AKSEN: Journal of Creative Industry, 8(2)
April 2024, 47-55 AKSEN
DOI : 10.37715/aksen.v8i2.4666

P-ISSN : 2477-2593
E-ISSN : 2477 -2607

FAÇADE INTEGRATED PHOTOVOLTAIC AS NET-ZERO ENERGY BUILDING : COMPARISON OF SIMULATED AND MEASURED RESULTS

Susan Susan
Architecture Department, School of Creative Industry,
Universitas Ciputra, Surabaya, Indonesia
alamat email untuk surat menyurat : susan@ciputra.ac.id

Received : March 2nd, 2024/ **Revised :** March 26th, 2024 / Accepted : April 2nd, 2024

How to Cite : Susan (2024). Façade Integrated Photovoltaic as Net-Zero Energy Building Strategy: Comparison of simulated and measured results. AKSEN : Journal of Design and Creative Industry, 8 (2), halaman 47-55. https://doi.org/10.37715/aksen.v8i2.4666

ABSTRACT

Building integrated photovoltaic is considered as one of many potential strategies towards net zero energy building. The implementation potentials are found both on building's horizontal and vertical envelope. For tropical area, it is known that solar incidence on a vertical plane is relatively lower than the one on a horizontal plane. However, potential of BIPV implementation can be found in high-rise buildings where huge façade areas are available for PV integration. To predict the energy generated by PV, many studies have already used a simulation method. Hence, the simulated result should be compared with the one recorded in real condition. This study aims to present the potential of façade integrated photovoltaic in tropical building area. A specified model is developed and used to calculate data of energy production based on the irradiance data generated by simulation and experiment. The results indicate the potential of PV's vertical installation for buildings in tropical area. In the specified model, the percentages of energy substitution reach 31.04% to 35.65%, exceed the mix-used energy target set by Indonesian Government. Simultaneously, this result indicates significant reduction of building's energy consumption and global emission that is derived from the use of non-renewable energy source. Hence, it can be considered as one potential strategy towards Net-zero energy building. Furthermore, the comparison of simulated results and measured results that less than 30% indicates that simulation using certain software can be considered as a powerful tool to design strategies towards net-zero energy building.

***Keywords:** façade-integrated photovoltaic, net-zero, measured results, simulated results.*

ABSTRAK

Panel surya yang terintegrasi dengan bangunan diasumsikan sebagai salah satu dari banyak strategi yang potensial menuju terciptanya bangunan dengan konsep *net-zero energy*. Potensi integrasi PV ditemukan baik pada implementasinya di bagian-bagian selubung bangunan yang horisontal maupun yang vertikal. Untuk area tropis, diketahui bahwa radiasi matahari yang diterima oleh bidang vertikal relatif lebih rendah daripada bidang horisontal. Namun demikian, bangunan-bangunan bertingkat tinggi dengan area dinding yang luas berpotensi untuk integrasi panel surya secara vertikal. Penelitian terdahulu banyak menggunakan simulasi untuk memprediksi jumlah energi yang dihasilkan panel surya. Untuk validasi, hasil simulasi tersebut perlu dibandingkan dengan hasil pencatatan daya luaran pada kondisi sebenarnya di lapangan. Studi ini bertujuan untuk mencari kelayakan potensi integrasi panel surya pada dinding bangunan di daerah tropis. Sebuah model digunakan untuk menghitung jumlah produksi energi berdasarkan data penerimaan radiasi matahari yang dihasilkan oleh simulasi dan eksperimen. Hasil studi menunjukkan potensi instalasi panel surya secara vertikal di area tropis. Pada model yang dikaji, persentase substitusi energi yang dihasilkan panel surya terhadap indeks kebutuhan energi mencapai 31.04% hingga 35.65%, melampaui target bauran energi yang ditetapkan oleh Pemerintah Indonesia. Hasil ini mengindikasikan berkurangnya konsumsi energi dan emisi global yang berasal dari penggunaan energi tak terbarukan. Instalasi panel surya secara vertikal pada dinding bangunan dapat dipertimbangkan sebagai salah satu strategi yang potensial menuju terciptanya bangunan *net-zero energy*. Lebih lanjut, perbandingan antara hasil simulasi dan hasil pengukuran lapangan dengan perbedaan kurang dari 30% mengindikasikan bahwa simulasi dengan perangkat lunak tertentu dapat dianggap sebagai alat yang baik dalam perencanaan strategi desain menuju bangunan *net-zero energy*.

