Effectiveness of Neighbourhood Retrofit Strategies in Mitigating the Urban Heat Island in Salcedo Village, Philippines

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Salcedo Village has become more susceptible to urban heat effects because of its continuous development. This study investigates urban retrofit strategies that effectively mitigates the heat through modelling and simulation in ENVI-met. It is identified to have a maximum of 1-1.4K heat increase over 100% of its area, recorded during December 23:00 at 2m from the ground. The temperature increase is used to measure the effectiveness of the neighbourhood retrofit strategies: provision of grass, water and trees at ground level, increase in vegetated area, and Leaf Area Density of trees, and pedestrian walk albedo. The effectiveness of each strategy is quantified by its temperature difference and percentage area affected, compared with the 2014 Case model. The most effective strategy is the Leaf Area Density of trees, followed by the increase in vegetated area and the planting of trees; while all the others showed insignificant effect. The individual effects of these strategies, however are relatively small compared to the 1-1.4K heat. It was found through a combined test case that the application of these strategies together can make, but not limited to 1-1.5K change over 26% of the area.
Keywords: urban heat island, Philippines, neighbourhood retrofit strategies, ENVI-met

INTRODUCTION

The capital region in Philippines, Metro Manila (MM) has been developing its cities as an urban area for the past decade, consequently it has become more susceptible to urban heat effects. The urban heat of MM has been studied by *Pereira & Lopez (2004)* and *Tiangco, et al. (2008)* in different studies. Both identified Makati City as one of the hottest and largest clustered surface area with the surface temperature increase. However, due to the city's large land area as well as the limitation of simulating tool, the study focuses on its neighbourhood, Salcedo Village [Figure 1] which represents the area better with its well distributed building height and land area cover (Pobre, 2015).

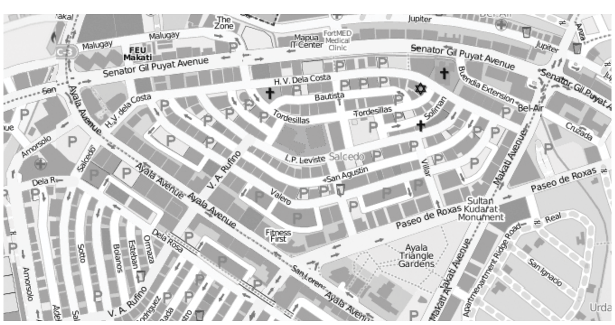

Figure 1: Salcedo Village, Makati, Philippines – Study Area (OpenStreetMap Contributors, 2015)

The aim of the study is to identify the effectiveness of UHI-mitigating strategies in Salcedo Village. The strategies included are those applicable for the neighbourhood's retrofit. They are tested and studied through the simulation tool, ENVI-met v3.1. The objectives of the study are as follows:

1. To identify the increase of heat (K) in Salcedo Village comparing the simulated air temperature difference between 1995 and 2014 models; the heat increase is used as a benchmark to assess the effectiveness of the strategy.
2. To determine and measure the most effective UHI-mitigating strategy/ies for Salcedo Village

REVIEW OF THE RELATE LITERATURE

MEASURING URBAN HEAT ISLAND (UHI)

Both *Pereira & Lopez (2004)* and *Tiangco, et al. (2008)* measured the UHI of MM using satellite imaging (surface based temperature). The latter compared the night-time temperature of MM to the adjacent rural areas', Bulacan (north of MM) and Cavite (south of MM). While *Pereira & Lopez (2004)* compared MM's surface temperature records between 1989 and 2002. Both methods can be done to study UHI but *Pereira & Lopez's (2004)* method is adapted to this study since their method allows a simpler modelling (Pobre, 2015).

STRATEGIES TO MITIGATE URBAN HEAT ISLAND

Albedo. Changing the albedo from low to high has been studied by researchers like *Akbari (2009), Giridharan & Kolokotroni (2009),* and *Radhi, et al. (2014)*. They concluded in their respective studies that changing a surface's albedo from low to high (0.1-0.9) generally lowers the urban heat by measuring the strategy's impact on air/surface temperature or a building's energy consumption.

