radiation, including short-wave radiation K^* and long-wave heat flux L^*;

K^* means short-wave radiation, including incoming solar short-wave radiation $K\downarrow$ and reflected short-wave radiation $K\uparrow$ by the urban surface;

L^* is long-wave heat flux, including atmospheric particles generated long-wave energy flux $L\downarrow$ and surface emitted long-wave radiation $L\uparrow$;

Q_F is heat generated during anthropogenic activities;

Q_H represents turbulent sensible heat flux;

Q_E is dissipated heat via evaporation and transpiration;

Q_S the heat stored in building or road systems;

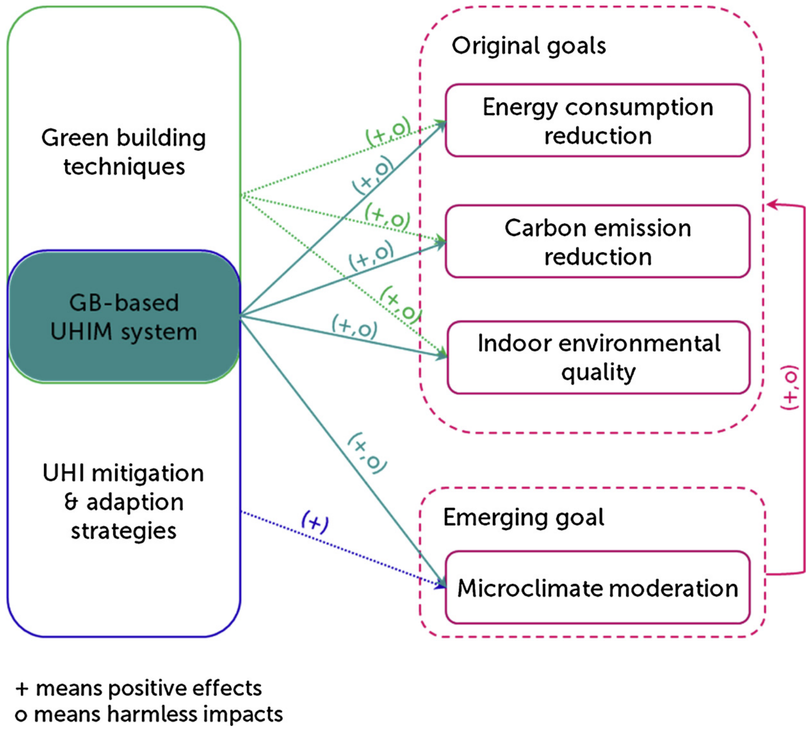

Fig. 1. The goals of GB-based UHIM system (All influences should be positive under stringent requirements, while all impacts should be harmless under easing requirements).

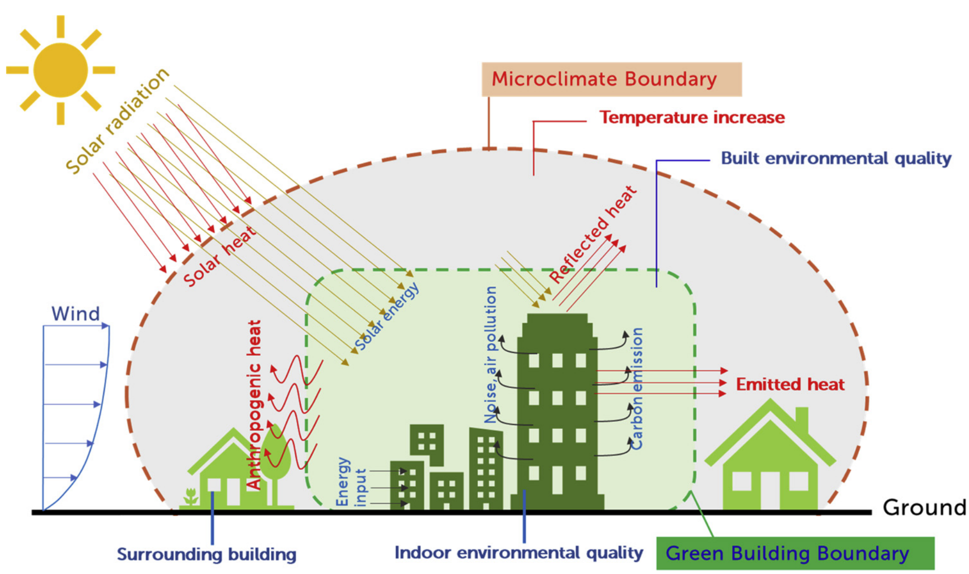

Fig. 2. The schematic diagram of the boundary, input and output for green building and microclimate.

ΔQ_A is net horizontal heat transferred into other systems.

For heat dissipation, there are three means such as convection, evaporation and transpiration, and energy storage. The convection represents turbulent sensible heat flux Q_H, shown by air temperature, evaporation and transpiration can dissipate heat via water system and vegetation transpiration Q_E, while energy storage means heat stored in building or road systems Q_S and net horizontal heat transferred into other systems ΔQ_A. As shown in Fig. 3, the latent heat release in urban area is lower, while the stored heat and sensible heat are much higher. The sensible heat is directly responsible for the temperature increase, while stored heat and anthropogenic heat are the factors affecting the sensible heat pattern.

Building is the important factor influencing the energy balance of the cities, and it can connect with their surrounding built environments in the building lifecycle from planning to design, construction, operation, maintenance, renovation, and demolition, as shown in Fig. 4. The planning and design stage do not generate impacts on urban heat directly, while the construction expands building footprints, thereby occupying more green lands, water bodies and agricultural lands (Zhao et al., 2017). The regulation of land use/land cover in planning stage potentially affects emitted long-wave radiation $L\uparrow$, reflected short-wave radiation $K\uparrow$, and latent heat Q_H. Design schemes can potentially affect building number, volume, material and inner equipment, in relation to heat storage of building or road systems Q_S, surface emitted long-wave radiation $L\uparrow$, and reflected short-wave radiation $K\uparrow$ and sensible heat flux Q_H. Building operation, maintenance and renovation concern

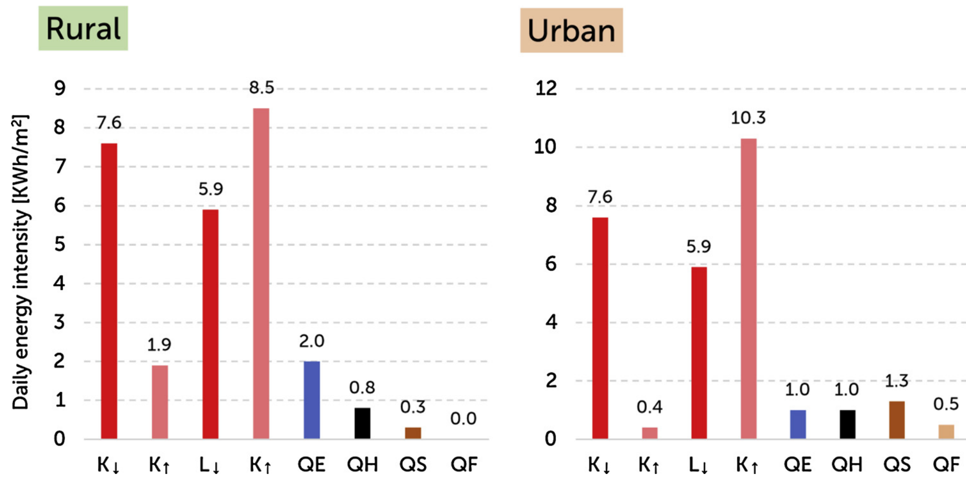

Fig. 3. A comparison of diurnal energy balance processes in rural and urban areas (Case of Houston), (Shepherd, 2005).

