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***Abstract*— Building is responsible for more than 40 percent of energy consumption and one third of greenhouse gas emissions. Europe has established the pathway towards nearly zero-energy buildings (nZEB), soon required in every new construction and large renovation in existing buildings by 2020. Achieving nZEB required the use of photovoltaic modules for generating electricity. The rooftops of residential, commercial and office building are ideal places for the installation of PV systems. Recently, in Vietnam, the nZEB becomes an important part of sustainable development and attracts the attention of scientists on the term of "green building" or "smart building", while photovoltaic systems are in most cases not used in building today. From this framework, we aim to implement the platform that will be dedicated to prototyping and tools to support research and training in the reference building. The first work presented in this paper aims at parametric analysis of 15 kWp PV system applied to a rooftop of a University building in Cau Giay - Hanoi. The study shows the effect of PV module types, and installation tilt angle on the electrical energy yield. The Photovoltaic simulation tool takes an important role in calculating the energy production from the solar panels. PVSyst software as a simulation tool was used to simulate several operating conditions as well as components. The research investigated a complete on-grid PV system by taking into account orientation of PV array under meteorological condition in Hanoi, solar cell technologies and inverter connections. Meteorological data was accessed by MeteoNorm and PVGIS. According to simulation results, the configurations of PV system for reference office building of the University of Science and Technology of Hanoi (USTH), was optimized to facilitate the next phase of smart building research in Vietnam.**

***Index Terms*— green building; photovoltaic source; simulation tool; rooftop; energy efficiency.**

I. INTRODUCTION

Energy consumption in buildings is studied in [1] concluding that this sector represents more 40 % of total energy use in EU and USA. Most of this energy is for the provision of lighting, heating, cooling, and air conditioning. The green and sustainable development movement in the world has placed green building in high priority as it is able to meet the building demand while mitigating the negative impacts of construction sector. High energy performance level in building can be attained by taking advantage of passive design techniques and active solar technologies such as solar collectors for hot water and space heating, PV panels for generating electricity. PV array installed in the building contributes to the reduction of the primary, conventional energy supply, as well as the reduction of CO2 emissions in the surrounding environment. Distributed PV system can be installed as façade or rooftop applications in order to maximize the benefits of clean and quiet power generation. Façade installation can be optimized by observing the orientation and distance to length ratio. Rooftop application can observe the tilted angle and curved installation [2, 3].

Energy consumption in Vietnam's building sector is growing quickly as a result of rapid industrialization and urbanization. In the report [4] have shown that, the residential sector is one of the main energy consumers in Vietnam, accounting for 33% share in 2012 and 35.6% in 2014, which will continue to increase in the future due to the pressure of increasing demand for buildings. The nZEB has become an important part of sustainable development and attracts the attention of scientists on the term of "green building" in Vietnam. However, the adoption of green building is still limited, the release of related regulations are slow and governmental support are lacking. It is recommended that the Vietnamese government should take stronger actions such as ratifying regulations or offering incentives to promote green building for sustainable development [5-7]. Besides, it has limited programs addressing renewable energy like PV generation deployment and energy efficiency use. Generally, the photovoltaic systems are yet to be used in the form of building-integrated systems nowadays. Such system is still at the research and demonstration stage. In this regard, it is required that the design and control strategies of green building are not straight forward since the buildings may involve complex integration of renewable sources, energy appliances, energy storages and may interact with the local smart grid.

Supported by the host university, our research project is a contribution for a better understanding of the problem. This paper mainly aims to: (1) present a platform for green building research and training; (2) estimate the building energy demand for lighting, HVAC, elevator, and other equipements; (3) use the PV system simulation software PVSyst to simulate performance of the 15 kWp PV system and investigate monthly energy production based on parameters including meteorological data of the installation site and PV array. Finally, simulation results will be used to advise the configurations of PV system for the building of the host university to contribute for the next phase of green building and nZEB research in our laboratory.

