



**Comparative Assessment of Energy Generation, Economic,  
and Carbon Footprint Reduction of Grid-Tied Solar Power  
Systems on the Rooftop of HM Building**

**BY**

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FACULTY OF ENGINEERING  
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PROJECT CERTIFICATE

Project Title Comparative Assessment of Energy Generation,  
Economic, and Carbon Footprint Reduction of  
Grid-Tied Solar Power Systems on the Rooftop  
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## **ABSTRACT**

The objective of this project was to develop an energy analysis for the HM building, with a specific focus on the implementation of a solar photovoltaic system on the rooftop in an on-grid configuration. The analysis was conducted using PVsyst software for precise energy calculations. The primary objective was to achieve energy conservation and reduce carbon emissions by implementing a PV grid-connected system. Economic indicators, including the payback period, net present value, and internal rate of return, were computed to confirm the financial feasibility of the proposed system. In addition to addressing environmental sustainability, a preliminary comparison of three types of solar panels: monocrystalline, polycrystalline, and thin film was carried out. The results of the experiment indicated that monocrystalline solar panels were the most suitable and cost-effective option for installation on the HM building.

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Mr. Tontrakul Srisamutnak

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## LIST OF SYMBOLS/ABBREVIATIONS

<b>Symbols/Abbreviations</b>	<b>Terms</b>
PV	Photo voltaic
NPV	Net present value
IRR	Internal rate of return
ROI	Return on investment
LCOE	Levelized Cost of Energy
CdTe	Cadmium telluride
CIGS	Copper indium gallium selenide
BIPV	Building-integrated photovoltaics
CO <sub>2</sub>	Carbon dioxide
tCO <sub>2</sub>	Tons carbon dioxide
kWh	Kilowatt hour
kWp	Kilowatt peak
LCE	Life cycle emission
IEA	International energy agency

# CHAPTER 1

## INTRODUCTION

This chapter will discuss the background and importance, objectives, scope, expected benefits, and procedures for carrying out the dissertation. Comparative Assessment of Energy Generation, Economic, and Carbon Footprint Reduction of Grid-Tied Solar Power Systems on the Rooftop of HM Building as depicted in the following section

- 1.1 Background and Significance
- 1.2 Objectives of the Study
- 1.3 Scope of Study
- 1.4 Expected Benefits
- 1.5 Methodology
- 1.6 Reference

### **1.1 Background and Significance**

Currently, renewable energy is increasingly utilized as a sustainable alternative to mitigate environmental impact caused by the use of fossil fuels, particularly in greenhouse gas emissions [1]. Solar energy, in particular, has emerged as a highly promising option for electricity generation in the present environmental context due to its cleanliness, unlimited availability, and long-term development. The installation of solar photovoltaic (PV) systems on building rooftops has become a contemporary and efficient method for energy production, especially in high-rise buildings with available roof space.

However, the efficiency and effectiveness of rooftop solar systems may vary significantly due to factors such as installation area, positioning, and climatic conditions [2]. Consequently, the assessment of both the quality and quantity of rooftop conditions plays a crucial role in system performance, investment feasibility, and carbon dioxide emissions reduction associated with electricity production and consumption [3].

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This study aims to collect energy consumption data within the HM building, which is an educational facility located at King Mongkut's Institute of Technology Ladkrabang. The objective is to design solar energy systems that optimize electricity generation, guarantee financial practicality, and minimize carbon dioxide emissions. The study employs the PVsyst software to create a grid-connected PV system on the rooftop of the building. It takes into account factors such as the overall energy usage in the building, the comparison of system efficiency among various types of PV modules (monocrystalline, polycrystalline, and thin-film), economic evaluation, and the carbon balance achieved by installing the PV system on the building's rooftop.

## **1.2 Objectives of the Study**

1. To design and on-grid PV rooftop system for year-round energy consumption by using PVsyst and compare the results of all 3 types of solar panels.
2. To study on grid PV rooftop system to minimize carbon emissions and reduce electricity costs for the supplied load to the building.
3. To calculate economic parameters, such as the payback period, net present value, and internal rate of return, ensuring financially viable.

## **1.3 Scope of Study**

1. Design the HM building system by defining the geographical location using latitude and longitude coordinates, specifically ( $13.7266^{\circ}$  N,  $100.7752^{\circ}$  E), and with an area of  $1,000 \text{ m}^2$ .
2. Utilize the PVsyst software to conduct a comparative analysis of the outcomes obtained from all three variants of solar panels.
3. Analysis financial parameters, including calculate the carbon dioxide emissions reduction of the system.

## **1.4 Expected Benefits**

1. Improved Energy Generation Efficiency: By implementing on-grid solar power systems on the rooftop of the HM Building, the thesis aims to assess how it enhances energy generation efficiency compared to conventional energy sources. This can lead to a more reliable and sustainable energy supply for the building.
2. Enhanced Economic Feasibility: The thesis seeks to evaluate the economic viability of installing on-grid solar power systems by analyzing factors such as initial investment costs, operational expenses, and potential long-term savings.

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Demonstrating the economic feasibility of such systems can encourage wider adoption in similar settings, leading to cost savings for building owners and stakeholders.

3. **Reduced Carbon Footprint:** One of the primary expected benefits is the reduction in carbon footprint associated with energy generation. By harnessing solar energy, the thesis aims to quantify the amount of carbon dioxide emissions avoided, contributing to environmental sustainability goals, and mitigating the impact of climate change.

### 1.5 Methodology

The research study's operational plan is depicted in Table 1.

Table 1.1 Operation plan

Topic	Year 2023				Year 2024	
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.
Preliminary design	←→					
Energy load profile		←→				
Project design			←→			
Financial analysis and component selection				←→		
Presentation and finalization					←→	

### 1.6 Reference

[1] Perea-Moreno, A. J. (2021). Renewable energy and energy saving: Worldwide research trends. *Sustainability*, 13(23), 13261.

[2] Carr, A. J., & Pryor, T. L. (2004). A comparison of the performance of different PV module types in temperate climates. *Solar energy*, 76(1-3), 285-294.

[3] Wang, M., Mao, X., Gao, Y., & He, F. (2018). Potential of carbon emission reduction and financial feasibility of urban rooftop photovoltaic power generation in Beijing. *Journal of cleaner production*, 203, 1119-1131.

## CHAPTER 2

### THEORY AND LITERATURE REVIEWS

In this chapter, the details, theories, and related research regarding the design of grid-connected solar PV system installation on rooftops using PVsyst software are discussed, as outlined in the following section.

- 2.1 Solar resources
- 2.2 Solar radiations
- 2.3 Position of the Sun and PV module
- 2.4 Types of PV module
- 2.5 On-grid and Off-grid systems
- 2.6 PVsyst software
- 2.7 Energy consumption
- 2.8 Financial analysis
- 2.9 CO<sub>2</sub> reduction
- 2.10 Related research
- 2.11 References

#### **2.1 Solar resources**

Solar resources refer to the energy derived from the sun's radiation, which is harnessed through various technologies such as solar panels and solar thermal systems. These resources are abundant and renewable, making them a crucial component of sustainable energy solutions. Solar energy offers numerous advantages, including its environmentally friendly nature, independence from fossil fuels, and potential for decentralized power generation. Additionally, solar resources are virtually unlimited and accessible to most regions globally, contributing to energy security and resilience. Furthermore, advancements in solar technology have led to increased efficiency and affordability, making solar power increasingly competitive with traditional energy sources. Despite these benefits, challenges such as intermittency and storage limitations remain, requiring further research and innovation to fully exploit the potential of solar.

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resources. Overall, solar energy stands as a promising and vital resource in the transition towards a more sustainable and resilient energy future.

## **2.2 Solar radiation**

Solar radiation, often referred to as solar energy, plays a pivotal role in our lives and ecosystems. This renewable energy source emanates from the sun and encompasses a spectrum of electromagnetic waves, including visible light, infrared, and ultraviolet radiation. Its significance lies in its ability to sustain life on Earth, drive weather patterns, and support the generation of electricity through photovoltaic technology.

Understanding solar radiation involves studying its variations based on geographical location, time of day, and atmospheric conditions. This comprehension aids in optimizing solar energy harvesting systems for maximum efficiency. Moreover, solar radiation influences climate dynamics, contributing to phenomena like the greenhouse effect and global warming. Harnessing solar radiation for energy production presents a sustainable solution to mitigate carbon emissions and reduce reliance on finite fossil fuels. Advancements in solar technology continue to enhance efficiency and affordability, making solar power increasingly accessible worldwide. As we delve deeper into the potential of solar radiation, we unlock possibilities for a greener and more sustainable future. [1]

## **2.3 Position of the Sun and PV module**

The position of the sun plays a crucial role in determining the performance of photovoltaic (PV) modules. As the sun moves across the sky throughout the day, the angle at which its rays strike the PV modules changes, affecting the amount of solar energy captured. Ideally, PV modules should be positioned to maximize exposure to sunlight, typically facing south in the northern hemisphere and north in the southern hemisphere. However, other factors such as tilt angle, shading, and geographical location also influence optimal positioning. Advanced tracking systems can adjust the orientation of PV modules to track the sun's path, further enhancing energy generation. Understanding the relationship between the position of the sun and PV module performance is essential for designing efficient solar energy systems, optimizing energy output, and maximizing return on investment in solar technology. [2]

## 2.4 Types of PV module

Types of Photovoltaic (PV) modules play a crucial role in the efficiency and performance of solar energy systems. There are several key categories of PV modules commonly utilized today. Monocrystalline modules are known for their high efficiency and sleek appearance, making them popular for residential and commercial installations. Polycrystalline modules offer a cost-effective alternative with slightly lower efficiency but broader availability. Thin-film PV modules, including cadmium telluride (CdTe) and copper indium gallium selenide (CIGS), are lighter and more flexible, suitable for unconventional applications such as building-integrated photovoltaics (BIPV) and portable devices [3]. Additionally, emerging technologies like bifacial modules and perovskite solar cells hold promise for further advancements in efficiency and performance. Understanding the characteristics and advantages of each type of PV module is essential for designing and optimizing solar energy systems to meet diverse energy needs efficiently.

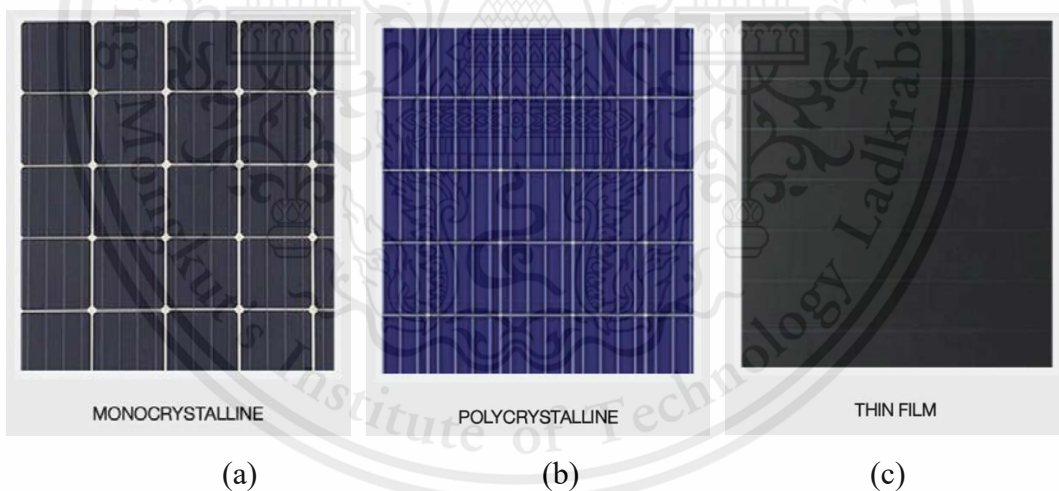


Figure 2.1 (a) Monocrystalline, (b) Polycrystalline, (c) Thin film

## 2.5 On-grid and off-grid solar cell systems

On-grid and off-grid systems represent two distinct approaches to energy management, each with its advantages and limitations. On-grid systems are connected to the main power grid, allowing for seamless access to electricity supply. They are reliable and require minimal maintenance, making them suitable for urban areas and

large-scale applications. However, on-grid systems are vulnerable to grid failures and may be subject to fluctuating electricity prices.

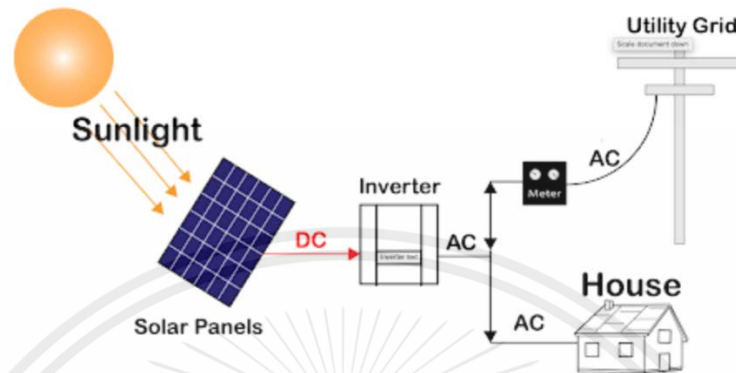


Figure 2.2 On-grid system

Conversely, off-grid systems operate independently of the main power grid, relying on renewable energy sources such as solar panels and wind turbines. These systems provide energy autonomy and are ideal for remote locations or areas with unreliable grid access. While off-grid systems offer sustainability and resilience benefits, they require careful planning, investment, and ongoing maintenance. Additionally, energy storage solutions are essential to ensure continuous power supply during periods of low renewable energy generation. [4]

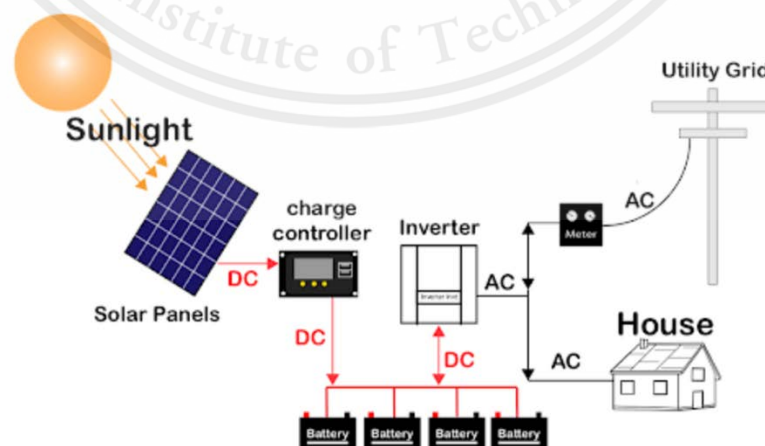


Figure 2.3 Off-grid system

## 2.6 PVsyst software

PVsyst is a widely used software tool in the field of photovoltaic (PV) system design and analysis. This software offers comprehensive features for simulating, designing, and optimizing PV systems. It allows users to model various components such as solar panels, inverters, and batteries, and simulate their performance under different conditions including shading, tilt, and orientation. One of the key strengths of PVsyst is its accuracy in predicting the energy output of PV systems. It takes into account various factors such as weather data, system configuration, and shading effects to provide realistic performance estimates. Additionally, PVsyst offers detailed financial analysis tools, allowing users to evaluate the economic feasibility of their PV projects.

