Photovoltaics and the Built Environment in Brazil

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1 Introduction and Background

Brazil has a diverse electricity-generation matrix. Through November 2022, the installed capacity was ~190 GW, divided among 9000 power plants [1–4]. Brazil's electricity supply is based mainly upon renewable-energy resources. For decades, hydropower has been the main source of electrical power and through 2021 represented about 62% of total capacity [2]. Wind (12.5%) and bioenergy (7.2%) accounted for the next largest renewable energy contributions [1, 4]. At the end of 2021, installed photovoltaics (PV) exceeded 13 GW [5, 6]—and the growth in Brazil's cumulative PV is presented in Fig. 1. Though the 2021 PV capacity was only at 7.7% on the electrical power generation in the country (about 18-TWh in terms of the electricity generation), solar-PV electricity is the fastest growing of the renewable sources. Brazil stands as the 11th largest producer of solar electricity in the world [6]. In 2021, Brazil added 5.7 GW of PV to its electric-power system, ranking fifth in the world in installations that year and has been identified as among the top-10 emerging PV world markets [6]. The incredible growth of Brazil's solar PV is certainly indicated by the announcement that PV now surpassed the electric-power capacity of wind at the end of 2022 [1]. The Ministério de Minas Energia, Empresa de Pesquisa Energética—MME/EPE—"Brazil 2031 Ten-Year Energy

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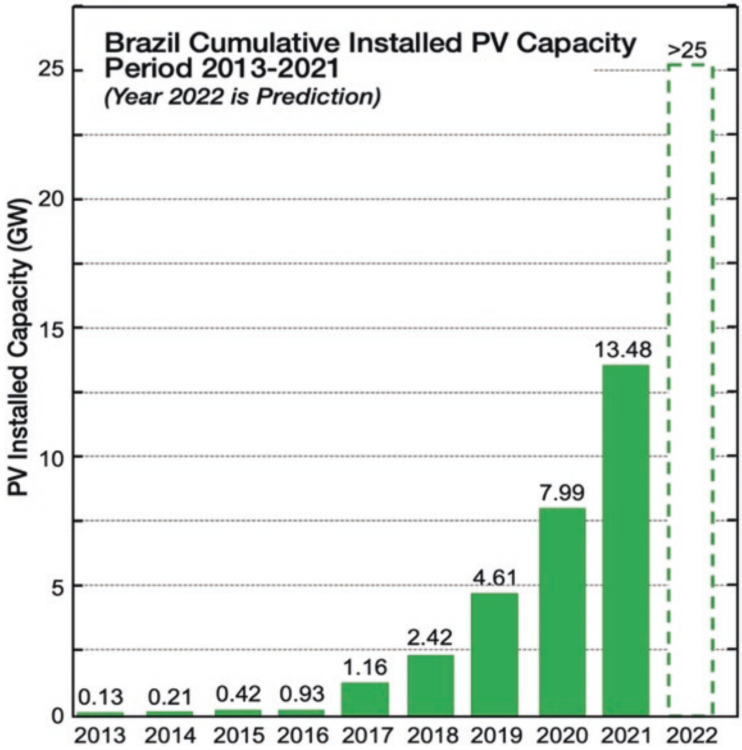

Fig. 1 Brazil's cumulative installed PV capacity over past decade. Brazil is on track to add 12 GW in 2022, leading to an installed capacity exceeding 25 GW. These data follow publications of Brazil's *Associação Brasileira de Energia Solar* (ABENS)l (http://www.abens.org.br). Brazil now is predicted to reach 54 GW by 2026

Expansion Plan" targets solar PV to exceed 67 TWh from distributed and centralized sources [7, 8]. It should be also expected that these targets will grow with the new government administration starting in 2023 and the mounting concerns for the environment and global climate change [8–10]. In general, PV will hold a significant portion of Brazil's energy sectors with contributions ranging from its current sizeable electric-power focus to expanding transportation and building segments that have vast potential [3, 4].

This chapter focuses on one sector of Brazil's growing investments in PV, that of the built environment. It is an area worldwide that PV has not yet played a substantial role, but the needs, state of development, and suitability of "buildings" make it a prime focus for growing investments to bring about a 100% renewable-electricity portfolio by mid-century [9, 10]. In particular, the dominance of hydropower in the Brazil electricity framework has highlighted some vulnerabilities. The onset of droughts has had effects on the operations of the hydro plant—leading to interruptions and equipment issues. The need for adequate power demand response opens the electricity suppliers to potentially rely more on fossil-fuel generation, building dependencies on non-renewable resources at the time the world is moving to combat climate change. This chapter highlights the evolution and recent growth of PV installations in Brazil and the potential for significant growth in the buildings sector. Certainly, the incredible decrease in PV module and system prices over the past decade makes this electricity source attractive for applications not thought to be competitive, such as air conditioning, cooking, hot water delivery, and even heating [11]. This new PV attention is also augmented by favorable policy and regulations, local meteorological and climate conditions, and economic and social considerations. The specific effects of government strategies are discussed, such as the Normative Resolution n° 482 published in 2012 by Brazilian Electricity Regulatory Agency (ANEEL) that regulated the net metering of photovoltaic and other renewable energy technologies classified as micro (≤75 kW) and mini (>75 kW and ≤ 1 MW) distributed generation (DG), the electricity auctions (started in 2014), and also the Incentive Program for Distributed Micro-Mini Generation [8]. The benefits of available commercial technology products are described and evaluated. Importantly, PV's growing impact and potential in the building sector is analyzed. The status, relative benefits, and trends of building-integrated and building-applied PV (BIPV and BAPV) are evaluated. Rooftop versus micro- and mini-grids are assessed for various social and building conditions—with some considerations of constraints for such PV systems in the Brazil Equatorial locations and various climate conditions. The effects of these aspects are compared with building applications and investments in other countries [11]. The potential and future for PV in the Brazil built-environment markets are considered and forecast. Special insight is also directed toward the coupling of innovation in the PV technologies and their special position in elevating the architectural and economic value and acceptance of solar PV in the buildings sector. Insights and projections for PV in the Brazil built environment are discussed relevant to worldwide prospects.

2 Brazil's Regulations and Policies

Often, the dominating considerations for PV deployment and innovations are the *technical* aspects. Certainly, component materials suitability/availability, device performance, reliability, and operating lifetime are essential to the viability of any electricity source. But of equal importance to the wide-ranging deployments are the policies and regulations that control and can incentivize and accelerate the adoption and use of energy resources. Table 1 summarizes some important regulations, laws, and policies that affected the adoption of PV in Brazil's electricity distributed-generation (DG) structure, including its built environment. A selection of these laws, programs, and regulations is discussed in this section in terms of their effects on the adoption of PV deployment and benefits to the buildings' markets.

During 2000–2020, Brazil's hydroelectric plants experienced a series of problems. Due to several long draught periods and a continuous increase in the demand for electricity, in 2002 this primary electricity source was forced to curtail services,

Table 1 Summary of selected laws and regulations that address DG and PV implementation in the Brazil electricity sector discussed in Sects. 2 and 6

Year	Law/Regulation/Policy	Ref.	Comments
2000/ (2016)	Law no. 9991/(law no. 13.280, amendment)	[19, 20]	Established that 1% of the annual net profit of the concessionaries and permissionaries be applied to R&D and energy-efficiency projects
2003	MME: Luz para Todos	[21, 22]	Implements electricity “universalization” in rural areas, where >80% of the people live without electricity. Includes: (1) extension of the distribution grid, (2) autonomous off-grid, isolated electricity generation using micro-grids, and (3) individual (stand-alone) electricity systems
2004	ANEEL resolution 012/2004	[22]	Provides for the use of individual decentralized energy systems, including PV systems in homes: Includes mini- and micro-hydro power plants, biomass, thermal, PV, wind energy, and hybrids
2004	Brazil law 10,848/2004	[15]	To increase the country’s energy security, to promote diversification of the national electrical mix, to promote energy efficiency measures, and to foster universal access to electricity
2004	CEPEL led: Brazil-US program of assistance for rural development in Brazil	[23, 24]	Evaluated the feasibility of different PV technologies in Ceará, Pernambuco, and Minas Gerais (CEPEL and U.S. DOE)
	PRODEEM: Energy program for small communities (includes*: Luz Solar & luz no saber (*Minas Gerais)	[25]	Provided objective for electricity to 90% of all rural households by 2008
2020	Decree no. 93570	[25, 26]	Extended electricity universalization target to 2022
2011	ANEEL strategic call for R&D no. 13	[23]	Supported technical and commercial arrangements for solar-PV generation, aimed at integrating PV in the Brazilian electrical power matrix. This call mobilized partnership between universities and 17 electric utilities
2012	ANEEL normative 482/2012	[27]	Introduced: (1) net metering compensation scheme for micro- (≤75 kW) and mini- (>75 kW and ≤ 1 MW) DG and qualified co-generation from renewable sources (solar); (2) electricity auctions (started in 2014); and (3) the incentive program for DG
2015	ANEEL resolution 687/2015	[29]	Changes to norm. 482/2012: (1) improved registration process for new PV-DG systems; (2) electricity credits validation expanded from 36 months to 60 months; and (3) A new power range for micro-generation (up to 75 kW) and mini-generation (above 75 kW and below 5 MW). But complicated solar PV in poor urban areas

(continued)

Table 1 (continued)

Year	Law/Regulation/Policy	Ref.	Comments
2017	ANEEL resolution 786/2017	[22, 23]	(1) installed power limit for microgeneration from water sources increased; (2) projects previously classified as commercial or utility committed, no longer classified as DG
2022	Brazil law no 14,300	[82]	Facilitated formation of cooperatives mandated distributors/developers to invest in low-income areas (e.g., favelas)

and customers were subject to strict electricity rationing measures [12, 13]. Additionally, social and environmental concerns limited the building of more hydroelectric dams [14]. To mitigate this serious problem, Brazil's electric-power sector was reformed through Brazil Law 10,848/2004 [15] in 2004 to increase the country's energy security, to promote the diversification of the national electrical matrix, to advocate energy efficiency measures, and to foster universal access to electricity. This legal framework also created the energy auctions, one of the primary policy instruments for diversifying its energy sector and increasing Brazil's renewable-power supply [16, 17].

