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Economic Feasibility Assessment of Motorized PV Louver System Considering the Near Shading Parameter, Array Incidence Losses and Other Environmental Factors

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Abstract

Seoul has good weather settings for incorporating renewable energies, hence, given its small land area living mode was mostly set in an apartment condition it is an ideal place for building applied photovoltaic (BAPV) for solar energy harvesting. On the other hand, the BAPV energy self-consumption hasn't been thoroughly examined considering the overall energy consumption requirement. Therefore, presented in this communication are the viability of PVL to produce electricity from solar energy and insights on modulating and improving energy harvesting efficiency. To accomplish this objective, three major factors were considered: 1) the photovoltaic (PV) positioning; 2) the solar tracking scenario; and 3) the mechanistic system energy consumption. The overall louver energy generation was thoroughly scrutinized from the net energy conception of the BAPV up to the mechanistic module energy expenditure. This work intends to provide insights into the economic feasibility of BAPV assessing its technological profitability in the specified location and building size.

Keywords

Photovoltaic Louvers, Energy Consumption, Tracking System, Building Integrated Photovoltaic, PVsyst

1. Introduction

Grasping that the electricity demand analogously increases as technology advances, it is imperative to devise a strategy for achieving technological innovation while respectively adopting new techniques to redirect the energy supply from traditional energy sources toward a renewable energy domain [1] [2]. Up to this day, a massive portion of the energy supply comes from exhaustible and damaging sources such as gas, coal and oil. In financial terms, the growth of nations is directly connected to the consumption and cost of energy. In this circumstance, alternative energy sources must be thoroughly explored to reduce our dependence on fossil fuels. One of the sought-after power-generating techniques to adverse our dependency on fossil fuels is solar photovoltaic (PV) systems [3] [4]. This can be correlated to its abundance, seamless harvesting strategies, simplistic mechanism, prominent installation prospects, low maintenance and pollution-free imprint.

As the standard of life and lifestyle improves the energy demand arises with it. The skyrocketing demand in residential and commercial buildings to adapt to the increasing population, analogously multiple energy consuming devices arise with it to maintain a comport living such as heating ventilation and air condition [5]-[7]. One of the suggested resolutions to this promulgating dilemma was the integration of PV systems directly into the buildings. This technology can play an important role in mitigating this energy and environmental concerns. The BAPV with the building's façade resolved the building energy demand and shortage in land availability, particularly in countries that have low land areas such as the Asia/ Pacific region [8] [9]. Several reviews and assessments were conducted to evaluate the performance of BAPV presenting energy generation capacity of ~100 MWhr/yr with an efficiency value ranging from 5% to 50% [10]. Sudhakar *et al.* reviewed the thermal evaluation of BAPV for it tends to get warmer in comparison with traditional PV [11]. Kalogirou *et al.* focused on the mechanical ventilation parameters of BAPV fortifying its ability to dissipate heat from the buildings [12]. Debbarma *et al.* reviewed the electrical and thermal efficiency of BAPV and BAPVT in different settings and locations [13]. On the other hand, Hepbasli *et al.* reviewed the critical factors and electrical parameters influencing the utilization of BAPV and BAPVT such as the shadowing effect, building direction and tilting angle [10]. Hence, most of these performance evaluation efforts focus on design and energetic parts while leaving the exergetic with very low attention and not comprehensively explored [14]. Here, we set an objective to assess the overall performance evaluation of BAPV and its relative economic feasibility using the PVsyst simulation system in a factual building setting. Numerous simulation software has been established to model photovoltaic systems, PVsyst was chosen among several simulation engines for its relatively high efficiency (~96%) relative to factual PV energy generation performance [2] [15]. The evaluation programming was set to Seoul (South Korea), given its low land mass area which drives its population to settle in an apartment building was a perfect scenario to assess the nominal power generation performance of BAPV. To undertake our objective, several factors were considered: 1) the photovoltaic (PV) positioning; 2) the solar tracking scenario; and 4) the mechanistic system energy consumption. The overall BAPV energy production was systematically analyzed from the net energy conception of the BAPV up to the mechanistic module energy expenditure. This work intends to provide insights into the economic feasibility of PVL assessing its technological profitability in the specified location and building size. It is anticipated that this study will be of assistance to researchers and practitioners involved in the design, analysis, simulation, and performance evaluation, financial development and incentives, new methods and trends of BAPV systems.

