แบบจำลองประสิทธิภาพเชิงนิเวศเศรษฐกิจสำหรับการออกแบบสภาพแวดล้อมภายนอกของโครงการอสังหาริมทรัพย์แบบผสมผสานการใช้งานในกรุงเทพ-มหานคร ประเทศไทย

The Eco-efficiency Model for Outdoor Environmental Design of the Mixed-use Real Estate Development in Bangkok, Thailand

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Abstract

Nowadays, the dramatically of urban land developments affect to various of environmental problems, especially in urban heat and the reduction of natural porosity surfaces, then increasing of outdoor temperature and surface water runoff problems. These problems relate to urban residents outdoor living, especially in the large mixed-use real estate developments in Bangkok; the capital city of Thailand. Therefore, the development concerned on mitigating such problems by applying the eco-efficiency modeling to use as a sustainable design guideline for the new project development. The term of eco-efficiency is defined as the ratio of improvement cost per unit of the environmental impacts. This study formulates the eco-efficiency model by using the change of construction cost of outdoor environmental and their impacts which refer to the Physiological Equivalent Temperature (PET) as indicator for thermal comfort index of humans and stormwater runoff. The cost is calculated by simple cost estimation technique. Meanwhile, the microclimate model ENVI-met BioMet (V4) was used for predicting the effect different design options on outdoor thermal comfort using PET, and the Stormwater Runoff Test (SRT) is also calculated by the academic Green Stormwater Infrastructure (GSI) for Autodesk Infraworks 360 software. The results present as the prediction function of the eco-efficiency of the outdoor environmental design. Research suggests that pervious paving materials are broadly capable of lowering temperatures and improving human thermal comfort, and when integrated with trees have potential to meet eco-efficiency objectives. Moreover, the models can be used as the useful guideline for outdoor environmental design to toward the eco-friendly for urban residents' outdoor living of mixed-use real estate development in Bangkok, Thailand.

Keywords
Eco-efficiency
Water Sensitive
Outdoor Thermal Comfort
Physiological Equivalent Temperature (PET)
Stormwater Runoff
Simulation

บทคัดย่อ

ปัจจุบันนี้ การเพิ่มขึ้นอย่างรวดเร็วของการพัฒนาที่ดินในเขตเมืองส่งกระทบต่อการเปลี่ยนแปลงด้านสิ่งแวดล้อมหลายประการ โดยเฉพาะอย่างยิ่งปัญหาด้านความร้อนและการลดพื้นที่พรุนน้ำในเขตเมือง สร้างปัญหาภาวะอยู่สบายนอกอาคารและน้ำฝนไหลนองของพื้นที่ ซึ่งกระทบต่อการอยู่อาศัยของคนเมือง โดยเฉพาะอย่างยิ่งกับโครงการขนาดใหญ่แบบโครงการอสังหาริมทรัพย์แบบผสมผสานการใช้งานที่ตั้งอยู่ในพื้นที่กรุงเทพมหานคร เมืองหลวงของประเทศไทย ดังนั้นการพัฒนาโครงการประเภทดังกล่าวควรให้ความสำคัญในเรื่องดังกล่าวเป็นอย่างยิ่ง ทั้งนี้เมื่อมีการนำดัชนีเรื่องประสิทธิภาพเชิงนิเวศเศรษฐกิจมาประยุกต์ใช้เป็นแนวทางในการพัฒนาโครงการ ซึ่งประสิทธิภาพเชิงนิเวศเศรษฐกิจคือการพิจารณาถึงความสัมพันธ์ระหว่างอัตราการเปลี่ยนแปลงของต้นทุนการพัฒนาต่อผลกระทบด้านสิ่งแวดล้อมที่เปลี่ยนแปลงไป โดยผลกระทบด้านสิ่งแวดล้อมที่พิจารณาในครั้งนี้คือค่าอุณหภูมิสมดุลทางสรีรวิทยา สำหรับการวัดภาวะอยู่สบายภายนอก และเลือกใช้ค่าน้ำฝนไหลนองในการวัดประสิทธิภาพของการออกแบบพื้นที่รับน้ำ และเลือกการประเมินค่าต้นทุนการก่อสร้างอย่างง่ายในการทำงานวิจัยครั้งนี้ จากนั้นเลือกใช้โปรแกรม ENVI-met BioMet (V4) สำหรับการหาค่าอุณหภูมิสมดุลทางสรีรวิทยา และ Green Stormwater Infrastructure (GSI) for Autodesk Infraworks 360 สำหรับวัดค่าน้ำฝนไหลนอง ซึ่งผลของการศึกษาพบว่าสามารถสร้างแบบจำลองในการประมาณค่าประสิทธิภาพเชิงนิเวศเศรษฐกิจของการออกแบ โดยข้อค้นพบที่สำคัญคือการเปลี่ยนเปลงพื้นผิวของโครงการส่งผลโดยตรงกับภาวะอยู่สบายและเมื่อประกอบกับการเพิ่มต้นไม้ใหญ่ในโครงการก็ยิ่งส่งผลทางบวก ทั้งนี้สามารถสรุปได้ในท้ายที่สุดว่าแบบจำลองประสิทธิภาพเชิงนิเวศเศรษฐกิจนี้สามารถนำไปใช้เป็นแนวทางในการออกแบบพื้นที่เพื่อสร้างความน่าใช้งานของพื้นที่ภายนอกอาคารให้แก่ผู้อยู่อาศัยในโครงการขนาดใหญ่ในกรุงเทพมหานคร ประเทศไทยได้