II. PLATFORM FOR GREEN BUILDING RESEARCH AND TRAINING AT USTH

A smart micro-grid platform at local level (building) with integrated Photovoltaic array and building energy management system is necessary to support green building research and eventually improve the current power grid by augmenting its performance and energy efficiency. This platform allows to study many aspects of smart building in Vietnam including building modeling with analysis of the differences between the model and the real system, understanding of distribution of energy in management issues under different scenarios. The power supply for this platform consists of a 15kWp PV generator to be installed on the rooftop, an electrical storage system and the power grid. The system extracts the maximum power obtainable from the PV array under different working conditions to provide a portion of the building power demand. The loads include the lighting system, HVAC system, laboratory equipment and the elevator.

Besides, the monitoring system allows data to be collected and utilized for the optimal operation. The energy controller reads all the data measured by the transducers to operate the equipment according to different selected modes. The energy manager controls the delivery of energy, and the charge or discharge of batteries.

The objective of the project is to benefit from PV power supply, to improve energy efficiency in the building and to reduce the cost of electrical consumption under different scenarios.

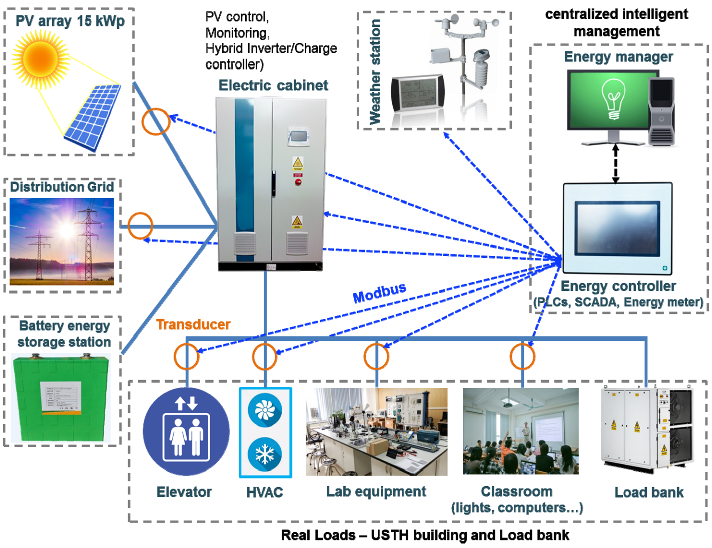

Fig. 1. Building energy management platform for University building

III. DATABASE COLLECTION

To set up a reliable PV system, it is important to identify the important data which affect the performance of the system. The data collection for this study divided into two categories which are the meteorological database and solar radiation, and total energy used by requirement loads.

A. Meteorological database and solar radiation

The building is located at N°.18, Hoang Quoc Viet Street, Cau Giay District, Hanoi, in the northern of Vietnam at a latitude of 21°N. It has one 37.9 meter high block, with a 939 m^2 rooftop consisting of three available installation areas. Total surface area for two flat roof is 420 m^2 and a flat (free standing system) with an available area of 130m^2, where PV panels can be installed (rooftop-mounted PV system).

The solar radiation climate database of a zone is extremely important to estimate the performance of a PV generation system. Vietnam is located in South East Asia, extending between latitudes 9°N and 23°N. The geographical location of the building and the local weather conditions influence the optimal tilt of the PV modules and is, therefore, of great importance. Several studies that addressed the solar resource maps show that global horizontal irradiation in annual daily average reaches around 3.4 kWh/m^2/day in Hanoi. In the case of direct normal irradiation the annual daily average is around 2.5 kWh/m^2/day, with approximately 1,500-1,700 hours of sunshine makes it a good site for promoting the use of PV systems [8]. Besides, ambient temperature and wind speed are also the main factors in PV production system.

The meteorological data embedded in PVSyst for this project is a synthetic hourly or monthly meteorological file set from Meteonorm in 2005 (the data collected from 1991 to 2010). It is a database containing climatological data for solar engineering and could also be used to calculate solar radiation on arbitrarily oriented surfaces [9, 10]. Fig. 2a shows the monthly average global irradiation of Hanoi in which the minimum value is in January, about 67.6 kWh/m^2, in contrast, the maximum value peak at 161.6 kWh/m^2 in July and August. And the average value is about 1,391 kWh/m^2 per year. Another data source, for instance, irradiance is Climate-SAF PVGIS which demonstrates the average daily global irradiance (Fig. 2b) with a relatively high amount of mean solar irradiation of 595 W/m^2 in July and August and 13 hours of sunshine.