The Brazil National Energy Efficiency Program has been very important for the research and development of renewable technologies [18]. ANEEL Law No. 9991 (July 2000) [19] and amending Law No. 13,280 (May 2016) [20] established that 1% of the annual net profit of the utilities, *concessionaries* (electric companies that only provide distribution), and *permissionaries* (locally owned concessionaries) must be applied to R&D and energy efficiency projects and related government funds (e.g., energy research fund, called CT-ENERG). Solar-thermal water heating has been strongly supported by the energy-efficiency program as a demand-side management technology to reduce the peak-hour demand (caused by electrical showers). Most concessionaries mandated that electrically heated showers be replaced by solar collector systems. The requirement to invest in R&D projects also provided wider support for solar thermal electrical generation, PV grid connections—and investments in solar buildings, including improved materials, insulation, and smart windows.

In 2003, Brazil's federal government (Ministry of Mines and Energy-MME) established the prominent National Program of Electric Energy Universalization for All (*Programa Luz para Todos*–Light for All Program) [21]. It implements electricity universalization in rural areas, where at that time, around 80% of the people lived without electricity. The objective is to benefit the rural isolated communities that have no access to electricity from the utility. One main feature is to ensure that low-income families would not be charged to grid extension costs [21]. Most of those benefiting from this program live long distances from the existing electricity-grid. The program prioritizes houses of low-income families, rural schools, "quilombolas"—the indigenous people, settlements, riverside dwellers, small farmers, families in extractive reserves affected by undertakings in the electricity sector, rural schools, and community water wells. Based on several successful renewable-energy projects, the *Luz para Todos* program set up 3 alternatives for electricity supplies to rural areas: (1) Extension of the distribution grid to rural homes, (2) Autonomous off-grid electricity generation (isolated) using micro-grid to rural villages, and (3) Individual (stand-alone) electricity supplies.

The Brazilian electric-energy regulation agency (ANEEL) introduced its first resolution (Res. 012/2004) to provide for the use of individual decentralized-energy systems, including PV home systems (stand-alone) [22] This framework supports technologies such as mini- and micro-hydro power plants, biomass, thermal, PV, and wind energy. Hybrid systems that encompass two or more of these technologies are included. The relative competitiveness of the different technologies for a rural-electricity supply depends on the local climatic and geographic conditions, as well as the electricity consumption density (defined as kWh/km^2/month) of the area to be supplied. In general, the average price for electricity increases with declining consumption and length of the distribution grid. Among the autonomous, off-grid technologies, PV has been used in both hybrid stand-alone and micro-grid systems [21, 22].

Luz para Todos was the first official government program that specifically addressed PV in buildings. However, before its enactment, several other programs evaluated solar technology feasibility. The earlier pioneering experimental "Program of Assistance for Rural Development in Brazil" evaluated the feasibility of different PV technologies in Ceará, Pernambuco, and Minas Gerais, led by CEPEL (Electricity Research Centre) in Brazil and the U.S. Department of Energy (USDOE) with its National Renewable Energy Laboratory (NREL) [23, 24].

PRODEEM's "Energy Program for Small Communities" (Programa de Desenvolvimento Energético de Estados e Municipios), and various State programs such as *Luz Solar* (home electrification) and *Luz no Saber* (electrification of schools) in Minas [25] were specifically beneficial to building's solar-energy use. A typical rural household and rural PV-electrified school through the *Luz Solar* and the *Luz no Saber* programs are shown in Fig. 2a, b, respectively. These programs were

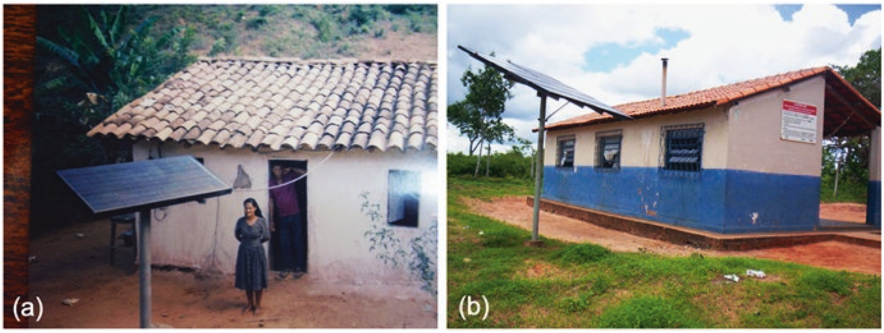

Fig. 2 Typical PV-electrified buildings through the (**a**) *Luz Solar* (single-family rural household); and (**b**) *Luz no Saber* programs (school). The PV was in these cases was not applied on the room in order to ensure security, structural integrity, and safety. Some homes did also have the PV systems roof-mounted if these three criteria were satisfied

established to provide electricity to 90% of all rural households by 2008. But the target date had to be extended by ANEEL Decree No. 93570 through 2022 because 300-thousand low-income rural families (especially in the North and Northeast) remained without electricity [25, 26].

Financing for renewable energy programs has been a barrier to solar deployment throughout the world. Several Brazil financing mechanisms for rural electrification have been enacted or extended from previous laws or initiatives under *Luz para Todos* [27]. Sectoral funds are available as grants from the Energy Development Account (CEE, Conta de Desenvovimento Energético), or as soft loans as part of the Global Reversion Reserve (RGR, Reserva Global de Reversão) [28] for concessionaries. Through 2021, 13-million households and more than 3-million consumer units located in rural regions in Brazil were served (again primarily in the North and Northeast) by the *Luz para Todos*. More than 6-thousand are PV stand-alone and 19 are PV mini-grid systems. Figure 3 shows one-representative household that was part of *Luz para Todos* [27].

The tipping point for grid-connected PV systems occurred in 2011 with the ANEEL "Strategic Call for R&D no. 13." This "Call" supported technical and commercial arrangements for solar-PV generation, aimed at integrating PV in the Brazilian electrical power matrix. The "Call" mobilized partnerships between universities and 17 electric utilities. These strategic projects analyzed the suitability of PV technologies for Brazil's electricity market, possible impacts on the electric-power system, and studies of the most suitable locations for the installation of solar plants considering solar irradiance levels [27]. In 2012, the Normative 482/2012 published by ANEEL was approved [27]. It introduced (1) the net metering scheme (compensation) in the country for micro- (≤75 kW) and mini- (>75 kW and ≤ 1 MW) distributed generation (DG) and qualified co-generation from renewable sources. It allowed the renewable energy system owner to feed excess PV electricity into the electrical grid and obtain energy credits (measured in kWh, non-monetary) that can be used during a 36-month period (2), Electricity auctions (started in 2014), and (3) the Incentive Program for Distributed Micro−/Mini Generation [41, 42]. This resolution was considered a noteworthy regulation mark for distributed generation of solar PV energy in Brazil [27].

Fig. 3 Example of PV household installation as part of *Luz para Todos* for home without access to electricity

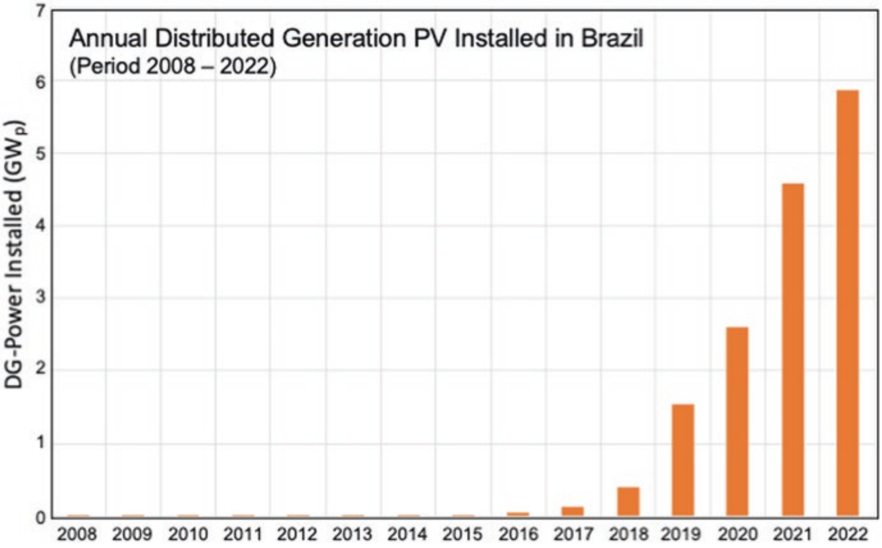

Fig. 4 Annual Distributed Generation (DG) PV-growth in Brazil as a function of time for the period 2007 to 2022

In 2015, a revision to ANEEL Normative 482/2012 led to resolution 687/2015. It enabled new PV-related businesses and promoted more flexibility for prosumers 29]. The main additions were: (1) Registration of new PV-DG systems was shortened from 82 days to 34 days, with the beneficial result of a more rapid approval process**;** (2) Electricity credit valid periods expanded from 36 months to 60 months (allowing more time for the consumer to use the credits); and (3) A new power range for micro-generation (up to 75 kW) and mini-generation (above 75 kW and below 5 MW) were defined (ANEEL, 2015) [29]. These changes in Brazilian net metering brought by Resolution 687/2015 were very beneficial to DG, responsible for the exponential growth of DG staring in 2014 (Fig. 4).

These policies, laws, and regulations, summarized in Table 1, evolved over the past two decades. In recent years, the laws have become more favorable to renewables and to PV in the built environment. Policy is critical to accelerating the use and acceptance of PV, whether as a plant or as a DG-electricity source on a residence connected to the grid.

3 Climate Conditions and Solar Resources

Climate is important for designing and use in the built environment. It not only affects the buildings' human comfort concerns, but for PV applications, it can significantly affect the power and related financial investments required. Brazil is the fifth largest country by area in the world, covering some 8.5 M km^2. As such, it has

Table 2 Climatic zones according to Köppen-Geiger and latitudes of occurrence [31]

Climate Zone	Latitude	
	North	South
Equatorial or tropical (A)	0° and 25°	0° and 25°
Arid and semi-arid (B)	30°	30°
Subtropical (C)	30° and 60°	30° and 60°
Snow (D)	60–70°	–
Polar (E)	70°	70°

a diversity of climatic zones due to its extensive territory, different landforms, and geographic location. Climate zones are defined by location, owing to the 1931-pioneering Köppen publication [30] that identified different "zones" according to latitude, as shown in Table 2. In this section, a high-level description of the climate diversity may complicate building design and PV incorporation in Brazil.

