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Evaluation on thermal comfort impact of the revegetation project at the Fremantle train line's corridor in Perth City - Australia

Nghiên cứu về tác động của dự án khôi phục thảm thực vật tại hành lang tuyến đường sắt Fremantle ở TP. Perth - Úc đến tiện nghi nhiệt của cư dân xung quanh

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ABSTRACT

Perth City is one of the state capital that has the highest urbanisation rate in Australia. The urbanization process has affected urban infrastructure, and at the same time created the urban heat island, increasing urban temperature and reducing the outdoor thermal comfort of dwellers. Greening projects have been carried across the city to improve the current circumstance, such as the revegetation program at the surrounding areas of the Fremantle train line. To evaluate the effectiveness of this project, the author applied Solar and Long Wave Environmental Irradiance Geometry-model (SOLWEIG) with inputs from the CSIRO (Commonwealth Scientific and Industrial Research Organisation), Geoscape, and Bureau of Meteorology (BOM). Results demonstrate distinct differences between areas covered by trees and areas exposed to the sky. Urbanisation together with vegetation deterioration raises urban temperature significantly, but policy makers could prevent this occurrence via urban revegetation projects thanks to their effectiveness.

Keywords: Revegetation project; thermal comfort; urbanization; urban heat island.

TÓM TẮT

Thành phố Perth là một trong những thủ phủ bang có tốc độ đô thị hóa cao nhất ở Úc. Quá trình đô thị hóa đã tác động lên hệ thống hạ tầng đô thị, đồng thời tạo ra hiệu ứng đảo nhiệt đô thị, khiến nhiệt độ trong đô thị tăng lên và giảm tiện nghi nhiệt của cư dân. Nhiều dự án phủ xanh đô thị đã được triển khai khắp thành phố, một trong số đó là dự án khôi phục thảm thực vật xung quanh tuyến đường sắt Fremantle. Để đánh giá mức độ hiệu quả của dự án đến tiện nghi nhiệt của người dân, tác giả đã áp dụng Mô hình sóng dài và bức xạ mặt trời (SOLWEIG) cùng các số liệu thu thập từ CSIRO (Tổ chức nghiên cứu khoa học và công nghiệp của khối thịnh vượng chung), Geoscape, và Cục Khí tượng (BOM). Kết quả nghiên cứu chỉ ra sự khác biệt rõ rệt về nhiệt độ giữa khu vực có cây xanh bao phủ và khu vực không có cây xanh. Đô thị hóa cùng sự suy giảm thảm thực vật làm gia tăng đáng kể nhiệt độ trong đô thị, tuy nhiên, các nhà hoạch định chính sách có thể ngăn chặn điều này thông qua các dự án khôi phục thảm xanh đô thị, nhờ hiệu quả rõ rệt của các dự án này.

Từ khóa: Dự án khôi phục thảm thực vật; tiện nghi nhiệt; đô thị hóa; hiệu ứng đảo nhiệt đô thị.

1. INTRODUCTION

Perth has a fast urbanisation rate as its urban footprint increased by 239 km^2 in 10 years starting from 2002 [23] due to the booming state economy at the beginning of the century [14]. Currently, Perth's population is more than two million after 180 years of development. However, this city will be home to more than 3.5 million people by 2050 under the current urbanisation rate [23]. The downside of this trend is the increase in urban temperature [24] as vegetation is replaced with man-made infrastructures [9].

Increasing urban temperature can cause urban dwellers serious health issues, such as fatigue and death [17, 24]. Outdoor thermal comfort is usually used to evaluate the influence of urban temperature on humans. The term thermal comfort refers to the state of mind that reaches satisfaction with the thermal environment [24]. On clear and hot summer days, outdoor thermal comfort variation is mainly affected by radiant temperature [3, 12]. The mean radiant temperature (T_{mrt}) is the net radiation that the human body exposes to under specific weather conditions [12].

Spatiotemporal variation of T_{mrt} is influenced heavily by urban street design. Some characteristics of the street profile that affect T_{mrt} are the asymmetrical building shape, the material of building facades, and the tree canopy cover [2, 11, 12]. Hence, increasing vegetation density can improve urban thermal comfort [16]. Street greening projects are being developed across Perth, and one of them is the revegetation program at the Western Suburbs.