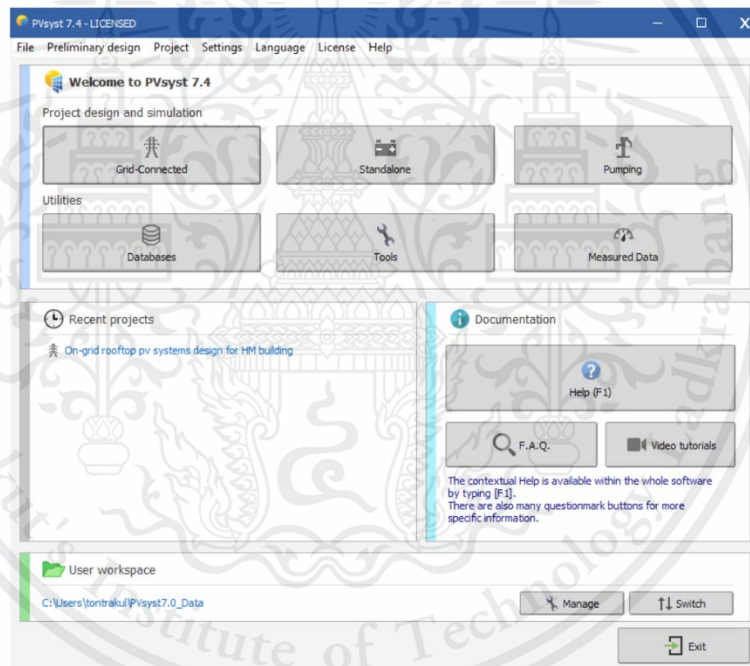


Figure 2.4 PVsyst Software

Overall, PVsyst simplifies the process of PV system design and optimization, making it an essential tool for engineers, researchers, and industry professionals in the renewable energy sector. Its user-friendly interface, coupled with its robust simulation capabilities, makes it a valuable asset in the development of efficient and cost-effective solar energy solutions. [5]

## **2.7 Energy consumption**

Energy consumption is a critical aspect of modern society, playing a pivotal role in various sectors such as transportation, industry, and residential usage. The demand for energy has been steadily increasing due to population growth, urbanization, and industrialization. This surge in consumption has raised concerns about sustainability, environmental impact, and resource depletion. Consequently, there is a pressing need to address energy consumption patterns and explore alternative sources of energy to mitigate these challenges. Efforts to reduce energy consumption involve technological advancements, policy interventions, and behavioral changes. Strategies such as energy-efficient appliances, renewable energy adoption, and energy conservation practices are being promoted to curb consumption levels. Additionally, policy frameworks aimed at promoting energy conservation and transitioning to cleaner energy sources are being implemented worldwide. However, addressing energy consumption requires a multifaceted approach involving collaboration between governments, industries, and individuals. By adopting sustainable practices and embracing innovation, societies can achieve a more efficient and sustainable energy future. [6]

## **2.8 Financial analysis**

In the realm of solar cell technology, financial analysis assumes a pivotal role in appraising the feasibility and viability of solar energy endeavors. This involves the calculation of key metrics such as return on investment (ROI), net present value (NPV), and payback period to gauge the economic potential of integrating solar cell systems. Various factors including initial investment outlay, operational expenditures, tax incentives, and potential revenue sources are meticulously evaluated to ascertain the profitability and financial sustainability of solar projects. Moreover, sensitivity analysis is routinely undertaken to assess the repercussions of uncertainties such as fluctuations in solar panel efficiency, energy pricing, and governmental policies on the financial performance of solar energy investments. Through thorough financial analysis, stakeholders are empowered to make well-informed decisions concerning the deployment of solar cell systems, thereby ensuring efficient resource utilization and maximizing the advantages of renewable energy adoption. Which can be calculated using the formula from PVsyst program [7] as follows:

**Payback period :** Recovered amount for year  $t$  = Net balance of year  $t$  + Self-consumption saving for year  $t$  + Redemption part of the loan for year  $t$  (1)

$$NPV = \sum_{t=1}^n \frac{R_t}{(1+i)^t} \quad (2)$$

**IRR:** value of the discount rate that makes the net present value (NPV) of all cash flows equal to zero (3)

$$\text{ROI: } \frac{\text{Net benefit at the end of lifetime}}{\text{Total investment}} \quad (4)$$

## 2.9 CO<sub>2</sub> reduction

Reducing CO<sub>2</sub> emissions is a critical priority in combating climate change, and solar cells offer a promising avenue for achieving this goal. By harnessing the power of sunlight to generate electricity, solar cells produce clean, renewable energy without emitting harmful greenhouse gases. One key strategy for enhancing the CO<sub>2</sub> reduction potential of solar cells is through advancements in their efficiency and scalability. Researchers are constantly developing innovative materials and technologies to improve the performance of solar cells, increasing their energy conversion efficiency, and lowering their cost. Additionally, integrating solar cells into various infrastructures such as buildings, vehicles, and electronic devices can further amplify their impact in reducing CO<sub>2</sub> emissions across different sectors. Through continued research and development efforts, solar cells have the potential to play a significant role in mitigating climate change by providing a sustainable alternative to fossil fuel-based energy sources. If carbon dioxide emissions are reduced in Thailand, it could lead to significant environmental benefits, including improved air quality, reduced greenhouse gas concentrations in the atmosphere, and slowed climate change impacts. Moreover, decreased CO<sub>2</sub> emissions can also contribute to the preservation of ecosystems and biodiversity, fostering a healthier environment for both current and future generations. This was computed using the formula in the PVsyst program: [7]

$$E_{\text{Grid}} \times \text{Project lifetime} \times LCE_{\text{Grid}} - LCE_{\text{System}} = \text{Carbon balance} \quad (5)$$

## 2.10 Related research

This thesis studies the Comparative Assessment of Energy Generation, Economic Feasibility, and Carbon Footprint Reduction resulting from the Implementation of On-grid Solar Power Systems on the Rooftop of HM Building. The related research comprises the following.

Sujoy Barua and R. Arun Prasath (2017) [8] conducted research on the total energy obtained and the value of the system. Their study focused on evaluating the energy output of a solar photovoltaic (PV) system installed in a tropical climate. They found that the total energy obtained from the system was significant, demonstrating the effectiveness of solar PV technology in harnessing solar energy. Additionally, they assessed the economic value of the system, highlighting its potential cost-effectiveness and sustainability as a renewable energy solution. This system produces a total of 62.8 MWh/year of energy and reduces CO<sub>2</sub> emissions by 42 tCO<sub>2</sub> annually.

A. Ahmed, T.B. Nadeem et al. (2022) [9] The study investigates the efficacy of photovoltaic (PV) panels through an examination of university building rooftops using remote sensing techniques and simulation with PV\*SOL software. The analysis reveals that these buildings possess the capacity to generate 5389.2 MWh/year, with an annual return rate of 1336.6 kWh/kWp. Furthermore, environmental assessments indicate a potential reduction in CO<sub>2</sub> emissions by up to 63,727.05 tCO<sub>2</sub>, alongside an economic evaluation demonstrating an electricity cost of 0.05 USD/kWh, a payback period of 11.17 years, a benefit-to-cost ratio of 1.4%, a net present value of 2,682,508.01 USD, and an internal return rate of 11.81%

Fouad Zaro (2023) [10] In this work, used the PVsyst program to carry out a thorough design and economic analysis of an on-grid solar rooftop PV system. Evaluating the viability of establishing such a system financially and practically was the goal. It was necessary to evaluate the rooftop's solar potential, choose the best tilt and orientation for the panels, and size the system's components during the design phase. The economic analysis concentrated on assessing the project's financial components. Considered the cost of the initial investment, which included the cost of buying and installing the necessary solar panels, inverters, and other hardware. We also included expenditures for continuous upkeep and operation, including cleaning, monitoring, and necessary repairs. The on-grid solar cell system demonstrates a

payback period of 5 years and yields a return on investment of 291.1%, equivalent to 15.83% annually.

## 2.11 References

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- [10] Fouad Zaro (2023) Technical and Economic Study of On-Grid Solar Rooftop PV system Using PV Syst Software: A Case Study

## CHAPTER 3 METHODOLOGY

In this chapter, the operational procedures for designing the solar panel installation system on the HM building's roof are discussed. The operational steps are outlined as follows:

- 3.1 Site assessment
- 3.2 Data collection
- 3.3 Preliminary design
- 3.4 System design
- 3.5 PV modules and inverter selection for system design
- 3.6 Financial evaluation
- 3.7 Carbon dioxide reduction
- 3.8 Detailed losses for practical usage
- 3.9 Near shading
- 3.10 Reference

### 3.1 Site assessment

In designing this system, the selection of the HM building (13.7266° N, 100.7752° E) located to the east of Bangkok was made. The average roof area of HM building is 1,000 m<sup>2</sup>, aligning with the installation pattern on apartments. To comprehend the energy usage patterns of the HM building, it is imperative to gather real-time data on the actual electricity consumption of various appliances. To calculate the energy consumption in the HM building, the following formula is used [1]:

$$kWh = \frac{\text{Watts} \times \text{time in hrs}}{1000} \quad (6)$$

Watts = Usually listed on the power cord. This is the rated power your appliance uses when turned on.

Time in hrs = Time appliance is on If minutes or seconds, convert to hours first.

1000 = Need to divide total by 1000, otherwise it would just be Wh, not kilo-Wh

If accessible, we will conduct a reassessment of the electricity bills as they provide valuable insights into the consumption of energy across diverse applications such as air conditioning, lighting, and other uses. This information can be used to identify patterns of energy usage and make informed decisions about energy conservation strategies. Additionally, analyzing electricity bills can help identify any abnormal energy consumption, which may indicate potential issues with appliances or electrical systems. Overall, analyzing electricity bills provides valuable insights into energy consumption patterns and can contribute to more efficient and sustainable energy usage.

### **3.2 Data Collection**

Starting the process of collecting data for the building's electrical appliances, cataloguing them, and determining their daily energy consumption [2]. The necessary data can be obtained from the labels affixed to each device. If the labels are not easily reachable, it is advisable to perform online searches using the brand and model of the appliance as an alternative. The basic classrooms in the HM building consist of three types of electrical appliances: fluorescent bulbs, air conditioners, and computers. These classrooms are used according to the teaching schedule. In the HM building, there are approximately 464 classrooms in total, with an average use of seven hours per classroom.

### **3.3 Preliminary design**

PVsyst serves as a fundamental tool for solar cell installation. It offers numerous functions for users. In the preliminary design mode, you can simulate the initial system design to gather area-related information before finalizing the design. Within this mode, users can select installation formats, including types of solar panels, as depicted in Figure 3.1. Additionally, users can access solar information from the database, as illustrated in Figure 3.2, and obtain total energy production details for the system, as depicted in Figure 3.3 PVsyst will simulate system performance as well as numerous statistics based on the actual space where we want to create the system, such as solar ray strength, monthly temperature, and so on. We can also use the preliminary mode.

Design is an alternative for designing a system prior to creating the actual system. To make the fewest mistakes possible

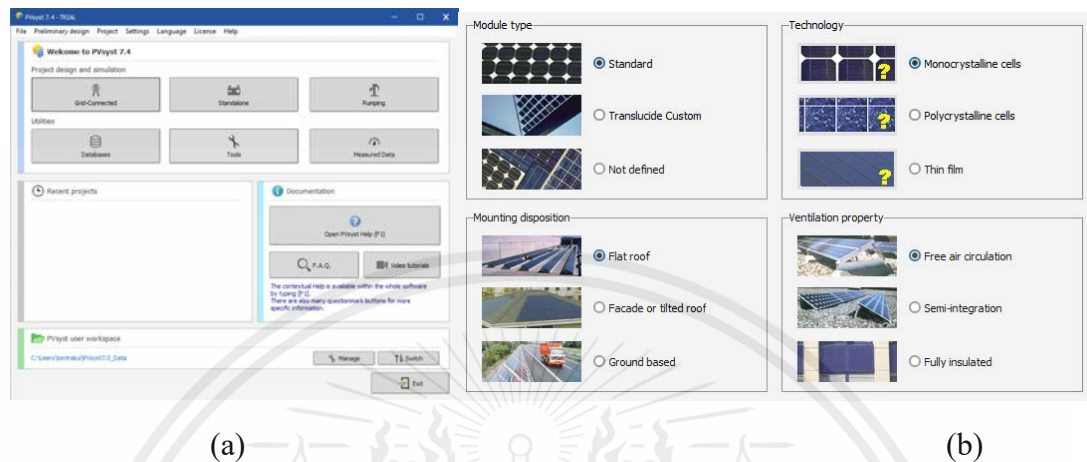


Fig. 3.1 PVsyst program (a) starter page for project design, (b) type of solar cell system for preliminary project design

Geographical Coordinates | Monthly meteo | Interactive Map

Site: **HM Building (Thailand)**

Data source: **Meteonorm 8, 1 (1996-2015)**

	<b>Global horizontal irradiation</b> kWh/m <sup>2</sup> /mth	<b>Horizontal diffuse irradiation</b> kWh/m <sup>2</sup> /mth	<b>Temperature</b> °C	<b>Wind Velocity</b> m/s	<b>Linke turbidity</b> [-]	<b>Relative humidity</b> %
January	135.8	63.5	27.1	1.30	4.769	67.3
February	134.2	77.6	28.5	1.60	5.521	69.9
March	159.2	85.9	29.7	1.80	5.779	70.9
April	166.0	88.4	30.4	1.80	5.094	73.0
May	156.8	84.1	30.3	1.70	4.289	74.3
June	141.0	79.7	29.4	1.70	3.953	77.1
July	139.2	77.2	29.4	1.80	3.913	75.4
August	135.0	80.9	29.1	1.80	3.882	75.9
September	123.7	66.2	28.2	1.40	3.991	80.9
October	126.6	81.2	28.6	1.10	5.135	77.5
November	125.2	67.6	28.0	1.30	4.527	70.8
December	133.4	67.1	27.3	1.29	4.336	65.5
<b>Year</b>	<b>1676.1</b>	<b>919.4</b>	<b>28.8</b>	<b>1.5</b>	<b>4.599</b>	<b>73.2</b>

**Global horizontal irradiation year-to-year variability 5.9%**

Fig. 3.2 Simulation data base of monthly meteo in PVsyst program

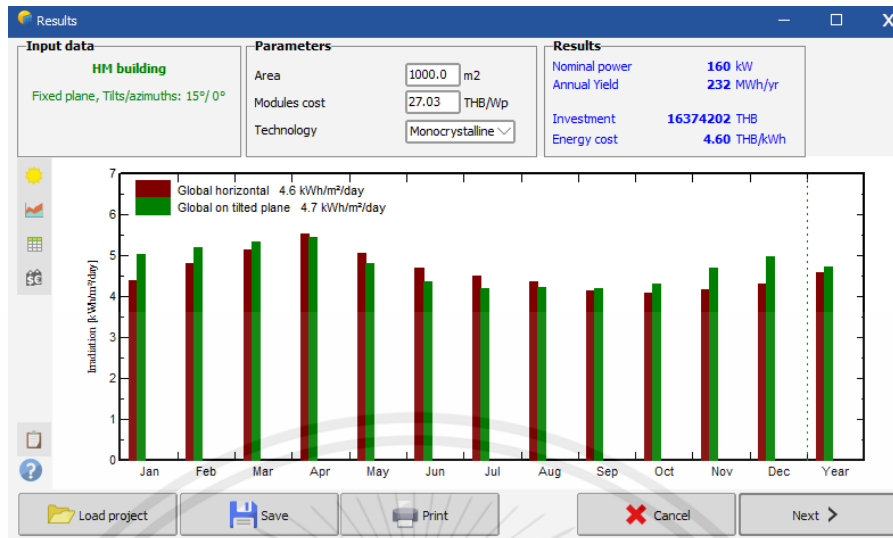


Fig. 3.3 Simulation of system energy production data from preliminary design mode.