Kata Kunci: dinding terintegrasi panel surya, net-zero, hasil pengukuran lapangan, hasil simulasi.

INTRODUCTION

Buildings are accounted for more than 30% of world energy consumption and contribute to almost 15% of world global emission ("World Energy Outlook 2022," n.d.). Awareness on buildings concepts that could overcome this issue are significantly raised. Related to this, the concept of net-zero energy buildings has frequently discussed in recent years. In many developed countries, the concept has becoming part of their energy policies (Liang, Bian, and Dong 2023; Sartori, Napolitano, and Voss 2012). Meanwhile, for several developing countries, a specified target has been defined towards net zero energy building. Indonesia as one of many developing countries has also issued the mix-used energy program that targeted on 23-31% substitution of its conventional energy by the renewable energy ("ENERGI INDONESIA 2019 SEKRETARIAT JENDERAL DEWAN ENERGI NASIONAL" 2019). All sectors are encouraged by this program to start switching their energy source into the renewable ones. Hence, in Indonesia, the availability of solar energy measured to be one of the largest among other resources. The potential reaches 207.8 GWp.

Aside of reducing the operational energy needs, net zero energy building put an effort to support the remaining portion of energy needs by renewable energy technologies. The use of on-site renewable energy such as in building integrated photovoltaic (BIPV) gives additional advantage, particularly in minimizing the loss of energy caused by distribution process. In this concept, photovoltaic (PV) is integrated to the building envelope. It can be installed on the horizontal envelope (roof, horizontal shading device) and or the vertical envelope (wall, vertical shading device, balcony railings). In the tropics, integrating PV on the horizontal envelope seems to be more advantageous due to its high amount of solar irradiation received. However, implementation on façade, in certain building typology, should also be considered. Particularly on mid to high-rise building typology where the huge area of façade can compensate the decreasing power due to un-optimum supply of solar radiation. Many of previous studies have already been conducted using a simulation method. Those studies indicated a positive result. Simulation of BIPV on south-oriented model found that PV contributes significance amount of annual energy yield as well as provides better visual comfort (Cannavale et al. 2017). Simulated result on semi-transparent BIPV window and daylight-dimming systems in hot and humid climate found its potential to generate electric power, reduce the cooling load, give larger annual lighting energy savings, particularly when it is integrated on specified orientation (Do et al. 2017). Zero energy potential of a high-rise office building was found also on a simulation study, in a Mediterranean climate (Giouri, Tenpierik, and Turrin 2020). Advantage on energy, environmental, and financial impacts were found on a study that do simulation for various TPV technologies in office building, in Europe (Pulli, Rozzi, and Bella 2020).

Previous studies described above are conducted using a simulation method, mostly in mid to high-latitude area. Strengthen by the facts of solar energy potential and the availability of vertical building envelope in multi-story buildings, this study therefore presents a study of façade integrated photovoltaic (FIPV) in the tropics. The study aims to present the potential, particularly when PV is integrated on the vertical building envelope. Experimental investigation is used and further simulation together with mathematical calculation is conducted. The simulated results are compared to measured results to complete the study.

METHOD

Site Selection

Climate and site selection are important constraints when a building want to apply BIPV concept (Wijeratne et al. 2019). Buildings located in tropical climate can use its solar energy potential to generate electricity through PV technology. However, the solar irradiance could also influence the PV temperature and decrease the power output (Amelia et al. 2016). Previous study found that in a real condition, the PV temperature can increase up to 20°C. Hence, the site selection should be carefully considered. Buildings that located in a site that free from surrounding obstruction is preferable to guarantee the solar access to the PV module (Xiong et al. 2022). Surabaya is the second big city in Indonesia. It is located in 7.9-7.21S and 112.36-112.54E. The geographical location itself indicates the availability of solar radiation and therefore it is chosen as the location of the study.

The potential area of building envelope may also be the constraint of site selection. An optimum proportion of opaque and transparent material on building façade will determine the availability area of PV to be installed as the wall cladding. Due to heat gain and cooling load considerations, buildings in the tropics are suggested to have 20%-40% window-to-wall ratio (Gupta and Deb 2023; Pathirana, Rodrigo, and Halwatura 2019).