คำสำคัญ
ประสิทธิภาพเชิงนิเวศเศรษฐกิจ
การตอบสนองต่อน้ำ
ภาวะอยู่สบายเชิงความร้อนภายนอกอาคาร
อุณหภูมิสมดุลทางสรีรวิทยา
น้ำฝนไหลนอง
การจำลองสถานการณ์

1. Introduction

This research has adopted the Whizdom 101, which is a mixed-use real estate development an area of 68,880 square meters, has been developed by Magnolia Quality Development Corporation Limited. The project is located at Sukhumvit Road, close to Punnawithi BTS station, midst of Bangkok, the Capital city of Thailand. The project consists of bundle of buildings and outdoor environmental elements (as present in Figure 1), which possibility impact to the outdoor environments and urban residents' outdoor living.

(**Source:** Whizdom101, 2019)

Figure 1. The image of the Whizdom 101

According to Whizdom101 (2019), the project has adopted the eco-efficiency as the development indicator. The eco-efficiency is the sustainable indicator introduced by the World Business Council for Sustainable Development (WBCSD) since 1992 (Lehni & Pepper, 2000). The term of eco-efficiency is defined as the ratio of the product or service value according to its environmental impact (Huppes & Ishikawa, 2005; Sorvari, Antikainen, Kosola, Hokkanen, & Haavisto, 2009; Thitisawan, 2009). Therefore, the ratio of improvement cost per unit of the environmental impacts was suggested as the suitable eco-efficiency function for the built environment project developments (Rinchumpoo, 2012). Meanwhile, the outdoor thermal comfort and stormwater runoff are the major environmental concerns being recently in Bangkok (Klaylee, 2015; Srivanit & Selanon, 2017; Sukul, Rinchumphu, & Suttiwongpan, 2017; Suropan, Rinchumphu, & Srivanit, 2017). However, there is no research evidence on using the mixed impact of outdoor thermal comfort and stormwater runoff in one project. Thus, this study presents the new research which combine two impacts and compare to their cost. The results present the eco-efficiency model of the outdoor environmental design to toward the eco-friendly for urban residents' outdoor living of mixed-use real estate development in Bangkok, Thailand.

2. Objectives

The objective of this study is to formulate the eco-efficiency model of the outdoor environmental design by using the change of construction cost of outdoor environmental and their impacts for using as the guideline for outdoor environmental design of the mix-used project in Bangkok.