Brazil is predominately located between the Equator and the Tropic of Capricorn. Hot and humid conditions prevail throughout the territory, with higher temperatures close to the Equator as a result of the more intense solar irradiation received in this region. The Köppen-Geiger model shown in Fig. 5 divides Brazil into three climate groups, A, B, and C, which characterize equatorial climate (blue), semi-arid climate (orange/red), and warm temperate climate (green) [31]. These climate zones are further divided into subgroups according to precipitation rates and air temperature. All parameters are important for PV building requirements.

Figure 6 shows the typical weather-related conditions with the average temperature for the coldest month of the year, July, and the distribution of the annual average temperature [32]. Figure 7 presents the accumulated precipitation data for the month of July, the winter season in the southern hemisphere, and for the month of January, the summer season.

The comparisons of Figs. 6 and 7 show that even in the coldest month of the year, the North, part of the Midwest, Northeast, and Southeast regions have average temperatures above 18 °C. And in none of the months of the year, temperatures are less than this value. These climate characteristics of the regions include them in the large Group A, according to the climatic methodology of Köppen-Geiger [31]. The Group A zone is the largest geographical area, accounting for approximately 81% of the Brazilian territory. The main reason for climate group A to dominate the country climate is the lack of limiting factors of altitude, rainfall, and higher temperature in these areas [33]. Among the subgroups, the Aw climate zone is the most representative of the country, accounting for approximately 26% [33].

Part of the Northeast region is included in climate Group B, due to higher temperatures and low precipitation, indicating higher potential for droughts in the summer and winter periods. The climatic zone of Group B presents an annual average temperature greater than 22 °C and the annual accumulated precipitation can reach values lower than 800 mm. This group spread through the states of Bahia, Sergipe, Alagoas, Pernambuco, Ceará, Piauí, the coast of Rio Grande do Norte, and a small part of the territory of Paraiba.

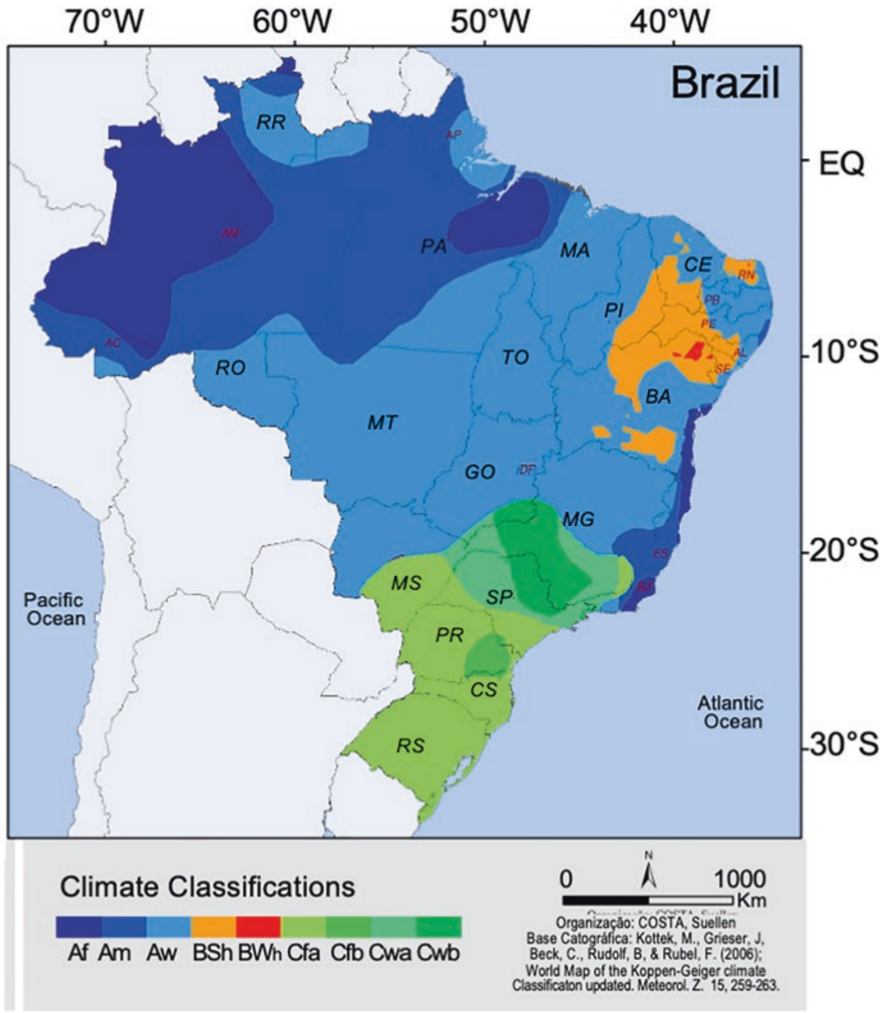

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Fig. 5 Köppen-Geiger climate classification for Brazil [31]

The South region and a small extension of the Southeast region of Brazil have average temperatures below 18 °C for the coldest month of the year and are classified in climate Group C. Group C covers ~13% of Brazil's territory. This is mainly in the southern regions of the country, typified by plateaus and mountains.

In summary, climate Groups A and B are distinguished by average annual temperature above 25 °C. Precipitation rates above 3000-mm represent sub-climates Af, Am, Cfa, and Cfb. Annual precipitation is higher in the north of the country, with rainfall and temperatures decreasing toward the south. Certainly, meteorological variables of temperature and solar and the regions in the semi-arid climate zone (B) have the highest levels of solar irradiance (above 2250 kWh/m^2), followed by

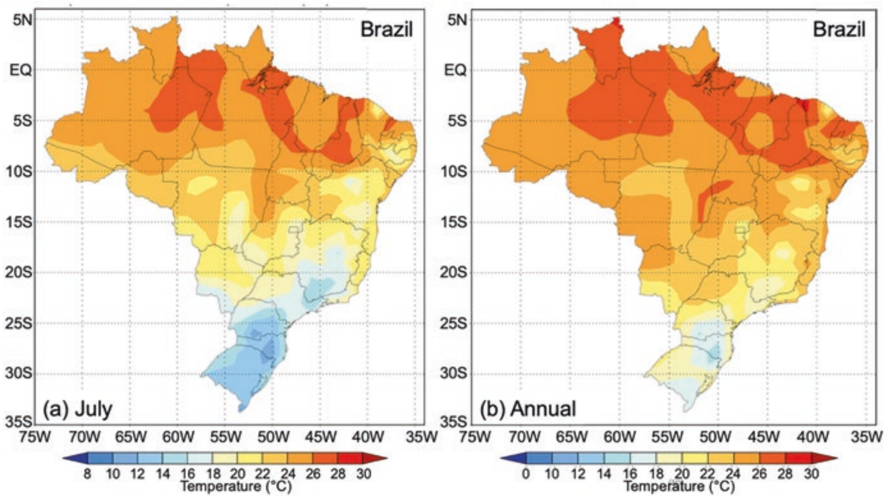

Fig. 6 Average temperatures for Brazil: (**a**) Average monthly temperature for the month of July (winter), and (**b**) Average annual temperature [32]

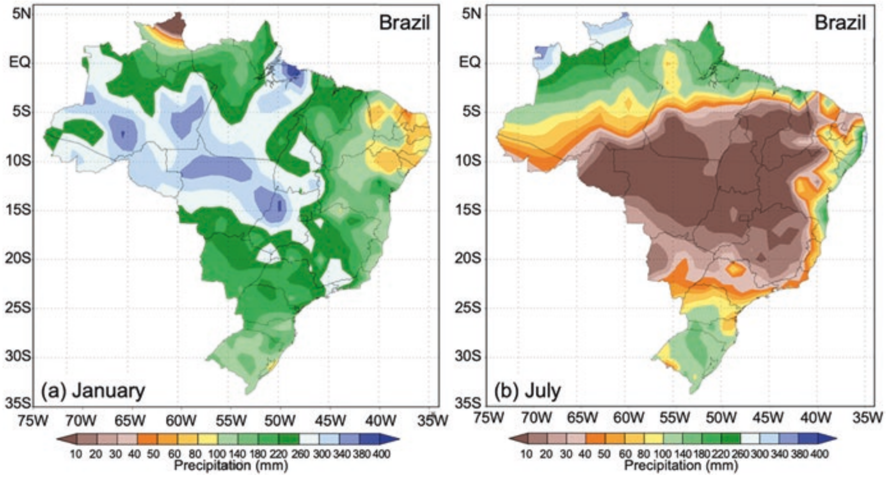

Fig. 7 Accumulated precipitation: (**a**) Month of January (Summer – rainy), and (**b**) July (Winter – dry) [32]

the Equatorial zone (A) with annual irradiance levels between 1750 and 2250 kWh/m^2 [34, 35]. The solar resource and corresponding PV-power maps of Fig. 8 certainly reinforce the fact that PV is an excellent electricity choice throughout Brazil.