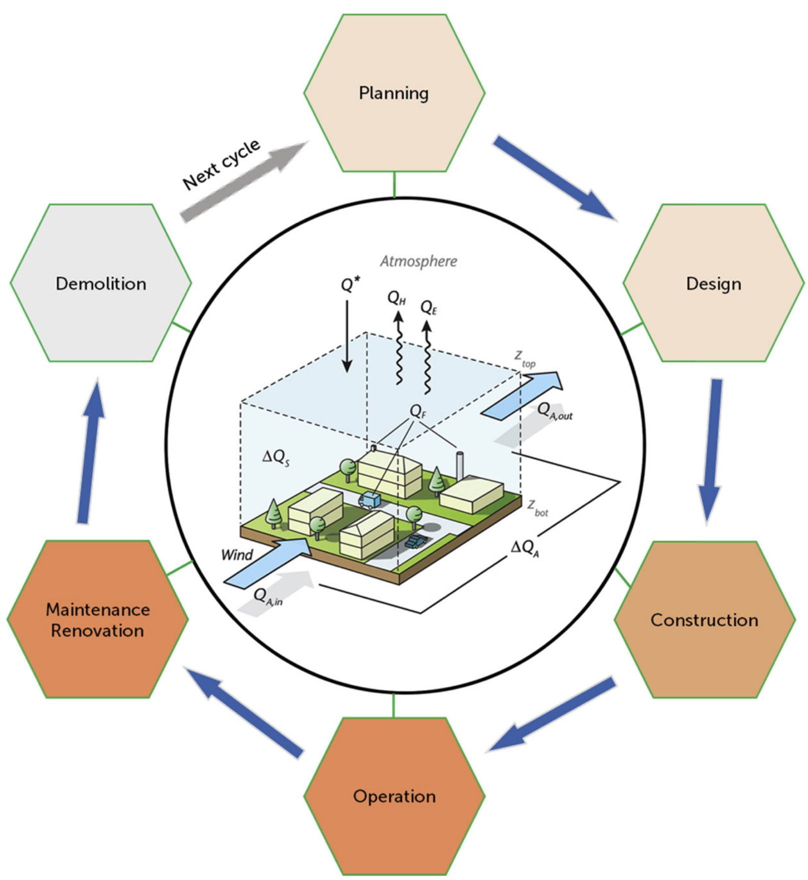

Fig. 4. The building and energy fluxes in the building lifecycle (Revised based on Oke, Mills, Christen, & Voogt, 2017).

people's activities (e.g., cooking, lighting, heating, cooling and traffic), affecting anthropogenic heat Q_F. The building demolition possibly affects heat balance while it depends on the next-step land use.

2.3. Building components for UHIM techniques

The building components for the inclusion of UHIM techniques are determined according to the excessive heat sources. As indicated by the energy balance equation of the built environment, the incident solar radiation $K\downarrow$ and incoming infrared $L\downarrow$are always constant for a specific location on the earth, while the reflected short-wave radiation ↑, outgoing infrared $L\uparrow$, sensible heat flux Q_H, latent heat Q_H, storage heat Q_S, and anthropogenic heat Q_F can be artificially intervened. The reflected short-wave radiation $K\uparrow$ and outgoing infrared $L\uparrow$ depends on the surface material albedos, and UHIM techniques should be implemented in the outdoor spaces and on the building envelope. Moreover, the built form (i.e. building height, street pattern, compactness, aspect ratio) is also related to them, as reflected and emitted heats may be trapped in the street canyon (Roth, 2013). The dissipation of sensible heat flux Q_H depends on its interaction with built form and surrounding meteorological conditions (i.e. wind) (He, Ding, & Prasad, 2019; He, 2018). The latent heat Q_H can be enhanced by the inclusion of vegetation and water systems in the outdoor spaces and on the building envelope. The storage heat Q_S can be regulated through building materials or the

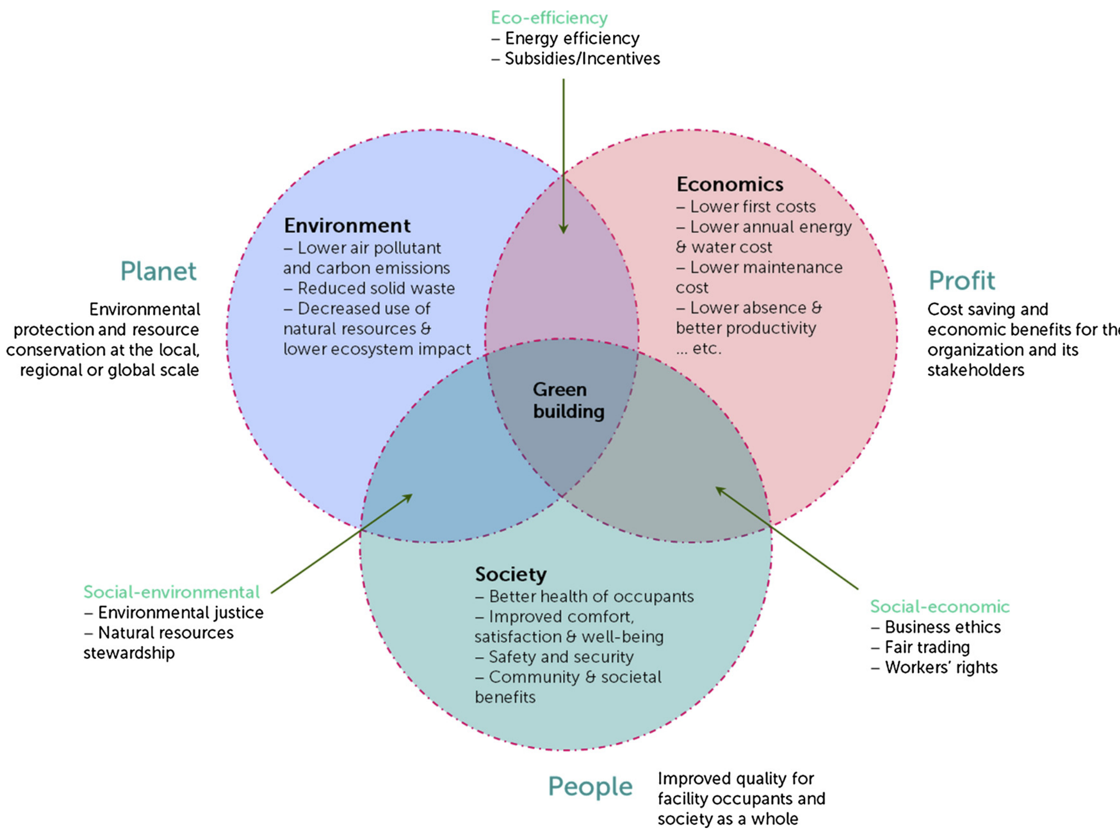

Fig. 5. The framework of the triple bottom line benefits of green building (EERE, 2013; Elkington, 1998).

introduction of cold sources. The reduction of anthropogenic heat Q_F is achievable through building operation pattern, building material and heat recovery equipment, the introduction of cold sources (i.e natural ventilation, geothermal heat). In addition, some accessory components such as shutter, awning and eave can shelter indoor and outdoor spaces from solar radiation and incoming infrared. Therefore, it is summarized that site configuration, building form, building envelope, building materials and equipment, other accessory components should be considered when developing the GB-based UHIM system.