2. Experimental

Precise recreation of the BAPV mechanisms demands integrated energy modeling tools to evaluate and examine the BAPV electricity generation accurately. The procedure exhibited in this study is analogous to the existing works that utilized a fully parametric BAPV model to validate its applicability on compact commercial or residential buildings. The PVsyst modeling tool was employed to confirm the actual energy harvesting performance in a compacted building setting. PVsyst is a modeling software that was devised to assess the required data for the setup of a PV system. This software presents the possible energy generation of a particular system used for constructing and designing the PV system. The produced data relies on the scaled simulation. Results may involve numerous simulation variables that can be shown at monthly, daily, or hourly rates. The model can also forecast the defect in the design through system and collection losses. The general research goal is to offer a guide on the application of BAPV, the idea is to stipulate acumens on the transcribed BAPV limitations. All the presented performances in this study are entirely stipulated using PVsyst simulation software, which established the overall performance of the BAPV system. The report consists of potential energy resources, system component sizing, and energy production from the SAPV system and system losses.

To give insight into the economic feasibility of BAPV in a building-dense location such as Seoul (South Korea), given its low land mass area which initiates its population to stay in apartment buildings was a perfect scenario to evaluate the power generation performance of BAPV. Moreover, due to the geographical location of Seoul which proliferated with an abundance of solar irradiation, energy generation is highly reliant on the solar irradiation intensity of the corresponding location [10]. Through the utilization of PVsyst software, the monthly and yearly energy accumulation at Seoul in a given setting was generated. The PV system is located in Seoul, South Korea, at a latitude of 37.57˚N and a longitude of 126.98˚E. The site is 33 meters above sea level and in the UTC + 9 time zone. The weather data used for the simulation is traced from Meteonorm 8.1, spanning the years 1991 to 2013, and consists of synthetic data. The PV system configuration is designated in the system summary, emphasizing the following components and settings: The grid-connected system employs PV field orientation with tracking sun shields and a facade orientation of 0˚. An astronomic calculation tracking algorithm is used to enhance energy capture throughout the day. The system information of the BAPV array consists of 2 modules, with a total nominal power of 250 Wp. The system includes one inverter, which has a nominal power of 200 W, resulting in a nominal power ratio of 1.250. The average daily radiation for the whole day is 4.90 kWh/m^2·day. Seoul, which is located in the middle of South Korea has an average ambient temperature with 27.8˚C and wind speed of about 0.7 m/s. All weather data collected determines the amount of sun energy reached by a panel in produced electrical energy [16]. Shading significantly affects the performance of PV systems. The provided system summary includes an analysis of near shadings, with linear shadings simulated slowly for accuracy and diffuse shading calculated automatically to assess real-world impact.

3. Results and Discussion

3.1. Ideal and Factual Solar Energy Harvesting Condition of BAPV

The utilization of PV has garnered immense interest in the past few years in correlation to the transition to renewable energy sources. The progressive advancement in PV systems acquired the development of BAPV aiming to enhance the solar harnessing capacity, taking advantage of the ever-growing skyscraper societies, allowing optimal energy-gathering capability [9] [17]. Hence, most of the investigation about BAPV is heavily efforts focused on design and energetic parts while leaving the exergetic with very low attention and not comprehensively explored [14]. Here, an objective was set to evaluate the overall performance of BAPV and its relative economic feasibility. In here PVsyst software was employed to verify the efficacy of the BAPV in a compounded building setting, providing solar irradiation analysis and energy generation. Comparatively with other parts of South Korea, the city of Seoul had undergone an accelerated industrial transformation, growing from ~2.5 million in 1960 to ~10 million in 2011 [9]. The assessment was set to Seoul (South Korea), granted its low land mass area which makes its population stay in an apartment building which makes a perfect scenario to assess the supposed power harvesting performance of BAPV [16] [18].