Western Suburbs Regional Organisation of Councils (WESROC) built a greening plan for several member councils [22]. One of the regional initiatives is greening the rail corridor at the Fremantle train line within these suburbs annually. This corridor will become a local greenway linking numerous remnant habitats of Western Suburbs, which are isolated from each other. The green linkage can reduce the isolation of these habitats, prevent the associated loss of ecological functions and natural species [7]. The environmental factor of this project has been evaluated carefully, while the thermal comfort assessment has not reached an equal level [6].

Therefore, the research aims to evaluate the effectiveness of the revegetation project at the Fremantle train line on outdoor thermal comfort. Various models have been developed to assess thermal comfort using T_{mrt} [4, 11, 15, 19]. SOLWEIG (Solar and Long Wave Environmental Irradiance Geometry-model) is the chosen one for this research as this model has been proven to be better than others [1, 10, 21]. The model is included as a feature in a free QGIS (Geographical Information System) plugin – UMEP (Urban Multi-scale Environmental Predictor). This open-source tool allows people to use it without restrictions [10].

2. MATERIALS AND METHOD

2.1. Study area

The study area is the rail corridor of the Fremantle train line in between Hamersley Road and Nicholson Road. This area is located in the City of Subiaco, approximately five kilometres to the west of Perth's central business district. The council carries the revegetation project annually on two sides of the railway, including Stubbs Terrance and Railway Road. Nine thousand native understorey species have been planted in a partnership between the city council and the Perth Transport Authority [7].

2.2. Data

Inputs of this research are collected from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Bureau of Meteorology (BOM). CSIRO has been providing Urban Monitor data of the Perth region since 2007. Data collection includes approximately 35000 frames of stereo digital aerial photography taken on clear-sky summer days. These images have a high spatial resolution of 20 cm [5]. Due to the limited dataset availability, only Urban Monitor data of 2007 and 2016 are retrieved from CSIRO. The remote sensing products are raster data as follow:

- Surface models, including digital surface model (DSM), digital elevation model (DEM), vegetation height (Vegetation DSM), contain the height above sea level of objects in general, bare ground, and vegetation.
- Categorisation data, including vegetation, grass, and tree, classify pixels as vegetation, grass, tree, and assign values 1 or 0.

The Urban Monitor data does not have building classification; thus, this data is acquired from Geoscape Building Lite (Polygon) dataset [8]. The weather information for two summer days is provided by BOM. They are average and extreme summer days – a random summer day between 2008 and 2018 with the air temperature at 13:30 in the 50th and 95th percentile.

2.3. Methodology

The study uses the same workflow for the 2007 and 2016 datasets. There are a few prior tasks that were performed before running SOLWEIG. Other QGIS tools outside the UMEP plugin are employed. The QGIS tools and prior tasks are as below:

- ***Rasterize*** is utilized to generate a building raster from the Geoscape building dataset.
- ***Reclassify by table*** is used to reassign values of vegetation, grass, tree, and building layers.
- ***Raster calculator*** is employed to create impervious and landcover layers from reclassified layers; change the unit of DSM, DEM, and vegetation DSM from millimetres to metres; and subtract the vegetation DSM from the DSM to make a ground and building DSM.

Then, the next step is tailed based on different features of UMEP. The plugin contains three main sections, and features related to this study are listed as follows:

- ***Pre-processor*** has the tools to prepare model inputs such as Sky View Factor, Wall Height and Aspect, and Land Cover Reclassifier.
- ***Processor*** contains several models such as SOLWEIG.
- ***Post-processor*** possess features to interpret the result, such as SOLWEIG Analyzer. Excel is also used to analyse the result.

Several points of interest (POI) are examined; they are located at railway sides (POI 1 and 2) and residential sides (POI 3 and 4) of Stubbs Terrace and Railway Road. These POIs represents a standing adult male under specific weather conditions. The workflow of UMEP is demonstrated in Figure 2.