3. Literature Review

The literature consists of four main topics which present the briefly information of the theory or principle on eco-efficiency model, physiological equivalent temperature, stormwater runoff, and basic cost estimation techniques; present as follow.

3.1 Eco-efficiency model

As presented in the Introduction, the eco-efficiency is one of the renowned sustainable indicators for modern business and industry sectors (Boonmee, 2005; Shonnard, Kicherer & Saling, 2003). Several studies adopted and reported the results of eco-efficiency on their application, including in industrial and built environment businesses. The eco-efficiency has a very simple definition which is the ratio of the product or service value according to its environmental impact. However, Huppes & Ishikawa (2005) suggested that it can be calculated by four definitions realms of:-

1) The environmental productivity eco-efficiency defines the ratio of product value by its environmental impact,

2) The environmental intensity eco-efficiency defines the ratio of environmental impact by unit of product value,

3) The environmental improvement cost eco-efficiency defines the ratio of value of the product by the unit expense of environmental improves, and

4) The environmental cost-effectiveness eco-efficiency defines the ratio of improvement cost per unit of the environmental impacts.

those definitions, Thitisawan (2009) recommended to use the environmental cost-effectiveness eco-efficiency as the most suitable realm for the real estate development business, because the construction cost is more precise and controllable compare to the selling price, which make the model more reliable for the practical implementation. Therefore, the eco-efficiency model of this study formulated by using the ratio of construction cost and their impacts of outdoor environmental as follow as the environmental cost-effectiveness eco-efficiency definition. Consequently, the essence information of the environmental impacts (outdoor thermal comfort and stormwater runoff) and the cost estimation technique using in this study presents in the next section.

3.2 Physiological Equivalent Temperature

According to the two emerging environmental concerns in Bangkok, the outdoor thermal comfort is one of the lists (another one is stromwater runoff), by using physiological equivalent temperature (PET) to indicate the outdoor environmental design quality. Moreover, PET is proposed based on the Munich Energy-balance model for individuals where physiological aspects were considered for calculating the thermal conditions of human, so that it was found as a more reliable indicator than other indices (Höppe, 1999). The study was conducted field survey to obtain the information of the land cover of the area of study (i.e. the percentage of each landscape parameter including grass, tree, hardened ground, water body and building) and then parameterize the corresponding models using ENVI-met V4. The output data from ENVI-met, including air temperature, relative humidity, wind speed, mean radiant temperature and the thermal comfort indices like PET values.

3.3 Stormwater Runoff

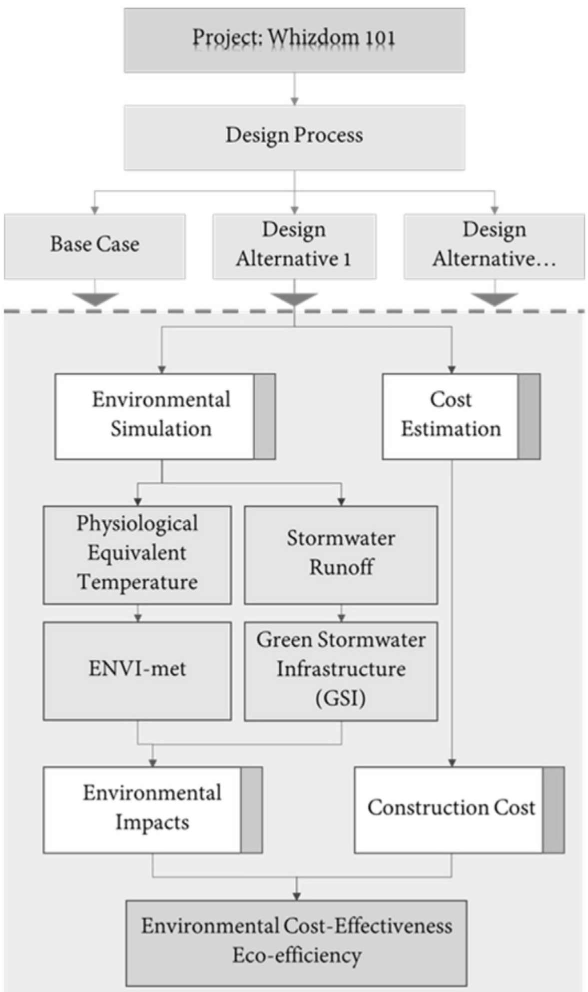
Bangkok locates at the central part of Chao Phraya Basin, which is considered the most important basin in Thailand, get impact from seasoning monsoon will cause of the stormwater runoff in urban area every year (Sukul, Rinchumphu & Suttiwongpan, 2017). Thus, the stormwater runoff is the important indicator for outdoor environment design, especially for large mixed-use real estate development. There are several methods to predict the runoff level such as the Rational Method, Runoff Curve Number (RCN) method. The Rational Method is function as the portion of rainfall that becomes direct runoff during an event, while the RCN is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess and for estimating peak discharges for small drainage areas. Therefore, the RCN is more suitable for the study which needs the empirical as objectives (McCuen & Bondelid, 1981). The runoff depth of RCN method can calculate by complex nonlinear mathematic functions (Jaber, Woodson, LaChance & York, 2012). Consequently, the using of Autodesk Infraworks 360 computer software to simulate the stormwater runoff depth by the outdoor space designs follows best management practices under Low Impact Development (LID) principle selected in recent several studies and practices (Chappell, 2015).

