Developing an Optimisation Model of Solar Cell Installation on Building Facades in High-Rise Buildings – A Case Study in Viet Nam

Quang Trung Nguyen*, Duc Long Luong, Anh Duc Pham, and Quynh Chau Truong

Abstract— *Designing envelope configurations of office buildings with low construction costs and the energy consumption is a discrete optimization problem. The configuration is currently determined merely on architects' experiences resulting in an inefficient expense or by building energy performance simulation which is time-intensive and involves complex processes. However, in order to reduce energy consumption in buildings, previous studies only focused on optimizing the facade design of the building or optimizing solar panels on the roofs of the building without focusing on combining the design solution, calculation, and installation of energy panels on the facade (vertical surface) of the building. This study presents a method to optimize the installation area of solar panels on the building facades in order to reduce the amount of heat absorbed in the building and create a large amount of renewable energy used in the building. The results revealed that if the investment to provide solar battery systems is < 360,000 USD, this upgrade is not economically efficient. In the case of an increase in investment to provide solar battery systems ≥ 360,000 USD, it will bring economic benefits for larger buildings.*

Keywords— **Optimization, building envelope, energy conservation, solar energy.**

1. INTRODUCTION

Global climate change (CC) is becoming more and more serious. The most obvious expression is global warming, melting ice and rising sea level. The unusual weather phenomena are occurring with frequency and alarm level because it affects human life [1]. According to a huge of studies about global warming, utilizing of fossil fuels in manufacturing and human life is confirmed as one of the vital causes of this phenomenon.

Due to the increasing demand for energy consumption, especially the rising use of fossil fuels has seriously impacted on global climatic conditions, environmental depression, resource depletion and the threat of global energy security. Therefore, there are more and more nations in the world paying to attention on the establishment of energy policy, focusing on two main issues, including lessening energy demand (using energy efficiently) and intensifying the use of renewable energy [2].

Firstly, how to reduce energy demand while ensuring the nation's economic development. There are many researches focusing on energy saving of buildings because IEA (2013) illustrated that more than one-third of total energy consumption comes from buildings. Additionally, according to XinLiang and et [3] also showed that 40% of the world's energy is consumed by buildings. Many studies of authors around the world aim to improve the energy efficiency of buildings. Most of the studies focus on the envelope design of building to lessen energy consumption in buildings [4-6].

Secondly, along with the development of science and technology, renewable energy resources recently have been increasingly attracted and accepted by society. Renewable energy resources have proven the ability to meet the demand for clean energy of many countries in the world [7]. Solar energy is one of the most abundant sources of renewable energy on the earth. The utilizing of solar energy with the main daytime generation will either diminish the pressure of the grid load or lessen the burden of system investment as well as reduce the use of conventional raw material to produce energy such as coal and gas. This approach will contribute to reduce greenhouse gas emissions and global warming.

Currently, commercial buildings utilize a great amount of energy for cooling, heating and lighting than residential areas [8]. Most of commercial buildings use glass as cover material so that a great deal of research recently has proposed to optimize the glass facade in buildings [9-12]. However, these studies only focus on how to select the type of glass or thickness of glass without considering the integration of solar panels on glazing surface, which can minimize the energy

Therefore, to fill this gap, the study proposes an approach to determine the type of glass covering in the building as well as optimize the solar cell installation area on the facade to reduce the energy demand during the operation phase of buildings. The paper aims to develop a decision-making support model for installing solar panels on different sides of buildings to minimize

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the energy consumption in buildings with the budget limitation. Revit software is used to simulate energy consumption. Matlab software is also utilized to develop genetic algorithms for optimization. A new approach is proposed to select a budget with different investments. Finally, an example of an office building in Danang city, Vietnam demonstrates the efficiency of the proposed model.

2. MODEL DEVELOPMENT

A framework for energy improvement decisions for a building consists of 3 phases as shown in Figure 1. Phase 1 is to determine energy consumption in buildings by using Revit software. Phase 2 is to determine the amount of renewable energy production in a case of installing solar pannels on the facades of buildings. Phase 3 is to develop a model that determines the ratio of solar panels on the facades.