2.4. Factors affecting the GB-based UHIM system

Climatic condition has always been an important factor affecting the GB performance and the adoption of specific techniques. The focus of GB techniques is to provide space heating for the cold winter areas, while the hot summer areas require the cooling response to the reduction of indoor temperature. The urban warming has consistently elevated the local temperature in both cold winter and hot summer areas, which can alleviate the heating load of the former, while it further aggravates the cooling load of the latter. Moreover, the impacts of UHI effects on the mortality and morbidity are also shifted due to the climatic difference. A study indicates the UHI is beneficial to the alleviation of cold related death, up to 4.0 decrease per million people taking the US as an example, while its national heat related death witnesses the 1.1 increase per million people (Lowe, 2016). The increase of heat related death is much severer in developing countries with unsound heat mitigation infrastructures (Azhar et al., 2014; Yang et al., 2019). Therefore, cold cities, from the only building perspective and regardless of the ecological system, can somewhat benefit from the UHI phenomenon. However, the GB-based UHIM system should be emphatically highlighted in subtropical and tropical climates. Because of climate change, the overheating in summer, a combination of urban heat island and heat waves, also makes the implementation of GB-based UHIM system pressing.

Geographical location is another factor influencing the selection of UHIM techniques. Cities can be located inland or near the seaside, which determines if they are under the influence of sea or lake breeze. The cooler sea breeze can normally penetrate 20–60 km inland, bring cold sources to cool the warming cities. Guiding sea breeze into cities is a promising approach to reducing UHI intensity by 1.3–4.0 °C, taking the Orlando, Florida in the US as an example (Yow, 2007). In addition, the penetration of sea/lake breeze is further confined by a variety of factors such as urban layout, density, size and terrain (He, 2018). The geographical location can also affect the effectiveness of UHIM techniques. For example, the water systems are less effective for the areas with humid features and adding water systems may lower the space comfort.

Building characteristics affect the urban heat patterns and the applicability of UHIM techniques. The urban heat patterns vary with building types such as the public, residential and industrial buildings. The operation of public buildings can generate more anthropogenic heats because of high daytime occupancy, high operation of air-conditioning system and high traffic volume. Comparatively, residential buildings witnessed the high occupancy at the nighttime when outdoor temperature is relatively low. Building height or volume means the material amount to absorb and store excessive heats that are mainly released in the nighttime. In general, high and large buildings can store more heats than the low and small buildings. Building configuration and its relationship with neighboring buildings also affect the exposure to solar radiation, and a west facing building suffers more heats and overheating during summer. In addition, the properties of building materials can also affect the heat stored or reflected.

3. Potentials to establish the GB-based UHIM system

This section firstly overviews the benefits of UHIM on the improvement of outdoor thermal comfort and its internal benefits to the improvement of GB performance in terms of energy consumption reduction, carbon emission reduction and indoor environmental quality improvement. By this, the necessity to build the GB-based UHIM system, or the upgrading of GB for UHIM can be indicated. Afterwards, the inclusion of UHIM techniques into the GB system is analyzed. As this study primarily focuses on developing 'zero UHI impact building' or the 'zero-heat building', the analysis in this study will mainly target at the areas that have hotter summers. For the wintertime, the negative impacts of UHIM techniques on the building and outdoor spaces will be considered for minimization, while enhancing the UHI phenomenon of cold areas for reducing heating demand and cold-related mortality and morbidity is not considered.

3.1. GB benefits versus UHI impacts

The GB practice has been widely accepted and promoted to reduce carbon emissions and alleviate energy consumption, on the basis of providing people with comfortable and healthy living spaces. The GB approach is very promising, as it generates benefits in at least environmental, economic and social aspects (as shown in Fig. 5), and sometimes resulting in regenerative outcomes via ecological design approaches. Therefore, the relationships between GB performance and UHI phenomenon will be analyzed in the environmental, social and economic dimensions.

The UHI phenomena are secretly devastating GB benefits and even completely offsetting them. Because of excessive heat load, the discomfort level in the public outdoor spaces is significantly enhanced, thereby changing the frequency and the pattern of outdoor activities (Soltani & Sharifi, 2017). A field investigation towards the public space and public life in the context of Adelaide, Australia indicated that the neutral thermal threshold in the public space ranged between 28 and 32 °C, and once ambient temperature hit the lower bound, the optional activities such as sitting, standing, eating and entertaining started to decrease, while the necessary activities like walking started to decrease once the ambient temperature reached the upper bound (Sharifi, Sivam, & Boland, 2016).

3.1.1. UHI impact on environmental dimension

Although people are compelled into indoor spaces that are cooler than the outdoor space, it does not necessarily mean the indoor space is comfortable. Moreover, during the summertime, there is a strong linear relationship between the outdoor temperature and indoor temperature (Nguyen, Schwartz, & Dockery, 2014), so that it is easy to exceed comfortable temperature range of 18–27 °C (ASHRAE, 2017), and even reach the maximum allowed health related temperature (Santamouris & Kolokotsa, 2016). Occupants have no effective method but to rely more on HVAC systems for the better indoor environment, resulting in the increase in electricity consumption and the release of anthropogenic heat, and even the ever-increasing outdoor temperature (Soltani & Sharifi, 2017). The cooling loads will be normally enhanced by 17% and even 42.5% for the Louisiana and Maryland (corresponding to 8.5% electricity increase per degree temperature increase) if the UHI intensity is between 2 and 4 °C. What's worse, under the heat waves, the UHI intensity may even reach 12 °C, meaining the electricity consumption may double (Santamouris & Kolokotsa, 2016). Without the assistance of HVAC systems, there report many GB cases suffering from the overheating problems (Huang, Huang, Lin, & Hwang, 2015; Jenkins, Peacock, & Banfill, 2009). This means the indoor environemtal quality of GBs is undermined by the occurrence of UHI phenomenon, and the energy consumption is significantly increased, thereby underlying the increased carbon emissions. The use of air-conditioning system to counterbalance indoor heat suffers the issue of cold source loss, especially for the commercial building. An empirical study indicates that the operation of air-conditioning system of commercial buildings lose a large amount cold source as the doors are always open to the outside (Sharifi et al., 2016). Nevertheless, it is also found the waste heat exhausted from air-conditioner can improve local air temperature by 2℃ (Salamanca, Georgescu, Mahalov, Moustaoui, & Wang, 2014). In addition, LEED-certified GBs can 12% outperform conventional buildings in water saving, while water efficiency will be compromised as every degree of temperature growth leads to 3.2% increase in water usage (Guhathakurta & Gober, 2007). To foster environmental benefits of GBs, UHI occurrence should be retained.