3.4 Cost Estimation Technique

The cost estimation is one of the most important tasks for all project decision making and development. There are several cost estimation techniques relating on difference development stages vary by the time consuming and estimation accuracy. However, due to the time constrain and limitation of design details, the most suitable cost estimation technique for the design stage should be the cost per unit area (volume) of the designs (Simion-Melinte, 2016).

4. Research Method

This study is to formulate the eco-efficiency model by using the environmental cost-effectiveness as the main concept. The research methodology comprises of several steps as present in Figure 2 below.



(**Sources:** Authors, 2018)

Figure 2. Research flow and framework

The PET has been simulated by using ENVI-met with necessary existing physical data such as the percentage of each landscape parameter including grass, tree, hardened ground, water body and building, and weather data from nearest standard metrological station. The in-site weather data was collected by standard mobile devices for model calibration process. In the other hand, the set of existing physical data using in ENVI-met has been use for predicting designs stormwater runoff in GSI plug-in for Autodesk Infraworks 360 software. Consequently, the simple construction cost has been estimated by cost per unit area technique. The example of ENVI-met and GSI plug-in for Autodesk Infraworks 360 software are presents in the Figure 3: below.

These processes apply for a base case and the 18 alternative cases, and then compute the different of alternative cases by the base case for all 3 results (PET, runoff, cost estimates) in unit of percentage. The ratio of green area pavements, ratio of trees cover area, and varies drainage soil structures in the outdoor designs are applied for all alternative cases. The major assumptions for two environmental impacts – PET and runoff – are equally weight impact for calculating total environmental impact of the design. The set of percentage differences are used for eco-efficiency modeling by using multiple regression analysis technique. The example of alternative cases present in Figure 4 below.

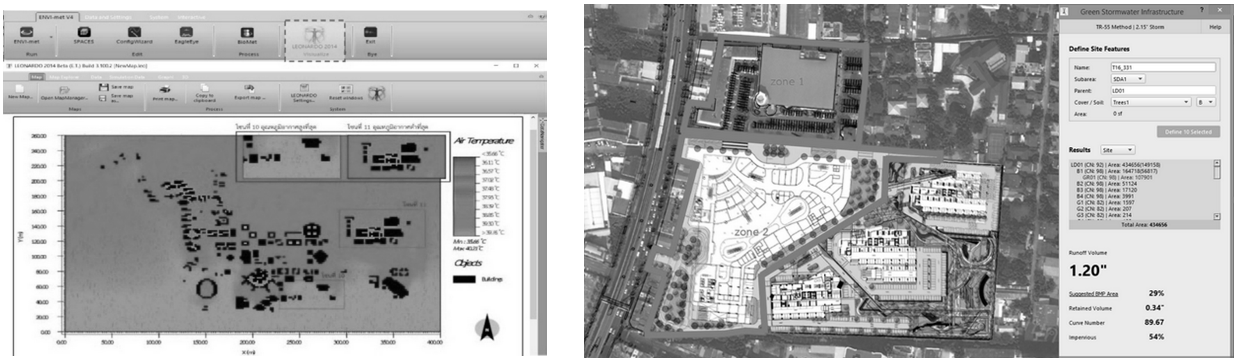
The 18 alternative cases are combination of 4 differences design indicators, which is:-