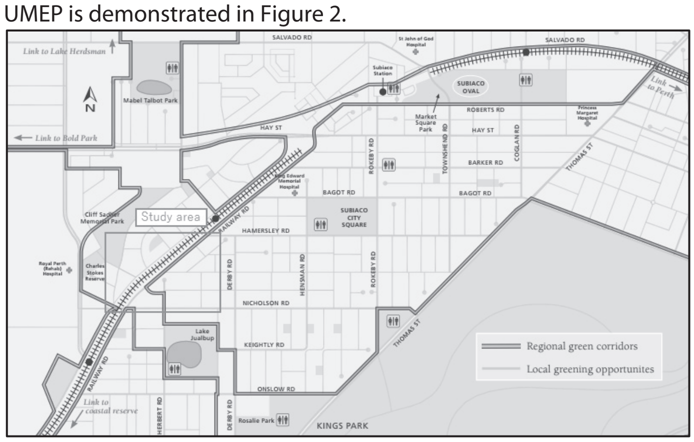


Figure 1. The study area [7]

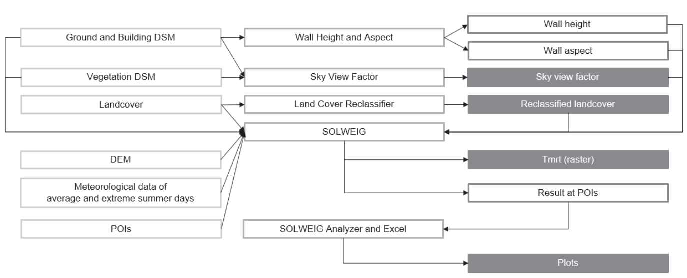


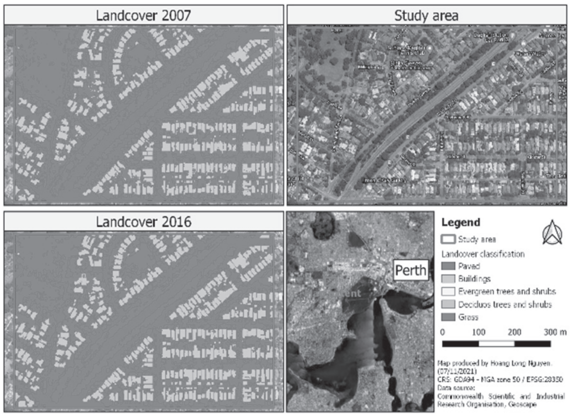
Figure 2. The workflow of UMEP.

Table 1. Workflow boxes legend

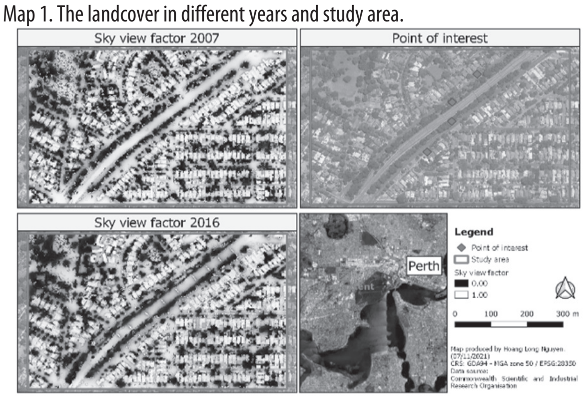
Type of boxes	*Description*
Yellow outline	Initial input
Grey outline	Tool
Blue outline	Output
Blue outline with shape fill	Output that will be presented

3. RESULTS

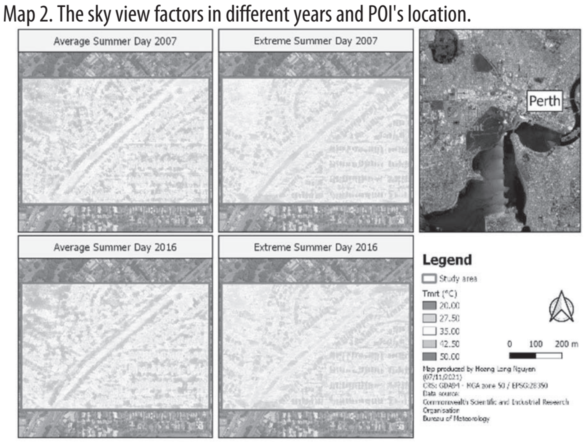
Map 1 demonstrates the change in landcover between 2007 and 2016. The increase in vegetation cover at the railway sides of Stubbs Terrace and Railway Road can be observed. The plant areas were fragmented in 2007, while in 2016, their gaps were filled. Hence, the railway's sky view factor decreases as more surrounding areas of the train line are covered by plants. Contradictory, the residential areas expose more to the sky because of a slight vegetation deterioration. These occurrences can be seen in Map 2.