Vegetated Area. The increase of vegetated area has been studied by *Shashua-Bar & Hoffman (2000), Wong, et al. (2007), Hamada & Ohta (2010),* and *Heinl, et al. (2015)*. They concluded separately that as the vegetated area increases, the lower the air/surface temperature around it; and the effects are more prominent, the closer to the vegetation. Researchers further studied the application of vegetation: *Wong, et al.'s (2003),* and *Yu & Hien's (2006)* studies showed the importance of the plant's leaf area index; while *Shashua-Bar, et al.'s (2009)* study compared the impact of grass and trees with different variation, and concluded that planting trees reduces the air temperature more.

Open Water. The presence of open water (natural or manmade) has been studied by *Hathway & Sharples (2012)* and *Steeneveld, et al. (2014)*. The conclusions of their studies have the opposite results, having different climate conditions. Due to the varying results depending on the climate conditions, all strategies though proven effective or otherwise are tested in Philippines' climate conditions to determine their magnitude of effectiveness.

FACTORS THAT AFFECT UHI

Climate. Cloud conditions, level of humidity, and wind flow have been reported by *Memon & Leung (2010), Ivajnsic, et al. (2014),* and *Tan, et al. (2015)*. They suggested a strong correlation between the cloudiness and relative humidity of a location to the UHI. While *Giridharan & Kolokotroni (2009)* and *Gago, et al. (2013)* have suggested to consider wind flow carefully as it can displace heat. Though climate conditions cannot be controlled, they are important to correctly set up the model for simulation.

Urban Morphology. *Gago, et al. (2013)* and *O'Malley, et al. (2014)* concluded that the building distribution determines the absorption of solar radiation and formation of wind flows. They said, respectively, that closely built tall buildings slows wind speed and traps heat, and that surfaces should be oriented to reflect heat away and not received inside the building or trapped in a niche where wind circulation is hard. *Sky-view Factor (SVF)* is the ratio of radiation received by a plane over that from the hemisphere. Both *Yamashita, et al. (1986)* and *Svensson (2006)* found strong correlation between the air temperature and the SVF. Their study results show that with high SVF, there is low temperature increase. Though urban morphology is already out of the study scope since the study focuses on retrofit strategies, it is important to note this as a factor affecting the results.

STUDY AREA: SALCEDO VILLAGE

Salcedo Village is a part of Makati City which is located at 14° latitude and 121° longitude. The area [Figure 1] is composed of about 120 hectares with the following profile (Pobre, 2015):

Table 1: 2014 Salcedo Village Land Cover (Built and Vegetation Profile)

	Area (ha)	**Percentage**
Built Area	37.1	31
Tree-covered Area	2.6	2
Grass-covered Area	17.0	14
Empty Area*	63.6	53

**No vegetation or buildings*

Table 2: 2014 Salcedo Village Land Cover (Soil Profile)

	Area (ha)	**Percentage**
Concrete Pavements	44.2	37
Loamy Soil	25.1	21
Asphalt Road	51.0	42

This profile is based on the 2014 built environment model. The built area is finished with concrete pavements, tree- and grass covered areas are with loamy soil, and roads are finished with asphalt. All test [strategies] cases are compared to this Base Case profile.

Built-area Profile. There are about 300 buildings in the modelling area that are mostly mid-to-high rise with an average of 63m height (about 20 levels). Most of the buildings are vertical residential or commercial developments. The wall and roof albedo adapted that of the typical local construction for these type of building uses: concrete wall and roof (albedo 0.3). (Pobre, 2015)

Vegetation and Soil Profiles. For simpler modelling, one kind of grass/shrub and trees are specified. Grass/shrubs are those that are dense and no more than 0.5m high while trees are also dense and but 10-15m high. For the Soil profile: building roof and parking area are paved; empty lots (not used as parking) are with grass; parks are covered in trees; and roads are in asphalt. (Pobre, 2015). All vegetation and soil profile were from the existing database of ENVI-met v3.1.