1) P is the percentage change of softscape pavement in the area.

2) T is the percentage change of cover tree in the area.

3) Sa is the porosity percentage of drainage material of the bio-retention cross section design in the area.

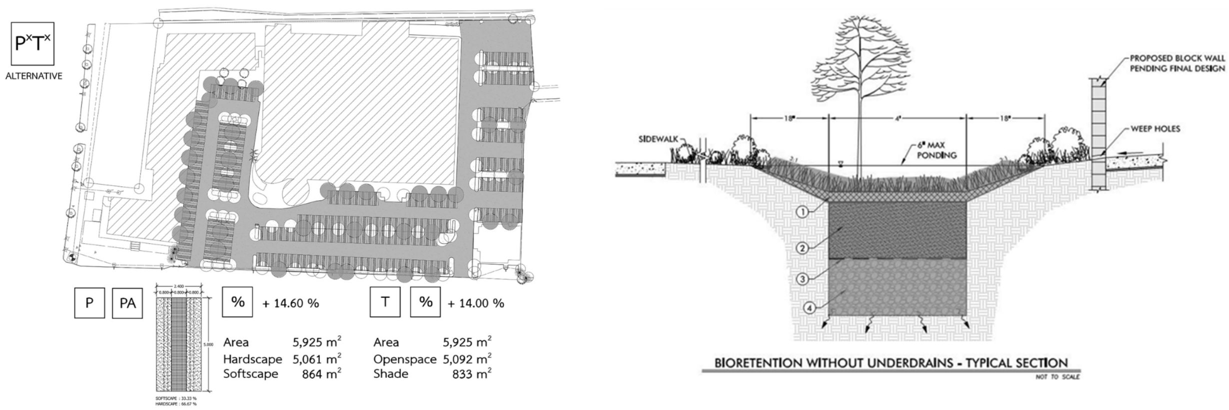
4) Sb is the drainage layer depth in centimeter of the bio-retention cross section design in the area.



(a) (b)

(**Sources**: Authors, 2018)

Figure 3. Computer user interface of (a) ENVI-met and (b) GSI plug-in for Autodesk Infraworks 360.



(a) (b)

(**Sources**: Authors, 2018)

Figure 4. The (a) example of schematic plan and (d) example of typical cross section design for bio-retention.

The combination matrix of the 18 alternative cases of this study present in the Table 1. below.

Table 1. The combination matrix of the alternative cases

Alternative Cases	P (%)	T (%)	Sa (%)	Sb (cm)
1	7.21	13.22	35	25
2	7.21	13.22	35	50
3	7.21	13.22	65	50
4	7.21	16.46	35	25
5	7.21	16.46	35	50
6	7.21	16.46	65	50
7	7.21	20.70	35	25
8	7.21	20.70	35	50
9	7.21	20.70	65	50
10	15.66	13.22	35	25
11	15.66	13.22	35	50
12	15.66	13.22	65	50
13	15.66	16.46	35	25
14	15.66	16.46	35	50
15	15.66	16.46	65	50
16	15.66	20.70	35	25
17	15.66	20.70	35	50
18	15.66	20.70	65	50

The results of each case present in the next section.

5. Results

The result are presented in Table 2 and the concluded information of the modeling presents in later section.