A model of a room sized 18m x 12m x 4m with 30% window-to-wall ratio will be used as the experiment and simulation context. The room will be associated to a very efficient building with an EUI ranges in 4.17-7.92 kWh/m^2/month or 50.04-95.04 kWh/m^2/year ("Pedoman Pelaksanaan Konservasi Energi Dan Pengawasan Di Lingkungan Departemen Pendidikan Nasional" 2006). Within this range, the EUI for the studied model is calculated around 10808.64-20528.64 kWh/year.

Comparative Study

This study is conducted to address the potential of façade integrated photovoltaic in tropical buildings. Study on measured-results are compared to simulated-results to address the objective.

The Measurement

Monocrystalline silicon is known as the type of PV with the highest efficacy and therefore is selected in this study. The detailed parameters of the PV which is provided by the manufacturer are shown in Figure 1 and Table 1.

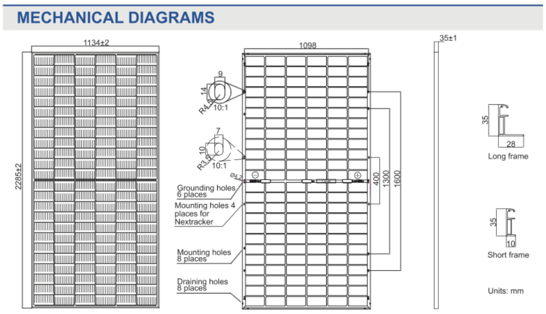

Figure 1. PV Mechanical Diagrams
Source : personal documentation, 2024

Table 1. PV Specifications

Cell	Mono
Weight	31.6kg±3%
Dimensions	2285±2mmx1134±2mmx35mm±1mm
No. of cells	144 (6x24)
Junction box	3 diodes
Front glass/ back glass	2.0mm/2.0mm
Efficiency	20.3%

The measurement is conducted on a prototype that is installed in Universitas Ciputra Surabaya, Indonesia.

Figure 2. Area of PV Installation
Source : personal documentation, 2024

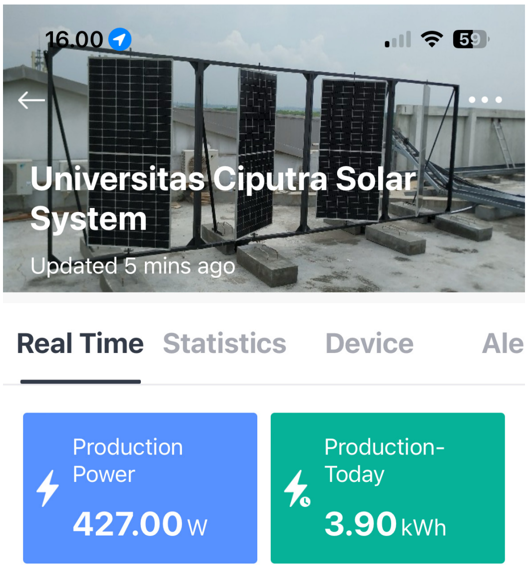

Figure 3. Recording system
Source : personal documentation, 2024

As shown in Figure 2, four modules of PV are located on the rooftop of the building and installed in vertical position to represent a vertical integration of PV to the building envelope. The PVs are oriented to south-east and south-west position, to give an optimum access to the highest nominal incident irradiance throughout the year (Ghazali et al. 2017). Real time data of production power is recorded using a system that is connected directly to the grid (Figure 3). This study used data that have been compiled for 12 months.

The Simulation

Following the setting for field measurement, monocrystalline silicon PV is used in the simulation. HelioScope is used to generate data of solar irradiance received. This software is chosen due to its ability to determine the average irradiance received, on an inclined plane, in certain orientation, by specified solar panel that can be selected on its manufacture's database. Additionally, data generated by HelioScope has also considered the system loss based on shading, reflection, soiling, irradiance, and temperature. Illustration of HelioScope data output is presented in Figure 7 and 8.

RESULTS AND DISCUSSION

Measured Results

The measured results on vertical installed PV have been recorded for 12 months (January – December 2023). The recorded data are presented in Figure 4. Total energy production for 12 months for four experimented vertical PV modules in 10.36m^2 area is measured at 1.34 MWh, which is equal to 129.34 kWh/m^2/year.