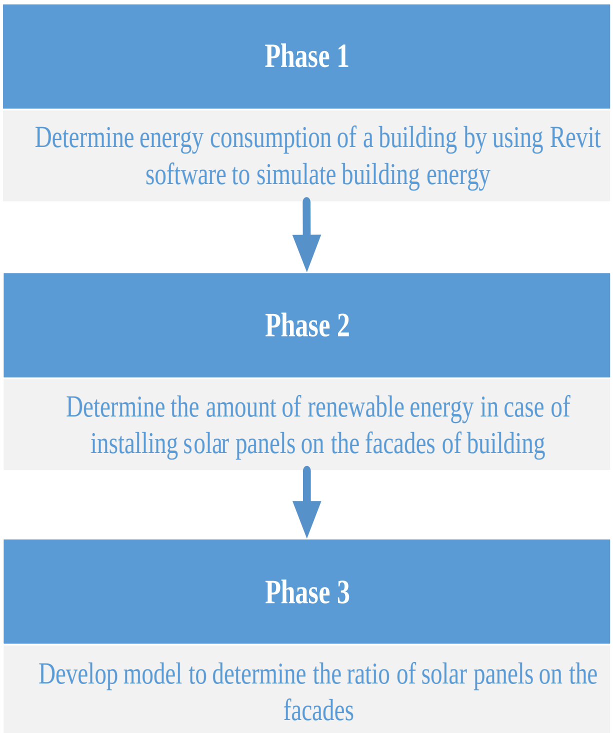


Fig.1. Model development.

2.2. *Determine energy consumption of a building with the glazing facade (Ei)*

In this study, the type of glass commonly used in commercial buildings in Vietnam is considered. In order to determine energy consumption, the main parameters as a light coefficient, heat transfer coefficient, solar heat absorption coefficient and glass thickness are employed.

The building model is simulated through Revit software. The simulation model is run by applying energy simulation analysis function through the model established by Revit – BIM with the climatic conditions at the location of the building.

The result of phase 1 will determine the amount of required energy (E_i) for the building in a year.

2.3. *Determine the level of renewable energy in case of installing solar panels on the glass surface with different sides of the building (Es)*

The level of renewable energy is determined by following formula:

$$E_s = \sum_{j=1}^{4}(S_{pin,j} * K_{s,j}) \quad (1)$$

in which,

E_s : The amount of generated renewable energy (kWh/year)

$S_{pin,j}$: Square area of solar pannel on each facade j with j = 1 (East), j = 2 (West), j = 3 (South), j = 4 (North) (m2)

$$S_{pin,j} = x_j * F_j \quad (2)$$

x_j : The ratio of solar panel on facade j^{th} (%)

F_j : Square area of glass on j^{th} facade (m^2)

$K_{s,j}$: The annual average level of generated solar energy per $1m^2$ on facade j with j = 1 (East), j = 2 (West), j = 3 (South), j = 4 (North) (kWh/m^2.year)

The annual average solar coefficient per $1m^2$ is calculated depending on the location of the construction site.

2.4. *Develop model to optimize installation area of solar panel on the facades of building*

X=[xj] is a decision variable used to select the energy-saving strategy of the building that minimize energy consumption in the building due to the solution of solar panel with the constraint of initial investment cost.

Objective function:

$$E_s = \sum_{j=1}^{4}(x_j * F_j * K_{s,j}) \rightarrow \max \quad (3)$$

Constraints:

$$Lb < x_j < Ub \quad (4)$$

$$IC = F_g * C_g + \sum_{j=1}^{4}\left(x_j * F_j * C_{pin}\right) < LB \quad (5)$$

subject to:

x_j : The ratio of installed solar panel area on j^{th} facade of the building (%)

F_g : Square area of glass on facade (m^2)

C_g : Construction cost for installing glass covering (USD/m^2)

C_{pin} : The installation cost of a solar panel (USD/m^2)

LB: Limited budget (USD)

Lb: Lower bound (%)

Ub: Upper bound (%)

The objective function (3) aims to support decision-makers to select the ratio of installed solar panels on different facades of a commercial building as well as minimize energy consumption in the building with constraints of the ratio of solar panel and initial investment.

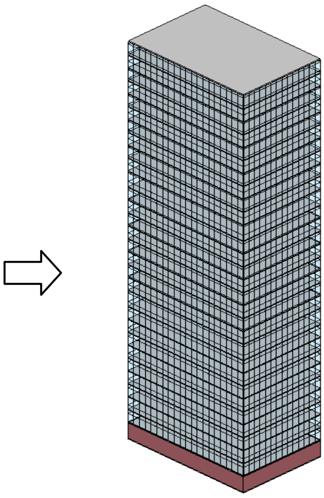
3. CASE STUDY

In order to prove the efficiency of the proposed model, an example is applied for an office building in Danang City, Vietnam.

