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The impact of urban green infrastructure as a sustainable approach towards tropical micro-climatic changes and human thermal comfort

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ABSTRACT

Green infrastructures such as living walls are technological solutions to replace the declined greenery at urbanized environment and also reliable applications for thermal regulation in buildings through insulation effect and escalates the energy use efficiency. Thermal comfort and local climate are spatiotemporally variable. The existing research gap should be addressed by evaluating the performance of vertical green walls in tropical condition. In this study, thermal performance, relative humidity (RH) and CO_2 concentration were quantified for basic three types of green infrastructures; such as (T_1) living walls, (T_2) indirect green façades and (T_3) direct green façades located in Colombo metropolitan in Sri Lanka. An in-situ experimental study was conducted considering temperatures at 1 m and 0.1 m distance in front of the green walls, inside the foliage, air gap and external wall surface comparatively to adjacent bare wall control. Three case studies per green infrastructure within Colombo metropolitan area were purposively selected. Simultaneously, RH and CO_2 concentration at 0.1 m in front of the green and bare walls were measured for the performance quantification. The internal thermal comfort simulation and occupants' satisfaction questionnaire survey was executed to assess the green infrastructure performances. The study revealed that vertical greenery systems were highly effective on external wall surface temperature reductions at 1100 h–1500 h time zones. T_1 and T_2 accounted for superior temperature reduction in the range of 1.61 °C–1.72 °C through the façade relative to the distance than T_3. Maximum temperature reduction compared to the bare wall control was obtained for the T_1 (0.28 °C–8.0 °C) followed by T_2 (1.34 °C–7.86 °C) and T_3 (1.34 °C–6.64 °C). Averaged RH increment (1.6%–1.81%) and CO_2 reduction (0.63%) occurred near green walls at day time compared to control. An average 28 °C simulated indoor temperature circumstantiate the indoor thermal comfort. 58% and 89.5% occupants' were satisfied with thermal and visual comfort respectively, thus emphasizing façade greening as a sustainable approach on micro climatic changes and human thermal comfort.

1. Introduction

The world population was 7.5 billion in 2017 and 9.8 billion of world population is predicted by 2050 (PRB, 2017). The rapid growth of world population creates high dense areas where social redistribution occurs and change the social life. This referred as urbanization (Wijerathne and Halwatura, 2015). Rapid urbanization is a transitory phenomenon with respect to the status of economic growth (Henderson, 2003). Virtually all world's population growth is suspected to be concentrated on urban areas within next 30 years of period; outstripping the capacity of resources for the survival and this largest urban agglomeration make debate on the relationship on sustainable cities with their environment in today's world (Glaeser, 2014; UNFPA, 2016). Greater Dhaka and Beijing provide a great example on this (Byomkesh et al., 2012; Zhang et al., 2015).

Unplanned urbanization create more impervious environment which decrease the vegetation cover and increase in urban heat island effect (UHI) which eventually leads to climatic changes (Liddle and Lung, 2011) and low living quality (Haaland and van den Bosch, 2015; Ranagalage et al., 2017). Magnitude of day- time UHI was found highly proportional to population size as a surrogate of city size in 8 selected Asian mega cities (Tran et al., 2006). Bangkok, Jakarta and Manila considered as main mega urban regions in South Asia where population more than 10 million exist. Green space is less concern in Asia due to

Abbreviations: VGS, vertical grennery system; RH, relative humidity; GW, green wall; BW, bare wall

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lack of capabilities, funds and political will (Kioe and Thuzar, 2012). Nationally, US loss 36 million trees annually (Nowak and Greenfield, 2018).

According to World Bank report 2015, Sri Lanka shows a faster expansion in urban areas (measured using nighttime light data) relative to the urban population in a ratio of more than seven. Continuous diffusion of green patches and expansion of built-areas results low density, sprawl development and ribbon development with expansion of transport corridors. They are main characteristics of the Sri Lankan urban footprint (Subasinghe et al., 2016).

Colombo is the commercial capital and the largest city in Sri Lanka with the extent of 40.78 km^2 that occupies 5.6% of the total extent of Colombo district (Wickramasinghe et al., 2016). The economic development of the country created a significant infrastructural constructions in Colombo city which dramatically changes the land use and land cover of the city (Li and Pussella, 2017). The normalized difference vegetative index (NDVI) differencing techniques revealed vegetation shrinkage from 31.0 km^2 in 1980–5.02 km^2 by 2015 with a 7.16 m^2 per capita value; less than World Health Organization standard of 8 m^2 (Li and Pussella, 2017). Nevertheless gradual decline of vegetation were recorded from 35.67% (14.54 km^2) to 22.23% (9.06 km^2) since 1956–2010 (Wickramasinghe et al., 2016).The change of annual green cover reduction rates of Colombo are given as follows (Table 1). Urban heat island effect (0.09–4.4 °C temperature intensity range over rural area) in Colombo creates thermally discomfort environment with inefficient building energy consumption in a way lead to the air pollution (Perera et al., 2012).