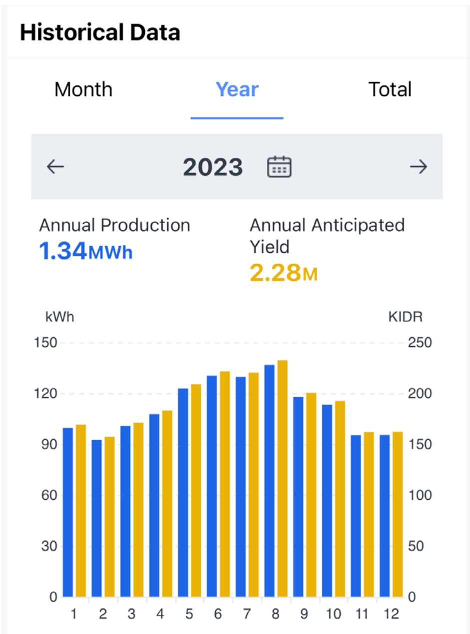

Figure 4. Recorded data for 12 months in 2023
Source : personal documentation, 2024

Simulated Results

HelioScope simulation is used to generate data of irradiance received, particularly for orientation that is set in 135° (Fig. 6) and 225° (Fig. 7).

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,782.1	
	POA Irradiance	810.7	-54.5%
	Shaded Irradiance	810.6	0.0%
	Irradiance after Reflection	766.3	-5.5%
	Irradiance after Soiling	751.0	-2.0%
	Total Collector Irradiance	**751.0**	**0.0%**

Figure 5. Data output for 135° orientation
Source : personal documentation, 2024

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,782.1	
	POA Irradiance	774.6	-56.5%
	Shaded Irradiance	774.5	0.0%
	Irradiance after Reflection	726.9	-6.1%
	Irradiance after Soiling	712.4	-2.0%
	Total Collector Irradiance	**712.4**	**0.0%**

Figure 6. Data output for 225° orientation
Source : personal documentation, 2024

The amount of irradiance received is then used to calculate the energy production (power output). The calculation which is presented in Table 2 is conducted following this formula.

PV_{eff} = output power / input power
or,
Output power = PV_{eff} x input power
where,
PV_{eff} = PV efficiency
Output power = energy generated by PV system
Input power = solar energy incident on the whole generator solar area over a certain period

Table 2. Calculation of power output

Ori	Irr. Rec. (kWh/ m²/year)	PV_{eff} (%)	Power output (kWh/m²/ year)
135°	751.0	20.3	152.45
225°	712.4	20.3	144.62

Potential of Vertical PV Installation

The measured result shows that in every square meter vertical PV installation, the annual power output generated is 129.34 kWh. Meanwhile, simulated result shows that in every square meter vertical PV installation, the annual power output generated is 152.45kWh and 144.62kWh, respectively for 135° and 225° orientation.

It is known that the simulation generates overestimated results and the differences between measured results and simulated results is calculated around 10.57% to 15.16%. ASHRAE Guideline 14-2014 explains that simulation result is acceptable when the accuracy of short-term performance of simulation to actual condition is less than 30% (American Society of Heating 2014).

To find the potential of vertical PV installation, the result of power output from simulation and measurement process is analyzed further using a model sized in 18m x 12m x 4m. The model illustration and detail are presented in Figure 8 and Table 3. PVs is set on south façade, as wall claddings, facing 135° and 225°.