As for the higher suitability of photovoltaic technology, the Northeast, the Southeast, and the Midwest regions are currently the primary areas for installations—despite higher temperatures that occur in some areas. Coastal areas in the South can have issues with humidity and clouds, which lower the PV

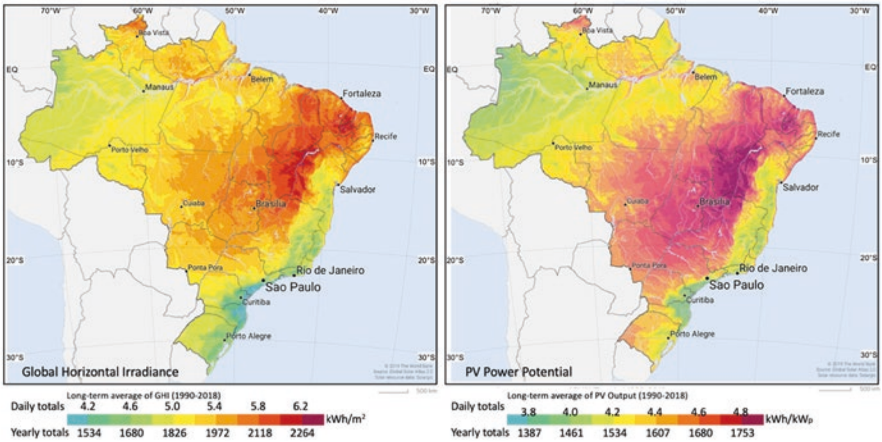

Fig. 8 Global horizontal irradiation (left) and photovoltaic power potential (right) for Brazil [34]

potential—though PV can still be a significant contributor to electricity generation. However, the major urban population centers provide viable solar resource locations for PV for the built environment.

4 PV and the Built Environment in Brazil: Applications and Relationships to Climate

“PV in the built environment” encompasses many facets for effective and cost-competitive utilizations. Urban areas are much different and more complex than suburban or rural localities. High-rise buildings impose different constraints than low-profile constructions such as single-family dwellings. Businesses usually have different energy and time-of-day requirements than family apartments or houses. Financial or income levels can impose limitations for solar adoption across the board. Consumer knowledge and understanding can be critical for confidence building and buy-in of new technology. And very important, the price and architectural value of PV in the built environment can be a tipping point for significant change to take place. *Most important* is that building-PV has to be coupled with building ***energy efficiency***. Energy efficiency is the most desirable, lowest cost, and biggest impact area in lowering the building’s energy consumption, related costs, and human comfort. And mandating building efficiency with PV use can exploit some aspects of PV technology beneficial for building energy conservation—as well as lowering the levels of building electricity needs for this somewhat capital-intensive technology component.

General Discussion of Building Considerations

Many aspects of building types, structure, design, use, and location are important for the effective use of PV for building electricity requirements. Of course, the climate and solar resource parameters have to be considered for system sizing as well as technology suitability. The considerations include the details of the surrounding structures that might limit the availability of solar irradiance. In this section, urban (most times high-density, high-rise types) and suburban/rural (lower density, lower profile) sectors are analyzed and discussed for PV suitability.

Shadowing caused by the high-density and high-rise buildings in urban centers is troublesome and a major obstacle to exploiting photovoltaics in cities. Constraints include the building shape and orientation that are critical for incorporation and electricity generation of the PV. Urban laws engender verticalization and densification in central areas. These areas attract businesses with greater ability to invest in PV power compared with private residents in apartments or condominiums. A problem is the verticalization of the city centers leading to small roof area and large façades. For dense building areas, such factors limit solar access and are not generally compatible for substantial or even adequate PV electricity generation.

In low-latitude countries like Brazil, the roof offers the greatest potential for harnessing solar energy [36]. Large roof surface buildings are generally low, podium-shaped buildings which, ironically, are more subject to shading from their surroundings. High-rise, tower-shaped buildings usually have vast façades but receive little solar radiation compared to low-rise building roofs. Both the commercial and residential sectors display examples of both building types. In the residential sector, these tower and podium typologies are more often discussed in terms of single-family and multi-family buildings, representing 88% and 11% of all homes in the country, respectively.

The Brazilian climate displays favorable conditions for adopting ecosystem services like solar energy and natural ventilation. Although the ubiquity of air conditioners has increased in recent decades, natural ventilation is still dominant in residences, used at the very least in hybrid mode with air-conditioning. Since natural ventilation depends on window operation, photovoltaic systems on façades are constrained to the available area available on façades. Roofs generally do not face these problems as zenithal openings are rare. And for Equatorial regions, flat roofs come with benefits for support, installation, orientation, and cost.

In the Brazil urban landscape, there are three major constraints to adopting photovoltaics: (1) The density of urban buildings provides severe shadowing over considerable buildings areas; (2) the most suitable, limited-shadow area for photovoltaic installations is usually on their roofs with the façades providing low solar irradiance for any PV; and (3) the even desirable roof area available for PV modules is frequently limited by other architectural elements such as ventilation, protection and safety components, and air conditioning and handling. These factors are considered in the analysis and discussion in the following sections to evaluate potential obstacles to adopting photovoltaic systems specifically in Brazilian residential and commercial buildings. *(ASIDE: Certainly, capital price is always an issue for the consumer, but PV prices have fallen to competitive levels in most regions of the world making PV the least expensive of the renewable-electricity technologies and lower than most non-renewable power-production choices.)*

Characterization of Building Electricity Consumption

Commercial and public buildings consume the most electricity in the building sector and are expected to account for 70% of the final energy consumption of all buildings by 2031 [37]. In contrast, the Brazil residential energy sector shares a sizeable portion of its use with natural gas for cooking and solar thermal or natural gas for water heating.

It is projected that the increase in the number of residential consumer units in Brazil will be 16% from 2021 to 2031, with an 18% increase in the average consumption for each residence [38]. This combination results in a 30–49% increase in electricity consumption depending on the scenario, with an average annual growth of 3.3%. With the projected annual increase of 0.5% in the population of Brazil [37], an improvement in the living standards is anticipated based on related experience in residential electricity use. A more significant increase is projected in the commercial sector, with the electricity consumption ranging from 40% to 63% and an annual average of 4.3% increase over the decade due to the economic consequences of COVID-19 [38].

Air-conditioned commercial and public buildings have electricity patterns closely coupled with the local climate as expected. An example is presented in Fig. 9 for corporate high-rise buildings ("towers") at various locations in Brazil. The

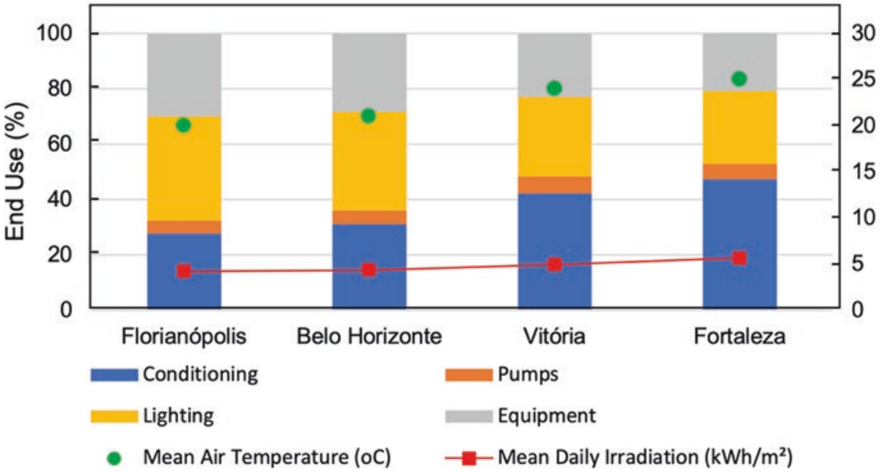

Fig. 9 End uses of a business-building of the tower type simulated in different Brazilian climates

consumptions do not meet the benchmark for high energy-efficiency for this class of building. The end uses are divided into pumps, air handling and office equipment, lighting, and air conditioning (mostly for cooling) [39]. The share of consumption caused by air conditioning follows the average annual mean ambient temperature that, in this case, ranges from 20 to 25 °C. The air conditioning electricity-use accounts for 28–47% of the building load, while that for lighting, 26–38%. Ambient comfort is the largest investment in such situations.

As the commercial and residential energy consumption continues to increase, technology improvements are being incorporated to offset added electricity usage. One recent advance is that of artificial intelligence (AI) air conditioning, which provides machine-learning unit control for more efficiency and levels of comfort. This mechanism avoids losses and excessive electricity use that can occur without sensing changes or relying only on direct human control.

The pattern of Brazil's increased energy use is exampled by equipment ownership, which has increased from 0.16 units per household in 2005 to 0.18 in 2019. In turn, the consumption share of air conditioning in dwellings grew from 12% to 16.5% over this same period. However, this average consumption is directly tied to income, ranging from 10.4% (lower income) to 35.5% (higher income) in 2019 [37]. With this in mind, [40] combined the differences in family income with two family lifestyles: traditional and contemporary, and three consumption patterns determined by Brazilian climates: predominantly cold (Bento Gonçalves, RS), seasonal with distinct summer and winter (São Paulo, SP), and predominantly hot (Belém, PA). The typical average monthly consumption of dwellings is presented in Fig. 10. The traditional lifestyle naturally presents a higher consumption since it is

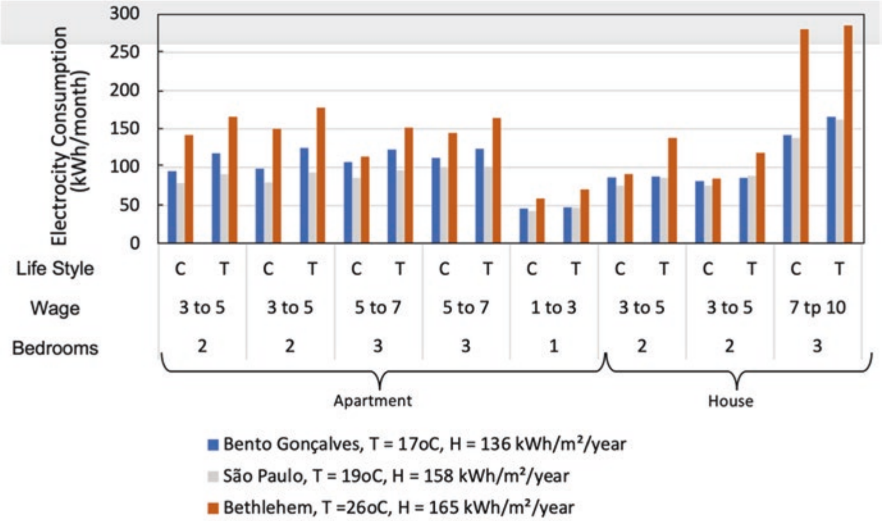

Fig. 10 Consumption patterns by climate and family lifestyle (*C* contemporary, *T* traditional) for five multi-family and three single-family housing models, based on projections for 2020

defined by spending more time at home than the contemporary style. However, climate and family income are the main factors determining consumption differences. Family income is related to the ability to acquire equipment, to the number of residents and, as shown in Fig. 10, the number of bedrooms. Furthermore, the first five cases in Fig. 9 refer to flats in multi-family buildings, while the last three refer to single-family houses.