METHODOLOGY

Modelling Setup. The Base model is first quality assured by testing its grid dependency, which dictates the resolution of the study. The grid size (the scale of each cell) tested are 18mx18m (G18), 16mx16m (G16), 13mx13m (G13), and 10mx10m (G10). The grid results [Figure 2] behave consistently but have an acceptable variation. Among the grids, G16 is the most feasible scale to be studied due to acceptable simulation length and faster model building.

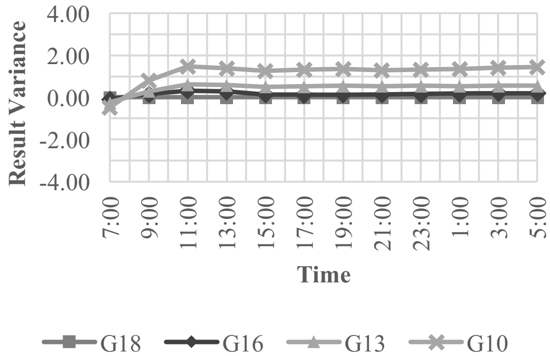

Figure 2: Grid dependency test – Result variance per time (Results are simulations from ENVI-met)

Monitoring Period. UHI varies as the season changes (Klysik & Fortuniak, 1999; Tan, et al., 2015). In this study, the test (strategies) cases are tested in two days of the year: a summer day (April) and a winter day (December). The monitoring is studied every hour of the day but the point of comparison is every 14:00 and 23:00 where the warmest and the coldest hour observed. The April climate conditions set are 1.8m/s, 135° wind speed and direction, 21.45 g/kg specific humidity, 77% relative humidity and cloud conditions of 4, 2 and 2 oktas, low, medium and high respectively. The December conditions with the same order of details are 2.7m/s, 129°, 13.69 g/kg, 66%, 2, 3, and 3 oktas. The climate data is from *METEOTEST (2005)*. *Monitoring Points*. There are four receptors spread within the model. All data reordered in this study is at 2m from the ground.

Urban Heat Island. The temperature increase in the area is measured by comparing the temperatures in the 2014 model and the 1995 model, when the area is not as developed as it is at 2014. The difference in temperature is the effects of increase in built area, and lessening of vegetated areas by about 9%. Modelling and simulation are run through ENVI-met v3.1. The 1995 model alone uses a different climate which coincides during that time. The April climate conditions set are 1.5m/s, 133° wind speed and direction, 20.95 g/kg specific humidity, 77% relative humidity and cloud conditions of 4, 2 and 2 oktas, low, medium and high respectively. The December conditions with the same order of details are 1.8m/s, 129°, 11.79 g/kg, 63%, 2, 3, and 3 oktas. The climate data is from (METEOTEST, 2005).

The results [Figure 3] show that UHI is more prominent in December, night-time 23:00; for this reason, this study focuses on this time and season. The increase of air temperature is about 1-1.4K over 100% of the space measured at 2m from the ground.

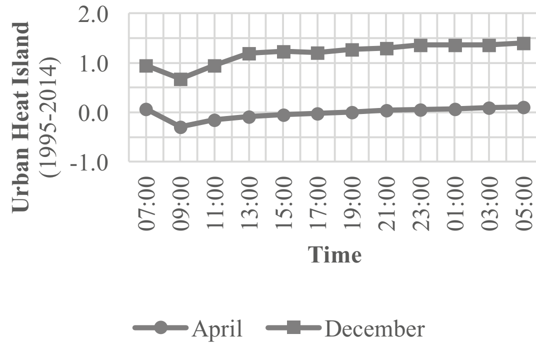

Figure 3: UHI of Salcedo Village from 1995 to 2014

Testing of UHI-mitigating Strategies. Based on the literature, a list of applicable strategies are identified to be investigated its effectiveness in mitigating the UHI in Salcedo Village. Hence each application or site coverage is limited to the 2014 morphology of the neighbourhood. The area difference is important to note when comparing their effects on the area. Each of the strategy's effectiveness is gauge upon its difference with the target (1.4K UHI) temperature to be mitigated.

Combined Test Case. Based on the test results, the identified effective strategies are applied and tested together to investigate its effectiveness compared to their individual performance, and to the target heat.