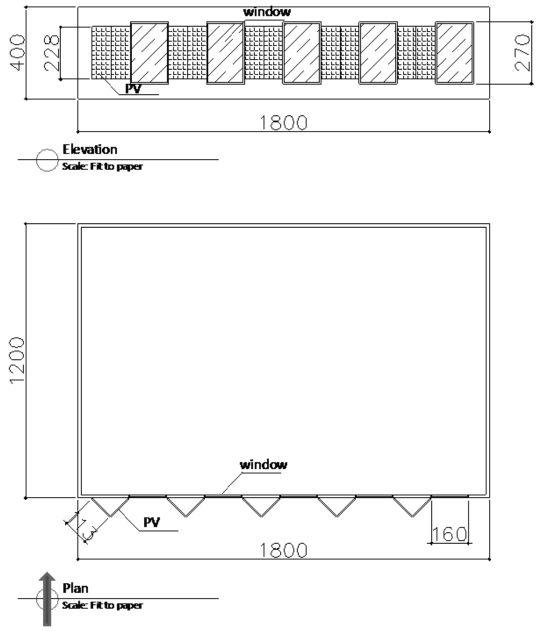

Figure 7. Model Ilustration
Source : personal documentation, 2024

Table 3. Model Detail

Length	18.00 m
Width	12.00 m
Height	4.00 m
Area	216 m²
WWR	30%
Window area	21.6 m² (5 x 1.6m x 2.7m)
PV area (135°)	12.97 m² (5 x 1.135m x 2.285m)
PV area (225°)	12.97 m² (5 x 1.135m x 2.285m)

The model is used to analyze the energy demands (needed by the room) and the energy production (generated by PVs). The energy demand, as calculated before, ranges around 10808.64-20528.64 kWh/year. Meanwhile, calculation of energy production is tabulated in Table 4.

Table 4. Calculation of Energy Production

Ori (°)	PV area (m^2)	Measured Result		Simulated Result	
		Irr (kWh/m²/year)	Power output (kWh/year)	Irr (kWh/m²/year)	Power output (kWh/year)
135	12.97	129.34	3355.08	152.45	1977.28
225	12.97			144.62	1875.72
Total power output			3355.08		3853.00

In this model, it is calculated that the PVs can generate electrical energy as much as 3355.08 kWh/year and 3853 kWh/year, respectively for measured and simulated results. When a very efficient building is set in the highest range of EUI, the PVs could only supply 16.34% to 18.77% of energy demand. Meanwhile, when the building is set in the lowest range of EUI, the PVs could supply 31.04% to 35.65% building's energy demand.

CONCLUSION

To response to issues of world energy consumption as well as global emission, buildings nowadays are designed with a concept of net zero energy. Two approaches that can be used here are minimizing the building energy consumption and switching building's energy sources into the renewable ones. Related to the first approach, a very efficient building is indicated with an EUI between 4.17-7.92 kWh/m^2/month or 50.04-95.04 kWh/m^2/year. Furthermore, PVs in terms of BIPV is associated with a potential microgeneration technology that comply to the second approach.

In the tropical area, it is known that the solar incidence on a vertical plane is relatively lower than the one on horizontal plane. However, potential is found in certain high-rise buildings with huge façade area. This study is conducted to present the potential of façade integrated photovoltaic in tropical buildings.

Study on a specified model shows that PVs which are installed vertically as wall claddings on a building envelope could supply significant amount of building's energy demand. When the model set in lowest rate of EUI, the integrated vertical PVs could supply 31.04% to 35.65% energy needed by the building. This number exceed the 23%-31% mix-used energy target set by Indonesian Government. This result indicates the potential of façade integrated photovoltaic to be implemented in tropical buildings.

Furthermore, this finding is derived from the comparison of simulated results and measured results. The difference captured in the comparison ranges between 10.57% to 15.16%. Based on the accuracy percentages determined by ASHRAE, this value can be considered acceptable since the difference is measured lower than 30%. The result indicates that simulation can be useful as a tool to design strategies towards net zero energy building.

ACKNOWLEDGMENT

- The study is funded by Lembaga Penelitian dan Pengabdian Masyarakat, Universitas Ciputra Surabaya, grant number 005/UC-LPPM/DIP/SP3H/IX/2023.

- Prototype of vertical PV was funded by Departemen Pendidikan Tinggi Indonesia under the grant scheme of Kedaireka – Matching Fund 2023.
- The study is supported by Aurora Solar Inc., who provide access to HelioScope cloud-based software, for an academic purposes.

REFERENCES

Amelia, A R, Y M Irwan, W Z Leow, Irwanto #1, I Safwati, and M Zhafarina. 2016. "Investigation of the Effect Temperature on Photovoltaic (PV) Panel Output Performance" 6 (5).

American Society of Heating, Refrigerating and Air Conditioning Engineers (Atlanta, Georgia). 2014. Ashrae Guideline 14-2014: Measurement of Energy, Demand and Water Savings. Vol. 14. Atlanta, Georgia: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2014.