Table 2. The eco-efficiency, percentage change of environmental total impact (ΔI), and percentage change of construction cost (ΔC)

Alternative Cases	Eco-efficiency	ΔI (%)	ΔC (%)
1	-0.68	-10.09	6.81
2	-1.19	-10.09	11.99
3	-1.84	-10.09	18.56
4	-0.72	-10.14	7.26
5	-1.23	-10.14	12.43
6	-1.87	-10.14	19.01
7	-0.78	-10.14	7.92
8	-1.29	-10.14	13.09
9	-1.94	-10.14	19.67
10	0.06	-11.67	-0.75
11	-0.35	-12.50	4.43
12	-0.88	-12.50	11.00
13	0.02	-12.59	-0.30
14	-0.39	-12.59	4.87
15	-0.91	-12.59	11.45
16	-0.03	-12.68	0.36
17	-0.41	-13.51	5.53
18	-0.90	-13.51	12.11

The multiple regression model from the alternative cases using eco-efficiency as the independent variable with four sets of dependent variables of the ratio of green area pavements (P, %), ratio of trees cover area (T, %), and varies drainage soil structures (Sa, % and Sb, cm). The statistics testing and model present in Table 3.

Table 3. The eco-efficiency model

	Coefficients	t Stat	P-value
Intercept	-0.206	-1.941	0.074
P	0.102	29.654	0.000
T	-0.011	-2.221	0.045
Sa	-0.019	-16.317	0.000
Sb	-0.018	-12.851	0.000

Note: R^2 = 0.993, Significance F = 1.07 x 10^{-13}

The model can write in the equation format as:-

$$EE = -0.206 + 0.102(P) - 0.011(T) - 0.019(Sa) - 0.018(Sb) \quad \text{(eq.1)}$$

The signs (+, -) present the direction of impact of increasing of each independent to the eco-efficiency model, and the magnitudes present the significant level to the eco-efficiency model as well. The model presents a very high R^2; mean the good fit of the model and high accuracy in prediction purposes. The model can use as the guideline for selection on design components of the Whizdom101 project and the research process is useful for the further project development in Bangkok.

6. Discussion

The study presents in the numerical modeling of eco-efficiency in outdoor environmental designs for the mixed-use real estate development, midst of Bangkok, the Capital city of Thailand, in developing a the eco-friendly for urban residents' outdoor living.

The eco-efficiency model was formulated by environmental cost-effectiveness concept, adopting total changing of two environmental impacts – PET and stormwater runoff, on the changing of their construction cost. The model presents the good fit for further prediction purposes. However, the most significant independent variable is ratio of green area pavements in the positive sign, which mean if the design adds more green outdoor space it generates the good benefit in both economic value and environmental.

On the other hand, the increasing of tree cover may not generate the positive, but the significant of it change is quite low. This is same as the results from drainage soil structure properties. There is a need of reason to explain the negative impact of tree covers, which can deep analyze in the raw date of the model. The trees cover is good to support the better environmental impact (more tree can reduce PET and runoff) but the cost of trees presents in the higher growth. So, the overall eco-efficiency of more trees goes negative. This situation explains for same reasons of the drainage soil structure improvements. However, the unit cost of tree and soil improvements can be reduced by the specification replacement or the construction experiences, and then the construct cost could be re-estimated.

Finally, the research suggests that pervious paving materials are broadly capable of lowering temperatures and improving human thermal comfort, and when integrated with trees have potential to meet eco-efficiency objectives with a small concern in tree and drainage soil improvement costs. Moreover, the models can be used as the useful guideline for outdoor environmental design of the mix-used projects to toward the eco-friendly for urban residents' outdoor living of mixed-use real estate development in Bangkok, Thailand.

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8. List of Abbreviation

ΔC	Percentage change of construction cost
ΔI	Percentage change of environmental total impact
GSI	Green Stormwater Infrastructure
LID	Low Impact Development
PET	Physiological Equivalent Temperature
RCN	Runoff Curve Number
SRT	Stormwater Runoff Test
WBCSD	World Business Council for Sustainable Development

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