STUDY CASES AND MODELLING

CASE 1: Conversion of parking areas into Grass Park. This proposal is taken from *Onishi, et al. (2010)* study where they covered all their parking areas in grass. This increases the vegetated areas (+6%) and decreasing the hard surfaces like pavements (6% conversion of pavements to loam soil).

CASE 2: Parking areas into an Open Water. *Hathway & Sharples' (2012)* and *Steeneveld, et al.'s (2014)* have concluded in their respective studies contrary results; one have claimed effectiveness of this strategy while the other otherwise. This Case investigates the results in this Salcedo Village and in comparison with the effects of grass, hence modelling changes are similar with Case 2: increase in body of water (instead of grass area), which decreases hard surfaces (6% pavements converted to body of water).

CASE 3: Parking areas into tree-covered areas. Another strategy to be investigated is *Onishi, et al.'s (2010)* proposal of covering the parking spaces in trees. This is also compared to Cases 1-2, hence modelling changes are similar with Cases 1 and 2: increase in tree-covered areas (+6%), and decrease of hard surfaces (6% pavements converted to loam soil).

CASE 4: All vegetated area are covered with trees. Shashua-Bar & Hoffman (2000) concluded in their study that shading from trees makes the ambient air cooler. In modelling, this Case is a continuation of Case 3 but converts its grass into tree-covered areas. The 14% grass is converted to tree-covered areas, which would in total covers 22% of the area. Similar to Case 3, there is 31% pavements, 27% loam soil and 42% asphalt road for this Case's soil profile.

CASE 5: Increase in vegetated area. The increase of vegetated areas, specifically of parks (trees) have been claimed by researchers like *Shashua-Bar & Hoffman (2000)* and *Lin, et al. (2015)* to be effective in lowering the air temperature of the area and its surroundings. Modelling takes from Case 4, and increases the tree-covered area by 10% more (total of 32%) and decrease of asphalt by 10% (results to 33% total asphalt) converted to loam soil.

CASE 6: Leaf Area Density (LAD) Variation. Based from *Yu & Hien's (2006)* study, the effectiveness of trees changes according to their LAD. This Case investigates the effectiveness of the trees in ENVI-met's database. Trees with LAD of $0.3m^2/m^3$ (Base Case), 0.5, 0.9, 1.2, 1.5, and 1.9 m^2/m^3 are tested. Land cover profile of this Case is the same with Case 3.

CASE 7: Pedestrian Walk Albedo. Building walls, roofs and roads have albedo; however this Case investigates only the pavements on the ground level since changing of commercial building façade and roofs are difficult. This Case tests 0.2 (asphalt), 0.4 (pavement), and 0.8 (granite pavement) albedo for 16% of the total area (from 6% pavement and 10% asphalt). These finishes are based and limited to ENVI-met's database.

RESULTS AND ANALYSIS

CASE 1-3 (Open Parks, Water, Trees). The 6% surface area tested made a 0.1K difference over 9%, 8%, and 27% in Cases 1, 2 and 3, respectively. Among the three, the result [Figure 5] shows that planting trees is slightly more effective than planting grass or having a body of water. *Shashua-Bar, et al. (2009)* have concluded the same when comparing grass and trees. The 0.1K difference however is insignificant compared to the target heat to be mitigated. It is hypothesized that the reason for their insignificant results is the area coverage of only 6% since Case 5 shows that the total area makes a difference. More explorations of planting trees are done in the next cases.

CASE 4 (All trees). An additional 20% of vegetation covered with trees is on this Case. This made a difference of 0.3K over 1% of the area, 0.2K over 11%, and 0.1K over 11% during December night-time (23:00). This changes about 23% of the area. The strategy's effect in temperature change and percentage coverage is small relative to the identified UHI.

CASE 5 (Increase in area). The tree-covered area in the model is 30% more. The results show there is difference in air temperature by 0.4K over 1% of the area, 0.3K over 6%, 0.1K over 63%; changing the air temperature about 70% of the model space. This shows the potential significance of total vegetated area in the air temperature, as was also concluded by *Lin, et al. (2015)* and other researchers. The strategy's effect in temperature change is relatively small but its percentage coverage has spread for majority of the area. Increasing the area of vegetation alone is not enough to mitigate the target heat.