3.1.2. UHI impact on social dimension

As shown in Fig. 5, the social benefits of GB lie in the better health of occupants, improved comfort, satisfaction and wellbeing, improved safety and security, and other community and societal benefits, while the indoor and outdoor thermal comfort, are under significant challenges. A case in Philadelphia in 1994 reported that the indoor temperature could be 18.8 °C higher than the outdoor temepraturе (35.6 °C) during heat waves (CDCP, 1994). Moreover, some GBs are less effective to provide comfortable indoor thermal environments, compared with the conventional buildings (Gou, Prasad, & Lau, 2013). Under heat wave condition, the occupants' health conditions are even under threats. Higher temperatures are more hazardous elder people and young children whose body thermoregulatory systems are too weak to stand (Vargo, Stone, Habeeb, Liu, & Russell, 2016), and the poor and low-income families who cannot afford for cooling systems are also significantly affected (Santamouris & Kolokotsa, 2016). In Australia, it is reported that the ambulance callouts witness the 46%, 14% and 16% increase in Melbourne, Sydney and Adelaide during heat waves, and the excess deaths increase by 62%, 13% and 37%, respectively (Climate Council, 2014). The studies in America also showed that more African American patients were suffering from the impacts of warmer and more humid indoor environments compared with other community groups (Roberts & Lay, 2013). Moreover, some sustainable buildings are aggravating the indoor overheating issues, because they aim at decreasing heat losses through the airtightness and building insulation, resulting in the insufficient ventilation and less heat release (Gupta & Kapsali, 2016). The indoor overheating also pushes the change in shading, orientation and people's living patterns (Lundgren Kownacki, Gao, Kuklane, & Wierzbicka, 2019). In general, the local urban warming has become a significant factor weakening GBs' performance in offering comfortable, healthy and environmental-friendly spaces, which further urges the transitions of GB design philosophy.

3.1.3. UHI impact on economic dimension

Once the environmental benefits and social benefits of GB cannot be guaranteed, the economic benefits will be undermined. First of all, it is understandable that the increasing electricity and water demands result in increased costs. For the working productivity, the IPCC report indicates that the increase of workplace heat stress has a significant relationship with the reduction of labor productivity (Smith et al., 2014), due to the concentration lapses, higher degrees of fatigue and bad decision making (Zander, Botzen, Oppermann, Kjellstrom, & Garnett, 2015). The absenteeism (staying at home during hot weathers) and presenteeism (less efficient during work under hot weathers) are the most evident responses. A study in Australia reported that because of hot weather, 7% people had been absent for at least one day in a year and more than 70% had been less productive (Zander et al., 2015). For the heat-related economic loss, it is estimated in Germany in 2004, the heat-induced labor productivity reduction resulted in the economic loss of US$ 0.77–3.4 billion (Hübler, Klepper, & Peterson, 2008). Compared with Germany, the summertime temperature in Australia is much higher, so that the heat-related economic loss is much severer, with the value of US$ 711 per person per year. Based on this, the Australian gross heat-induced economic loss was US$ 1560.6 billion in 2014, accounting for 0.33-0.47% of the national GDP (Zander et al., 2015). It is predicted for hot Asian and Caribbean countries in the hot months that the labor productivity may reduce by 11–17% in the far future (2080), and globally by up to 20% in the moderate future (2050) (Zander et al., 2015). In addition, overheating can lead to the physical damage and aging to road and building materials, as well as the damage to machinery and equipment (NCE, 2018). Likewise, the indoor activities, such as reasoning, learning, memory, attention, reaction, gaming and mathematical processing, are also negatively affected by the high temperature (Bao & Fan, 2018). It is also indicated that the suitable temperature for indoor working ranges between 21 and 22 °C and the working productivity starts to decrease when temperatre reaches 23–24 °C. Meanwhile, 8.9% reduction in working productivity is observed when temperature reaches 30 °C (Seppanen, Fisk, & Lei, 2006). Therefore, the reduction in economic performance indicates the necessity to include the UHIM into not only GBs but also conventional buildings.

In summary, the temperature increase caused by the UHI phenomenon and which sometimes accompanies with the heat waves, generates negative impacts on environmental, social and economic dimensions. In comparison, the numerous studies focusing on the UHIM techniques have verified their positive effects on the building energy and water efficiency and indoor thermal comfort. For instance, green roofs show stable cooling effects to moderate indoor temperature by 3–4 °C in tropical wet and dry climates, humid subtropical climates and Mediterranean climates (Anwar, Rasul, & Khan, 2013; Jim & Tsang, 2011; Niachou, Papakonstantinou, Santamouris, Tsangrassoulis, & Mihalakakou, 2001), because of increased thermal resistance by extra soil layers and cooling effects of planted vegetation. This means green roof can help lower the energy use for HVAC operation, and the use of HVAC system in reduced by more than 35%, compared with older buildings without insulation in a subtropical Mediterranean climate (Jaffal, Ouldboukhitine, & Belarbi, 2012). Moreover, the long-term field observations in Puigverd de Lleida, Spain, presented that green roof could be a passive approach to reducing summertime cooling load by 16.7% (Coma, Pérez, Solé, Castell, & Cabeza, 2016). Meanwhile, roofs that are characterized by high solar reflectance and infrared emittance can reduce peak cooling load and overall cooling load by 11–27% and 18–93%, respectively (Synnefa, Santamouris, & Akbari, 2007). Therefore, the antagonistic relationships between UHI impact and GB benefits require people to take effective UHIM measures to foster GB benefits.

3.2. GB design techniques versus UHIM approaches

The realization of GB depends on a series of technologies, such as active and passive design strategies, new materials and advanced equipment to utilize renewable energies, for outstanding performances in the energy efficiency, carbon emission reduction and thermal comfort improvement. Some of them such as configurations of green spaces and water bodies, as well as utilization of green façades, green roofs and cool materials can help reduce local temperature and improve indoor and outdoor thermal comfort. Some techniques are aslo adverse to UHIM, while the impact of some techniques have not been recognized. Therefore, for developing the GB-based UHIM system, it is essentil to understand how to incoproate the techniques into buildings for versatile functions in GBs and UHIM.

Before adding intervetions into the building and microclimate system for cooling, it is essential to have a clear understanding of the heat exchange and transfer between buildings and surrounding environments. The energy balance in the cities have been revealed by Oke (2002), and the thermal exchanges between the building and outside environment have also been presented (La Roche, Quiros, Bravo, Gonzalez, & Machado, 2001). Based on them, the model for heat exchange and transfer between buildings and surrounding environments is established, as shown in Fig. 6.

For the outdoor spaces, the direct solar radiation, diffuse solar radiation, roof reflected short-wave and emitted long-wave heats, ground reflected short-wave and emitted long-wave heats, tree reflected short-wave and long-wave heats are the vertical heat flows, while the waste heat from the vehicles and air-conditioning units, façade reflected solar radiation and façade long-wave heat emittance are the horizotal heat flows. The possibility of façade and ground reflected and emitted heats flowing into the atmosphere depends on the sky view factor. A higher sky view factor means the larger openness, and higher possibility flowing into the atmosphere, while a lower one indicates the heats more possible to be trapped in the street canyons (Svensson, 2004). Moreover, a higher sky view factor indicates the higher possibility of direct and diffuse solar radiation penetrating into the street canyon, although this also depends on the building orientation (Oke, 1988). The cooling sources are generally the evaporative cooling of vegetation and water bodies. The shade effect of buildings can also shelter the surrounding building and street canyons from the solar radiation, forming cooling spaces. The cooling effects of wind depends on the temperature of wind sources and morphological characteristics (He, Ding et al., 2019; He, 2018).

The indoor temperature can be elevated because of the envelope (roof and façade) conduction, window solar radiation and heat conduction, occupants heat contribution, waste heat from electic lights and applicances (La Roche et al., 2001). To reduce indoor temperature, these heat flows should be prevented. The building natural ventilation heat transfer may be conducive to the reduction of indoor temperature, if the coming wind is cool (He, 2018); Otherwise, the indoor temperature will be elevated if the coming wind is hot. The indoor-earth heat conduction can generally help decrease indoor temperature when earth temeprature is lower. The cool source should be enhanced for better indoor cooling performance.