### 3.4 System design

The process of designing the system commences with accessing the Orientation mode, wherein the angle and direction for the installation of the solar panels are established. Specifically, in this system, the panels will be set at a 15-degree angle and oriented towards the south during installation. This positioning in Thailand is chosen for its optimal efficiency in harnessing solar energy.

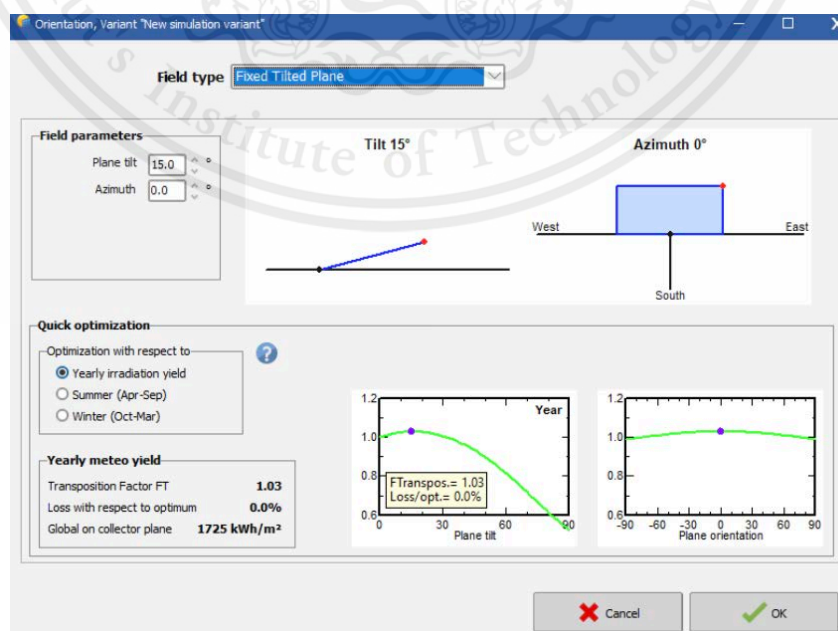


Fig. 3.4 Orientation mode

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Upon determining the direction and extent of the installation process, the subsequent stage involves formulating the installation system. This includes accessing the System mode, wherein the system will undergo a design phase. Accurate measurements, specifically encompassing an area of 1,000 m<sup>2</sup> will be taken into consideration for delineating the space. Subsequently, the selection process for solar panels and inverters will commence. Three types will be evaluated: Monocrystalline, Polycrystalline, and Thin film, aiming to conduct a comparative analysis of their system performance. The primary criterion for panel selection centers around their suitability for installation within our confined space. Consequently, our objective is to opt for highly efficient panels to maximize the overall system efficiency.

### 3.5 PV modules and inverter selection for system design

In this section, the focus will be on selecting the type of monocrystalline (LR5-72HIBD-545M G2 Bifacial), polycrystalline (JAP72-S10-345-SC) and thin-film (SL2-150 [G2.3+]), the inverter type (SUN2000-100KTL-M1-480Vac), in restricted installation area of 1000 m<sup>2</sup>.

While formulating the system design, we will adopt the area qualifier rather than Kwp, considering that each variant of solar panel necessitates a distinct installation space. Given the confined spatial constraints within the building, it becomes imperative to configure the area value, as depicted in **Figure 3.5**

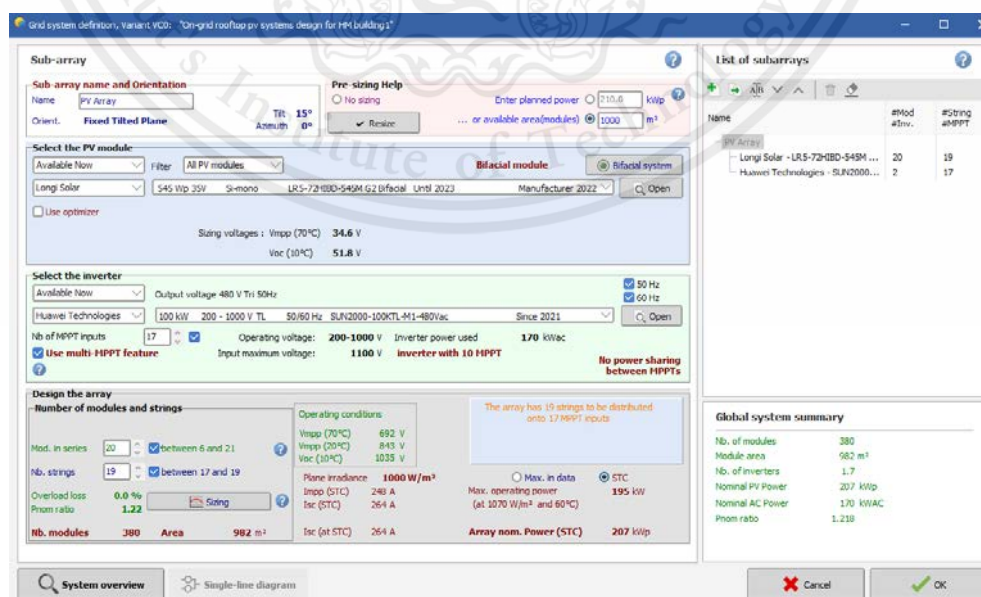


Fig. 3.5 System design mode

The feasibility of our system's utilization can be assessed by reviewing the chosen inverter in the Sizing section. It is imperative to verify whether the selected inverter aligns with the system's requirements. Specifically, attention should be paid to the power limitation, ensuring it remains below 3%. Alternatively, a range of 0.2% to 3% is acceptable. Notably, an indication of 0.0% signifies optimal efficiency of the inverter, as shown in **Figure 3.6**

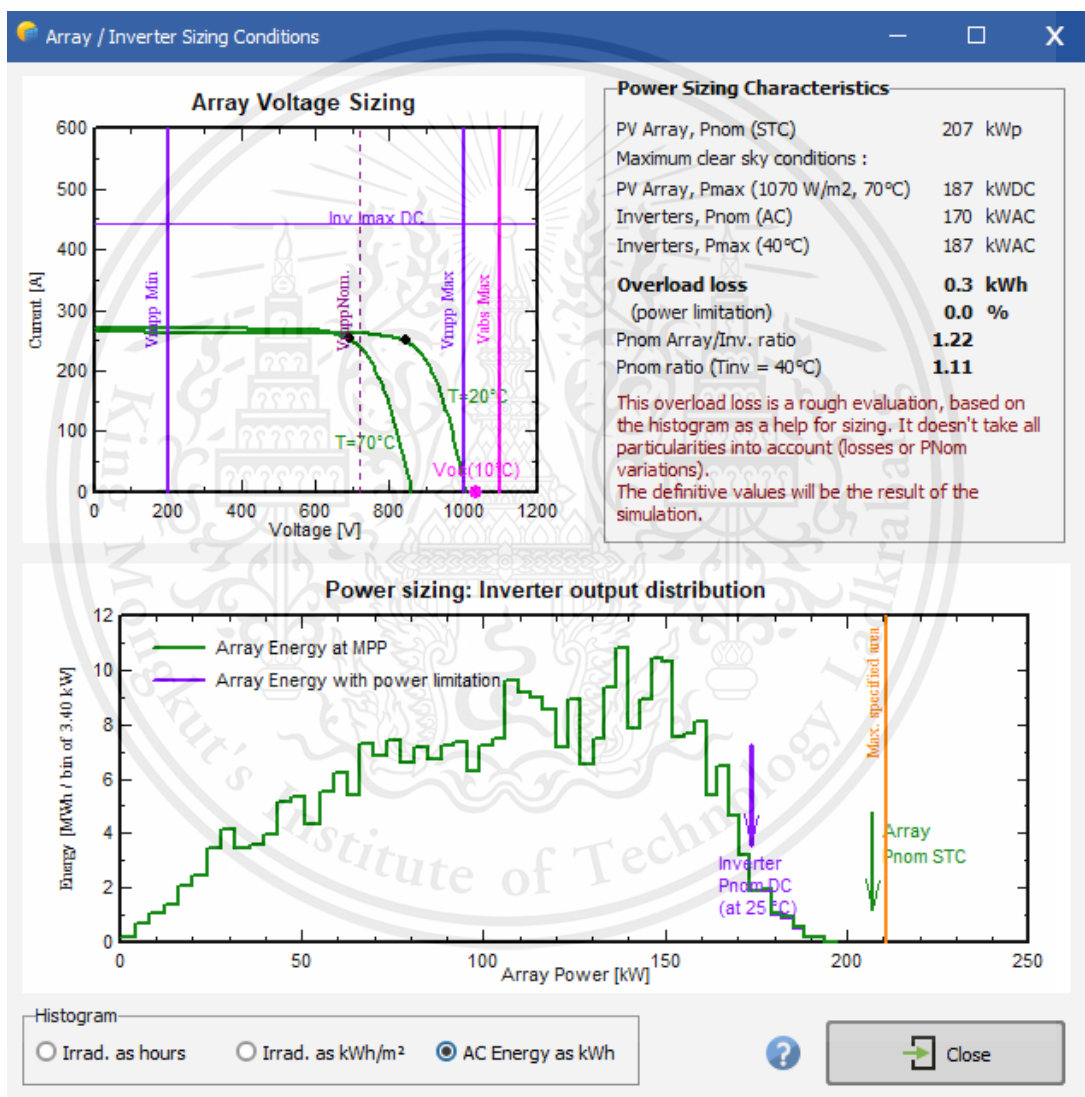


Fig.3.6 Sizing mode for power sizing characteristics

### 3.6 Financial evaluation

The financial evaluation involved the calculation of the payback period, net present value (NPV), internal rate of return (IRR), and return on investment (ROI). This was calculated using the formula in the PVsyst program by [3]

**Payback period :** Recovered amount for year  $t$  = Net balance of year  $t$  + Self-consumption saving for year  $t$  + Redemption part of the loan for year  $t$  (7)

$$NPV = \sum_{t=1}^n \frac{R_t}{(1+i)^t} \quad (8)$$

**IRR:** value of the discount rate that makes the net present value (NPV) of all cash flows equal to zero (9)

$$ROI: \frac{\text{Net benefit at the end of lifetime}}{\text{Total investment}} \quad (10)$$

This section outlines how project expenses are evaluated and the calculation of carbon balance is determined. The analysis is divided into five key components including; (1) Investment and charges (2) Financial aspects (3) Sale of electricity (4) Financial result (5) Carbon balance.

1. investment and charges, it is important to determine various costs including solar panel expenses, inverter costs, operational expenditures, installation fees, and other related expenses.

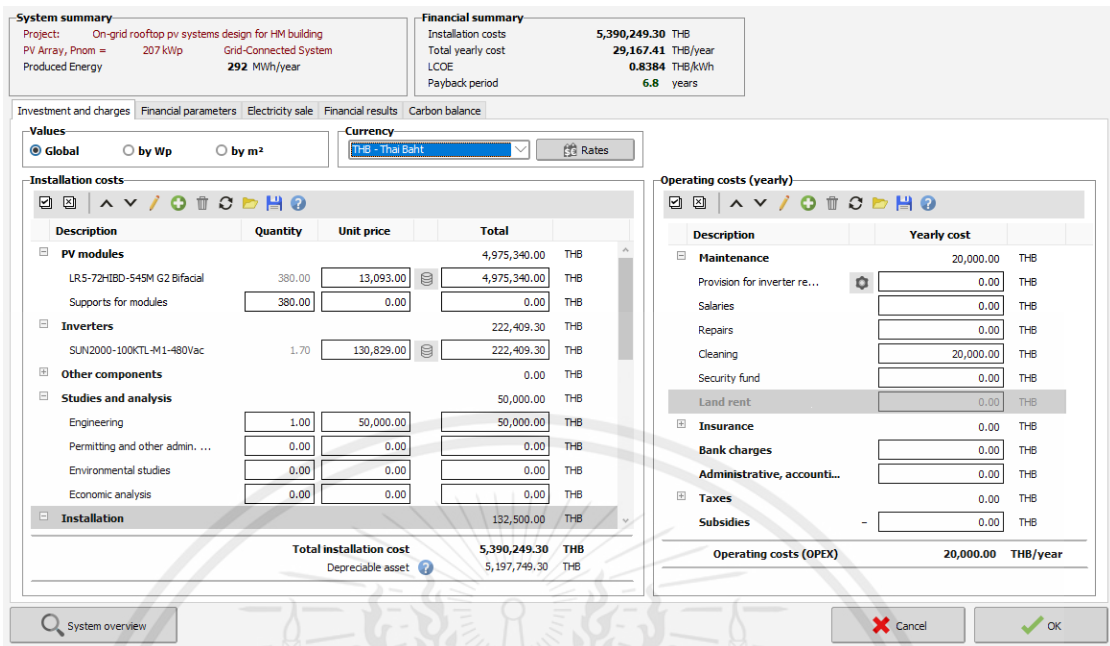


Fig. 3.7 Part of investment and charges

2. Financial parameters this section focuses on establishing the financial metrics pertinent to the installation of a system within a building, distinguishing it from the setup of a power plant. Hence, the critical values to ascertain encompass the Project lifetime, Inflation rate, Start year, and income tax considerations.

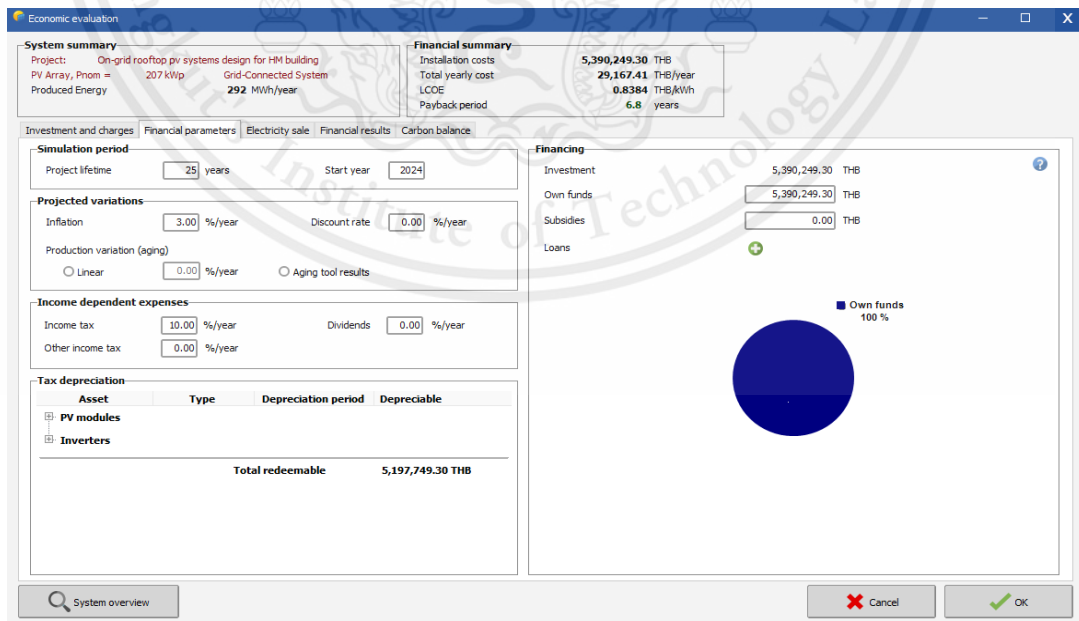


Fig.3.8 Part of financial parameters

3. Electricity sale the objective here is to ascertain the electricity sales rate. However, given our status not as a power plant, we have established the Feed-in Tariff in alignment with the standard building electricity rate.