Map 1. The landcover in different years and study area.



Map 2. The sky view factors in different years and POI's location.



Map 3. The T_{mrt} in average and extreme summer days of different years.

Map 3 illustrates T_{mrt} distribution on average and extreme summer days of the two years within the study area. On an average summer day of 2007, T_{mrt} varies from 24.51°C to 39.53°C. This variation remained unchanged in 2016, but the maximum and minimum values are slightly different, 24.72°C and 39.59°C. On an extreme summer day of 2007, T_{mrt} is higher and varies from 29.42°C to 43.07°C. The trend of average summer day also appears here as T_{mrt} in 2016 changes from 29.45°C to 43.22°C.

Figure 3 demonstrates T_{mrt} changes at different POIs on an average summer day of 2007. T_{mrt} at POI 1 increases gradually from 10°C at 6:00 to 69°C at 10:00, remains at this temperature for 5 hours, then decreases steadily to 15°C by 21:00. At POI 2, T_{mrt} rises from 19°C at 6:00, reaches a peak at 39°C at noon, then declines to 21°C by 21:00. There is one anomaly in POI 2's trendline, which is 48°C at 8:00. T_{mrt} at POI 3 has a similar trendline with POI 2 except for the anomaly, having lower starting and ending temperature values but a higher maximum value. T_{mrt} at POI 4 increases gradually from 6:00 to 11:00, then surges steeply till it peaks at 62°C at 15:00 and decreases to 16°C by 21:00.

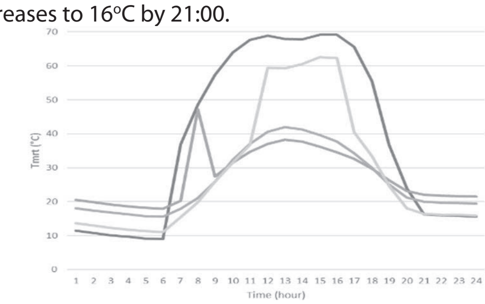


Figure 3. T_{mrt} at POIs in an average summer day of 2007

Figure 4 shows the variation of T_{mrt} at different POIs on an average summer day of 2016. T_{mrt} at POI 1 decreases significantly and has the same trendline with that at POI 2 in the first scenario except for the anomaly. POI 2 experiences the same T_{mrt} fluctuation; however, the anomaly is removed. T_{mrt} at POI 3 increases significantly; its trendline has the same shape and values as POI 1 in the previous case. T_{mrt} trendline at POI 4 remains the same shape, but the magnitude is higher as the peak increases.

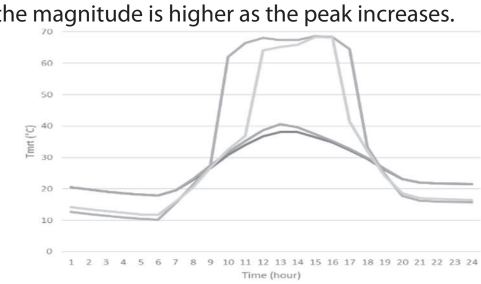


Figure 4. T_{mrt} at POIs in an average summer day of 2016

Figure 5 illustrates the change in T_{mrt} at different POIs on an extreme summer day of 2007. POI 1 experiences a steady increase in T_{mrt} from 10°C at 6:00 to 74°C at 16:00, then a steep decrease from the peak to 23°C at 21:00. T_{mrt} at POI 2 also surges gradually from 20°C at 6:00 to 45°C at 14:00 and declines steadily to 32°C at 21:00. The anomaly still appears in this trendline. T_{mrt} at POI 3 increases sharply from 19°C at 6:00 to 42°C at noon, then peaks at 66°C at 14:00. After that, T_{mrt} decreases dramatically to 49°C at 15:00 and reaches 30°C by 21:00. The trendline of T_{mrt} at POI 4 remains the same as the average summer day scenario, but the values are higher.