Based on the heat exchange and transfer between buildings and the surrounding environments, Table 1 presents the principle to counterbalance heat issues, with the heat contributions to be lowered, controlled or enhanced.

For the site configuration, existing GB pursues harmonious coexistence of building and nature so that naturally outdoor environment is a dominant medium to realize dialogues among building, nature and inhabitants. Therefore, site planning should attach importance to create a natural landscape and focus on the harmony between ecology and building. There have been many GB assessment tools proscribing compulsory items on greening and landscape. For instance, in LEED and BREEAM, greening surrounding buildings have been emphasized, e.g., setting the limit of minimum green space rate in residential areas. In parallel, around buildings, natural water systems, wetlands and vegetation must be preserved. Urban layout should be well configured to prevent the coming solar radiation and enhance the heat release, especially in the street canyons. Meanwhile, urban layout should also respect the urban ventilation for weakening heat strength and enhancing excessive heat dissipation (Gago, Roldan, Pacheco-Torres, & Ordóñez, 2013; Oke, 1988). In addition, waste heat from vehicle should be limited, for which purpose the fuel vehicle should be replaced by electric vehicle or the bicycle, and reasonable urban layout is promising to reduce vehicle load.

For the building form, GB design stipulates the optimization of building shape, orientation and distance to neighboring buildings (MOHURD, 2015). They are of vital significance to UHIM as building configuration is a critical factor influencing solar radiation absorption and urban ventilation. In general, the building height and orientation control the urban ventilation, as the building is a prominent barrier. In comparison, the orientation reflects the exposure to the solar radiation, thereby the heat penetrating into buildings through window and door, and the heat conducted into indoor spaces. Moreover, the building size indicates the heat storage, where a larger building responds to a larger amount of heat storage. In addition, there should be a consideration of the shade formed by buildings, which can shelter surrounding buildings and streets from solar radiation.

Building envelope largely determines heat absorption and dissipation. Apart from window and door, external wall and roof account for

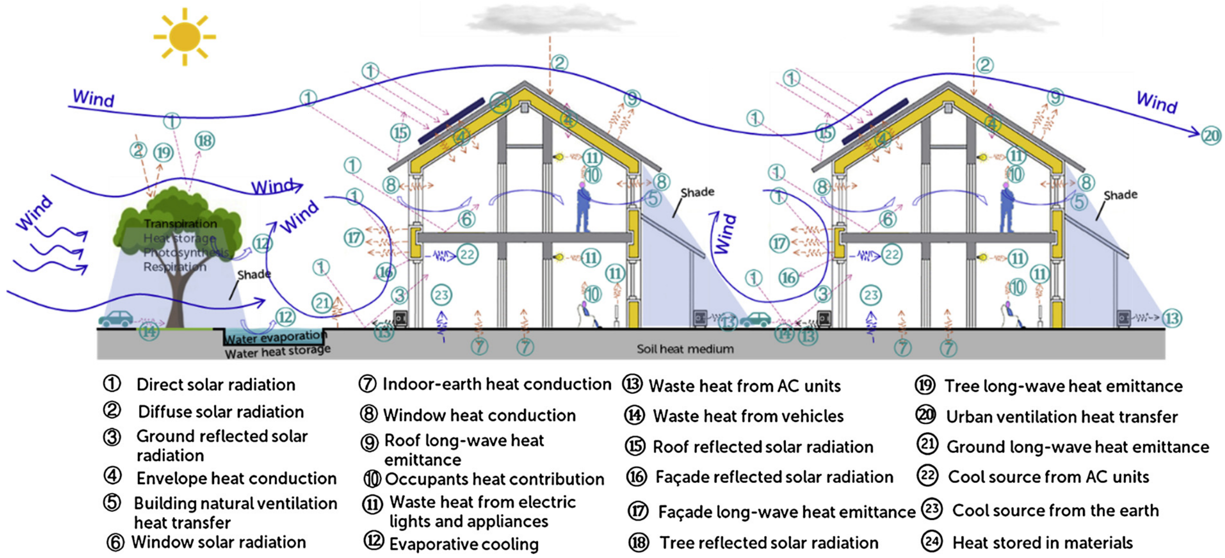

Fig. 6. Heat exchange and transfer between buildings and surrounding environments, revised based on La Roche et al. (2001) and Oke (2002).

more than 80% of total envelope area (He et al., 2014b), so that thermal performance of envelope has received much emphasis in GBs. The thermal insulation materials with low thermal conductivity and low heat transfer coefficient are mostly adopted to reduce indoor-outdoor heat transfer during summertime. Moreover, the cool roof can reduce the solar radiation absorption and improve heat emittance while green roof and green façade can shelter buildings from solar radiation, thereby avoiding the process of solar heats transferring into indoor spaces. The outdoor ground should be capable of preventing solar radiation, increasing heat emittance or enhancing evaporative cooling, while indoor ground should enhance heat conduction if the ground is cooler. In addition, to reduce the heat storage of building materials, the phase change wall is suggested because of their excellent performance of heat absorption. The building natural ventilation, through window and door, will be optimal, if the airflow (derived from building shade side, surrounding trees or water bodies) is much cooler (He, Yang, & Ye, 2014).

Building equipment can provide indoor spaces with cooler air, while the waste heat generated by the air conditioning unit and electric light and appliances can elevate the temperature in both outdoor and indoor spaces. Therefore, for the air conditioning unit, it is essential to alter the path of the heat release, where the waste heat can be collected and recovered by the energy storage materials or the earth that contains a large amount of cold source if possible. Moreover, the air-conditioning unit can be replaced by the ground source heat exchange system, where the ambient air can be cooled in advance by the earth before entering the indoor space. Meanwhile, the efficiency of electric light and appliance should be increased to reduce heat generation.

Table 1
A principle matrix for heat mitigation according to building components.

Building components		Heat flows to be lowered	Heat flows to be controlled	Heat flows to be enhanced
Site configuration	Trees	Direct solar radiation		Reflected solar radiation
		Diffuse solar radiation		Long-wave heat emittance
				Evaprative cooling
	Water body			Evaprative cooling
	Vehicle	Waste heat		
	Building layout	Direct solar radiation	Urban ventilation heat transfer	Reflected solar radiation
		Diffuse solar radiation	Building natural ventilation heat transfer	Long-wave heat emittance
		Waste heat from vehicle		
		Water heat from AC unit		
Building form	Building height	Direct solar radiation	Urban ventilation heat transfer	Reflected solar radiation
	Building orientation	Diffuse solar radiation		Long-wave heat emittance
	Building size		Heat storage	
Building envelope	Roof	Direct solar radiation	Heat induction	Reflected solar radiation
	Façade	Diffuse solar radiation		Long-wave heat emittance
	Window and door			
	Ground			Reflected solar radiation
				Long-wave heat emittance
				Evaporative cooling
	Material	Heat storage		
Building equipment	AC heat exchanger	Waste heat		Cool source from AC unit
	Electric light and appliance	Waste heat		
	Air-ground heat exchanger			Cool source from earth
Accessory	PV panel		Heat conduction	
	Canopy	Direct solar radiation		Reflected solar radiation
	Shutter	Diffuse solar radiation		Long-wave heat emittance
Occupant behavior	Acitivity type	Occupant heat contribution		
	Living/working pattern		Selection of living room	
			Selection of working position	

Table 2
A summary of the regulation of UHIM in GB assessment systems.