3.1 Determine the amount of energy consumption in a year (Ei)

Energy consumption analysis is performed in a simulation building located in Danang City, Vietnam. The 3D simulation model is developed by using Revit software (Figure 2).

a. Real building



b. Simulation building

Fig. 2. Real building (a) and simulation building (b)

The reference building has 30 floors (the 1st floor is 4.00m high, the others high 3.6m). The first floor is designed to be built with bricks and stone tiles. Building size: 20m x 30m and the building is located in the East–West direction. The space inside the building is completely empty to serve as offices for business.

The building is located in Danang City with parameters of climatic conditions that will affect the amount of energy consumption in the building.

Table 1. Geographic and climatic data at case study locations

Altitude above sea level [m]	5 m
Latitude [°]	16.05°N
Longitude [°]	108.20°E
Yearly average temperature [°C]	25.8°C
Average hours of sunshine in a year (hrs)	2,182 (hrs)

Using Revit software to run the simulation energy model with tempered glass (being the glass commonly used in a high-rise building in Vietnam) with following the parameters:

Table 2. Main parameters of glass used in research

Type of glass	Thickness (mm)	Light coefficient (%)	Heat transfer coefficient	Coefficient of solar heat absorption	Shading coefficient
Tempered white glass	8	88%	5.7 W/m2.K	0.82	0.94

The simulation results of energy consumption in the building is showed in the Table 3 and Figure 3.

Table 3. The total energy used in the simulated building in 1 year (Ei)

Type of glass	Unit	Total
Tempered white glass	Kwh/year	1,847,550

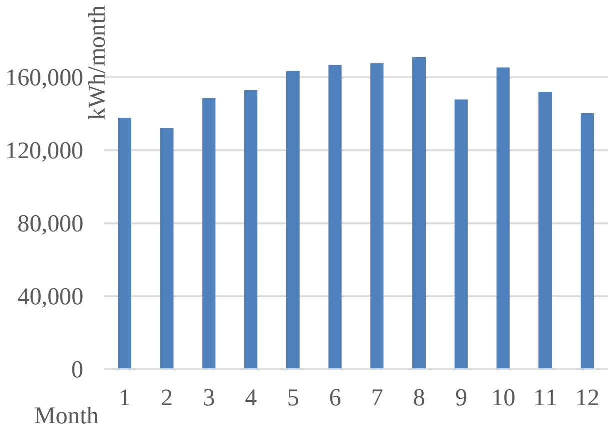


Fig. 3. The monthly amount of energy consumption in the building.

3.2 Determine the amount of generated energy when using solar panels on the glass surface (Es)

According to Eq. (1), in order to determine the amount of generated energy in case of installing solar panels on the glass covering, the annual average amount of energy produced from solar on 1 m^2 of j^{th} facade with j = 1 (East), j = 2 (West), j = 3 (South), j = 4 (North)) (Kwh/m^2.year).

According to the research result of the Polytechnic Solar Investment and Development Joint Stock Company, the annual average amount of energy produced from solar on 1 m^2 of j^{th} facade is presented in the Figure 4.

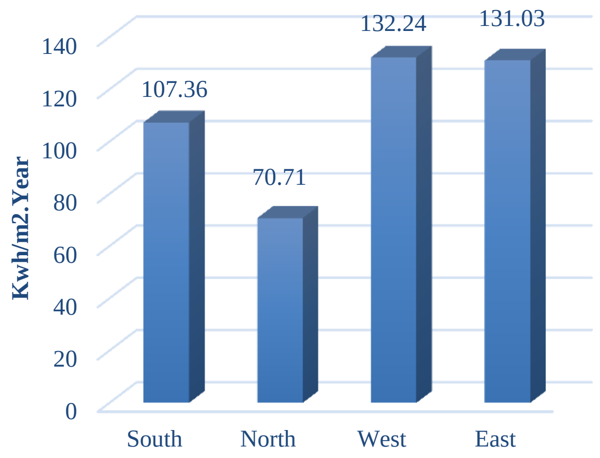


Fig. 4. The annually average energy generated from solar panels in the building sides ($K_{s,j}$).