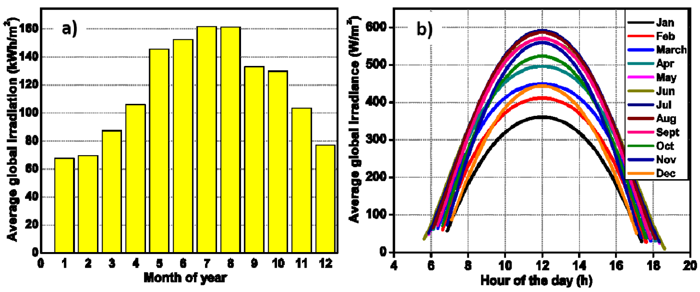

Fig. 2. Value of average global irradiation in kWh/m^2 from Meteonorm (a) and in W/m^2 from Climate-SAF PVGIS (b)

B. Estimated energy demand and consumption

TABLE I. BUILDING ENERGY DEMAND FOR A DAY IN JUNE 2016

Load	Power (kW)	Use (hour)	Energy (kWh)
HVAC	369.8	4	1479.2
Elevator	38.4	2	76.8
Lighting	51.6	4	206.4
Office equipment	71.9	6	431.4
Total	531.7		2193.8

TABLE II. BUILDING ENERGY CONSUMPTION IN MONTHS (KWH) 2015

Jan	Feb	Mar	Apr	May	Jun
21,600	14,480	21,120	28,880	34,080	42,400
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
36,160	37,680	37,040	24,400	31,840	31,840

TABLE III. BUILDING ENERGY CONSUMPTION IN MONTHS (KWH) 2016

Jan	Feb	Mar	Apr	May	Jun
27,200	18,080	21,680	26,240	38,080	48,800
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
44,000	40,400	---	---	---	---

We obtained previous electric bills since 2015 as the case study and building energy audit to determine what can be done to reduce electricity usage. In this case, we did not take into account the energy demand of specialized laboratory equipment. The total amount of energy demand of the building for this purpose was estimated about 2193.8 kWh during a day, for example in June 2016 when energy consumption peaked, as shown in TABLE I. The energy demand consumption is estimated based on the daily power used and its operating time. To be certain, we studied same building's bill again by comparing its consumption with our estimated energy demand. As can be seen in TABLE I, II and III, building energy consumption in one month is acceptably lower than our estimated energy demand, thus this estimation is valid for our purposes.

IV. SYSTEM CONFIGURATION

A photovoltaic system mainly composes: solar panels; power electronic equipment such as charge-discharge controller, inverter, and battery for energy storage and auxiliary power generation equipment. The parameter selection of every component is very important to fulfil the system configuration.

A. PV Panels

TABLE IV. PARAMETERS OF SUNMODULE XL SW-335

Quantity	Value
Area of module	1.96 m2 (72 cells/module)
Nominal power	335 Wp
Avg. panel efficiency	17.05 %
Rated voltage	37.8 V
Rated current	8.93 A
Open-circuit voltage	47.4 V
Short-circuit current	9.62 A
Nominal operating cell temperature	46°
Power temps coefficient	-0.304 %/K

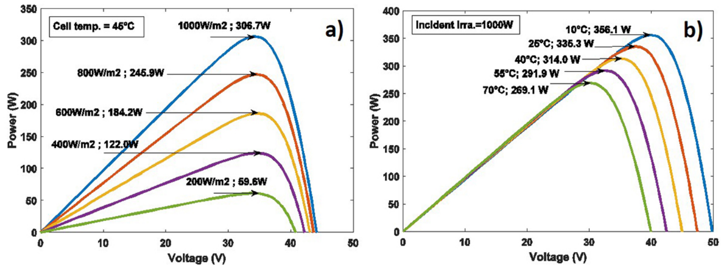

Fig. 3. Effect of irradiance and temperature on power output of solar cell, simulation results from PVSyst

The performance of PV modules depends on the cell temperature, solar irradiance and module type. According our requirements, we selected crystalline silicon cells. A 15 kWp PV system was simulated in PVSyst using the modules of XL SW 335 rated at 335 Wp, whose specifications are shown in TABLE IV. Based on the space availability for the correct orientation of PV array, it was estimated that 48 modules with total peak power 16.09 kWp that can be installed on the building's rooftop.