No.	Assessment system	Country	Item
1	Leadership in Energy and Environmental Design	United States	To minimize UHI impacts on microclimates and human and wildlife habitats: 1 Use roofing materials with a solar reflectance index equal to or greater than the specific values for a minimum of 75% of the roof surface; 2 Install a vegetated roof that covers at least 50% of the roof area; 3 Install high-albedo and vegetated roof surfaces in combination.
2	Building Research Establishment Environmental Assessment Method	United Kingdom	To ensure the development provides a comfortable outdoor environment through the control of climatic conditions on a micro scale. 1 A microclimatic simulation or study shows the effect of urban morphology on the external microclimate of the development and surrounding area. 2 The development is designed to minimize adverse conditions, including negative microclimatic factors 3 An appropriate and diverse range of favorable microclimatic conditions have been created throughout the development to cater for a wide range of personal preferences. 4 The design of public space optimizes microclimatic conditions throughout the year. 5 The location and design of pedestrian/cycling routes takes full account of microclimatic conditions.
3	Deutsche Gesellschaft für Nachhaltiges Bauen	Germany	Zonal thermal room simulation: The simulations regarding thermal comfort must be based on .... with data for extreme winter and extreme summer conditions must be used, taking into consideration both the city effect (urban heat island), ...
4	Green Star	Australia	To encourage and recognize projects that reduce the contribution of the project site to the heat island effect. At least 75% of the total project site area in plan view comprises building or landscaping elements that reduce the solar reflectance of the site. To meet the credit, by one or a combination of the following: ● Vegetation; ● Green roofs; ● Roofing materials, including shading structures; ● Un-shaded hard-scaping elements; ● Hard-scaping elements shaded by overhanging vegetation or roof structures; ● Water bodies and/or water courses; and ● Areas directly to the south of vertical building elements, including green walls and shaded by these elements at the summer solstice.
5	CASBEE for Heat Island Relaxation (CASBEE-HI)	Japan	CASBEE-HI is a tool aimed for more detailed quantitative assessment of heat island reduction measures in building design. In CASBEE-HI, the criteria deal with more detailed conditions in the outdoor thermal environment and heat island load on the surroundings.
6	Assessment Standard for Green Building	China	Take following measures to mitigate UHI effects: 1 Planting arbor or setting flower shelf to provide shade to outdoor spaces that are not sheltered by building shade, such as sidewalks, recreation areas, courtyards, plazas; 2 For vehicle roads that are not sheltered by building shade, surface albedo should not be less than 0.4, or trees along road should be longer than 70% of the road section in length; 3 Apart from green roof and solar panels, the roof albedo of more than 75% of the remaining area should not be less than 0.4.

For building accessory, the PV panel installed on the rooftop can convert solar radiation into electricity, lowering fuel consumption and carbon emission. Meanwhile, it is shown that PV panel can shelter rooftop from solar radiation and result in temperature reduction (Qi et al., 2019). However, it is essential to set sufficient distance from the rooftop, or the high temperature under the PV panel will be conducted into the indoor space. Canopy can be installed to prevent the indoor space from solar radiation. The indoor shutter can also be an option to prevent solar radiation. In addition, occupant behavior also affects indoor heat gain, and activity intensity should be lowered to ensure the indoor thermal comfort, especially under overheating conditions. Living room and indoor working position can be moved to cooler position.

There have already been numerous studies reporting and examining the advantages of UHIM techniques, on which basis there exist many papers that have holistically summarized and compared the applicability and effectiveness in different contexts. Therefore, the GB-based UHIM system can be achievable based on existing review papers (Gago et al., 2013; Kuznik, David, Johannes, & Roux, 2011; Peretti, Zarrella, De Carli, & Zecchin, 2013; Santamouris, 2013, 2014; O'Brien & Gunay, 2014; Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014; Qin, 2015; O'Malley, Piroozfar, Farr, & Pomponi, 2015; Kalnæs & Jelle, 2015; Soni, Pandey, & Bartaria, 2015; Akeiber et al., 2016; Santamouris et al., 2017; Taleghani, 2018; Deilami, Kamruzzaman, & Liu, 2018; Lai, Liu, Gan, Liu, & Chen, 2019; Qi et al., 2019) for adding UHIM techniques onto building components such as site configuration, building form, building envelope, building equipment, other accessory components and adjusting occupants' behaviors.

4. Pathway to GB-based UHIM system implementation

From the perspective temperature reduction, GB and UHIM are two approaches targeting at different scopes, where GB mainly focuses on the alleviation of global warming, while the UHIM is designated to address local urban warming. Nevertheless, the implementation of GB and UHIM techniques shares the similar goals to provide occupants with healthy and comfortable indoor and outdoor living spaces without environmental impacts. The microclimate neutral building that exhibits the synergies in achieving this, should be the next generation of GB for UHIM. The preliminary analysis of the UHIM techniques in various building components indicates the symbiotic in GB techniques and UHIM techniques. Meanwhile, there are solid potentials and possibilities to include UHIM into GB system for economic and social benefits. Nevertheless, to implement and realize zero-heat building, many issues and challenges should be concerned.

4.1. Current situation

GB has been a very popular practice in the building sector and had received great promotion and implementation in many countries. Overall, although there are still some barriers during the GB promotion (Darko, Chan, Ameyaw, He, & Olanipekun, 2017, 2018), the GB development has already entered a mature stage, with more than 30 countries that have developed integrated, comprehensive and coordinated assessment tools to technically instruct people how to construct GBs in either voluntary or mandatory way (Wei, Ramalho, & Mandin, 2015). Adhering to GB assessment tools, a series of codes and regulations, product certifications, and subsidies and incentives for various professionals have been established to drive GB implementation (Darko et al., 2018). Meanwhile, to adapt to local climatic, geographical and economic conditions, many local governments have contextualized the national GB assessment tools, standards, codes and regulations (Gou & Lau, 2014). The techniques that can fit into local contexts have also been widely discussed and explored (Liu et al., 2019). Overall, to assist GB trades and markets achieve a well-off transition, national and local levels of support has been established.

The UHI phenomenon has been evidenced for more than 200 years since it was recorded by Luke Howard, while the concerns on the UHIM have not been formally in the building design for a long time. In recent years, UHIM has received a variety of academic concerns. However, there are limited governments that have formally implemented of UHIM techniques, and technical, political, economic and social support has not been formed. In terms of building sector, there are some traditional building cases focusing on the avoidance of building overheating, and a few GB practices have been engaged to include and guide UHIM techniques, as shown in Table 2. It is observed that UHIM are going to be highlighted. Nevertheless, the suggested UHIM techniques are very limited and the description is very discrete, such as the high-albedo and vegetated roof surface in the LEED system and the qualitative instructions in the BREEAM. Therefore, extensive efforts are required to provide a comprehensive UHIM system for GB construction.

Compared with UHIM implementation, GB is a very successful model with substantial experience in technical, policy and financial aspects, while UHIM is still in its early stage without obvious implementation. UHIM is increasingly becoming an important part of the GB construction, because of its severe impacts on occupants' comfort and its negative implications on the energy efficiency and carbon emissions. Moreover, according to the co-benefits approach, the GB system can provide environmental, institutional, financial and social opportunities to fetch up barriers in implementing UHIM (He, Zhu et al., 2019). Overall, in the future, the GB-based UHI system should practically offer more opportunities to facilitate UHIM.