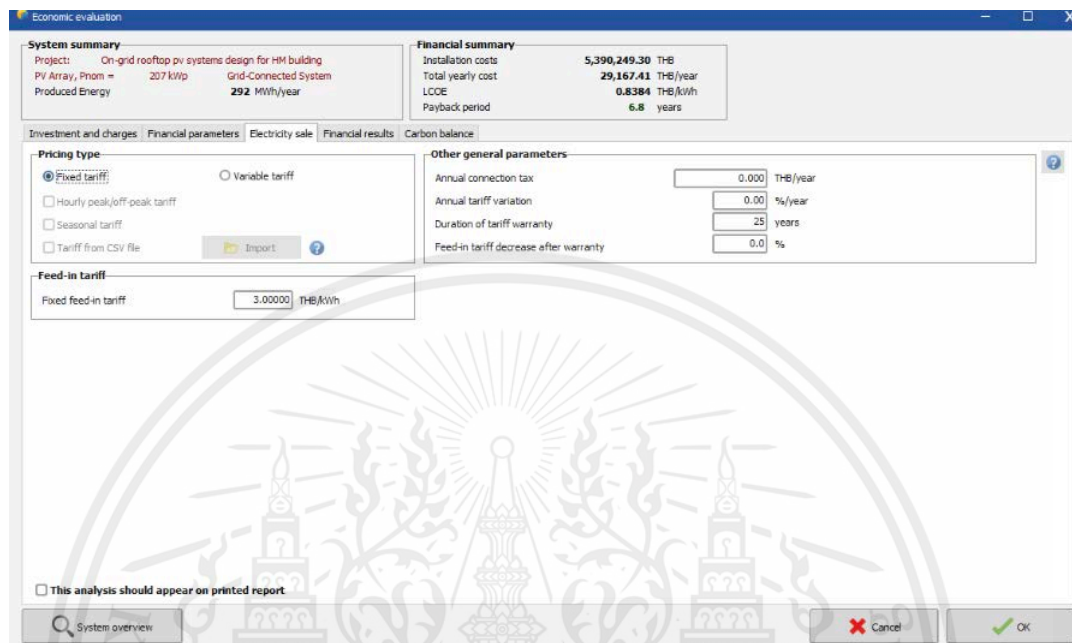


Fig.3.9 Part of electricity sale

4. Financial result this section presents the financial overview of the project, encompassing key metrics including Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, and Return on Investment (ROI)

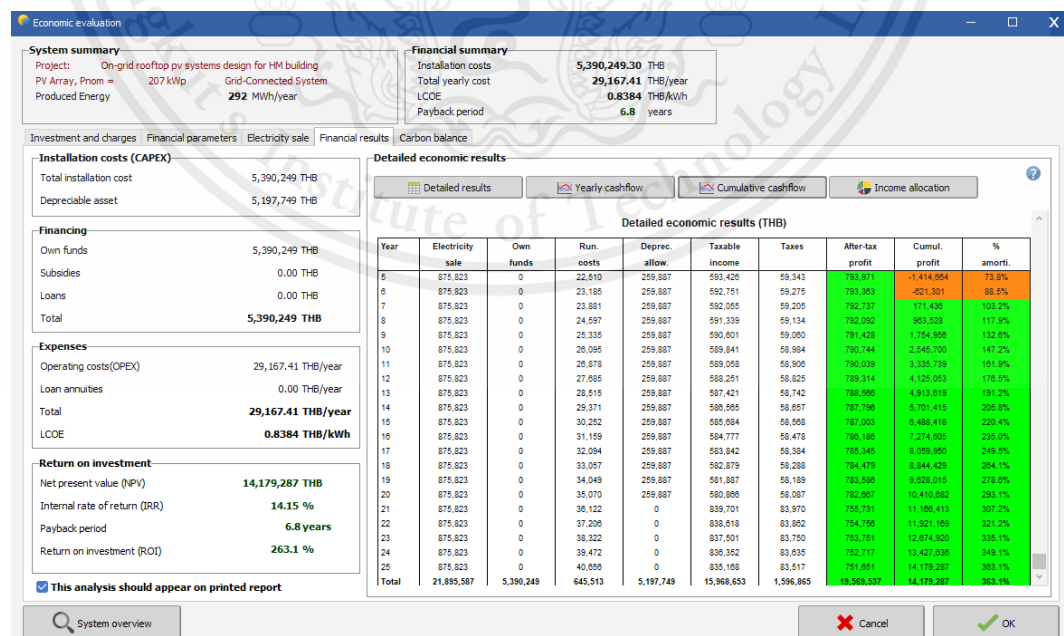


Fig.3.10 Part of financial result

### 3.7 Carbon dioxide reduction

This was computed using the formula in the PVsyst program:

$$E_{\text{Grid}} \times \text{Project lifetime} \times \text{LCE}_{\text{Grid}} - \text{LCE}_{\text{System}} = \text{Carbon balance} \quad (11) [3]$$

Here, E Grid represents the system's energy production or energy output from the solar energy system installation, Project lifetime denotes the project's operational lifespan, LCE Grid indicates the average amount of carbon dioxide emissions per unit of electricity produced, a value disseminated by the International Energy Agency (IEA). LCE System refers to the total carbon dioxide emissions resulting from the construction and operation of the solar energy system installation. Carbon balance is the outcome of the carbon dioxide reduction quantity.

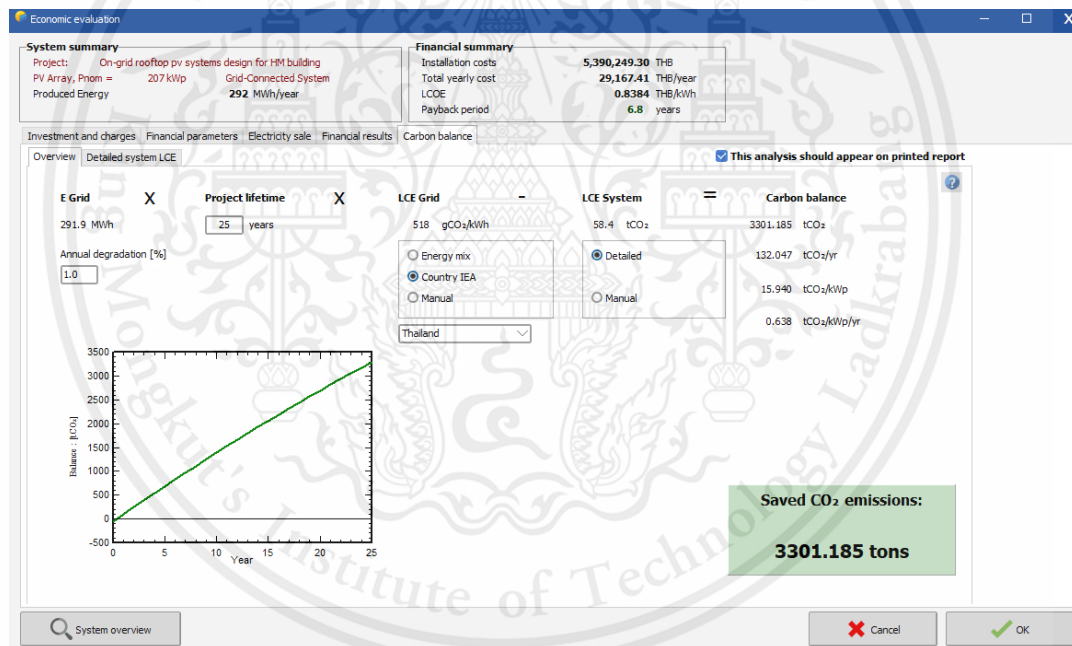


Fig.3.11 Part of carbon balance

### 3.8 Detailed losses for practical usage

Due to practical constraints, the system cannot operate at full efficiency, incurring losses from factors such as power transmission distance and heat dissipation. These losses reduce the overall system performance [4]. As a result, defining loss parameters is critical for ensuring that the system is as similar to real-world conditions as possible.

In this operational state, comprehensive details pertaining to diverse system losses will

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be input. It is imperative to provide the precise loss values to facilitate the system's accurate calculation, aligning it as closely as possible with real-world conditions. The determination of nine specific values is required, encompassing Thermal parameter, Ohmic losses, Module quality – LID -Mismatch, Soiling Loss, IAM Losses, Auxiliaries, Aging, Unavailability, and Spectral correction.

### **1. Thermal parameter**

This section will establish the cooling system, which will be selected as a semi-integrated system with an air duct positioned behind. This choice is informed by the requirements of the solar cell installation system on the roof.

### **2. Ohmic losses**

This parameter will determine the extent of wire losses incurred during the system installation, with the magnitude of loss contingent upon the size and distance of the wires involved.

### **3. Module quality – LID -Mismatch**

The value represents the loss attributed to the interconnection of solar panels, a quantity challenging to quantify accurately therefore, it is defaulted to reference the average derived from the system.

### **4. Soiling Loss**

This numerical representation signifies the mean percentage of dirtiness loss, indicating an average reduction of 3%.

### **5. IAM Losses**

The decline in panel efficiency resulting from varying sun angles cannot be precisely quantified. Therefore, it will be established based on the defined parameters of the photovoltaic (PV) module.

## **6.Auxiliaries**

The energy consumption associated with the inverter's nighttime operation in sleep mode or when displaying the inverter screen represents a negligible loss to the system and, therefore, does not consideration due to its minimal impact.

## **7.Aging**

The presented value represents the percentage decrease in the efficiency of the solar cell panel, with an anticipated annual reduction ranging from approximately 0.5% to 0.8%, contingent upon the specific model of the panel.

## **8. Unavailability**

In the context of this study, the term refers to the duration, expressed in hours per year, during which the system is unable to generate electricity. This parameter will be assigned a randomized value denoted as 'Set random.

## **9.Spectral correction**

The spectral value of the panel is contingent upon the specific model selected for use, eliminating the necessity for manual configuration.

### **3.9 Near shading**

In this operational mode, the system undergoes three-dimensional simulation, replicating solar parameters sourced from actual geographical locations. The installation site encompasses an area of 1,000 m<sup>2</sup> featuring panels oriented towards the south at an installation angle of 15 degrees. In **Figure 3.14** depicts a model of the real region where the device was installed.

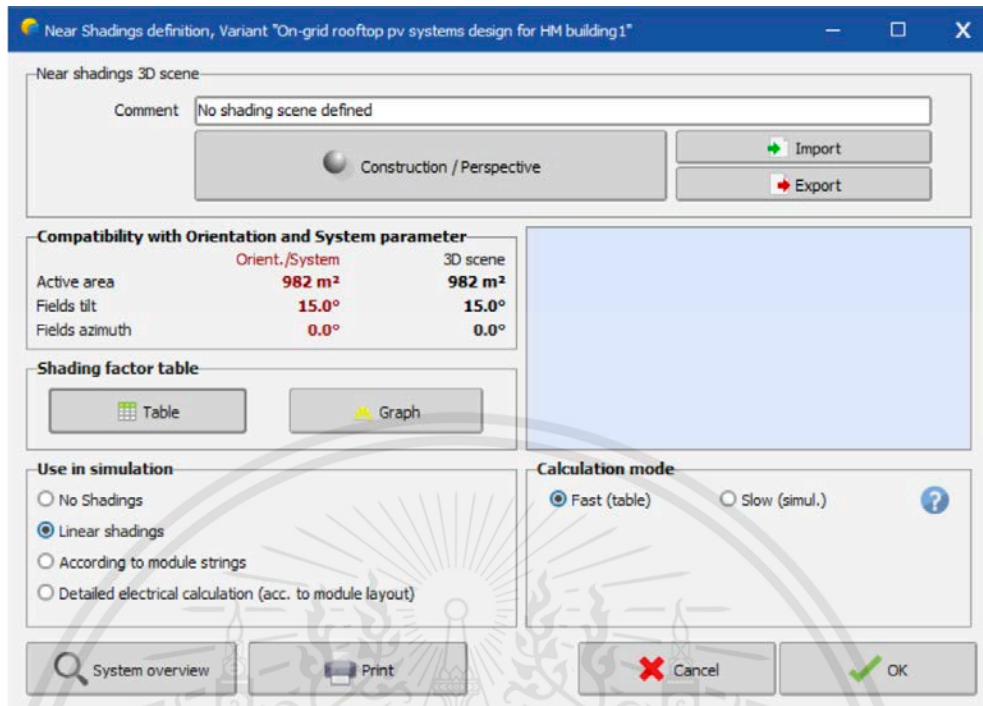


Fig. 3.12 Near shading mode

A total of 380 panels will be used, 19 strings, 20 panels per string.