To receive the maximum amount of solar radiation, all modules are placed on the same plane, the PV array needs to be placed at a certain angle. The placement of the PV array is described using the plane azimuth A_m and the tilt angle θ_m. The tilt angle, is the angle between the horizontal plane and the PV module. The azimuth has different definitions, but in this paper the plane azimuth, is defined as the angle between the orientation of the collector plane and south (in the northern hemisphere). For geographical locations installations with fixed modules in the northern hemisphere like Hanoi, typically the array should be oriented to face south at 0° azimuth. The optimal tilt angle will be presented in section V. For simulation, two main factors of concern are incident irradiance and cell temperature. In Fig. 3a, the maximum power of solar cell SW 335 mono-crystalline at its NOCT (45°C) is proportional to the incident irradiance. One panel can generate 306.7 W under incident irradiation 1,000 W/m^2. The generated electric power drops quickly with decreasing incident irradiance, when the irradiance is 200 W/m^2, the panel can only produce 59.6 W. In Fig. 3b, the power output depends strongly on temperature with negative coefficient. A PV cell generated power from 269 W to 356 W under 1,000 W/m^2 incident irradiance when the cell operating temperature varies from 10°C to 70°C.

B. Inverter and matching PV array/Inverter

The inverter takes the DC power from the PV array and converts it into standard AC power used by the building appliances. Some factors that we have to take into account in choosing inverter include:

- The generated power of PV array: The power of inverter is the output power of system. When the power of inverter is higher than generated power from the array, it increases cost unnecessarily. On the contrary, when the array generates more than the power that inverter can handle, the exceed power is waste and the efficiency of the system decreases.

- Voltage and current ranges: The highest output voltage and current of the array have to be under the peak voltage and current that inverter can handle. In operation mode, basing on the highest and lowest produced Vmpp of the array, we have to select inverter that having a suitable operating range. The DC input current range of inverter has to be considered similarly to be suitable with the DC output current of array.

- Energy appliances and installation: There are two kinds of inverter: Central inverter and string inverter. Central inverter is suitable for a homogenous system when all panels have the same orientation and the same DC output voltage. This kind of inverter can reduce the cost per unit of power due to the better performance and footprint size (in comparison with string inverter). However, when strings work in different conditions, the mismatch among them will reduce the efficiency of harvesting system. The complication of high DC voltage wiring could be another problem, which increases the risk of fire. In the other hands, string inverter is suitable for the system that contains various modules with different orientations.

The simulation only consider about choosing which type of PV module and inverters. PVSyst has a built in system that matches the number of inverters with the number of strings. It also proposes a number of modules in each series, and the number of strings based on the sizing parameter. This is to assure that all requirements regarding current, voltage and power levels are met. When an inverter have multiple MPPT inputs, in PVSyst, it divide the operating power between the inputs. Two inputs take half the nominal power at each input. It is not possible to share the power unequally between each MPPT input. The main reason for choosing two different modules of Sunmodule XL SW 335 and two kind of inverters is to compare the performance of different types of well known (TABLE V). These technique conditions are used together with the numbers proposed by PVSyst to set design the configurations in (TABLE VI).

The ratio between peak power of array (in standard testing condition 1,000 W/m2 irradiance and 25°C) and the power of inverter (15 kWp) is 1.07. This ratio is acceptable since the high efficiency of inverter choosing, and the high insolation in Hanoi [11, 12].