Cannavale, Alessandro, Maximilian Hörantner, Giles E. Eperon, Henry J. Snaith, Francesco Fiorito, Ubaldo Ayr, and Francesco Martellotta. 2017. "Building Integration of Semitransparent Perovskite-Based Solar Cells: Energy Performance and Visual Comfort Assessment." Applied Energy 194: 94–107. https://doi.org/10.1016/j.apenergy.2017.03.011.

Do, Sung Lok, Minjae Shin, Juan Carlos Baltazar, and Jonghun Kim. 2017. "Energy Benefits from Semi-Transparent BIPV Window and Daylight-Dimming Systems for IECC Code-Compliance Residential Buildings in Hot and Humid Climates." Solar Energy 155: 291–303. https://doi.org/10.1016/j.solener.2017.06.039.

"ENERGI INDONESIA 2019 SEKRETARIAT JENDERAL DEWAN ENERGI NASIONAL." 2019. https://www.esdm.go.id/assets/media/content/content-indonesia-energy-outlook-2019-english-version.pdf.

Ghazali, Azhar, Elias @.Ilias Salleh, Lim Chin Haw, Sohif Mat, and Kamaruzzaman Sopian. 2017. "Performance and Financial Evaluation of Various Photovoltaic Vertical Facades on High-Rise Building in Malaysia." Energy and Buildings 134 (January): 306–18. https://doi.org/10.1016/j.enbuild.2016.11.003.

Giouri, Evangelia Despoina, Martin Tenpierik, and Michela Turrin. 2020. "Zero Energy Potential of a High-Rise Office Building in a Mediterranean Climate: Using Multi-Objective Optimization to Understand the Impact of Design Decisions towards Zero-Energy High-Rise Buildings." Energy and Buildings 209 (February). https://doi.org/10.1016/j.enbuild.2019.109666.

Gupta, V., and C. Deb. 2023. "Envelope Design for Low-Energy Buildings in the Tropics: A Review." Renewable and Sustainable

Energy Reviews. Elsevier Ltd. https://doi.org/10.1016/j.rser.2023.113650.

Liang, Hanwei, Xin Bian, and Liang Dong. 2023. "Towards Net Zero Carbon Buildings: Accounting the Building Embodied Carbon and Life Cycle-Based Policy Design for Greater Bay Area, China." Geoscience Frontiers. https://doi.org/10.1016/j.gsf.2023.101760.

Pathirana, Shakila, Asanka Rodrigo, and Rangika Halwatura. 2019. "Effect of Building Shape, Orientation, Window to Wall Ratios and Zones on Energy Efficiency and Thermal Comfort of Naturally Ventilated Houses in Tropical Climate." International Journal of Energy and Environmental Engineering 10 (1): 107–20. https://doi.org/10.1007/s40095-018-0295-3.

"Pedoman Pelaksanaan Konservasi Energi Dan Pengawasan Di Lingkungan Departemen Pendidikan Nasional." 2006. Jakarta.

Pulli, Emilio, Elena Rozzi, and Federico Bella. 2020. "Transparent Photovoltaic Technologies: Current Trends towards Upscaling." Energy Conversion and Management. Elsevier Ltd. https://doi.org/10.1016/j.enconman.2020.112982.

Sartori, Igor, Assunta Napolitano, and Karsten Voss. 2012. "Net Zero Energy Buildings: A Consistent Definition Framework." Energy and Buildings 48 (May): 220–32. https://doi.org/10.1016/j.enbuild.2012.01.032.

Wijeratne, W. M.Pabasara U., Rebecca J. Yang, Eric Too, and Ron Wakefield. 2019. "Design and Development of Distributed Solar PV Systems: Do the Current Tools Work?" Sustainable Cities and Society. Elsevier Ltd. https://doi.org/10.1016/j.scs.2018.11.035.

"World Energy Outlook 2022." n.d. www.iea.org/t&c/.

Xiong, Wei, Zhongbing Liu, Zhenghong Wu, Jing Wu, Fanghan Su, and Ling Zhang. 2022. "Investigation of the Effect of Inter-Building Effect on the Performance of Semi-Transparent PV Glazing System." Energy 245 (April). https://doi.org/10.1016/j.energy.2022.123160.