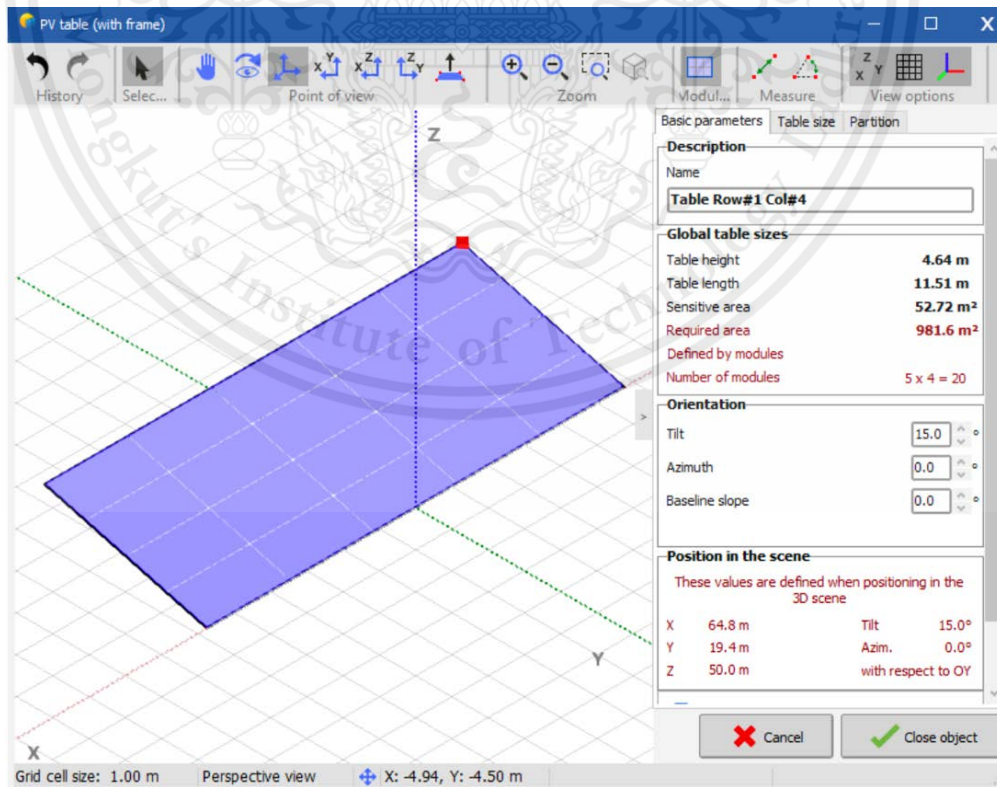


Fig.3.13 PV table

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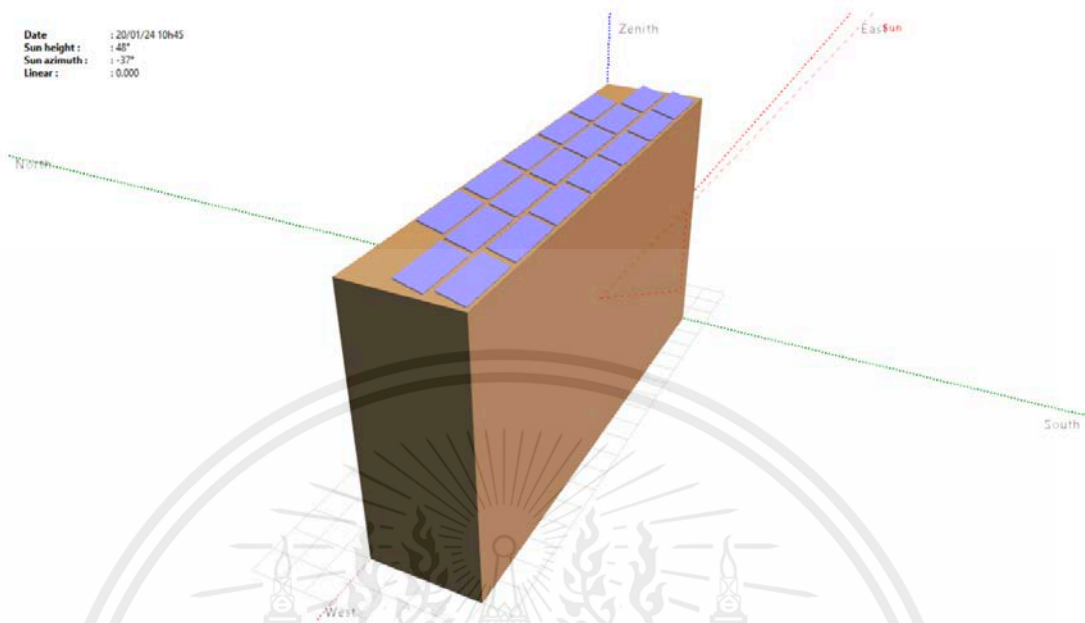


Fig. 3.14 Shading scene construction

### 3.10 Reference

- [1] Perea-Moreno, A. J. (2021). Renewable energy and energy saving: Worldwide research trends. *Sustainability*, 13(23), 13261.
- [2] Sharma, S., Kurian, C. P., & Paragond, L. S. (2018, March). Solar PV system design using Pvsyst: a case study of an academic Institute. In *2018 international conference on control, power, communication and computing technologies (ICCPCT)* (pp. 123-128). IEEE.
- [3] Pvsyst [Online] 2024 Source [https://www.pvsyst.com/help/financial\\_balance.htm](https://www.pvsyst.com/help/financial_balance.htm)
- [4] Islam, S., Islam, F., & Habib, A. (2022). Feasibility analysis and simulation of the solar photovoltaic rooftop system using Pvsyst software. *International Journal of Education and Management Engineering (IJEME)*, 12(6), 21-32.

## CHAPTER 4

### EXPERIMENTAL RESULT

In this section, we discuss the outcomes of designing a solar panel installation system on the rooftop of building HM. The favorable results are as follows:

- 4.1. Energy use in HM building
- 4.2. Performance of designed PV off-grid system
- 4.3. System performance after setting Detailed losses

#### 4.1 Energy consumption in HM building

After collecting data of electrical appliances in the building and their respective usage durations, the objective is to determine the energy consumption within the HM building. The data, depicted in Table 4.1, facilitates the calculation of the maximum kilowatt value (kWp) resulting from daily use. Thus, it becomes imperative to segregate energy consumption per room, as illustrated in Table 4.2.

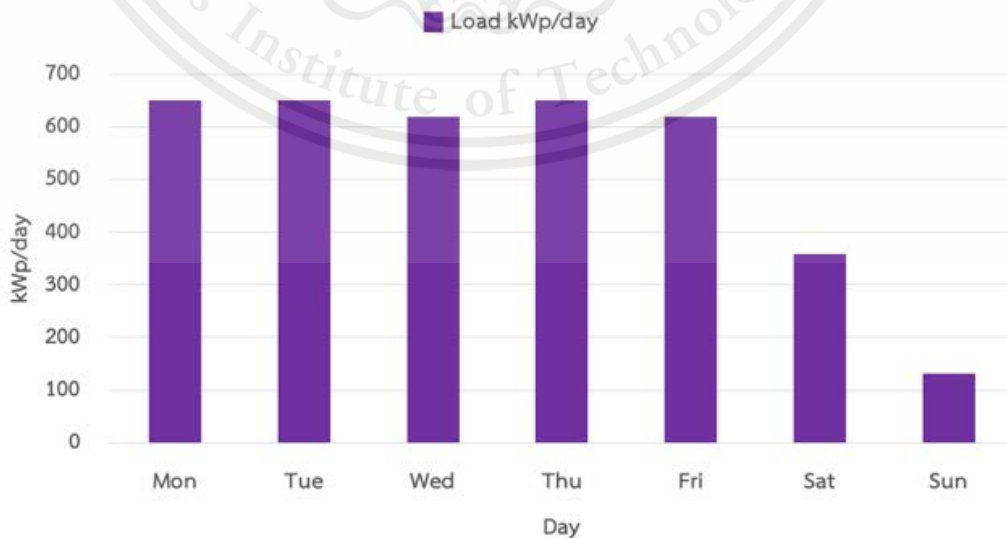
**Table 4.1** Data of appliance in HM building

Appliance	No. of Appliance	Power (W)	Usage Hours (hr)	Energy consumption (kWh/day)
LED	96	10	7	6.72
Fluorescent	1300	36	7	327.6
Air Con.	154	920	7	991.76
PC	36	240	7	60.48
Elevator	4	8115	7	227.22
Total				1613.78

**Table 4.2** Data of appliance in 1 room

Appliance	No. of Appliance	Power (W)	Usage Hours (hr)	Energy consumption (kWh/day)
Fluorescent	20	36	7	5.04
Air Con.	4	920	7	25.76
PC	1	240	7	1.68
Total				32.48

Afterward, multiply the number of rooms with energy consumption during each time interval, and for each room in the HM building. This will yield the highest energy consumption for each day, as illustrated in Figure 4.1. The highest recorded power consumption is approximately 650 kWp on Mondays, Tuesdays, and Thursdays. This is attributed to the increased use of classrooms for teaching activities on those days. Conversely, the lowest recorded power consumption is around 150 kWp on Sundays, reflecting a reduced use of classrooms and subsequently lower energy consumption due to fewer teaching activities. In the normal system design, kWp values are commonly used to determine the production output close to actual energy consumption. However, in this case, the parameter for sizing is specified as the area, specifically 1000 m<sup>2</sup>. This choice is made due to the limited space of the HM building. If the kWp values were set uniformly, each type of panel would require a different area size. Therefore, it becomes necessary to use the sizing parameter as the area of the HM building instead.



**Figure 4.1** The peak energy consumption in HM building for each day

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## 4.2 Performance of designed PV off-grid system

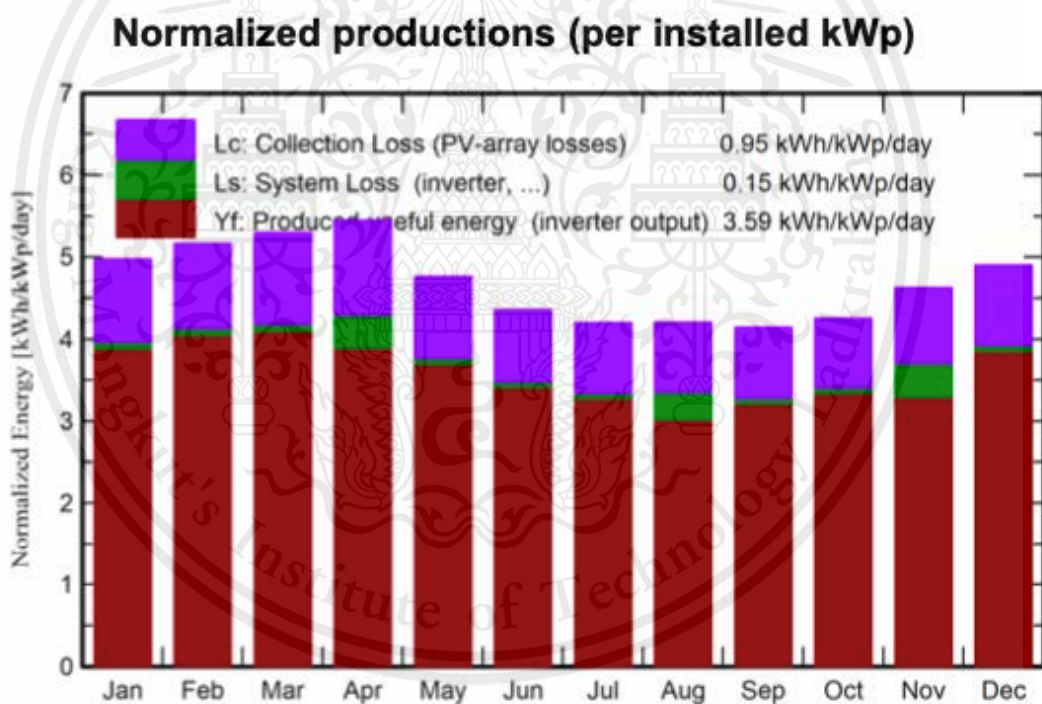
After calculating the internal energy consumption within the building. We designed and compared the system by selecting monocrystalline, polycrystalline and thin-film solar panels. and inverter, this study will involve a comparison of the results from all three types of panels: Monocrystalline, Polycrystalline, and Thin film. The outcomes were presented in Table 4.3

**Table 4.3** illustrates a comparative analysis of the results from three types of panels

	Monocrystalline	Polycrystalline	Thin film
Situation	Latitude 13.73 °N , Longitude 100.78 °E	Latitude 13.73 °N , Longitude 100.78 °E	Latitude 13.73 °N , Longitude 100.78 °E
PV Field Orientation	15/0°	15/0°	15/0°
PV Model	LR5-72HBD-545M G2 Bifacial	JAP72-S10-345-SC	SL2-150 [G2.3+]
Inverter Model	SUN2000-100KTL-M1-480Vac	SUN2000-100KTL-M1-480Vac	SUN2000-100KTL-M1-480Vac
Nominal (STC)	207 kWp	170 kWp	159 kWp
Nb.of modules	380 units	494 units	1062 units
Nb.of inverters	2 units	2 units	2 units
Module area	982 m <sup>2</sup>	991 m <sup>2</sup>	998 m <sup>2</sup>
Total installation cost	5,390,249.30 THB	3,573,577.70 THB	6,477,573.70 THB
Produced Energy	292 kWh/year	239 kWh/year	233 kWh/year
Performance Ratio PR	82.33%	82.06%	85.50%
Payback period	6.8 years	5.6 years	10.7 years
Net present value (NPV)	14,179,287.27 THB	12,271,781.54 THB	8,118,602.74 THB
Internal rate of return (IRR)	14.15%	17.57%	7.78%
Return on investment (ROI)	263.10%	343.40%	125.30%
CO <sub>2</sub> Emission Balance	3301.2 tCO <sub>2</sub>	1578.3 tCO <sub>2</sub>	2373.3 tCO <sub>2</sub>

The simulation results of the system using the three types of panels from Table 4.3 reveal differences in energy production. Despite each system having an identical installation space of 1000 m<sup>2</sup>, the simulation indicates that Thin film panels utilize the highest amount of installation space, requiring 998 m<sup>2</sup> and 1062 units respectively. Additionally, they incur the highest installation cost and longest payback period among the panel types. Consequently, Thin film panels are deemed unsuitable for installation on the HM building due to space inefficiency and cost concerns. Thus, Monocrystalline and Polycrystalline panels are considered instead, given their comparable system efficiency.

More analysis reveals that Polycrystalline panels offer a lower installation cost and higher ROI and IRR. However, upon examination of Monocrystalline panels, a notable reduction in carbon dioxide emissions of 3301.2 tCO<sub>2</sub> is evident, which is twice that of Polycrystalline and the highest among all three systems. Monocrystalline panels also exhibit the highest energy production, panel utilization, and area coverage, with a significantly higher NPV value of 14,179,287.27 THB for a smaller installation. In addition, the efficiency of each type of solar cell panel in generating energy varies, as illustrated in Figures 4.2, 4.3, and 4.4. It is evident that monocrystalline panels can produce energy at a rate of 3.59 kWh/kWp/day.