Rodrigues et al. [40] analyzed the end uses as functions of regional and climate projections reported for 2020 [41]. Figure 11 compares the end uses by climate type with the reported average national projections [37]. When comparing consumption rates in the same income range, a root-mean-square error (RMSE) of 11% and a mean bias error (MBE) of 8% were found, with 288 samples compared to 48 averages from the PDE 2031. This considers the categories: lighting, leisure, water heating, food conservation, environmental comfort, and general services. In contrast, the differences between the reported averages [40] and the reported national averages [37] for 48 samples dropped to 7% RMSE and 5% MBE (see Fig. 12). Therefore, after confirmation of the consumption patterns in Fig. 9 by the benchmarking and Fig. 10 by national projections, they were adopted for discussing the photovoltaic potential according to the building type. In turn, the Brazilian building categories do not present a sufficiently relevant climatic differentiation by region. Thus, standard models were adopted for all the locations discussed [42].

This analysis was carried out within the framework of Brazilian electricity tariff policies. The most widely adopted tariff in Brazil for the commercial sector is *hourly seasonal*, while the conventional residential tariff does not present hourly or annual price variations. In 2011 a voluntary "white tariff" with hourly variation was introduced in the residential sector, but it had little effect and adoption due to its small differences in off-peak hours compared to the conventional one [43].

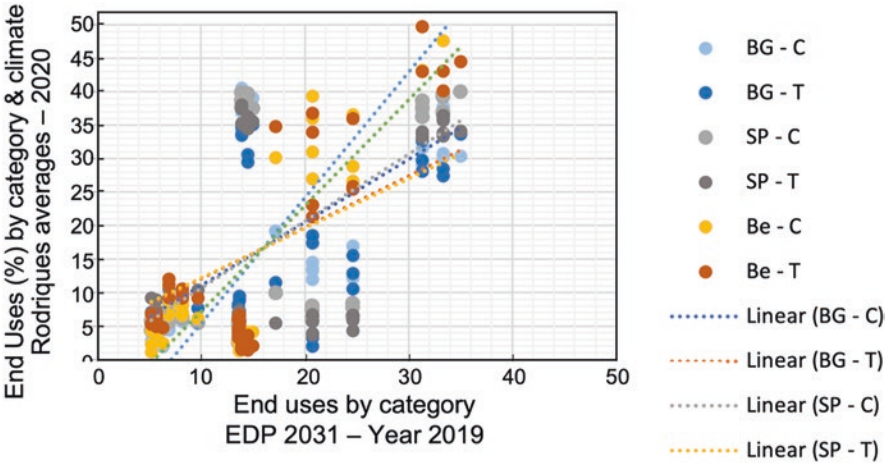

Fig. 11 Difference between the end uses of the consumption patterns of Fig. 10, which are differentiated by climate and the national average projections of PDE 2031

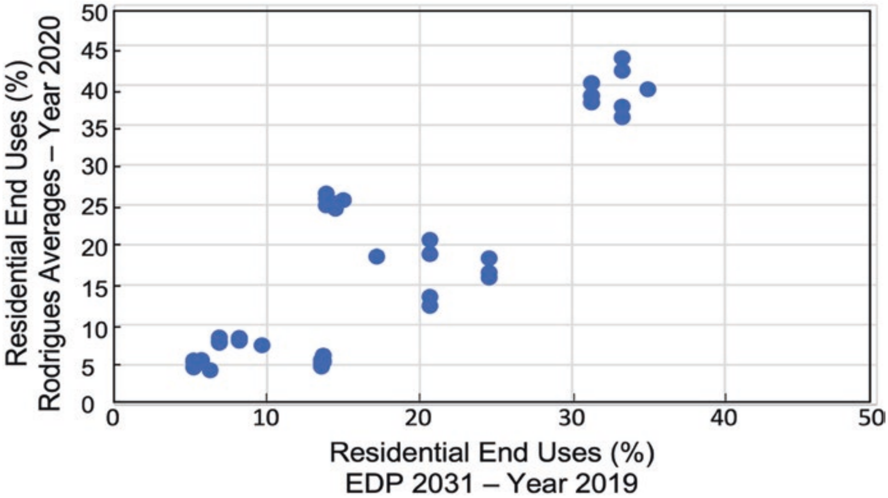

Fig. 12 Difference between average end uses of consumption patterns in Fig. 9, without differentiation by climate and the national average projections of PDE 2031

Photovoltaics in Buildings: Energy Patterns

For commercial buildings in areas with no obstructions causing shading, the "podium" shape (also known as pedestal or platform construction) is the most advantageous for photovoltaic generation. Podium structures have been the common construction type since the 1960s. This is because of their high-performance benefits, including long-term durability, low-maintenance, and fast-track site erection. This structure has been typical for residential apartments, hostels, prisons, schools, and a range of other commercial buildings. The "tower" buildings analyzed in Fig. 9, when fitted (simulation) with thin-film PV systems on its façades, only generated ~10% of the consumption for the evaluated climates. This accounts for 27% to 32% of the consumption by lighting or between 17% and 36% of the consumption by the air conditioning system of the building. But an analysis for a podium-type supermarket in the same bioclimatic zone of Belo Horizonte [44] reaches 31% of the total building electricity needs.

For the tower building in Fig. 10, the installation of thin-film PV on the glazed surfaces caused an additional thermal load on the buildings in Florianópolis (Lat 27°67′ S) and Belo Horizonte (19°55′ S). In turn, this increased the air conditioning load by 8% and 3%, respectively. Consequently, these cities reduced their energy balance total (Fig. 13), although photovoltaic generation ensured a positive yield. Thus, the benefits of photovoltaic energy require accounting for increases in thermal system consumption.

Single- or multiple-family residences present different situations. Considering the residential building configurations (stock structures) in Fig. 14, the energy payback times were estimated. They were evaluated in 55 cities between latitudes 14°

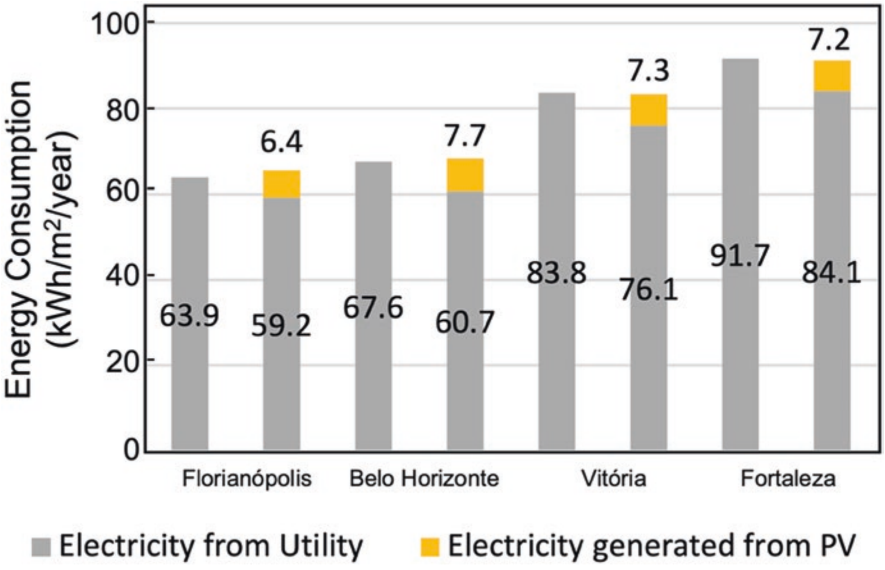

Fig. 13 Electricity-consumption billed concessionary and consumption resulting from the photovoltaic generation of thin films on the façades

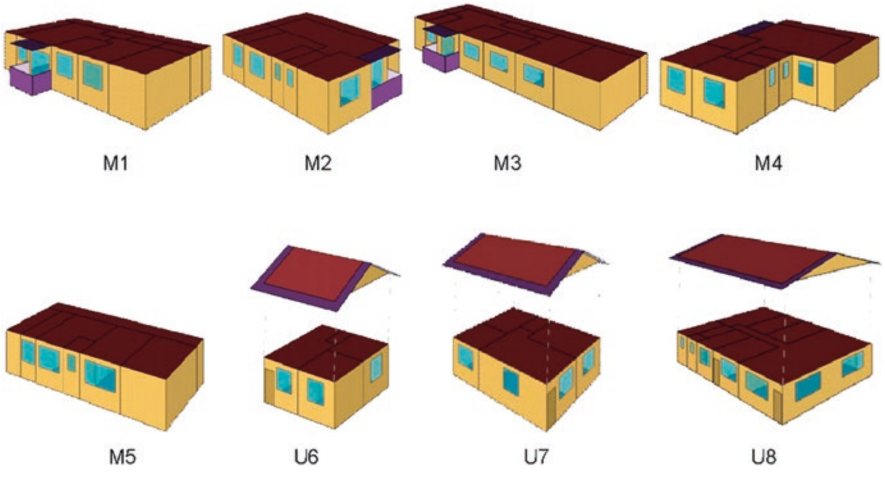

Fig. 14 Shapes of the study's representative multi-family and single-family dwellings

S and 28° S and 7 of the 8 Brazilian bioclimatic zones—ABNT, 2005 (Fig. 15). These data compare "cooling degree days" and the annual average of the daily totals of global horizontal irradiation. Monocrystalline-Si PV (Area: 1.98 m^2) modules were configured on the northern façades of the multi-family dwellings (M1 to M5) and the north-facing roof areas of the single-family dwellings (U6 to U8). The

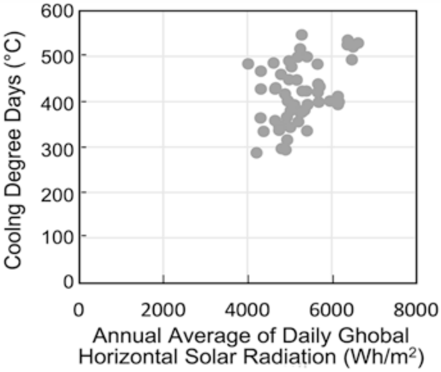

Fig. 15 Characterization of climates between latitudes 14° and 28° S by global horizontal irradiation and by the cooling degree days at a base temperature of 10 °C

Table 3 Characteristics of the representative dwellings

	M1	M2	M3	M4	M5	U6	U7	U8
Area (m^2)	53.3	60.8	66.8	67.7	33.2	30.7	55.5	142.9
Dorms	2	2	3	3	1	2	2	3
Residents	3	3	4	4	2	3	3	4
Consumption (kWh/month)	80–200	80–200	80–200	80–200	0–80	80–200	80–200	200–500

consumption patterns were equivalent to those in Fig. 10 but adjusted according to the climate and characteristics summarized in Table 3.