Applying higher albedo surfaces (Akbari et al., 2001) and vegetative canopy cover with optimum spatial configuration are vital in UHI mitigation (Bao et al., 2016). Larger areal green covers store heat and reduce surface heating (Tam et al., 2015). Any building in the environment has its direct and indirect longer impact on own microclimate and the relationship should be positive to self-sustain with a healthy environment (Hunukumbura, 1999). Hence, vertical greening is more effective both in summer and winter by improving the micro climate (Manso and Castro-Gomes, 2014).

Vertical greening systems (VGS), vertical garden, green vertical system, green wall, bio shader, vertical landscaping or green façade are simply, plants grown on vertical surfaces which can be established on interior or exterior building walls using one or more plant types to be naturally grown or man-made in a way of standing independently or with structural supports to attach the wall (Perini et al., 2011a; Safikhani et al., 2014; Shiah and Kim, 2011; Wong et al., 2010a). The dichotomy of VGS is the foremost applicable classification where green facades are classified as direct or indirect (double-skin) and living walls are classified as continuous or modular (Hunter et al., 2014; Manso and Castro-Gomes, 2014).

VGS is a well-known concept in European countries. Italy (Blanco et al., 2017; Schettini et al., 2016), North America (Chicago etc.), Japan (Hoyano 1988), Africa (Holm, 1989) Canada (Wong et al., 2010a), Thailand and recently Asian countries implement VGS for its aesthetical and architectural value and as a technological solution to improve building performances and reduce the building impact on the environment along with its other enormous advantages (Ibraheem et al., 2017; Köhler, 2008; Safikhani et al., 2014). English ivy, Japanese ivy, Honeysuckle, Virginia creeper, Ivy gourd (*Coccinia grandis*), Mexican creeper (*Antigonon leptopus*) and Blue trumpet vine are highly used in green walls as it helps to reduce the heat flow by 75% and also reduce the heat flux from interior surface to interior air (Perez et al., 2011; Sunakorn and Yimprayoon, 2011).

Table 1
Declined rate of green space at Colombo over time.

Year	Declined rate ($km^2 yr^{-1}$)	Reference
1980–1988	0.46	Li and Pussella (2017)
1988–1997	0.39	Li and Pussella (2017)
1997–2001	0.37	Li and Pussella (2017)
2001–2010	0.41	Wickramasinghe et al. (2016)
2001–2011	1.37	Li and Pussella (2017)
2011–2015	0.71	Li and Pussella (2017)
1956–2010	0.10	Wickramasinghe et al. (2016)

VGS provide environmental and socio – economic benefits to community despite of socio – economic status (Schindler et al., 2018). Urban heat island (UHI) mitigation, temperature control, cooling and shading, dust and pollution control with particulate matter (CO_2, NOx and SO_2) and aerosol deposition, noise attenuation are primary advantages and promotion of human health (Maas et al., 2006), building energy saving, biodiversity restoration and water conservation can be considered as secondary advantages (Azkorra et al., 2015; Köhler, 2008; Ottelé et al., 2010; Sheweka and Mohamed, 2012; Susorova et al., 2013). Plant selection, mass and the thickness, inclination angle (more than 60° of angles can nearly block the day light), plant substrate and foliage thickness are several factors which determines the success potentiality of green façade (Ibraheem et al., 2017; Köhler, 2008; Lunain et al., 2016; Rayner et al., 2010). Green facade energetics are highly involve with building cooling load, ambient temperature and surface cooling (Safikhani et al., 2014). Since vertical greenery systems are to be newly applied in many Asian countries, perceptions of common society and the reliability of implementation is necessary to be evaluate for a clear future expansion. Hence, aspects regarding comfort and occupant satisfaction are equally important during building design and operation in means of energy efficiency (Gossauer and Wagner, 2008).

Gap of research evidence in means of practical application, spatio-temporal variability, and all aspects of green facades in tropical condition has been identified through the literature (Köhler, 2008; Peiris et al., 2014; Wong et al., 2010a). This paper reveals the impact of vertical greenery systems on micro −climatic changes in the buildings with the objectives (a) to quantify thermal performances and obtain the RH and CO_2 concentration profile of existing green facades in Colombo district (b) to compare the green façade performances according to their typologies in practical application and (c) to evaluate the occupant satisfaction/perception for green façade in considered buildings.

2. Materials and methodology

The research consists with in-situ experimental study with a simulation and questionnaire survey. The study was conducted within Colombo metropolitan region in west coast of Sri Lanka.

2.1. In-situ experimental study

Three basic types of vertical greening systems were identified as; (T_1) living wall systems, (T_2) indirect green facades which are attached to exterior walls with supportive structures and (T_3) direct green facades that directly plants grown on exterior walls (Hunter et al., 2014; Manso and Castro-Gomes, 2014). A building consist with such a constructed vertical greenery system was considered as a case study and purposively selected nine case studies were categorized into T_1, T_2 and T_3 systems representing three cases per each system (Fig. 1). Those nine greenery systems showed many similarities in plant type and material used except some characteristics as orientation and façade age (Table 2). Hence three replicates in each category; T_1, T_2 and T_3 were hypothesized as almost similar for the study. All the building walls were made of concrete bricks with a plaster coating for both interior and exterior surfaces. Total width of a wall was mostly 0.12m. The micro – climatic environmental variations in terms of temperature, relative humidity and carbon dioxide (CO_2) concentration for the selected vertical greenery systems were evaluated under this stage.