**Figure 4.2** Normalized productions of monocrystalline

### Normalized productions (per installed kWp)

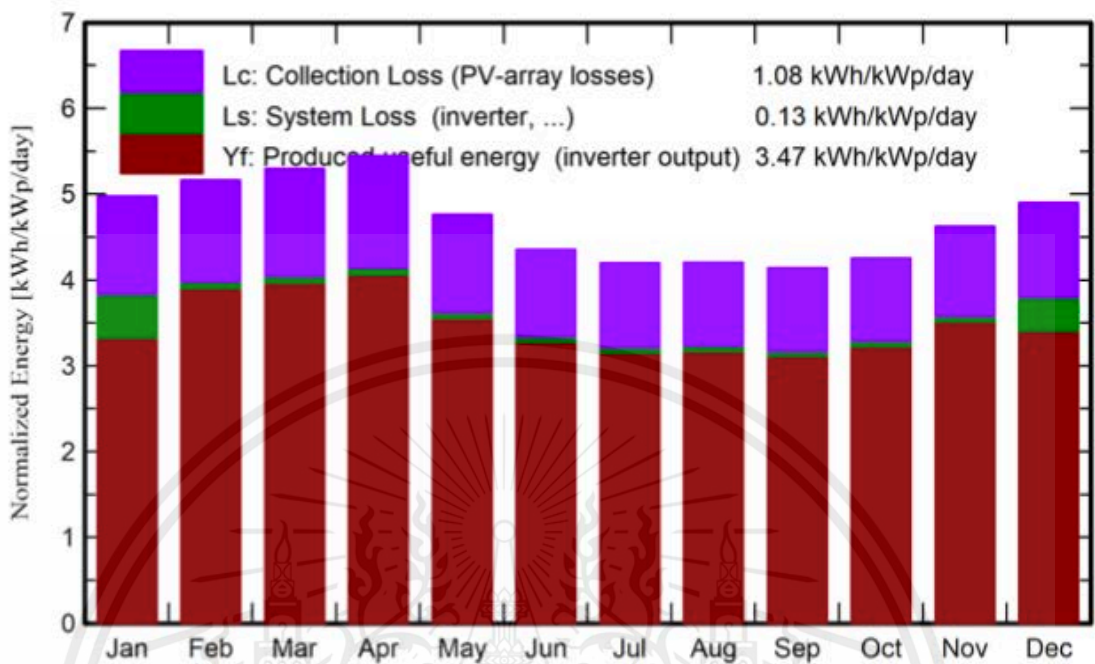


Figure 4.3 Normalized productions of polycrystalline

### Normalized productions (per installed kWp)

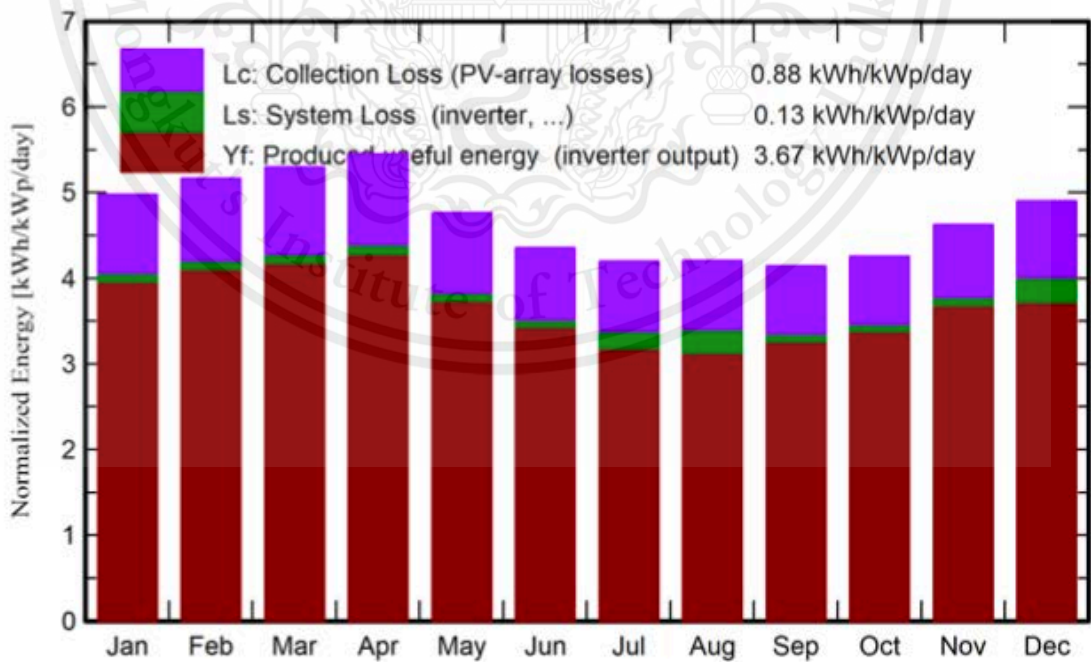


Figure 4.4 Normalized productions of thin film

Cost of the system			
<b>Installation costs</b>			
Item	Quantity units	Cost THB	Total THB
PV modules LRS-72HIBD-545M G2 Bifacial	380	13,093.00	4,975,340.00
Inverters SUN2000-100KTL-M1-480Vac	2	130,829.00	222,409.30
Studies and analysis Engineering	1	50,000.00	50,000.00
Installation Settings	1	100,000.00	100,000.00
Grid connection	1	32,500.00	32,500.00
Insurance Building insurance	1	10,000.00	10,000.00
		Total	5,390,249.30
		Depreciable asset	5,197,749.30
<b>Operating costs</b>			
Item			Total THB/year
Maintenance Provision for inverter replacement			8,896.37
Cleaning			20,000.00
Total (OPEX)			28,896.37
Including inflation (3.00%)			42,141.62
<b>System summary</b>			
Total installation cost		5,390,249.30 THB	
Operating costs (incl. inflation 3.00%/year)		42,141.62 THB/year	
Produced Energy		271 MWh/year	
Cost of produced energy (LCOE)		0.9503 THB/kWh	

Figure 4.5 Cost of the monocrystalline system

Cost of the system			
<b>Installation costs</b>			
Item	Quantity units	Cost THB	Total THB
PV modules JAP72-S10-345-SC	494	6,500.00	3,211,000.00
Inverters SUN2000-100KTL-M1-480Vac	1	130,829.00	170,077.70
Studies and analysis Engineering	1	50,000.00	50,000.00
Installation Settings	1	100,000.00	100,000.00
Grid connection	1	32,500.00	32,500.00
Insurance Building insurance	1	10,000.00	10,000.00
		Total	3,573,577.70
		Depreciable asset	3,381,077.70
<b>Operating costs</b>			
Item			Total THB/year
Maintenance Provision for inverter replacement			34,015.54
Cleaning			20,000.00
Total (OPEX)			54,015.54
Including inflation (3.00%)			78,774.67
<b>System summary</b>			
Total installation cost		3,573,577.70 THB	
Operating costs (incl. inflation 3.00%/year)		78,774.67 THB/year	
Produced Energy		216 MWh/year	
Cost of produced energy (LCOE)		1.0260 THB/kWh	

Figure 4.6 Cost of the polycrystalline system

Cost of the system			
<b>Installation costs</b>			
Item	Quantity units	Cost THB	Total THB
PV modules SL2-150 [G2.3+]	1062	5,758.00	6,114,996.00
Inverters SUN2000-100KTL-M1-480Vac	1	130,829.00	170,077.70
Studies and analysis Engineering	1	50,000.00	50,000.00
Installation Settings	1	100,000.00	100,000.00
Grid connection	1	32,500.00	32,500.00
Insurance Building insurance	1	10,000.00	10,000.00
		Total	6,477,573.70
		Depreciable asset	6,285,073.70
<b>Operating costs</b>			
Item			Total THB/year
Maintenance Provision for inverter replacement			34,015.54
Cleaning			20,000.00
Total (OPEX)			54,015.54
Including inflation (3.00%)			78,774.67
<b>System summary</b>			
Total installation cost		6,477,573.70 THB	
Operating costs (incl. inflation 3.00%/year)		78,774.67 THB/year	
Produced Energy		214 MWh/year	
Cost of produced energy (LCOE)		1.5816 THB/kWh	

**Figure 4.7** Cost of the thin film system

In considering installation, one must account for the investment cost of the system, as depicted in Figures 4.5, 4.6, and 4.7. It is evident that thin film panels entail the highest installation costs. The choice narrows down to monocrystalline and polycrystalline panels. However, a comparison with Table 4.3 reveals that monocrystalline panels offer the highest value and returns. Given the limited space of 1000 m<sup>2</sup> on the HM building, opting for the most efficient and valuable panel type is paramount. Monocrystalline panels emerge as the optimal choice, occupying only 982 m<sup>2</sup> and requiring 380 units. They can generate an annual energy output of up to 292 kWh/year and boast a high NPV of 14,179,287.27 THB, while also substantially reducing total carbon dioxide emissions by 3301.2 tCO<sub>2</sub>. Hence, it can be concluded that installing monocrystalline panels is the most appropriate and cost-effective solution for HM buildings.

### 4.3 System performance after setting Detailed losses

When installing a solar cell system, losses occur within the system, as illustrated in Figure 4.8. These losses, attributed to factors such as heat and dirt, manifest within the system, including losses from dirt accumulation, temperature differentials, inter-panel losses, as well as losses within the inverter and wiring. Consequently, these losses diminish energy production capability, resulting in a decrease in efficiency from 334 kWh to 271 kWh. This reduction in energy production not only impacts the overall efficiency of the system but also affects its cost-effectiveness parameters, including the reduction of CO<sub>2</sub> emissions, as depicted in Table 4.4. Specifically, the system efficiency decreases to 76.49%, with a total energy output of 271 kWh and a corresponding reduction of CO<sub>2</sub> emissions by 3062.8 tCO<sub>2</sub>.

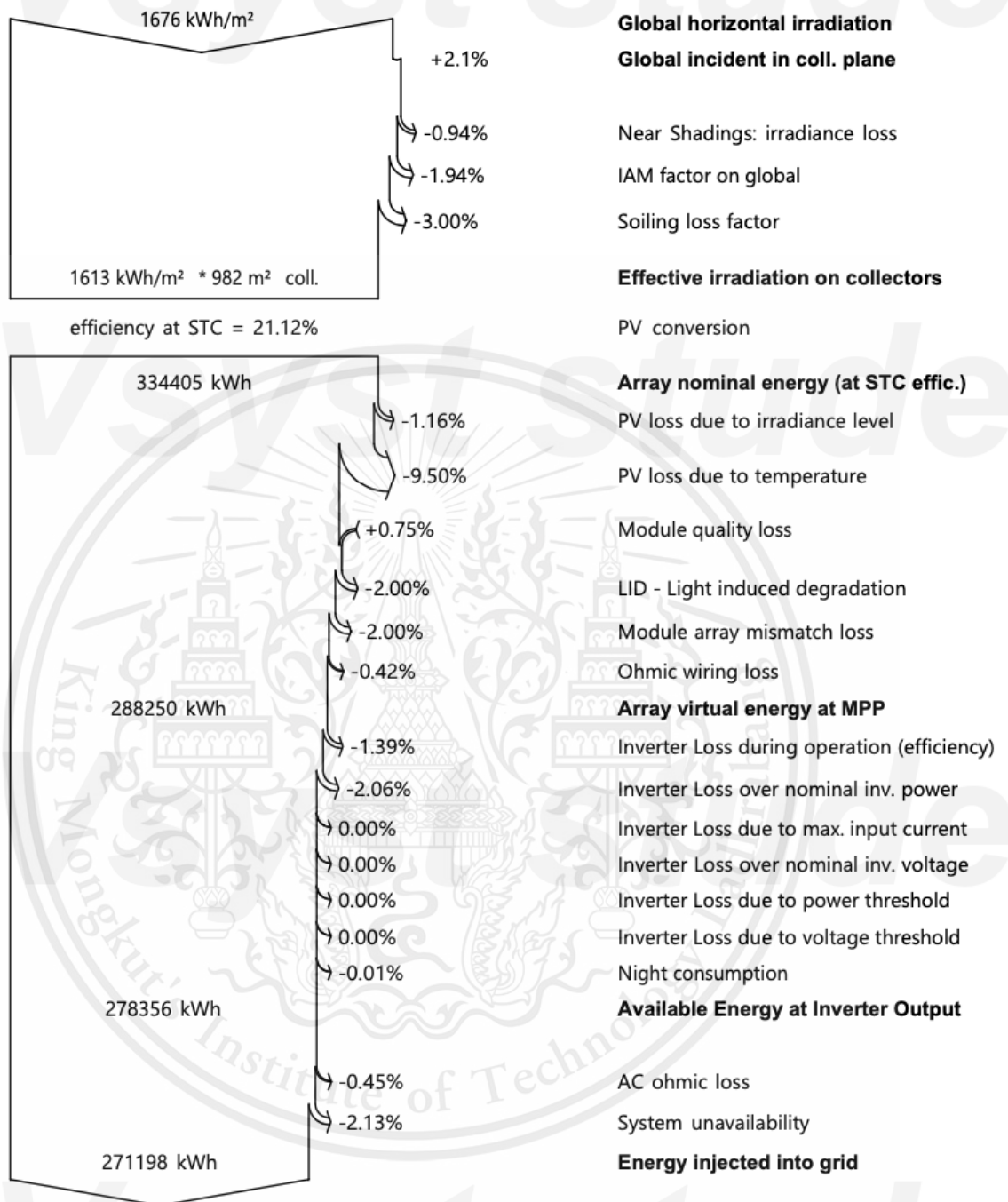
Reducing carbon dioxide emissions has positive impacts on the environment and human health. Choosing clean and sustainable energy sources, using environmentally friendly technologies, and adjusting residential settings to reduce energy consumption are crucial options that help decrease greenhouse gas emissions and play a significant role in building a sustainable and happier society in the long run.

**Table 4.4** illustrates the results before and after setting the loss parameters

Monocrystalline	Before setting detailed losses	After setting detailed losses
Situation	Latitude 13.73 °N , Longitude 100.78 °E	Latitude 13.73 °N , Longitude 100.78 °E
PV Field Orientation	15/0°	15/0°
PV Model	LR5-72HIBD-545M G2 Bifacial	LR5-72HIBD-545M G2 Bifacial
Inverter Model	SUN2000-100KTL-M1-480Vac	SUN2000-100KTL-M1-480Vac
Nominal (STC)	207 kWp	207 kWp
Nb.of modules	380 units	380 units
Nb.of inverters	2 units	2 units
Module area	982 m <sup>2</sup>	982 m <sup>2</sup>
Total installation cost	5,390,249.30 THB	5,390,249.30 THB
Produced Energy	292 kWh/year	271 kWh/year
Performance Ratio PR	82.33%	76.49%
Payback period	6.8 years	7.4 years
Net present value (NPV)	14,179,287.27 THB	12,489,050 THB
Internal rate of return (IRR)	14.15%	12.79%
Return on investment (ROI)	263.10%	231.70%
CO <sub>2</sub> Emission Balance	3301.2 tCO <sub>2</sub>	3062.8 tCO <sub>2</sub>

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**Figure 4.8** Loss diagram of monocrystalline system

## **CHAPTER 5**

### **CONCLUSION**

In this section, will discuss the experimental results summarization and recommendations for the design of a solar panel installation system on the roof of HM building. The following are the topics:

5.1 Summary of experimental results

5.2 Suggestions

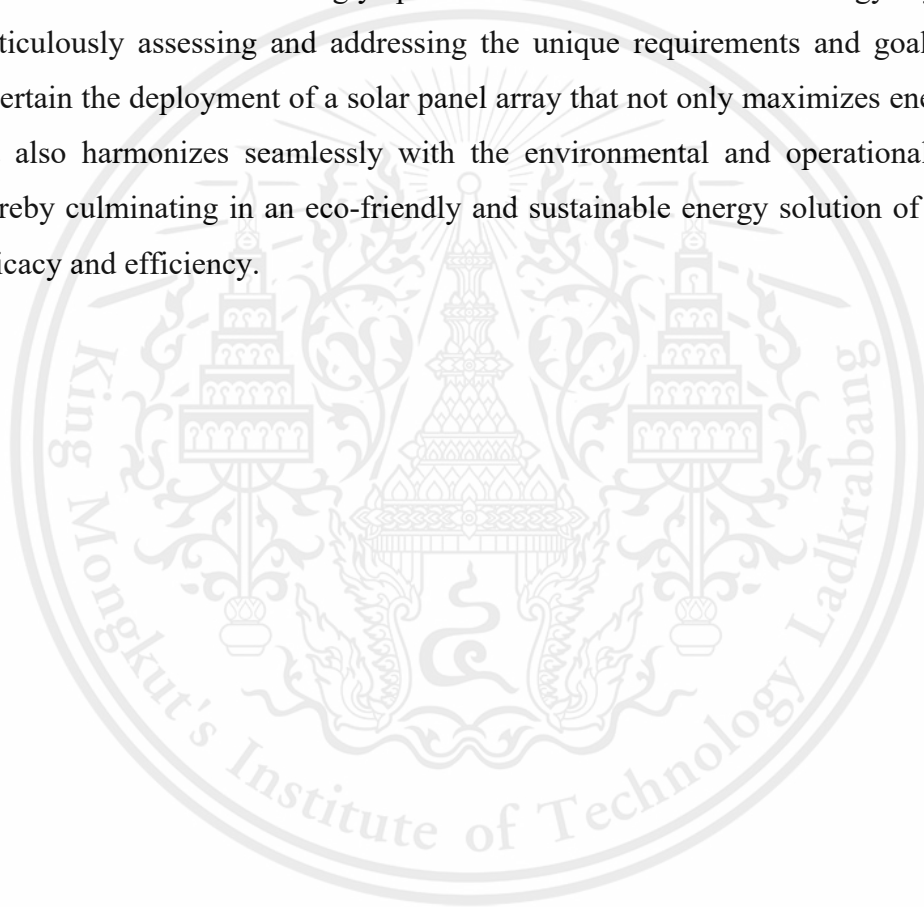
#### **5.1 Summary of experimental results**

This research examined the solar cell system design approach using the PVsyst software within the HM building with an off-grid installation system. Results were compared across three types of panels: monocrystalline, polycrystalline, and thin film. An assessment was conducted to determine the overall investment feasibility, considering environmental concerns related to carbon dioxide emissions resulting from solar cell system installations.