CASE 6 (LAD variation). Figure 4 shows the air temperature change from the Base Case which uses $0.2m^2/m^3$ LAD. The temperature change shown in LAD $0.2m^2/m^3$, however is the effects of the increase in vegetation area since this Case adapts Case 3 model (6% increase in tree vegetation area). The results show that there is an increase in the change if air temperature as the LAD also increases; hence the highest LAD is the most effective. The results are in parallel with the observation of *Yu & Hien (2006)* in their study. The LAD $1.9m^2/m^3$ lowered the air temperature by 0.4-0.8K over 10% of the area, 0.3K over 5%, 0.2K over 12%, and 0.1K over 10% during December at 23:00. This changes 57% of the modelling area. The strategy has a good temperature change but is concentrated on specific spots. High LAD of trees is an effective strategy for its immediate surroundings. The location and spread of strategy is important to be effective. Similar conclusion were derived from *Yu & Hien (2006)*.

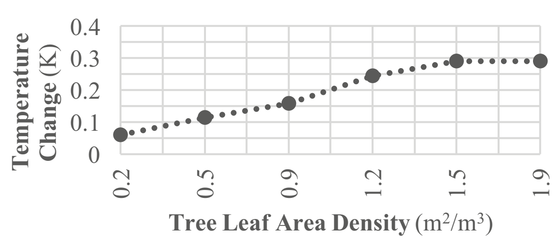

Figure 4: Receptor average air temperature difference per Tree LAD variation in December 23:00 at 2m height (Results are simulations from ENVI-met)

CASE 7 (Pedestrian Walk Albedo). The 0.2, 0.4 and 0.8 albedo tested over 16% surface area barely made any difference. The results on the 0.8 Albedo Test showed a maximum change of 0.1K difference in the air temperature over 7% of the area. It is hypothesize that the effect should increase as the total area coverage increases.

However, this case has not been further explored as it did not have a large effect even with 16% coverage.

ALL CASES. Ideally, the results have high Temperature Change and with small Area Percentage Coverage: large effect with little coverage application. Figure 5 shows the combined results from Case 1 to 7. Among all, high LAD (Case 6) makes the most effective strategy – having 6% application coverage and about 0.3K difference (receptor average). This is followed by Vegetation Area (Case 5) and Planting of Trees (Case 4), having a respective change of 0.2K with 30% coverage, and 0.1K with 20% coverage.

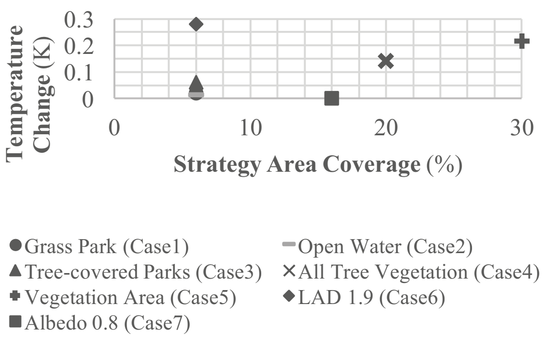

Figure 5: Receptor average Air Temperature Change and Area Percent Coverage of the cases from the Base Case during December at 2m high (Results are simulations from ENVI-met)

COMBINED TEST CASE

The application of effective Cases, 4-6 are tested all together to ensure that the combination can make a significant change over most of the area. This model has a land cover of 27% tree-covered area, 1% grass area, 41% asphalt, and 28% loamy soil.