TABLE V. PARAMETERS OF INVERTERS

Inverter	Number	Nominal power	Operation voltage	DC input peak
Ingecon Sun 15 TL M	1	15 kW	300-820 V	50A (2 inputs 20/30 A)
Conext RL 5000E	3	5 kW	100-540 V	36A

TABLE VI. SIMULATED ARRAY/INVERTER COMBINATIONS

Inverter	Num.	Mod. in series	String	MPPT input/String input
Ingecon Sun 15 TL M	1 (three phase)	12	4	2/2
Conext RL 5000E	3 (mono-phase)	8	6	1/2

C. Batteries and battery charge controller

Several studies have suggested that battery storage co-located with grid-integrated building-scale PV generation benefits electricity distributors in maintaining system voltages within acceptable limits [13]. Energy storage can supply more flexibility and balancing to the grid, providing a back-up to intermittent solar energy. Locally, it can improve the management of distribution network, reducing costs and improving efficiency. The design principle for sizing the system's battery is to compensate for daily variations in solar radiation and not to act as seasonal energy storage [14]. PV modules are not an ideal source for battery charging. The PV output is heavily dependent on weather conditions, therefore an optimum charge/discharge cycle can be guaranteed, resulting in a low battery state of charge (SOC) [15]. Low battery SOC drives to shorten the life of the battery. The battery proposed is Lithium battery LiFePO4 with 100 Ah battery capacity, with three blocks of 5 kWh/each. Then the nominal voltage for each cell is 54 V. The battery has columbic efficiency by 97%.

V. PV SYSTEM PERFORMANCE ANALYSIS

The performance evaluation of this study is based on the PVSyst software simulation. This part discuss the output from the simulation tool such as the potential energy resources, the optimum tilted angle of PV array and energy production from the PV array as well as system losses.

A. Tilted angle optimization of PV array installation

To optimize the tilted angle θ_m for the rooftop PV array, an ideal case was built with azimuth equal to $A_m = 0^0$. The tilted angle of the free standing system was adjusted from 0° to 30°. The result of simulation is shown in Fig. 4 and 5. The specific energy product and system energy product indicates that the best tilted angle is 15°, however the difference between the results is small for the range of tilt angles of 9, 12, 15, 18, and 21 degree. Therefore, the tilt angle of South faced PV system for this building can be flexible between 9 and 21 degree. In reality, optimum PV array output can also be achieved using tilt angle approximately equal to the site's latitude of 21°N for Hanoi. Mono crystalline cell is better choice than poly crystalline cell. Central inverter is better choice than string inverter. With the mono-crystalline and central inverter, simulation shows an annual system production of PV 15 kWp system of 19,348 kWh/year, and the specific yearly production is 1,205 kWh/kWp/year. The overall performance ratio (PR) is 0.849 and the normalized production is 3.3 kWh/kWp/day. The PR is a measure for the overall losses of a PV system and is defined as the ratio of final energy yield of the PV system in kWh/kWp to a reference yield, which takes only solar irradiation into account.

The building requires single phase voltage for lighting and office equipment like computers, laptops and three phase voltage to supply the elevators and HVAC system, therefore three separable single phase inverters configuration is chosen. The following section presents the analysis of simulation results to evaluate the system performance for the mono-crystalline and string inverter variant.