3.3 Model results

After collecting data and relevant information for the case study, the research team determines the model's parameters including:

- The model was implemented with a budget of 200,000 USD to 700,000 USD for the cover structure and solar panels.

- To ensure the light transmission capacity of the building, the percentage of solar battery is limited from 0% (Lb) to 80% (Up) of the building surface.

Table 4. Results of running the model

Direction	LB = 200,000		LB = 300,000	
	x_j (%)	Es (kWh/năm)	x_j (%)	Es (kWh/năm)
East	0.00	73,488	0.00	161,647
West	0.29		0.63	
South	0.00		0.00	
North	0.00		0.00	
Direction	LB = 400,000		LB = 500,000	
	x_j (%)	Es (kWh/năm)	x_j (%)	Es (kWh/năm)
East	0.17	249,401	0.51	336,752
West	0.80		0.80	
South	0.00		0.00	
North	0.00		0.00	
Direction	LB = 600,000		LB = 700,000	
	x_j (%)	Es (kWh/năm)	x_j (%)	Es (kWh/năm)
East	0.80	421,451	0.80	493,022
West	0.80		0.80	
South	0.04		0.27	
North	0.00		0.00	

- C_g = 12 USD / m2
- C_{pin} = 150 USD / m2

The results show that the percentage of solar batteries varies in the building facades with each LB value. The results are shown in Table 4.

The results also show that the largest solar energy generated for each budget case is shown in Figure 5.

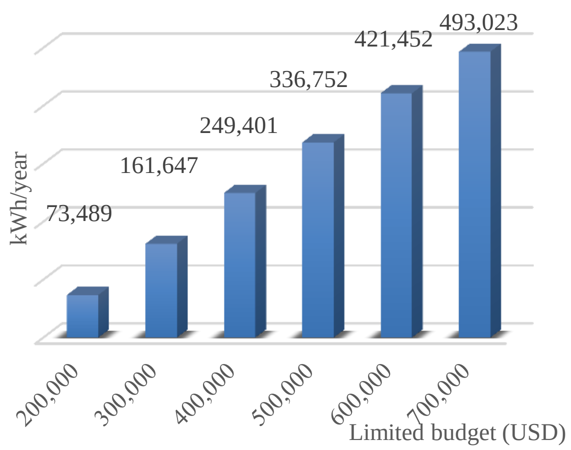


Fig. 5. The largest solar power generated for each budget case.

3.4 Energy analysis

To evaluate the effectiveness of the model, the team focused on analyzing the energy used in the building using solar panels on the sides of the facades.

The analysis will look at the annual energy consumption over the entire building‘s life (E_i). It is the amount of energy needed to consume in 1 year to operate in the building. In addition, in this study, the authors determined the total electricity used in a year, which is calculated by the principle of energy conservation. This means, the energy does not disappear, but changes from one form to another form. For instance, in the process of operation, solar batteries absorb energy and generating renewable electricity. This amount of renewable electricity is the amount of energy absorbed by the simulation building after the battery system is installed.

Therefore, the actual energy used for the building is equal to the difference of the total energy in the simulated building without the use of the solar battery system minus the energy generated by the solar panels. . At the same time, renewable energy will be reused to serve the building, so the actual energy use of the building (E) in 1 year is determined by the formula:

$$E = E_i - 2*E_s \tag{6}$$

With the formula (6) we can determine the actual energy level that the building will use in 1 year as shown in Figure 6.

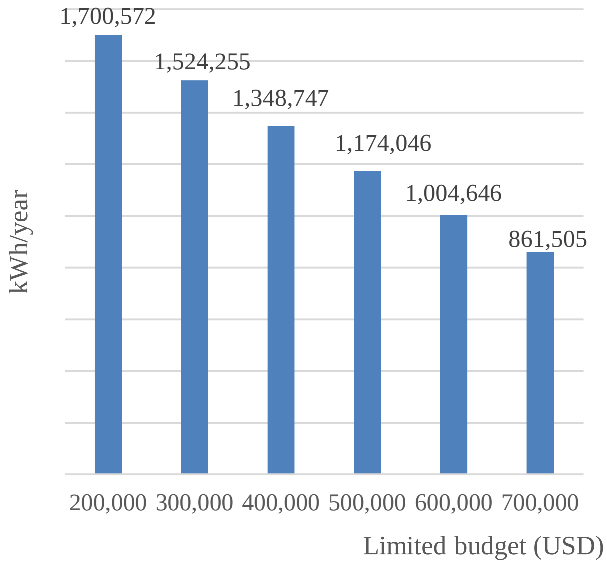


Fig. 6. Actual energy consumption of the building after using solar batteries on the building facades.