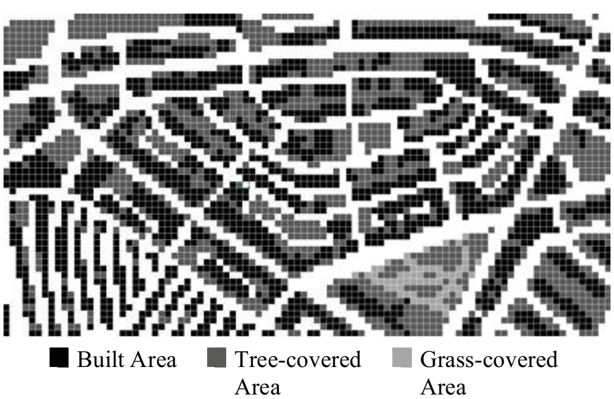

Figure 6: G16 Combined Test Case Model

The results [Figure 7] showed that 94% of Salcedo Village has changes in air temperature by at least 0.5K: 26% has 1-1.5K change, 70% with 0.5K and 4% with less than 0.5K. Though this test has not yet mitigated the 1.4K UHI of Salcedo Village, it shows the potential of these strategies to mitigate the heat if applied to particular location. Figure 6-7 show respectively the model (application of the strategies) and the air temperature changes.

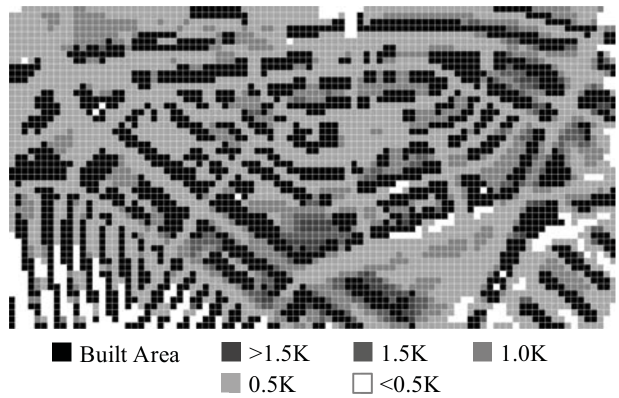

Figure 7: Temperature Change Colour Map (created by the Authors based from ENVI-met results)

CONCLUSION

Salcedo Village is a part of Makati City, which *Pereira & Lopez (2004)* and *Tiangco, et al. (2008)* identified to have UHI in their respective researches. This study has measured a maximum of 1.4K UHI (recorded on December 23:00) by comparing the air temperature of the area in 1995 and 2014, with considerations to the urban and climate changes in the modelling. It has been observed, and supported by other journals, that the highest UHI appears during winter (December in this case) night-time, hence the study uses the recorded temperature during this specific season and hour to gauge the effectiveness of the strategies.

Academically proven strategies that are applicable to neighbourhood retrofit are collated and tested to measure their effectiveness in Salcedo Village. The tests on the provision of grass (Case 1) versus water (Case 2) versus trees (Case 3) showed that the planting of trees affects the air temperature more than the other two. Cases 4-5 are continuation of Case 3 with the conversion of all existing vegetation to trees (Case 4), and with the increase in vegetated areas (Case 5). This showed changes in the air temperature of maximum 0.3K and 0.4K in specific areas, respectively. There is however changes in about 23% and 70% of the area with at least 0.1K in the respective cases. The LAD variation of trees (Case 6) was also tested; it was found, as was similarly concluded by *Yu & Hien (2006)* that the higher the LAD is, the more significant the effect is on cooling of the air temperature. The 1.9m^2/m^3 LAD made a maximum of 0.8K in specific areas but have affected 57% of the area with at least 0.1K difference. Albedo (Case 7) has insignificant effects.

Changes made by Case 4 and 5 is small relative to the change made by Case 6. However, if applied all three together, just like in the Combined Test Case, the temperature change and its magnitude makes a significant impact to the UHI. This investigation shows the importance of high-LAD trees, and the total vegetated area for the effective mitigation of UHI in Salcedo Village.

FURTHER STUDIES

Tests on Cases 6 and 7 are limited to the plant and soil profiles available in database of the tool. The results of the test would be more applicable should the database be updated to the local biodiversity. E.g. Case 6 is limited in its tests with a 1.9 m^2/m^3 LAD but according to *Asner, et al. (2003),* the LAD of plants in tropical countries are usually between 1.8 and 5.2 m^2/m^3. Hence the effects of plants higher than 1.9 LAD is not tested.

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