All figures were commenced through simulation measurements on two different BAPV positions, shown **Figure 1(a)**, **Figure 1(b)** is the illustration of the simulation design. The panels were positioned in an ideal configuration running a single building [19]. On the other hand, the factual conditions were stipulated to mimic the actual environmental setting. The panels are automated to trail the sun's movement tracking the apex of solar radiation through with single-axis orientation. This is to affirm the power harvesting in terms of the BAPV systems which are highly reliant on access to solar irradiance. This will confirm the power harvesting viability of BAPV using PVSYST software in Seoul in a daily setting for a year. Variations in the azimuthal setting were arranged from 0 to 90°, where solar irradiance was tracked ensuring direct sunlight projection. Due to the spherical configuration of the earth, different solar intensities can be observed, therefore, elliptical solar paths were considered in the modeling situation. Demonstrated in **Figure 1(c)**, **Figure 1(d)** is the iso-shading diagram through PVsyst on actual and factual settings to evaluate its relative transmission capacity, where different shading conditions (1%, 5%, 10%, 20% and 40%) were presented. The profile depicts the debilitation of solar irradiance transmission concerning the panel position and environmental surroundings. It can be realized that ideal setting conditions follow a relatively similar line profile depending even on the seasonal change having the lowest shadow factor at azimuth 0° following the sun's path. This evaluation gives conjectures on the systematic shading allocation according to the period and the time of day throughout the year. Furthermore, the factual condition where the panel was set in a building congested setting demonstrates a relatively high magnitude of shading loss with a massive decline at 10 h at 75˚. The difference in performance can be ascribed to the shading factors of the surrounding buildings which is the actual landscape of Seoul. The solar attenuation deviation from the ideal to factual framework is ascribed to the decrease of radiation conveyance due to high shading incidents in factual settings.