4.2. *Challenges of the GB-based UHIM system*

Although the GB-based UHIM system can be promising, the barriers that limit the transitions towards the GB-based UHIM system should also be considered. The GB-based UHIM system requires the techniques adopted in buildings should play double roles in alleviating environmental issues and UHIM, or at least working in one aspect without negative impacts on the other. This means selection of suitable techniques will be a challenge compared with the current GB version. In practice, the cost-effectiveness of the techniques in GB-based UHIM system should be considered as the effectiveness depends on the climatic condition, geographical location and building characteristics. It is essential to enhance cost-effectiveness, or it will be a kind of resource waste without expected outcomes. The evolution towards next generation of zero UHI impact building requires the support of policies and regulations, while they are currently not mature.

4.2.1. *Technical barriers and challenges*

At current, GB techniques have focused more on its performance in enhancing energy efficiency, reducing carbon emission and improving indoor environmental quality, while their performance of heat resistance has not been emphatically highlighted. As a result, the GB techniques may be opposed to UHIM techniques, so that the GB techniques database will be narrowed. It is indicated that the most effective UHIM techniques lies in passive packages, namely the combination of natural landscape, building surface improvement and internal heat gain reduction (Gunawardena, Wells, & Kershaw, 2017; Gupta & Gregg, 2013). However, the operation of active system generally generates waste heats, under which situation the use of active system in GB conflicts with UHIM. For instance, the air-conditioning for cooling that releases a large amount of heat into outdoors should be restricted when considering the UHIM (Salamanca et al., 2014). Otherwise, this requires the upgrading of techniques for the waste heat collection. Another case lies in the insulation and tightness for limiting heat losses become another barrier to the reduction of indoor heats (Gupta & Gregg, 2013). Moreover, GB requires the high loading capability of construction materials, while their good heat storage capability can aggravate UHI intensity.

Another consideration is the negative impacts of UHIM techniques on the original GB goals. The cool roofs are effective to mitigate UHI effects in summer and improving indoor environmental quality, thereby increasing the building energy efficiency. However, cool materials are still effective to reflect solar radiation in winter, lowering the indoor temperature, at which time the indoor environmental quality is reduced. Therefore, it is necessary to balance the benefits of temeprature reduction in summer and the drawbacks of temperature reduction in winter, which is particularly important for the areas that are characterized by cold winter and hot summer. Due to the high reflectance to solar radition of cool materials, the use of light-colored materials causes glare and visual discomfort, leading to the risk of eye-related disorders and road accidents (Qi et al., 2019). GBs also pursue the aesthetic benefits, while the light-colored materials make buildings monotonous, so that many owners are reluctant to use the light-colored materials (Akbari et al., 2006). Moreover, adding trees can alter the biophysical properties of built area through providing shading and evapotranspirative cooling, while the dense tree crown forms the barrier blocking the wind penetration into street canyon, limiting wind cooling effects and pollutant dispersion (Gromke & Ruck, 2007). The problems will be much severer for the street canyons with high traffic volume, as the rooms at the lower storeys may suffer air pollution during door or window ventilation.

It is also essential to consider the localization of UHIM techniques, as the cooling efficiency of same techniques under different situations varies significantly. In response to local climatic, geographical and economic conditions, localized GB assessment standards have been developed (Gou & Lau, 2014). In comparison, there has been limited knowledge of the sensitivity analysis of the effectiveness of UHIM techniques. On the building performance, predictably, most UHIM techniques are beneficial to improve GB performance. However, most existing studies have concentrated on the potentials of strategies to reduce local temperature, while their impacts on GB performances (such as building energy efficiency and indoor thermal comfort) have been scarcely examined (Besir & Cuce, 2018; Santamouris et al., 2017). This, therefore, becomes a shortcoming to hamper the combination of UHIM and GB system. Many local characteristics can constrain the use of cooling interventions. For instance, for many compact areas, there are limited spaces for adding interventions through site planning, so that the cooling efficacy of UHIM techniques should be enhanced on other building components. Meanwhile, the cool and green roof cannot affect the temperature at the street bottom, when building height exceeds 60 m, so that other interventions should be considered (Santamouris et al., 2017; Zhang, He, Zhu, & Dewancker, 2019). In addition, the use of UHIM techniques on tall buildings is much harder than that on low-rise and midrise buildings because of the consideration of structural safety.

In addition, the transitions towards zero UHI impact building requires the professionals to well understand the effect of a specific technique, as well as the combination of different techniques, on UHIM and GB. However, the UHIM is always not in the scope of planners, designers and engineers, but the disciplinary issues in the field of urban physicist and meteorologists. Although some techniques can have positive impacts on UHIM and GB, it is necessary to let planners, designers and engineers have an updated understanding in these two dimensions.

For GB design and construction, there have already been several aspects including site, material, land, water, energy, indoor environmental quality and so on. Therefore, the inclusion of heat resistance, for planners, designers and engineers, means the increase in GB complexity. Alternatively, the inclusion of urban physicist and meteorologists also faces the challenges to let them understand building design and construction.

4.2.2. Political and financial barriers and challenges

There have been various studies focusing on the UHIM benefits, while the extra costs have been mostly neglected. To generate positive economic benefits, the increase in the added cost by including UHIM techniques into GB system should lower than the monetary values generated by the cooling performance. However, the study in the context of California concludes that the increase of albedo adds little economic values when considering the monetary values of electricity saving and carbon emission reduction (Pomerantz, 2018). This requires the extra costs in aspects of materials and labor should be very low (Pomerantz, 2018). Comparatively, in Singapore, from the life cycle perspective, only intensive green roof could generate positive net saving with the consideration of energy saving, while the extensive could not (Wong, Tay, Wong, Ong, & Sia, 2003). Although it may be economically viable among various international contexts in the long-term, the increase of initial and maintenance cost can still make roof clients and practitioners reluctant (Ulubeyli & Arslan, 2017). Moreover, the high cost of GB and UHIM techniques that may limit the diversity and lower expected performance also poses challenges to the realization of GB-based UHIM system.

As a result, for the inclusion of UHIM techniques, it is essential to set legal policies and fiscal subsidies and incentives to improve clients' awareness and economic benefits to include UHIM techniques. From the perspective of developer and owners, this is of vital significance to improve the cost-effectiveness of adopting UHIM techniques. Meanwhile, for governmental and non-governmental organization and institutions, the subsidies and incentives are very important to drive the willingness of developers and owners, as the UHIM decides not only the private benefits, but also more on public and societal concerns. All over the world, only a few governments have developed legal regulations and fiscal incentives to promote UHIM techniques implementation (City of Toronto, 2007; Plant Connection, 2018). Apart from this, there are also very few standards provided to regulate planners, designer and engineers' activities in building construction. The incomplete political and financial barriers for UHIM can further limit the general publics' awareness to the UHIM.

Comparatively, although for GB development, there have been various standards, codes, regulations, subsidies and incentives, the zero UHI impact building should be supported by that of both UHIM and GB. However, the presently incomplete regulations and standards on UHIM implementation may inhibit its combination with GB systems. From the UHIM instructions in the existing GB systems, as shown in Table 2, it is found that the current linkage between GB and UHIM is less holistic and comprehensive. The combination, just in an affiliated, simple and desirable way, cannot really persuade developers and owners to adopt them. In addition, although national and local governments have been implemented to promote GB construction, it is always under the disputes of lack of fiscal incentives and policy supports (Darko et al., 2017, 2018; Li, Yang, He, & Zhao, 2014). The inclusion of the UHIM system without insuffient support from laws, codes and regulations, will aggravate the risks and uncertainties of GB system (He, Zhao, Zhu, Darko, & Gou, 2018).