Experimental findings revealed that monocrystalline solar panels demonstrated superior efficiency, suitability, and investment returns when compared to the other two types. Monocrystalline panels utilized an installation area of only 982 m<sup>2</sup> and proved to be the most cost-effective with a return on investment of up to 12 million Baht within a 7.4-year timeframe. Additionally, the installation helped reduce carbon dioxide emissions by 3062.8 tCO<sub>2</sub>. In conclusion, this study suggests that monocrystalline solar panels are the most suitable choice for installation on the HM building.

## 5.2 Suggestions

The efficiency and effectiveness of the solar power system are contingent upon the meticulous selection of the optimal type of solar panel that aligns seamlessly with the specific operational necessities, encompassing the diverse geographical features pertinent to its installation. Thus, it is imperative to carefully deliberate and choose the type of solar panel that best fits the intended application and objectives, ensuring the attainment of an exceedingly proficient and robust solar energy system. By meticulously assessing and addressing the unique requirements and goals, one can ascertain the deployment of a solar panel array that not only maximizes energy output but also harmonizes seamlessly with the environmental and operational demands, thereby culminating in an eco-friendly and sustainable energy solution of paramount efficacy and efficiency.



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## APPENDIX



Version 7.4.5

### PVsyst - Simulation report

#### Grid-Connected System

Project: On-grid rooftop pv systems design for HM building2

Variant: On-grid rooftop pv systems design for HM building2

No 3D scene defined, no shadings

System power: 170 kWp

HM building - Thailand

#### Author

Tontrakul Srisamutnak (Thailand)

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## Project: On-grid rooftop pv systems design for HM building

Variante: On-grid rooftop pv systems design for HM building1

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### PVsyst V7.4.5

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Project summary				
<b>Geographical Site</b> <b>HM Building</b>	<b>Situation</b>		<b>Project settings</b>	
	Latitude	13.73 °N	Albedo	0.20
Thailand	Longitude	100.78 °E		
	Altitude	11 m		
	Time zone	UTC+7		
<b>Meteo data</b>				
HM building				
Meteonorm 8.1 (1996-2015) - Synthetic				

System summary			
<b>Grid-Connected System</b>	<b>Tables on a building</b>		
<b>PV Field Orientation</b>	<b>Near Shadings</b>	<b>User's needs</b>	
Fixed plane	Linear shadings : Fast (table)	Unlimited load (grid)	
Tilt/Azimuth			
	15 / 0 °		
<b>System information</b>			
<b>PV Array</b>		<b>Inverters</b>	
Nb. of modules	380 units	Nb. of units	1.7 units
Pnom total	207 kWp	Pnom total	170 kWac
		Pnom ratio	1.218

Results summary			
Produced Energy	271198 kWh/year	Specific production	1310 kWh/kWp/year
		Perf. Ratio PR	76.49 %

Table of contents	
Project and results summary	2
General parameters, PV Array Characteristics, System losses	3
Near shading definition - Iso-shadings diagram	5
Main results	6
Loss diagram	7
Predef. graphs	8
Cost of the system	9
Financial analysis	10
CO <sub>2</sub> Emission Balance	13



Project: On-grid rooftop pv systems design for HM building

Variant: On-grid rooftop pv systems design for HM building1

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General parameters			
<b>Grid-Connected System</b>		<b>Tables on a building</b>	
<b>PV Field Orientation</b>		<b>Sheds configuration</b>	
Orientation		Nb. of sheds	19 units
Fixed plane		Identical arrays	
Tilt/Azimuth	15 / 0 °	<b>Sizes</b>	
		Sheds spacing	6.51 m
		Collector width	4.60 m
		Ground Cov. Ratio (GCR)	70.6 %
		Top inactive band	0.02 m
		Bottom inactive band	0.02 m
		<b>Shading limit angle</b>	
		Limit profile angle	30.2 °
<b>Horizon</b>		<b>Near Shadings</b>	
Free Horizon		Linear shadings : Fast (table)	
		<b>Models used</b>	
		Transposition	Perez
		Diffuse	Perez, Meteorom
		Circumsolar	separate
		<b>User's needs</b>	
			Unlimited load (grid)
PV Array Characteristics			
<b>PV module</b>		<b>Inverter</b>	
Manufacturer	Generic	Manufacturer	Generic
Model	LRS-72HIBD-545M G2 Bifacial	Model	SUN2000-100KTL-M1-480Vac
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	545 Wp	Unit Nom. Power	100 kWac
Number of PV modules	380 units	Number of inverters	17 * MPPT 10% 1.7 units
Nominal (STC)	207 kWp	Total power	170 kWac
Modules	19 string x 20 In series	Operating voltage	200-1000 V
<b>At operating cond. (60°C)</b>		Max. power (=>40°C)	110 kWac
Pmpp	182 kWp	Pnom ratio (DC:AC)	1.22
U mpp	724 V	No power sharing between MPPTs	
I mpp	252 A		
<b>Total PV power</b>		<b>Total inverter power</b>	
Nominal (STC)	207 kWp	Total power	170 kWac
Total	380 modules	Nb. of inverters	2 units
Module area	982 m <sup>2</sup>		0.3 unused
Cell area	911 m <sup>2</sup>	Pnom ratio	1.22
Array losses			
<b>Array Soiling Losses</b>		<b>Thermal Loss factor</b>	
Loss Fraction	3.0 %	Module temperature according to irradiance	
		Uc (const)	20.0 W/m <sup>2</sup> K
		Uv (wind)	0.0 W/m <sup>2</sup> K/m/s
<b>Serie Diode Loss</b>		<b>LID - Light Induced Degradation</b>	
Voltage drop	0.7 V	Loss Fraction	2.0 %
Loss Fraction	0.1 % at STC	<b>Module Quality Loss</b>	
		Loss Fraction	-0.8 %
<b>Module mismatch losses</b>			
Loss Fraction	2.0 % at MPP		
<b>DC wiring losses</b>			
Global array res.	16 mΩ		
Loss Fraction	0.5 % at STC		



Project: On-grid rooftop pv systems design for HM building

Variant: On-grid rooftop pv systems design for HM building1

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**Array losses**

**IAM loss factor**

Incidence effect (IAM): User defined profile

0°	25°	45°	60°	65°	70°	75°	80°	90°
1.000	1.000	0.995	0.962	0.936	0.903	0.851	0.754	0.000

**System losses**

**Unavailability of the system**

Time fraction 2.0 %  
7.3 days,  
3 periods

**AC wiring losses**

**Inv. output line up to injection point**

Inverter voltage 480 Vac tri  
Loss Fraction 0.97 % at STC  
Inverter: SUN2000-100KTL-M1-480Vac  
Wire section (2 Inv.) Copper 2 x 3 x 50 mm<sup>2</sup>  
Average wires length 50 m



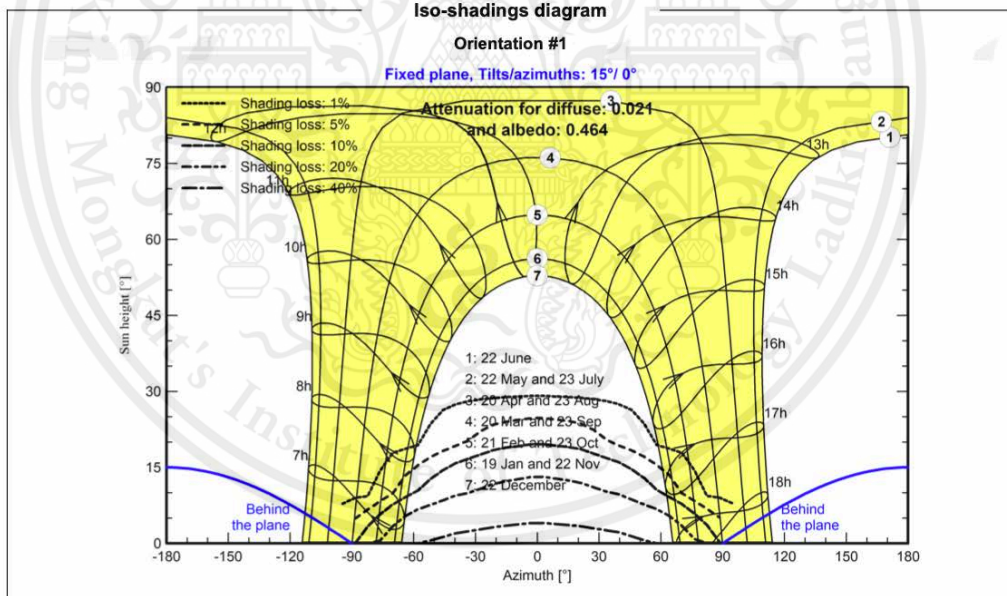
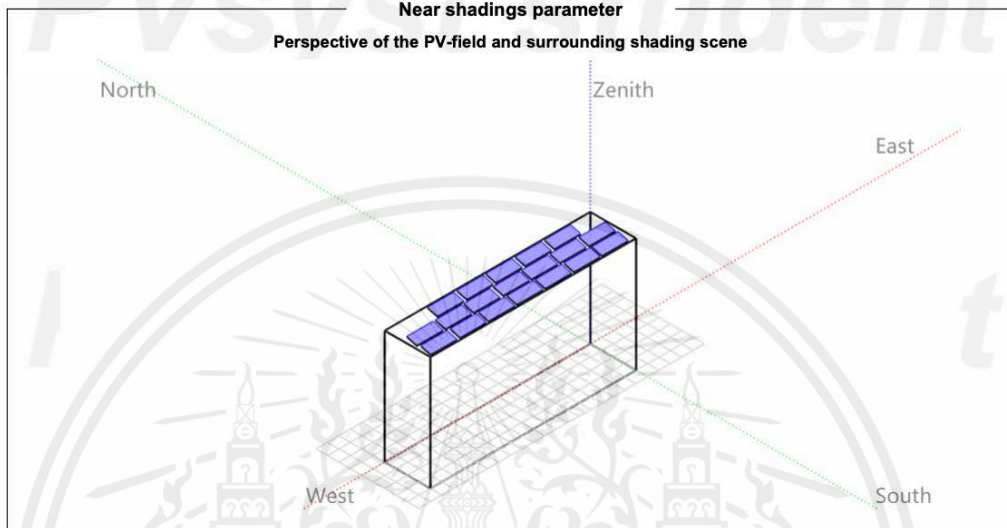
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Main results

System Production

Produced Energy 271198 kWh/year Specific production 1310 kWh/kWp/year  
Perf. Ratio PR 76.49 %

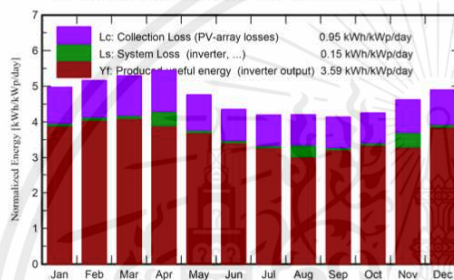
Economic evaluation

**Investment**  
Global 5,390,249.30 THB  
Specific 26.0 THB/Wp

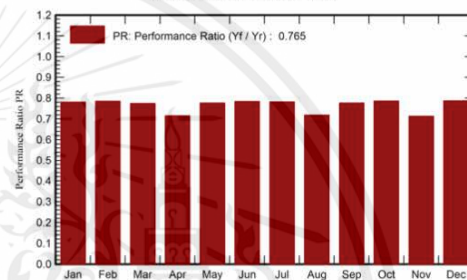
**Yearly cost**  
Annuities 0.00 THB/yr  
Run. costs 42,141.62 THB/yr  
Payback period 7.4 years

**LCOE**  
Energy cost 0.95 THB/kWh

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor kWh/m <sup>2</sup>	DiffHor kWh/m <sup>2</sup>	T_Amb °C	GlobInc kWh/m <sup>2</sup>	GlobEff kWh/m <sup>2</sup>	EArray kWh	E_Grid kWh	PR ratio
January	135.8	63.49	27.14	154.2	145.7	25443	24956	0.781
February	134.2	77.61	28.48	144.6	136.7	23967	23518	0.785
March	159.2	85.89	29.73	164.2	155.2	26853	26341	0.775
April	166.0	88.45	30.36	163.4	154.3	26716	24205	0.715
May	156.8	84.05	30.28	147.6	138.6	24201	23749	0.777
June	141.0	79.67	29.36	130.7	122.4	21630	21231	0.784
July	139.2	77.20	29.35	130.1	122.0	21460	21058	0.782
August	135.0	80.87	29.07	130.3	122.5	21555	19402	0.719
September	123.7	66.15	28.16	124.2	116.9	20371	19980	0.777
October	126.6	81.18	28.58	132.0	124.3	21916	21506	0.787
November	125.2	67.64	28.00	138.8	130.9	23058	20490	0.713
December	133.4	67.10	27.34	151.9	143.6	25238	24761	0.787
Year	1676.0	919.30	28.82	1712.0	1613.1	282408	271198	0.765

Legends

GlobHor Global horizontal irradiation  
 DiffHor Horizontal diffuse irradiation  
 T\_Amb Ambient Temperature  
 GlobInc Global incident in coll. plane  
 GlobEff Effective Global, corr. for IAM and shadings  
 EArray Effective energy at the output of the array  
 E\_Grid Energy injected into grid  
 PR Performance Ratio