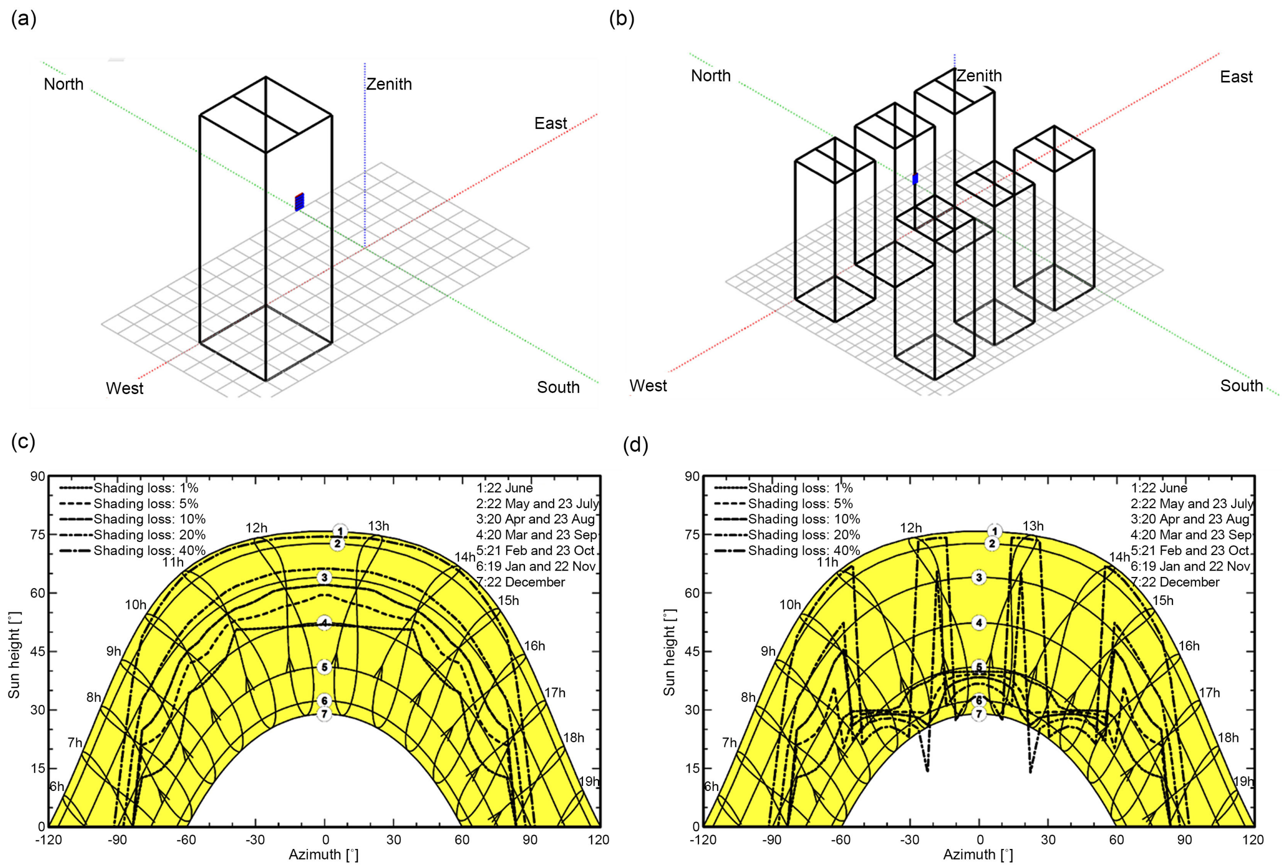

Figure 1. Solar energy harvesting condition of BAPV. (a) ideal and (b) factual perspective of the field and surrounding shading scene. Iso-shadings diagram of (c) ideal and (d) factual conditions.

3.2. Performance Analysis Ideal and Factual Solar Energy Harvesting Condition of BAPV

As one of the advantageous clean energy harvesting techniques without any harmful emissions PV systems have received massive amounts of attention these past few years [8]. One of the incremental advances is the assimilation of PV systems through seamless integration with the current infrastructure employing BAPV. Like other energy harvesting infrastructure, BAPV demands immense fundamental investment, and evaluation of its relative efficiency and economic feasibility is imperative. Therefore, the assessment of the PVBP efficacy must be thoroughly scrutinized in factual conditions. All energy generation assessments were obtained through PVsyst, the simulations were set to gather monthly data for one year. The evaluation was set by tracking sun activity at the axis 0˚ - 90˚, at rotation phi limits −60˚ - 60˚. The energy generation estimates of BAPV in Seoul were thoroughly scrutinized. A comparison of the energy harvesting capacity between ideal and factual conditions was presented and summarized in **Figures 2(a)-(d)** and **Table 1**, **Table 2**. These data will act as an illustration of ideal and factual energy harvesting expectations with the consideration of fluctuations in solar radiation on BAPV installation in Seoul [20]. The experiment is also definitive on the losses, orientation effect, obstruction and other operational factors affecting the harvesting capability of BAPV. A substantial variation in the overall monthly energy harvesting can be realized within the middle of the year which is attributable to the seasonal change of the region. A difference in the production of useful energy can be discerned between actual and factual harvesting conditions, with the ideal conditions obtaining higher energy generation of 2.45 kWh/KWp/day compared with 2.01 KWh/KWp/day of the factual condition. Inversely, an increase in the collection losses increases with the decrease in energy production in the factual condition relative to the ideal BAPV harvesting setting, with 1.08 KWh/KWp/day for the ideal condition and 1.55 KWh/KWp/day for the factual condition. This energy production fluctuation difference can be ascribed to the shading occurrence in the factual settings. On the other hand, the system loss roughly maintains its stature in both conditions signifying that the difference in the energy collection capacity is influenced by other factors such as the shading effect. The variations in the monthly energy generation reflected on the overall yearly power harvesting capacity obtaining an overall energy injected into the grid of 223.78 KWh/year on ideal conditions and 182.96 for factual setting accounting for a ~42% decrease in energy generation. Analogously the performance ratio (PR) demonstrated the same discrepancy between the ideal and factual settings, obtaining 0.647 and 0.582 respectively in reference to Equation (1) [2].