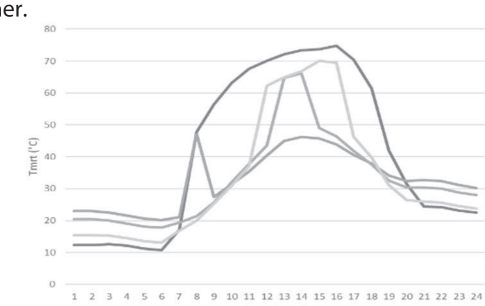


Figure 5. T_{mrt} at POIs in an extreme summer day of 2007

Figure 6 demonstrates the change of T_{mrt} at different POIs on an extreme summer day of 2016. T_{mrt} trendline at POI 1 decreases dramatically and has the same shape as POI 2 in the prior scenario. POI 2 also exhibits the same trend as the previous case, except for the anomaly. POI 3 increases dramatically, its trend resembles the T_{mrt} trendline at POI 4 in the prior case, but the magnitude is higher. Moreover, an anomaly appears at 17:00 when T_{mrt} sudden increases to 68ºC and decreases right after that. POI 4 experiences the exact change in T_{mrt} in 2007; however, the values are higher.

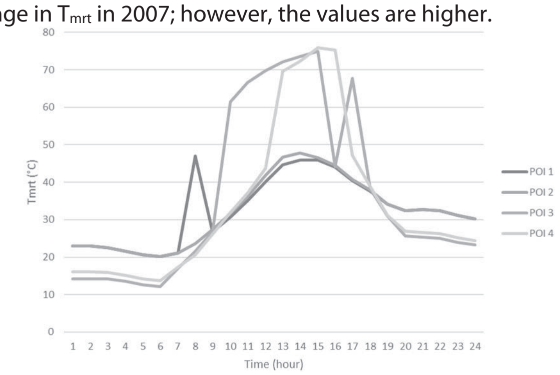


Figure 6. T_{mrt} at POIs in an extreme summer day of 2016

4. DISCUSSION

In nine years, starting from 2007, more vegetation was planted by the greening project at the two sides of the railway, increasing the canopy cover of this area. As a result, less surface area is exposed to the sun. The amount of net radiation in this area is reduced as more longwave and shortwave radiations are reflected back to the sky [11]. T_{mrt} at POI 1 on average and extreme summer days decrease significantly, complementing the prior statement. There were no trees at POI 1 in 2007; however, a tree cluster appeared at this location in 2016. POI 2 does not experience much change between 2007 and 2016 as there were already trees at this location in 2007. This finding demonstrates that single trees or a small cluster of trees can positively affect the thermal environment [18, 20].

On the other hand, deterioration of vegetation was recorded at the opposite sides of Stubbs Terrace and Railway Road. The decrease in vegetation canopy cover increases the sky view factor of this area to close to one, exposing this area more to the sun. Subsequently, the net radiation rises as more longwave and shortwave radiations are absorbed by surfaces [11]. The effect of tree removal can be observed at POI 3. This location had plantations in 2007, but they were removed in 2016, exposing the ground surface. As a result, POI 3 experiences a dramatic surge in T_{mrt}. In addition, vegetation deterioration can be observed in the whole study area, especially the northwest residential region. The distinct differences in Tmrt between regions with and without trees can be seen clearly [18]. Despite having trees, the shape of the T_{mrt} trendline at POI 4 remains almost identical between the two years, but the values are increased. This occurrence appears possibly due to the fast urbanisation rate of Perth in this period as buildings replace vegetation [9].

5. CONCLUSION

Future research can further improve the evaluation of thermal comfort at the Fremantle line between Hamersley Road and Nicholson Road. More data from CSIRO, Geoscape, and BOM can provide valuable information. In addition, an advanced computer can be used to analyse higher spatial resolution data. Even without these improvements, this study demonstrated the effectiveness of the revegetation project developed by WESROC. Adding single trees or a small cluster of trees can reduce T_{mrt} and raise the outdoor thermal comfort for citizens. Moreover, the decrease of plantation can bring significant differences in T_{mrt} to the area. Vegetation deterioration is a drawback of Perth's high urbanisation rate. Therefore, the research suggests the City of Subiaco should review the urban planning scheme and continue the current revegetation project. Additionally, the council can consider a greening plan for the opposite sides of the train line on Stubbs Terrance and Railway Road, and the residential areas to raise the overall outdoor thermal comfort.

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