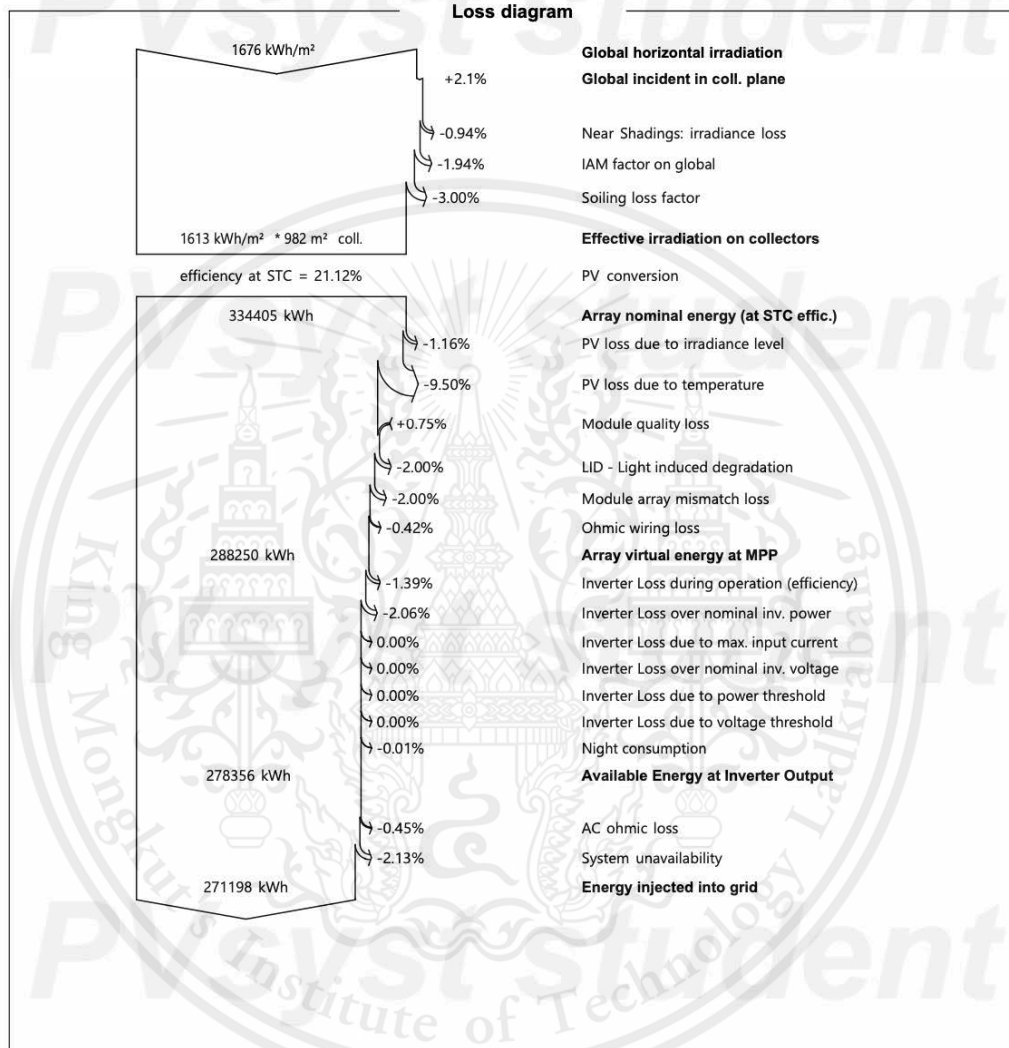
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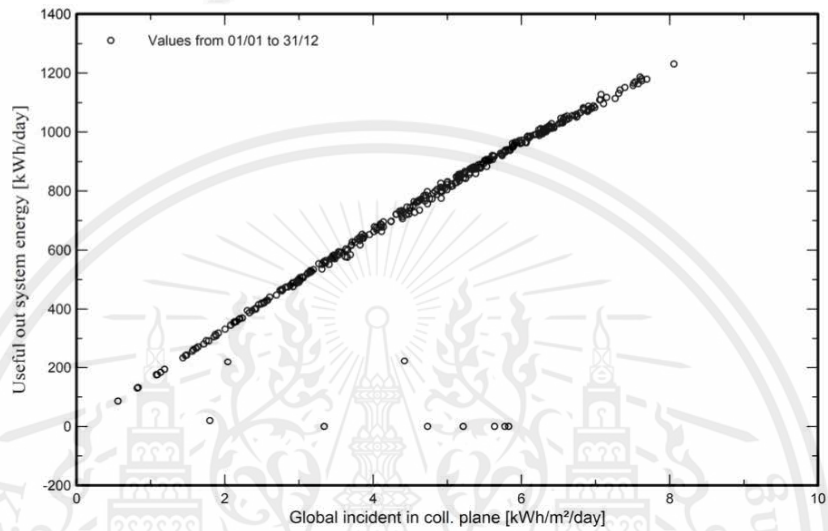
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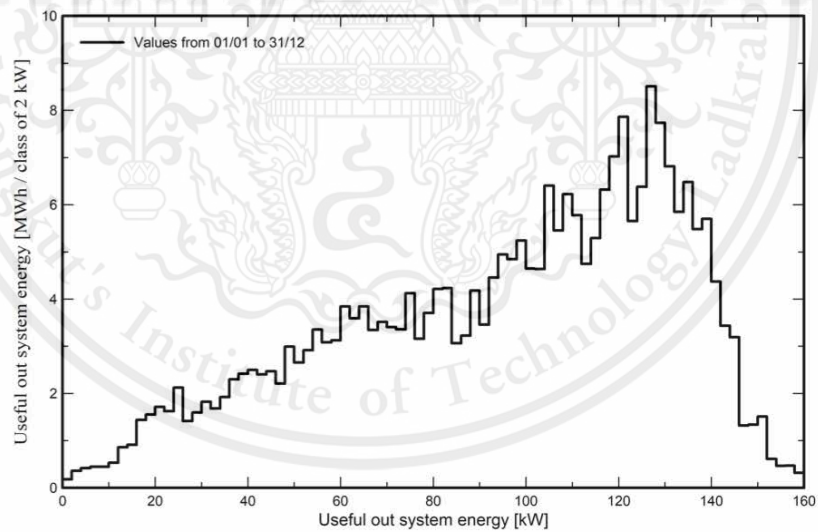
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Predef. graphs

Daily Input/Output diagram



System Output Power Distribution





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**Cost of the system**

**Installation costs**

Item	Quantity units	Cost THB	Total THB
PV modules			
LRS-72HIBD-545M G2 Bifacial	380	13,093.00	4,975,340.00
Inverters			
SUN2000-100KTL-M1-480Vac	2	130,829.00	222,409.30
Studies and analysis			
Engineering	1	50,000.00	50,000.00
Installation			
Settings	1	100,000.00	100,000.00
Grid connection	1	32,500.00	32,500.00
Insurance			
Building insurance	1	10,000.00	10,000.00
		Total	5,390,249.30
		Depreciable asset	5,197,749.30

**Operating costs**

Item	Total THB/year
Maintenance	
Provision for inverter replacement	8,896.37
Cleaning	20,000.00
Total (OPEX)	28,896.37
Including inflation (3.00%)	42,141.62

**System summary**

Total installation cost	5,390,249.30 THB
Operating costs (incl. inflation 3.00%/year)	42,141.62 THB/year
Produced Energy	271 MWh/year
Cost of produced energy (LCOE)	0.9503 THB/kWh



Project: On-grid rooftop pv systems design for HM building

Variante: On-grid rooftop pv systems design for HM building1

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Financial analysis

Simulation period

Project lifetime 25 years Start year 2024

Income variation over time

Inflation 3.00 %/year  
Production variation (aging) 0.00 %/year  
Discount rate 0.00 %/year

Income dependent expenses

Income tax rate 10.00 %/year  
Other income tax 0.00 %/year  
Dividends 0.00 %/year

Depreciable assets

Asset	Depreciation method	Depreciation period (years)	Salvage value (THB)	Depreciable (THB)
PV modules LR5-72HIBD-545M G2 Bifacial	Straight-line	20	0.00	4,975,340.00
Inverters SUN2000-100KTL-M1-480Vac	Straight-line	20	0.00	222,409.30
		Total	0.00	5,197,749.30

Financing

Own funds 5,390,249.30 THB

Electricity sale

Feed-in tariff 3.00000 THB/kWh  
Duration of tariff warranty 25 years  
Annual connection tax 0.00 THB/kWh  
Annual tariff variation 0.0 %/year  
Feed-in tariff decrease after warranty 0.00 %

Return on investment

Payback period 7.4 years  
Net present value (NPV) 12,489,075.56 THB  
Internal rate of return (IRR) 12.79 %  
Return on investment (ROI) 231.7 %



Project: On-grid rooftop pv systems design for HM building

Variant: On-grid rooftop pv systems design for HM building1

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Financial analysis

Detailed economic results (THB)

Year	Electricity sale	Own funds	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amortl.
0	0	5,390,249	0	0	0	0	0	-5,390,249	0.0%
1	813,677	0	28,896	259,887	524,893	52,489	732,291	-4,657,958	13.6%
2	813,677	0	29,763	259,887	524,026	52,403	731,511	-3,926,447	27.2%
3	813,677	0	30,656	259,887	523,134	52,313	730,708	-3,195,739	40.7%
4	813,677	0	31,576	259,887	522,214	52,221	729,880	-2,465,859	54.3%
5	813,677	0	32,523	259,887	521,267	52,127	729,027	-1,736,832	67.8%
6	813,677	0	33,499	259,887	520,291	52,029	728,149	-1,008,682	81.3%
7	813,677	0	34,504	259,887	519,286	51,929	727,245	-281,438	94.8%
8	813,677	0	35,539	259,887	518,251	51,825	726,313	444,876	108.3%
9	813,677	0	36,605	259,887	517,185	51,718	725,354	1,170,229	121.7%
10	813,677	0	37,703	259,887	516,086	51,609	724,365	1,894,595	135.1%
11	813,677	0	38,834	259,887	514,955	51,496	723,347	2,617,942	148.6%
12	813,677	0	39,999	259,887	513,790	51,379	722,299	3,340,241	162.0%
13	813,677	0	41,199	259,887	512,590	51,259	721,219	4,061,460	175.3%
14	813,677	0	42,435	259,887	511,354	51,135	720,106	4,781,566	188.7%
15	813,677	0	43,708	259,887	510,081	51,008	718,961	5,500,527	202.0%
16	813,677	0	45,020	259,887	508,770	50,877	717,781	6,218,307	215.4%
17	813,677	0	46,370	259,887	507,420	50,742	716,565	6,934,872	228.7%
18	813,677	0	47,761	259,887	506,028	50,603	715,313	7,650,185	241.9%
19	813,677	0	49,194	259,887	504,596	50,460	714,023	8,364,209	255.2%
20	813,677	0	50,670	259,887	503,120	50,312	712,695	9,076,904	268.4%
21	813,677	0	52,190	0	761,487	76,149	685,338	9,762,242	281.1%
22	813,677	0	53,756	0	759,921	75,992	683,929	10,446,172	293.8%
23	813,677	0	55,368	0	758,309	75,831	682,478	11,128,650	306.5%
24	813,677	0	57,029	0	756,648	75,665	680,983	11,809,632	319.1%
25	813,677	0	58,740	0	754,937	75,494	679,443	12,489,076	331.7%
<b>Total</b>	<b>20,341,929</b>	<b>5,390,249</b>	<b>1,053,540</b>	<b>5,197,749</b>	<b>14,090,640</b>	<b>1,409,064</b>	<b>17,879,325</b>	<b>12,489,076</b>	<b>331.7%</b>

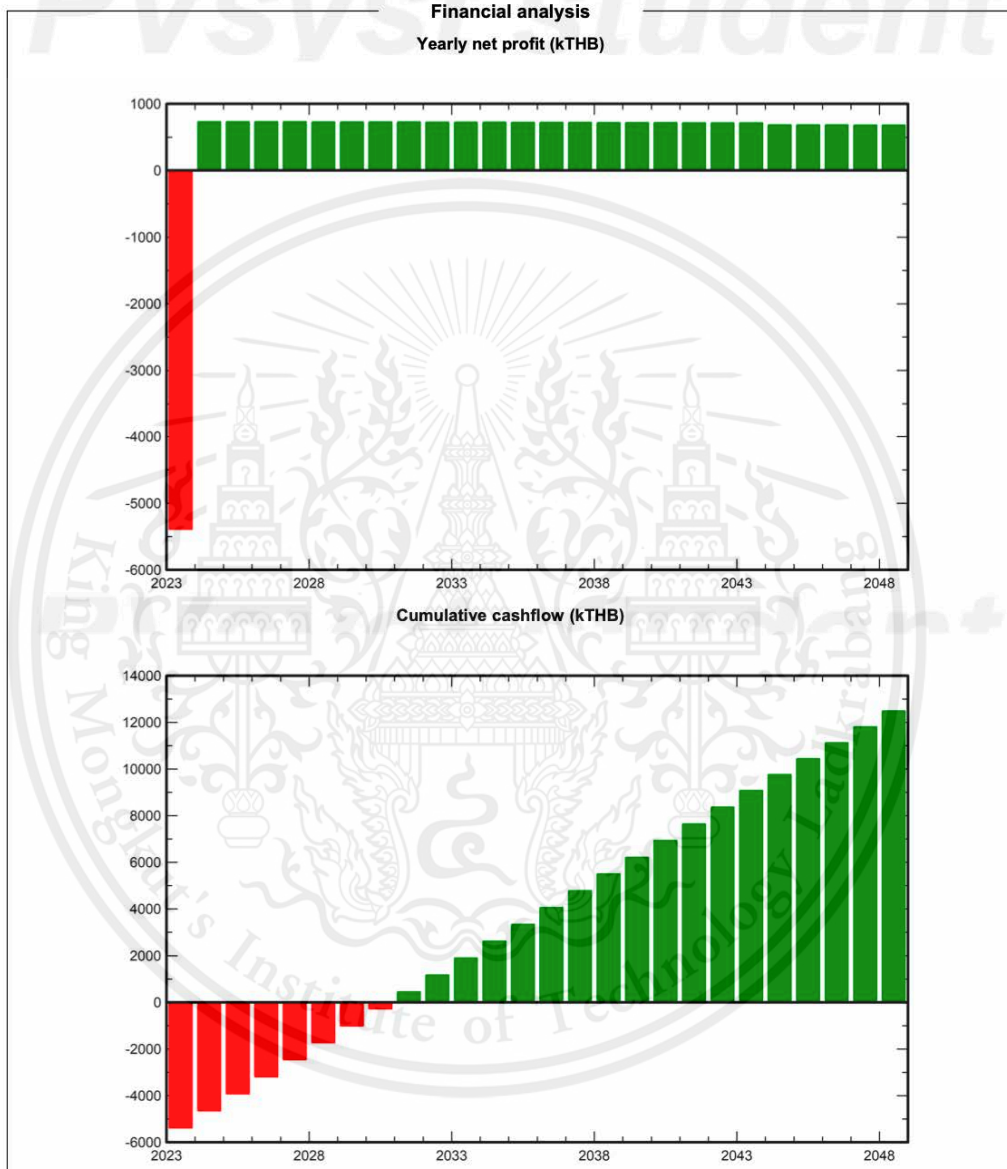


Project: On-grid rooftop pv systems design for HM building

Variante: On-grid rooftop pv systems design for HM building1

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Project: On-grid rooftop pv systems design for HM building

Variant: On-grid rooftop pv systems design for HM building1

Tontrakul Srisamutnak (Thailand)

**PVsyst V7.4.5**

VC0, Simulation date:  
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