$$\mathrm{PR} = Y_f / Y_r \tag{1}$$

Considering the building dominion landscape in Seoul to provide high-density utilization per square foot of land. Having ~646,891 buildings in a 605.2 Km^2 land area in 2012 according to KOSIS survey [9]. The results demonstrate the influence of the structural elements of the utilization of BAPV. Considering the two major energy losses which are collection loss and system loss. As discussed, the system losses are consistent which is highly influenced by the mechanical attribute of the PV system. Moreover, the massive energy harvesting loss can be associated with an inevitable system limitation of the shading effect of the different bodies in the area casting shadows in the BAPV thereby limiting its access to solar irradiation.

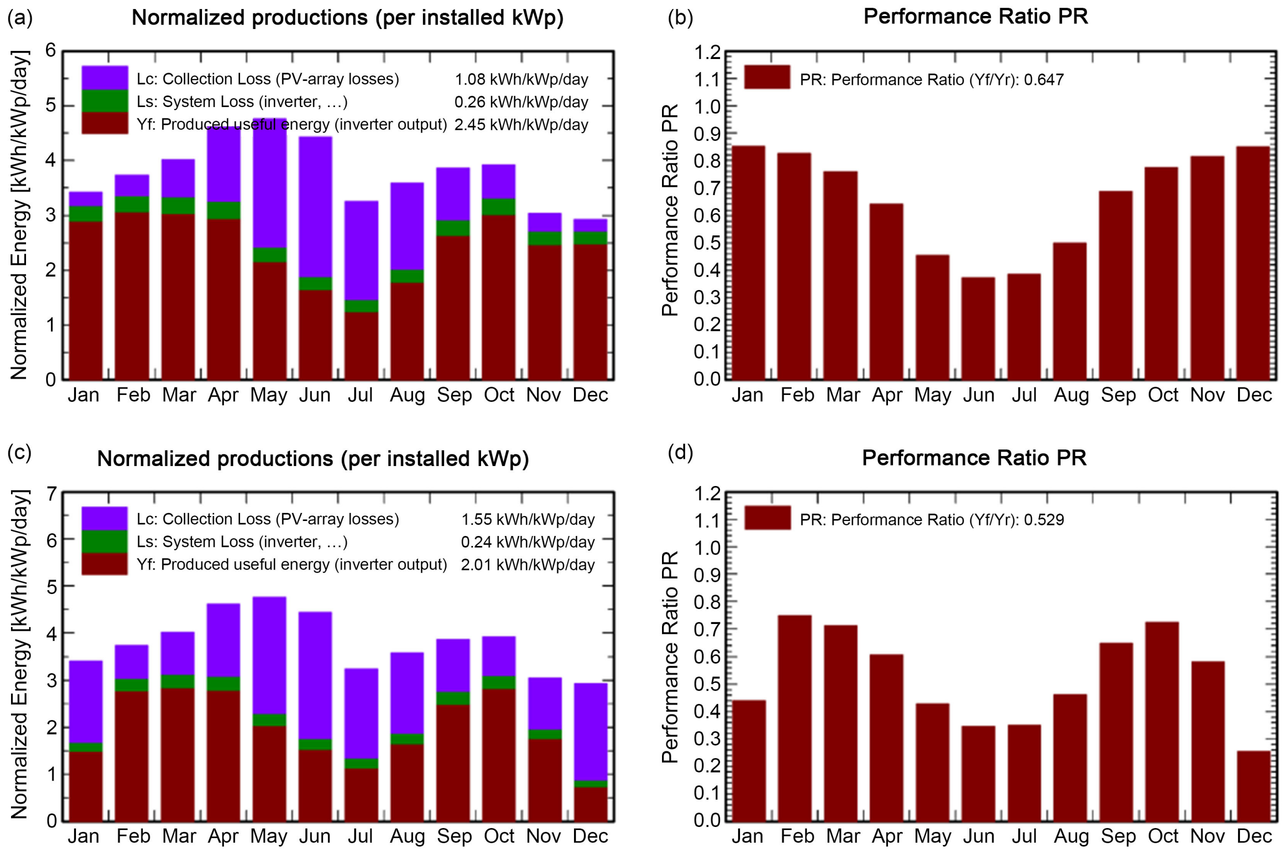

Figure 2. (a, c) Ideal and (b, d) factual condition's normalized energy production and performance ratio.