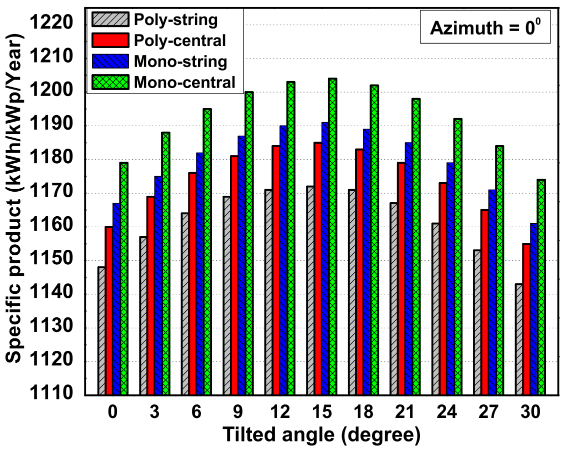

Fig. 4. Specific product of PV system for $A_m = 0^0$ by tilted angles

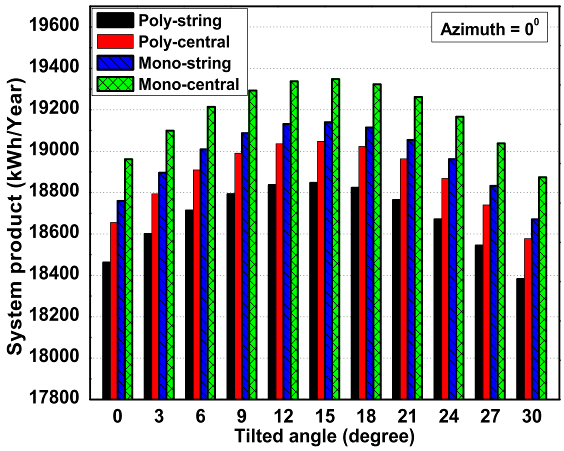

Fig. 5. System product of PV system for $A_m = 0^0$ by tilted angles

B. Analysis of power output and energy production

Using an optimally orientated PV array with $A_m = 0^0$ and $\theta_m = 15^0$, PV mono-crystalline modules and string inverter are mentioned in this simulation, when the yearly data is averaged over 24 h period for each month by estimated in PVSyst, we get the average power production of PV array profile for different months as shown in Fig. 6. It can be observed that:

- The average monthly peak power ranges between 8.7 kW in August and 5.2 kW in January. This indicates that the PV array on an average only produces around 60 % of its rated power even in the sunniest month of the year. The rated power of the PV array using 48 modules of XL SW 335 is estimated under standard test conditions, i.e. 1,000 W/m^2 and 25°C. However, according to Fig. 2, the average global irradiance in August is 595 W/m^2 and the ambient temperature is about 37.5°C.

- PV array generates energy for 13 hours during summer months while it is only 11 hours in winter.

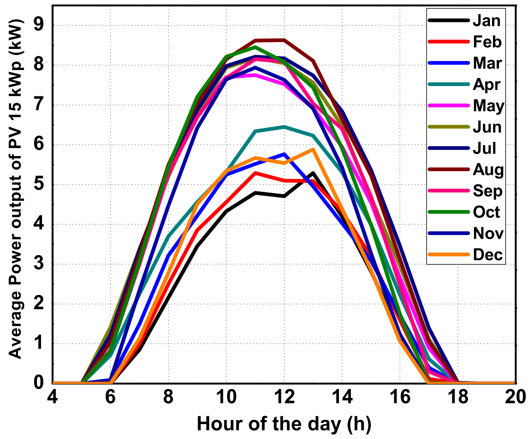

Fig. 6. Average power output of 15 kWp PV array as a function of time of the day for different months.

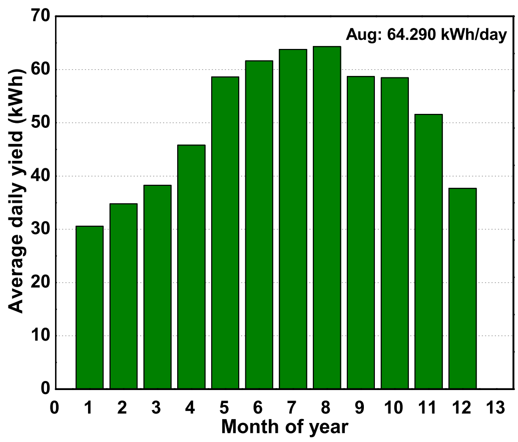

Fig. 7. Average daily yield of 15 kWp PV array for different months.

Fig. 7 and 8 show the average daily yield of PV system for different months. The different of PV yield of two time can be observed between January and August. In August, PV yield always reaches a high level with almost no fluctuation around the average value approximately 64.290 kWh/day. There are also cloudy days with low daily yield about of 30 kWh which is showed in these months from May to November. By contrast, in January, PV yield fluctuates dramatically among days in month. There are cloudy days with low daily yield of < 5 kWh and sunny days with yield > 70 kWh. This trend also occurs in the winter: in December, January, February and March.