The photovoltaic systems were dimensioned to meet the monthly consumption of the building, minus the minimum conventional residential tariff's worth of electricity. This tariff refers to the cost of the availability of the distribution network and is equivalent to 30, 50, or 100 kWh/month according to the building's number of power phases. The area available for module installation on the façade or roof was the constraint to the photovoltaic sizing.

Finally, the financial electricity-billing use of the 440 cases with and without the contribution of PV generation was calculated. Figure 16 shows that there were cases of positive energy balance in dwellings M5, U6, U7, and U8. The positive balance of M5 was due to the low consumption typical of a single resident, which frequently only reaches up to the minimum monthly consumption. In the other dwellings, the positive balance was due to the availability of the roof area combined with the high solar heights that ensure greater intensity of solar radiation on low slope surfaces. When comparing these results to the payback in Fig. 17, dwelling M5 emerges as the least promising due to low consumption. Although there are climates in which dwellings M1 to M4 obtain low paybacks, only the geometries of the single-family dwellings U6 to U8 guarantee advantageous investments.

For the remaining cases, flat dwellings (M1 to M4), 42% have payback times equal to or less than 6 years, which can be considered a time limit for investments that will still fall within the family budget. None of these cases presented a payback $\leq$3 years, considered suitable for investments in the residential sector.

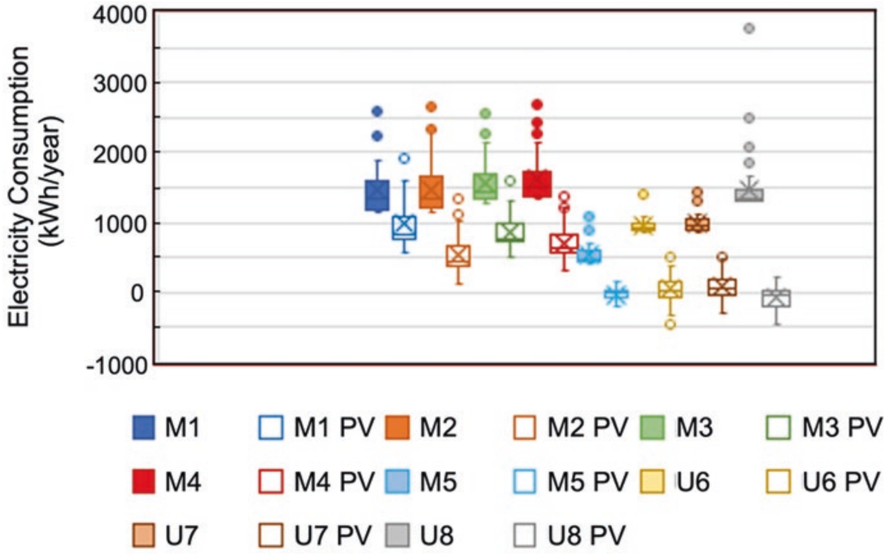

Fig. 16 Electricity consumption as billed by the energy utility companies, of the case study dwellings with and without photovoltaic energy

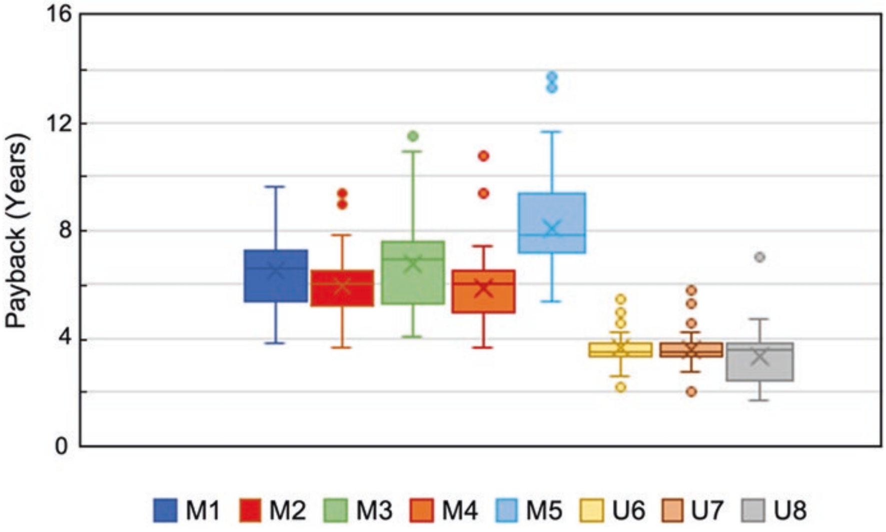

Fig. 17 Electricity consumption as billed by the energy utility companies for the case study dwellings with and without photovoltaic energy

Although the present economic scenario may be marginal for these dwellings, climate change scenarios may reduce the payback times in the coming years for these buildings. Air conditioning for cooling is a growing problem in the residential sector, both due to the increased penetration of splits in dwellings and the forecasts of future scenarios. In these, the total home consumption in Brazil will grow from 30% to 49% over 10 years growth in the consumer air-conditioning markets. While new, more energy-efficient electronics are improvements in the system efficiency and meeting comfort levels, many of the thermal comfort needs could be met by passive strategies thermal comfort, which, in principle, could be achieved with passive strategies.

5 BIPV/BAPV in Brazil: Examples and Issues

The markets and interest involving the installation of PV on residential and commercial buildings are increasing in Brazil. There are growing concerns for the environment in Brazil, issues of power outages and brownouts (many associated with increasing periods of drought affecting the hydroelectricity), and growing electricity prices that make this technology attractive to the consumer that have led the consumer and developers to seriously consider PV. The use of BAPV in particular has been increasing, spurred by the lower cost of PV panels, the lower cost if incorporated in the initial design and construction [4, 10, 11], the growing awareness of the viability of this technology by the consumer, and the availability of small PV systems in the "home improvement" and other retail outlets. A few BIPV and BAPV installations are exampled in the section to give some look into how this PV is being used in its still initial stages in the build environment in this South American country.

A Mini-Tour of BAPV and BIPV in Brazil

Among the first grid-connected BIPV systems was that at Universidad Federal Santa Catarina (UFSC) LabSolar in 1997 (Fig. 18) [45]. This pioneering system utilized a 2-kWp amorphous Si:H (a-Si:H) thin-film technology. This thin-film PV design utilized opaque and semi-transparent glass-PV laminates. In this period of time, the a-Si:H technology was the leading thin-film PV alternative, with products developed specifically for roofing materials [46]. The requirements and benefits for BIPV in the urban building structures (façades, rooftops), especially grid-tied, have been covered in the literature [47, 48, 49]. PV prices that make this technology attractive to the consumer provide the potential for BIPV.

The Brazil single-family residential sector is typified by low-angle roofs using red ceramic tiles or grey to white-colored cement. The most common installations are 1-kW to 4-kW (Fig. 19a–c), though larger systems are becoming more common (Fig. 19d). Brazil also has a large commercial production of solar thermal hot-water systems that have been used extensively and successfully on residences, condominiums, and commercial buildings. These are certified following the government standard [44].

Fig. 18 The first grid-connected BIPV system in Brazil, installed on the LabSolar building in 1997 at the Federal University of Santa Catarina (UFSC) in Florianopolis, Brazil. This was one of several BAPV and BIPV systems pioneered at the university over the past two decades. (Source: Dr. Ricardo Rüther, UFSC, and Ref. [47])

BIPV has to be considered a priority for the future of the built environment. Not only because PV has already become a cost-effective electric-power technology in most parts of the world [4], but it can add architectural and aesthetic value to buildings, rather than just using “cookie-cutter” modules on building areas that are visible. The building-integrated approach can add financial value to the property. In many cases, the use of PV is less expensive than many architectural approaches. A PV façade is more economical than using marble or granite. Transparent PV windows can help engineer the light needed and serve to reflect portions of the sunlight that would provide unwanted heat to the building. The future of BIPV lies in the fact that it can provide the needed power as a roof, façade, window shade, etc., and it is just considered the normal building structure. A casual observer may not know it is “PV,” but it provides efficient, clean electricity.