Table 1. Normalized performance coefficients of BAPV ideal system yielded in Seoul simulation.

	Glob Hor kWh/m²	Diff Hor kWh/m²	T_Amb °C	Glob Inc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	63.7	34.36	−2.7	105.8	102.2	24.67	22.55	0.852
February	77.9	47.52	0.09	104.3	97.8	23.49	21.52	0.825
March	109	67.13	5.67	124.3	109.9	25.84	23.49	0.759
April	130.1	77.94	11.95	138.4	105.5	24.41	22.13	0.64
May	145.6	89.36	17.83	147.5	82.4	18.5	16.84	0.455
June	132.2	89.49	21.86	132.8	63.1	13.77	12.04	0.386
July	101	84.43	25.27	100.6	51.4	11.4	9.72	0.386
August	109.6	82.57	25.97	111	71	15.69	13.85	0.606
September	105.9	77.42	21.97	115.7	94.1	18.03	15.2	0.64
October	76.5	55.26	14.78	121.4	101.8	25.71	20.43	0.774
November	62.3	37.52	7.07	91.4	87.7	21.04	18.59	0.814
December	55.3	24.06	−0.3	90.9	87.7	21.14	19.3	0.804
Year	1188.1	761.03	12.44	1384.3	1068	247.8	223.78	0.647

Table 2. Normalized performance coefficients of BAPV factual system yielded in Seoul simulation.

	Glob Hor kWh/m²	Diff Hor kWh/m²	T_Amb ˚C	Glob Inc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	63.7	34.36	−2.7	105.8	54.2	13.07	11.63	0.44
February	77.9	47.52	0.09	104.3	63.3	15.54	13.89	0.499
March	109	67.13	5.67	124.3	100.3	23.12	20.62	0.711
April	130.1	77.94	11.95	138.4	99.3	23.41	20.89	0.708
May	145.6	89.36	17.83	147.5	83.4	19.08	17.04	0.495
June	132.2	89.49	21.86	132.8	61.5	13.57	11.86	0.346
July	101	84.43	25.27	100.6	45.4	9.03	7.89	0.318
August	109.6	82.57	25.97	111	65.5	14.57	12.74	0.426
September	105.9	77.42	21.97	115.7	76.4	17.85	15.85	0.544
October	76.5	55.26	14.78	121.4	88.5	22.61	18.41	0.581
November	62.3	37.52	7.07	91.4	71.4	17.64	15.23	0.524
December	55.3	24.06	−0.3	90.9	66	14.23	13.08	0.525
Year	1188.1	761.03	12.44	1384.3	886.6	204.57	182.96	0.529