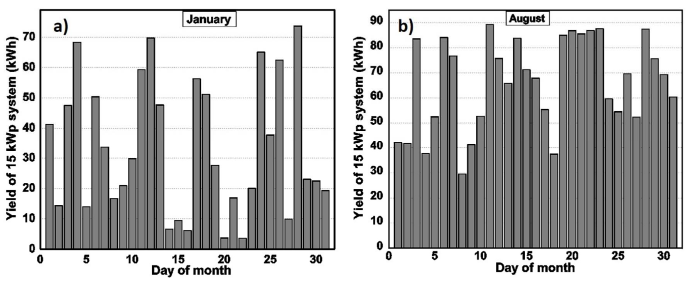

Fig. 8. Average daily yield of 15 kWp PV array for January and August.

C. System Losses

PV array failed to generate 100% the energy delivered from the sun because of some losses. Fig. 9 explored the overall system loss diagram for site installation. A collector plane received about 1,391 kWh/m2 of global incident irradiation. But the effectiveness plane receives the irradiance only at 1,366 kWh/m2. The biggest losses happen in PV array production energy. Energy produced from the PV array affected by several factors such as ambient temperature which takes the main part of loss (9.4%), solar incidence, manufacture mismatch and ohmic wiring. The loss in inverter is 3.1% since the efficiency of inverter in specification of producer is 96.9%. Other losses in inverter operation is zero, shows that PV array and inverter perfectly fit each other. The actual energy supplied to the load can identify after through the losses of regulator and battery storage. These annual system production of PV 15 kWp system of 19,138 kWh/year.

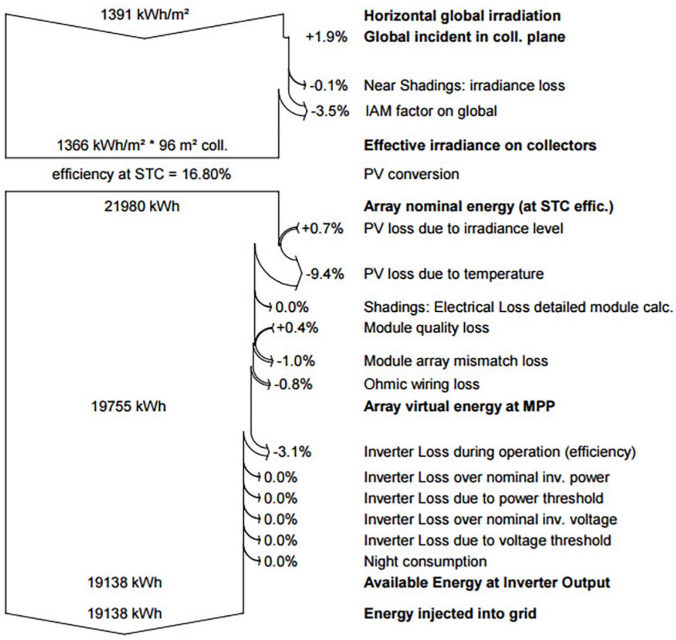

Fig. 9. Overall system losses in case: azimuth at 0° and tilted angle at 15°, simulation result from PVSyst [9, 10]

VI. CONCLUSION

This paper presents the use of PVSyst as a simulation tool to evaluate the PV array installed on building's rooftop. This software enables the PV project designer to select system configurations as well as predict its energy production. System sizing depends strongly on the geographical location of the installation site. This work studied a PV system which is applied for low-voltage grid connection at building-scale, with electrical storage system in the scope of our research on energy efficiency dedicated to the green building. The simulations shown that the average monthly peak power ranges from 8.7 kW in August to 5.2 kW in January. This indicates the PV array on an average only produces of 60 % of its rated power even in the sunniest month of the year. It is also helpful as a pre-decision of installation. The results indicated that the optimal tilt for PV modules installed on building's rooftop in Cau Giay-Hanoi to get maximum yield is 15°.

For future works, the sizing of grid-connected PV system should be extended to all component and an economic analysis should also be performed. In addition, measurement equipment such as pyrometer can be used to obtain on-site irradiance data in real time. Such measuring equipment could be used monthly in order to correct the simulation results provided by PVsyst with the output and real production from the PV installation.

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