BIPV is starting to be part of the urban Brazil areas. Two interesting examples are presented in Figs. 20a, b. The first is the “Museu da Amanhã” in Rio de Janeiro [50]. This modern architectural structure has skillfully woven into the façade, 5492 crystalline-Si PV units in 48 circuits with a power of 181.2 kWp—providing about 9% of the building’s electricity. The theme of the museum reflects the reality of PV technology—“Amanhã é hoje,” the future is here. The second is for an office complex “TOTVS” in São Paulo [51]. The glass façade is lined 200 m^2 of thin-film organic PV (OPV) sheets. This emerging technology is an example of the ideal

Fig. 19 Examples of BAPV in Brazil: (**a**) 4-kW on red tile roof; (**b**) 3 KW on cement roof; (**c**) 4 kW on galvanized steel roof; and (**d**) 6 kW on tile roof

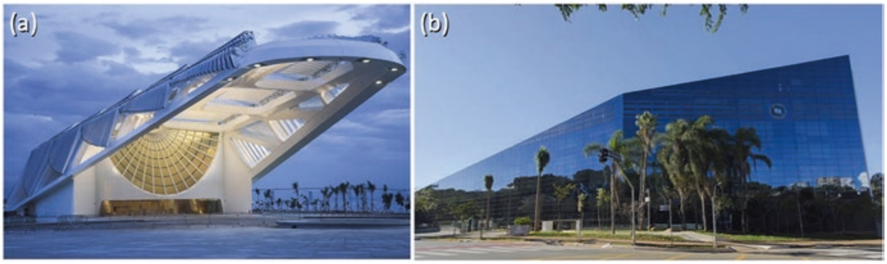

Fig. 20 Examples of BIPV in commercial buildings in Brazil: (a) Museo da Amanhã in Rio de Janeiro with 181.2-kW of crystalline-Si PV; and (b) TOTVS office building in São Paulo with a 200-m^2 area façade of organic PV (OPV)

match for thin films, which are almost transparent, produce the power from the sunlight, are low cost to produce, and can conform to any surface because of their flexibility. In this case, the OPV is produced in Brazil [52]; an example of the current trend toward producing the solar product in the region that the PV is used.

One final set of examples presented for the two airports: *Santos Dumont* in Rio de Janeiro [53], Fig. 21a, and *Hercílio Luz International Airport* in Florianopolis,

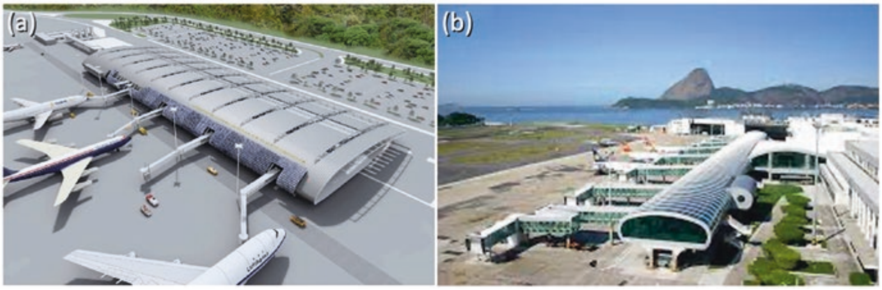

Fig. 21 Airport terminal integrated PV: (**a**) Hercílio Luz International Airport in Florianopolis, (**b**) Santos Dumont in Rio de Janeiro

Fig. 21b. These are really examples of the blend of BIPV and BAPV, with the latter solar components [54] installed in areas that are not very visible to the airport public. Both airports are situated at lower latitudes, with the large-area curved roof providing good acceptance for the sun orientation. The PV sun baffles (architecture term "brise soleil") extend over the windows and building surfaces as well at Florianopolis, which has 1.5 MWp solar installed.

Finally, one cannot mention the built environment and photovoltaics in Brazil without showing PV used in the "futebol" stadiums. For the World Cup in 2014, 4 stadiums were equipped with PV. One example is shown for *Mineirão* in Belo Horizonte in Fig. 22. Because of the structure of the existing stadiums, it was difficult to have the PV visible to the public as planned. However, the facilities provided monitoring kiosks that feature the PV installations, described is function and power levels, and showed what the current production of electricity is there. Mineirão has 6000 modules in its PV power plant—enough to completely power the stadium or 1200 Brazilian households [55]. In fact, the annual electricity needs of the stadium are 1600 MWh, and the PV produced 10% more than this. The extra power is directed to the customers of the "utility" (CEMIG) that built the power plant.

Issues: Soiling and Shading

Windows and façades in buildings are subject to ambient particulate accumulation and have to be cleaned periodically for aesthetics and for optimizing natural lighting in the living spaces or the offices. BAPV panels and BIPV surfaces likewise are subject to soiling, and in this case, the soiling limits the irradiation impinging on the solar converter's surface and decreases the needed power output. The degree to which this affects the panel's performance depends upon the location, local environmental conditions, orientation of the panels, and the condition of the panel's surface (usually glass with some anti-reflection coating). The issues of soiling, associated cleaning methods, and required cleaning periods to minimize power and financial losses have been reported extensively [34, 56–59]. Soiling mitigation cases specific

Fig. 22 Mineirão Stadium in Belo Horizonte, Brazil (1.3 MW crystalline-Si PV). One of four Brazil football stadiums integrated with PV for the 2014 World Cup

to buildings have been investigated—having applications to both normal "windows" and building PV-installations [60, 61].

One case study for Minas Gerais, Brazil, provides some insights into the effects on the importance of location, weather conditions, and especially the issues relating to emissions caused by vehicular traffic in urban areas [62]. This report is for BAPV on a commercial building and compares performance to ground-mounted systems. The performances of a similar power output monocrystalline-Si and poly- (also termed mult-) crystalline Si systems installed in Belo Horizonte were compared (Figs. 23 and 24). The 3.15-kWp monocrystalline-Si technology system was ground-mounted, with a tilt equal to the latitude of 20° in 2010, in a region away from high-traffic roads. The 3.64-kWp polycrystalline Si system was installed in the same year and with the same 20° tilt on the roof of a building close to a high-traffic road. Electrical and thermal parameters, and incident solar irradiance data on the inclined photovoltaic module were monitored during Spring time periods. The first observation is that rain provides a natural cleaning of the modules. The data showed that the output power of the systems increased after the rain, due to the natural cleaning of the modules.

A comparative performance analysis showed that the polycrystalline silicon technology system had a lower performance ratio (0.55–0.57) than the monocrystalline silicon technology system (0.68–0.76). This result can be justified due to the

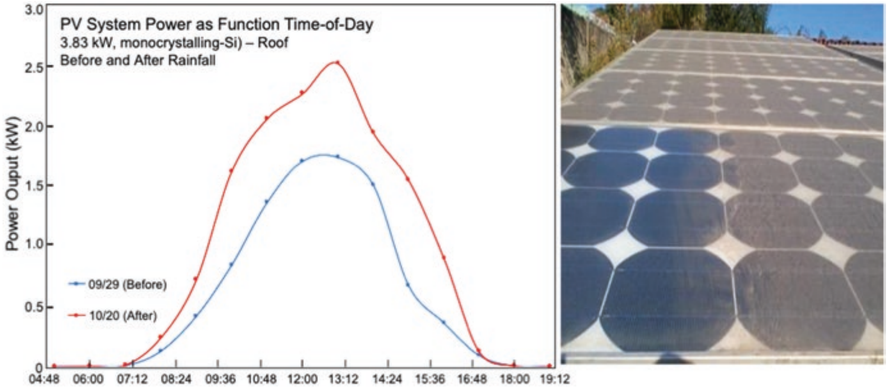

Fig. 23 Power output before and after rainfall from PV system of 3.15-kW$_p$ (monocrystalline-Si) DG installed on roof in Belo Horizonte, Brazil

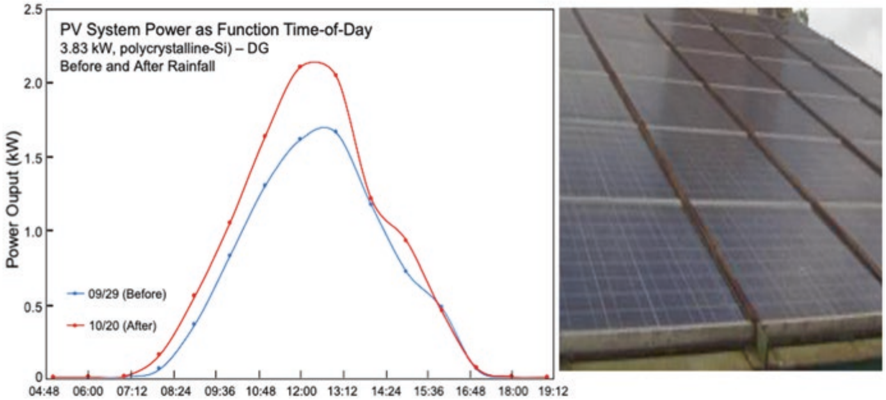

Fig. 24 Power output before and after rainfall from DG PV system of 3.63-kW$_p$ (polycrystalline-Si) DG installed ground-mounted in Belo Horizonte, Brazil

dirt deposited on it, which showed high adhesion to the surface due to the existence of organic matter and a high percentage of carbon, evidencing the presence of a biofilm formed by microorganisms that are difficult to remove by natural cleaning, such as rain and wind [63–66].

Issues: Early Experiences with Rooftop Installations

For the residential PV rooftop sector in particular, Brazil has experienced some issues relating to proper installations and certification. These issues have been experienced in other countries when the new PV buildings' markets started to expand.

Many systems under-perform because they have either been improperly installed or were designed for other climates, applications, or roofing configurations and materials [67–69]. Of course, environmental and location factors are important, the potentially negative performance factors shading [70, 71], cell/module aging [18–20], damage to due handling [21], climate, and ambient temperatures [72].

The operating temperature of the module is a critical factor for ensuring best-possible performance. For typical rooftop installations, the temperature is most affected by the roofing material and the separation between the module and the roof surface. Simulation of a roof-mounted PV-system can be used to optimize real PV-module power-generation by determining the correct installation parameters forecasting the system's capability [71, 73]. As an example, the common roof materials used in Belo Horizonte, Brazil, buildings are red ceramic, cement fiber, and galvanized steel. One study of these modeled crystalline-Si modules mounted on each of these roof types (see Fig. 25 showing installed PV on roofs as part of survey and experimental evaluation set-up in Minas Gerais) determined the optimal separation for the local conditions [73].

The ideal installation distance varies depending on the roof material. In the case of red ceramic tile, the ideal distance is calculated to be between 10-cm and 20-cm; for fiber cement the ideal installation distance of the PV module is around 10 cm, and in the case of galvanized steel the ideal installation distance of the PV module is between 10-cm and 20-cm. These have been experimentally validated. Interestingly, at the 30-cm distance between the PV module and the roof, an increase

Fig. 25 (**a**) Two PV roof installations in Minas Gerais (formed part of survey); and (**b**) Installations for determining the optimum module-roof separation for 3 common roofing materials in Belo Horizonte, Brazil. Left to right: Red-ceramic tile; galvanized steel, cement (based upon the report of Guimaraes [73])

in temperature was recorded for all materials, suggesting that large installation distances might not be desirable [73].