In addition, in order to demonstrate the economic aspect of the model, the research team analyzed the increased initial investment cost when installing solar panels and the cost of electricity after using energy-saving measures to create C_E (electricity costs used in buildings when using solar panels)

$$C_{\Delta} = IC - (F_g * C_g) \quad (7)$$

$$C_E = E * C \quad (8)$$

C_{Δ} : Investment cost when installing solar panels

C_E : electricity costs used in buildings when using solar panels

C : electricity price (USD/kWh) (on average of market price: 0,18 USD/kWh)

The result is shown in Figure 7. Figure 7 shows the relationship between the additional cost of investing in a solar cell system on the building's surface and the cost of electricity for the building in 1 year. As the results show, the low investment in the supply of battery power systems is related to the relatively high cost of electricity costs of the building. That means the building will not be economically viable without increasing the investment budget for providing solar battery systems. In other words, large additional investments for solar panels will reduce the building's electricity consumption costs during the year of use. Therefore, the optimization of the battery ratio on the facade of the building will go hand in hand with minimizing the annual electricity costs of the building.

As shown in Figure 7, if the investment to provide solar battery systems is < 360,000 USD, this upgrade is not economically efficient. In the case of an increase in investment to provide solar battery systems ≥ 360,000 USD, it will bring economic benefits for larger buildings. The analysis of model results will help decision-makers choose the budget for investing in solar panel area to create the largest renewable energy level.

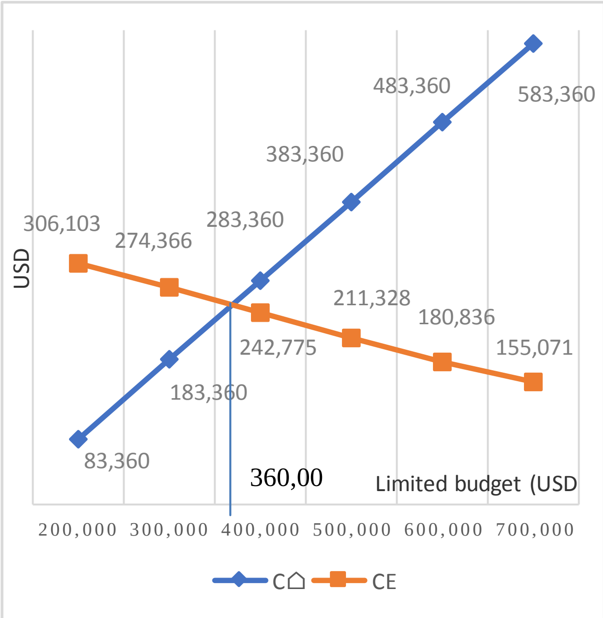


Fig. 7. The relationship between the additional cost and the cost of electricity consumed by the building for 1 year.

4. CONCLUSION

In order to decide the investment on solar battery systems, decision-makers will have to answer two basic questions as follows: (1) the amount of investment budget needed to maximize power amount of solar energy is generated for building use and (2) the economic benefits of using this solar battery system for the building. This study answered these questions through a model of optimizing the solar battery area in different directions of the building's façade with the constraints of raising the initial investment budget. At the same time, the model also provides details of the required budget during the investment process as well as the amount of saving costs, which can help decision makers to select the appropriate options.

The model is applied in an office building built in Danang City, Vietnam. The results of the model have determined the percentage of solar battery area in different directions of the building as well as the largest solar energy generated for that battery area. In addition, based on energy and economic analysis, the model has also supported decision-makers to consider choosing additional investments to achieve the highest economic benefits. This new method enables investment decision-makers to plan or evaluate their investment strategies simply and effectively.

However, the proposed model may be more effective if we consider the life cycle cost of the whole project (LCC), not just the cost of electricity to be paid in 1 year of use. Therefore, future studies need to consider these cost-related issues to be able to optimize the proposed model.

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