3.3. Analysis of the Overall Power Generation of BAPV

The efficiency of the BAPV system conditions in actual and factual conditions was compared by harnessing the maximum solar power generated towards the system energy accumulation [21]. The overall system energy consumption of the BAPV automatic system's components was summarized and shown in **Figure 3**, consisting of several key components: PV louvers, motors, sensors, system controllers, power supply, and a communication interface. Each component plays a critical role in the operation and efficiency of the BAPV system. With motors responsible for modifying the angular position of the BAPV. Sensors accumulate environmental information critical for operational management such as solar intensity, temperature and probably wind speed. The energy consumption of parts was collected to obtain the overall energy generation of the BAPV system. The motor energy consumption was estimated in the BAPV with the listed specification of 8 channels enabled, operating frequency from 100 Hz to 10 kHz in a louver is 1KWh, considering total run time for 0.4 KWh/day (146 KWh/yr). The energy consumption of the sensors on the other hand was obtained assuming the solar position sensation was applied, with a relative specification of 2 mA at 3.3V is approximately ~0.1861 W/h, deeming an 8h run time per day reaching an energy consumption of 1.08 KWh/yr for two sensors. Moreover, the control system energy consumption was estimated at 244 Wh for actuators for a run time of 10 min/day (14.86 KWh/yr) considering its different components such as the microcontroller, LCD, communication interface, communication interfaces, actuators output and volume regulation. Another part of the control system is the control base power 5W for an 8 h runt time obtaining 14.6 KWh/yr. Accumulation of the total control system energy consumption 29.46 KWh/yr [7]. A summary of the typical power consumption of BAPV louver automatic system components is presented in Table 3. Calculating the overall power consumption of an automatic BAPV considering the energy requirements of its different components where the ideal condition obtaining an overall BAPV system power generation is presented in Table 4. It should also be noted that this power consumption calculation may vary based on various factors such as efficiency improvements, backup power and differences in the component configuration. It can be realized that a massive decline in the overall power generation is observed in the factual scenario due to the shading occurrence caused by surrounding buildings. Considering that this simulation was set to account for the maximum probable energy harvesting, it is safe to say that there's a chance that the BAPV will not produce power but rather consume it to maintain its operation if it were installed in the wrong location. The results suggest that the environmental topography should be thoroughly scrutinized before BAPV installation. This also gives us an understanding of how BAPV will perform in a building-packed location like Seoul. Additionally, these findings drove us to consider any energy-saving feature to decrease the overall BAPV louver system power consumption [22].

Table 3. BAPV louver automatic system typical components.

BAPV system component	Power consumption (KWh/yr)
Motors	146.00
Sensors	1.08
Control System	
-Actuators	29.46
-Control base power	
Total	176.54

Table 4. Overall BAPV louver automatic system power generation.

BAPV system component	Power consumption (KWh/yr)	Component power consumption (KWhh/yr)	Overall system power generation (KWh/yr)
Ideal condition	223.78	176.54	47.24
Factual condition	182.96	176.54	6.42

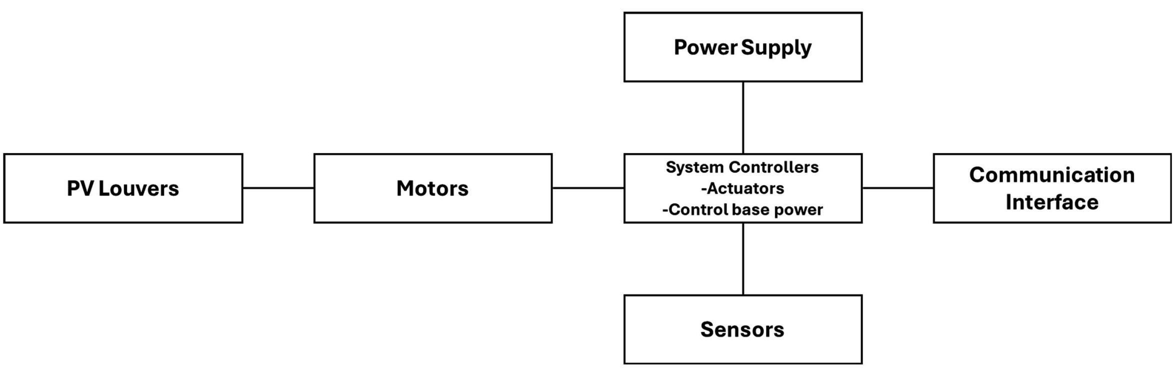

Figure 3. PV louver automatic system typical components.

4. Conclusion

This study sought to configure the ideal and factual performance of the BAPV using PVsyst software to consider the shadowing effect of the surrounding buildings. Seoul was chosen to be the location setting given its high building density which is ideal for the observation of the shadowing effect. The results were thoroughly scrutinized to determine the economic feasibility of BAPV on the utilization of solar energy on a louver exterior media. The findings also strengthened the hypothesis that progressive simulation tools can be applied to standardize feasibility surveys on the installation of BAPV using PVsyst software. The organized BAPV simulation affirmed the importance and effect of the location-building topography on the solar energy harvesting capability. These results can be set as a basis for BAPV building feasibility. The assessment not only validated the BAPV environmental setting dependency but also cleared the tradeoffs that impact the power generation capability.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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