Models predict that the placement of the PV panel directly on the roof (i.e., 0-cm separation) is a configuration that should be avoided. This is a convention discouraged by most installers and suppliers to avoid the loss of power output due to potential higher panel temperatures [53]. Mounting with no separation results in the largest module temperatures for any of the 3 roofing materials. Although field (no-roof mounted) modules (mounted at the latitude near 20°) at this site operate typically <50 °C, direct roof mounting results in modules with temperatures 55 °C to more than 70 °C. Though for the fiber cement thermal properties are best roof-panel operations in these studies, losses of at least 3–4% in module power were observed over the reference field-mounted modules. For the case of galvanized steel, the measured power losses were 10–15% for the modules mounted with no separation. In a survey of the PV roof system installers in 2019–2020, (41%) indicated that they mount panels directly on the roof. These installations lose useful and considerable power for the consumers. There are, of course, also worries about long-term degradation or failure of these modules operating at higher temperatures under conditions that can be avoided. In the survey, 29% responded that 10 cm between PV generator and roof is used, 12% answered that it depends on what the installation location would permit (e.g., obstructions, ability to support the modules, security, etc.), 6% answered that the distance is 15 cm or more, and 12% answered that this “distance is not important.”

The best installation (separation) depends also on the roofing material. For example, the optimal separation is about 10 cm for the fiber cement and the red tile roofs and 20–30 cm for the galvanized steel. For all cases, the module temperature rises for separations greater than the optimal one due to increased radiation from larger exposure to roof areas. And in all cases, the roof-mounted PV panels operate at higher temperatures than those that are field-mounted [73].

The installation landscape in Brazil has been changing rapidly with the influence of the government and university laboratories, the manufacturers, and the initiation of certification procedures. The early-stage experience with installations is similar to what other countries have experienced. However, as knowledge, increased use of technology, and training advance, the occurrences of incorrect installations are diminishing.

6 Concerns and Promise for the Working-Class Neighborhoods

Electricity service to the poorer and working-class neighborhoods in Brazil remains a concern [74]. The growth of these “favelas” began in the 1950s when many people migrated from the rural areas to the cities, mainly seeking jobs, improved living, and better wages. However, due to their lack of adequate financial resources, many of this population established themselves in their own-built communities that lacked adequate roads, sewerage, water, medical support facilities—and especially electricity. These favelas are present primarily throughout the larger cities (Rio, São Paul, etc.), where today the largest such areas exist. But favelas have now extended into most states in Brazil. Services to these communities have improved in the past several decades, but still about 20% of the favela populations do not have electricity. The government has promoted metered service to the communities, but with the financial limitations of most of the families, electricity if still "stolen" to provide essential needs. It has to be realized that these are built-environment communities in which the people are in need of reliable electrical service in order to provide even the minimal improvements in their lifestyle. PV has been investigated as an alternative to serve this purpose [75, 76].

Despite the potential for PV in these poorly served communities, the use of this seemingly well-paired technology to the application really faces some major barriers and questions:

- Through these communities benefit from the exceptional Brazil solar resource (Sect. 3), how can it be used effectively and economically to provide and maintain this clean electricity?
- How can the risks (installation, theft, breakage, regulations, maintenance, etc.) be mitigated or eliminated to ensure constant and reliable service?
- How to finance and continue this service in communities that can have high economic limitations.
- At what level can solar be used in these communities with the potential limitations of solar-oriented roof space, solar availability, building structure support for solar installations, and the concerns that environmental issues (heavy rains, land movements, floods) can destroy the entire infrastructure?
- Are the current Brazil legal and regulative condition (Sect. 2) restricting or promoting the use of PV in these higher-risk areas?
- Can the residents buy into this technology, competing with the illegal "business as usual" methods in getting the electricity for free. What programs are needed to help these communities understand the value to improving their lifestyles and social conditions?

Most of these questions have already started being addressed (and continue to be answered with the increase PV availability) for the favela use of solar by the government, by research groups, by the utilities that serve these communities, and in many cases by the residents themselves. BAPV presents a viable electrical power approach. A recent report at the World Conference on Solar Energy Conversion (WCPEC-8) evaluated the solar roof potential in on large favela in Niteroi (near Rio de Janeiro) that may be typical of these neighborhoods [77]. Caetano et al. found that ~30% or more of the roofs were suitably oriented to accept PV panels for very good power output [77]. The report did raise concerns about the structural integrity to support installations, but noted that in some dwellings (exclusive of environmental calamities), this may not be a problem—but may call for additional work on the structures. For most of these communities that exist in densely packed urban areas, adjacent open land for the installation of mini-power plants is not available as an alternative.

The favelas in Rio may best serve as examples of the BAPV potential in this special type of built environment. The favelas were hit particularly hard with frequent and extended electricity outages in the 2015–2020 timeframe [76, 77]. In 2021, a small group from the communities of Babilónia and Chapéu Mangueira formed *Percília e Lúcio* solar cooperative, having raised some $19 K through a collective funding campaign to establish solar PV electricity to serve the community, began their solar enterprise [78–81]. The installation includes 58 PV panels, mounted on the 177 m^2 roof area in Babilônia (Fig. 26). The electricity generates 35,000 kWh annually, enough for ~35 houses. The PV power is fed to the electricity grid, Light S/A in Rio, which in turn, provides discounts in the energy bill of residences and businesses associated with the cooperative for the electricity generated from the PV installations. With the low-income levels of the population, this is a substantial contribution that can be measured at ~10% of the annual income of those consumers.

This BAPV accomplishment is but a small example of what is possible to assist these under-served communities in gaining needed and reliable electricity. The PV electrify has not only had the economic benefit from lowering the monthly bills for these consumers but has also created jobs thought the work of the cooperative. But the expansion and duplication of this effort is not easy under current Brazilian regulations (Normative No 687, 2015, in Section 2 and Table 3). Communities are required to have permits to share small-scale energy generation. These legal

Fig. 26 Partial view of PV module installation in Babilônia community (Rio de Janeiro)

requirements stipulate that there be two or more consumers, a legal cooperative, and that the location of the PV be different from the place where the energy will be consumed. It is time-consuming and inconvenient to comply with these regulations—which are certainly not within the power of PV to bring electricity to the point of use. In 2022, Brazil has implemented a new law (Lei No. 14.300, Section 2) that can help this PV application for the favela communities by making it easier for the cooperatives to be formed and mandating distributors/developers to invest in these low-income areas [82].

The incorporation of PV into the electricity structure of these poorer and working-class neighborhoods is a challenge. But the revolution toward providing clean, reliable solar power to these segments has begun. And BAPV is part of the first steps of this revolution.

7 Conclusions and Innovation and the Energy in Built Environment

Photovoltaic technology, like all electronics, is in a constant state of advancement. Innovation is key to bringing the needed next-generation of devices and systems to meet the economic and performance expectations of consumers and the world situation. Silicon PV technology continues to evolve with **innovation** in device understanding and engineering to ensure that every possible photon is captured, and every carrier survives long enough to contribute to the photoelectric process. Thin films have held great promise because of their efficient materials utilization, form factors, and potential for performance improvement. They have a current place in the power market, but innovation has recently produced advances in improvements in established and in new technology. All PV depends on innovation along the entire value chain from materials, through devices and manufacturing, to systems, standards, and policy. But PV has great prospects to advance beyond its current major focus on the power market. Concerns with land use have been diminished through the implementation of careful and smart “agrivoltaics,” in PV power generation can enhance crop production while producing locally needed electricity, and “floating PV,” which can utilize the available water areas of reservoirs and lakes. The built environment presents challenges and opportunities to not only help transform this important end high-energy consumption sector to use of clean, renewable electricity—and help the world advance toward a 100% renewable energy future.

The performance estimation of a photovoltaic system must consider the influence of local climatic conditions, as well as installation and maintenance conditions. Solar irradiance and ambient temperature are the climatic factors that directly affect the output current and voltage of a photovoltaic module, respectively. However, the wind speed, for example, can contribute both to the cooling of the module and to the cleaning of dirt deposited on this device depending on the direction of the wind that falls on it. For this reason, for the building applied photovoltaics (BAPV) and building integrated photovoltaics (BIPV) attention should be paid not only to the solar resource available in the locality, but also to evaluate the best installation conditions by proposing adequate distance of the modules from the surface, in order to promote free air circulation and, consequently, the exchange of heat between the photovoltaic and air (module cooling), install in places without shadow projection, adequate inclination (> 5° as suggested by manufacturers) in order to reduce the soiling deposition.

As PV continues to grow as part of our clean energy future—and potentially the major player in a 100% renewable-electricity future—the need for expanding the PV presence in the built environment becomes necessary. Just as Brazil is now emerging as a major market for PV, it will also emerge in the major use of PV in the built environment. This aspect has already materialized in the PV portfolio in Brazil. It can be anticipated that in the near term BAPV will dominate for the consumer, with BIPV finding a great place in the commercial and urban environments. Although a rationale mix of BIPV and BAPV has to be a prominent part of the future, it is a disruptive path from what we are doing today—needing significant resource investment and the buy-in from all participant segments.

Such a major transformation requires the engagement of PV scientists and engineers with architects and architectural engineers to make the best decisions and accelerate the transformation. Additionally, the manufacturing industry has to expand to provide products specifically designed for BIPV. Policy and decision-makers play an equal role to make this happen in a reasonable time. This will be a major paradigm shift in accomplishing this trend toward higher architectural value while continuing to provide high standards of performance. The opportunity exists. Currently, renewables account for about 29% of the world's electric-power area, but only about 2% of the much larger energy demand in the buildings sector [4]. And this is where the nexus of innovation in PV science and architecture is important. *There has to be both a movement toward energy efficiency in the built environment and better ways to bring solar technology into this important and large energy-consuming segment.* And a major target for the future has to be a major change in how we unite solar technology with buildings—specifically to make BIPV the major expectation for our built environment. This nexus cannot be "business as usual." But "amanhã é hoje"—tomorrow is today and the change has begun!

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