4.3. Future work to overcome barriers and challenges

Although the current analysis indicates the zero UHI impact building can achieve the original GB goals and microclimate regulation, the UHIM is still in an exploration period. Existing GB system can provide a mature platform promoting the transitions towards zero UHI impact building in practice, while the barriers in technical, political and economic aspects should be overcome.

4.3.1. Science and technology studies

UHIM techniques, either in passive or active form, are the key realize the zero UHI impact building. The first consideration is the development of heat-mitigation techniques for overcoming technical barriers. (1) According to paths of heat incident, reflectance, absorption, emittance and storage, it is essential to build a holistic heat-mitigation system that includes the reduction of anthropogenic heat generation and release, the decrease of material heat storage, the reduction of building exposure to solar radiation and the improvement of heat release into the atmosphere. This maximizes the cooling performances of UHIM techniques in specific contexts. (2) An upgrading of cooling effectiveness of UHIM techniques, such as the high performance UHIM building materials and equipment, reasonable urban configuration and effective surface cover and materials. This does not only ensure the higher cooling effects under the combination situations, but also guarantee the expected cooling performance if many other interventions are not suitable in real and complex contexts. (3) More UHIM techniques should be developed, not only to fit into various conditions, especially when there are limitations in space, building height and other building characteristics, but also to provide alterative to the techniques that have drawbacks in health, aesthetic, air quality and other aspects. Furthermore, this can provide more UHIM technique options to avoid their conflicts with GB techniques. (4) In addition, heat transfer models are required to examine the indoor-outdoor and ground-indoor heat release and dispersion efficiency varying with material, equipment, structure, mechanism, climatic and urban boundaries.

Suitability and optimization analysis are required to improve the cooling effectiveness of GB-based UHIM system. The cooling effectiveness of UHIM techniques varies significantly with the climatic conditions, surrounding geographical conditions and building characteristics. (1) It is first to determine the cooling effects of different techniques in different contexts and then decide the proportion of UHIM techniques in the specific climates for expectance. This will also affect the cost-effectiveness of the UHIM techniques. (2) Assessment and optimization models are required to balance the GB performance and UHIM expectance. The cooling and heating requirements in different climates are different, so that the trade-off of adding UHIM interventions and GB techniques should be assessed and optimized for their optimal combinations and outcomes. Meanwhile, this can also help determine if the UHIM techniques are required for different climates, and then guarantee the summer cooling and avoid the winter drawbacks if necessary. (3) The holistic models to assess environmental, economic and social benefits of the zero UHI impact building, should be developed, and results can facilitate people to select the best techniques and reasonable combination for the highest cost-effectiveness. Moreover, this can help developers and owners improve their understandings of the zero UHI impact buildings and improve their awareness to promote the zero UHI impact building in practice.

4.3.2. Creation and revision of assessment standards

The science and technology of UHIM and GB techniques should be presented in the form of guidelines and assessment standards, so as to reduce the complexity of selecting specific techniques in implementation. To achieve this, two step work is required, where the first one is to establish holistic and localized UHIM guidelines and checklists, and the second one is to revise current GB assessment standard to include the UHIM techniques into building instructions.

Creating localized UHIM guidelines and checklists are capable of instructing planners, designers, engineers and suppliers to readily adopt UHIM techniques. (1) However, until now, there have been very few guidelines available all over the world. Although the existing guidelines have implications on a specific region or area, while it cannot be copied to other areas, because of the variations of climatic conditions and geographical situations. Moreover, in the same climatic zone, the national and regional level guidelines cannot be directly used to instruct people to use them. Therefore, the localized UHI guidelines should be compiled. The use of UHIM techniques is also limited by the cost issues, so that localized guidelines should also respect local economic levels. (2) The material and equipment checklists are also needed for the achievement of UHIM techniques. The implementation of various emerging UHIM techniques cannot realized by only guidelines, the material and equipment suppliers should be involved to provide the necessary products.

Revising existing GB assessment standard and systems can practically promote the transitions towards the zero UHI impact building. (1) The various UHIM techniques should be incorporated into GB assessment standards, to enrich the heat mitigation goal, as current version has mainly focused on energy, carbon, indoor environmental quality and other concerns. This can help overcome the issue of the oversimplification of UHIM techniques shown in Table 2. (2) The techniques should be also distributed into different aspects, such as the Sustainable sites, Water efficiency, Energy and atmosphere, Materials and resources, Indoor environmental quality, Innovation in design, Regional priority in LEED assessment system. Therefore, the techniques can be physically integrated into different aspects by professionals. (3) The existing GB techniques that may enhance UHI phenomenon should be downgraded or eliminated to respect UHIM. For areas suffering from severer UHI phenomenon, the weight of UHIM techniques should be increased or set as mandatory terms. (4) Upgrading the GB product evaluation system to include the heat resistant performance of material, equipment and structure. (5) The knowledge of UHIM technique and selection should translated from urban physical and meteorological language into planner, designer and engineer' language, for the GB assessment standard upgrading. This can help moderate the problems caused by the different disciplines.

4.3.3. Political and economic regulations

Political regulations are highly recommended to promote the whole society to understand the zero-heat buildings, as the heat disasters have been the biggest threats to many countries. The policies are one of the best ways to convey the governmental intention to drive the transitions towards heat mitigation buildings. (1) In the near future, the zero UHI impact building can be implemented in the voluntary way, during which process the governments can encourage the pilot projects and enhance the propaganda, in order to enhance the awareness of the general public (He, Zhu et al., 2019). (2) After several years' promotion, the governmental can gradually mandate the zero-heat buildings in new building construction and building retrofit, as the legislation is the most effective in implementing policies (Li et al., 2014).

Economic subsidies and incentives are important for not only the science and technique studies, but also the developers, suppliers and owners' choice. (1) Research and development are important to overcome the prominent technical barrier, so that the governments should provide sufficient financial resources and charisma for encouraging scholars and engineers to develop more suitable techniques and to establish various theoretical and applicable models. Meanwhile, financial support should be offered for building the guidelines, checklists, assessment standard and systems, and educating more interdisciplinary professionals in both GB and UHIM scopes. (2) To promote the zero-heat buildings, economic incentives are also needed to encourage developers and owners to adopt the GB-based UHIM system. Moreover, suppliers should be also economically motivated to be involved.

5. Conclusions

Cities are undergoing the urban overheating issues caused by both global warming and UHI phenomenon. Buildings are an important cause of the lcoal urban temperature increase, so that this paper proposes the concept of GB-based UHIM system, or 'zero UHI impact building', or 'zero-heat building' or 'microclimate neutral building', aiming to lower or even eliminate the heat related impact of building on surrounding environment, on the basis of the energy efficiency, carbon emission reduction and indoor environmental quality improvement. This study preliminary analyzes the relationship between UHI impacts and GB performance, indicating the urgency of including UHIM techniques into the existing GB systems. Afterwards, the integration of UHIM techniques with different building components such as site configuration, built form, building envelope, building materials and equipment, and other accessory components. Nevertheless, extensive efforts are required in science and technology studies, creation and revision of assessment standards, and political and economic regulations to overcome the barriers and challenges in realizing the GB-based UHIM system. Overall, the zero UHI impact building should be highlighted and further developed, as it indicates the evolution of GBs in response to ongoing climate change.

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