Applicability of PV Rooftops Versus Agriculture Rooftops in the Residential Buildings of Nasr City, Cairo

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Abstract: Urban rooftops in the Egyptian built environment are a clear example of a massively wasted resource. They can contribute to energy and food production as well as increase the return on investment in the real estate sector by implementing Agri and PV rooftop systems. The paper aims at tapping into the unexplored case of multi-unit residential buildings of Cairo to assess the Agri and PV systems' applicability on their rooftops. For this purpose, it conducts a spatial analysis for one of the Cairene middle-income districts; Nasr city. Overlaying multiple layers of applicability aspects derives a conclusion about the percentage of applicable rooftops for Agri versus PV systems in the district's different blocks typologies.

Keywords: Rooftop Agriculture; Urban Agriculture; Solar Rooftops; Green Buildings; Rooftop Architecture

1. Introduction

Agri and PV rooftop systems can provide multiple benefits that help reduce the excessive use of resources in Egypt while making use of urban rooftops as an overlooked resource. Food insecurity and malnutrition levels are increasing annually as a result of the increasing food prices and diminishing agricultural land in favor of urban expansion [1,2]. Agri-rooftops are a promising urban agriculture method that can secure local food production and healthy food provision for different segments of the society [3,6].

Rapid population growth, massive urbanization trends, and extensive heat waves are leading to increasing electricity demands [4,5]. Energy sources' diversification and the support of on-site generation by PV rooftops are key strategies for facing this demand [6].

The residential land use makes up 64% of all land uses in Cairo [1,7], thus its rooftops represent a huge under-utilized area. It is suitable for Agri-rooftops where the unit owners can easily follow up on the systems and benefit from the high-quality produce. It is also the highest consuming sector of electricity, consuming around 50% of the low and medium voltages [5,8]. Thus, it possesses a huge potential for hosting both systems.

The selection of the middle-income segment as a target group of the conducted analysis is accounted for being the most untapped segment. Almost all Agri and PV rooftops projects in Egypt targeted the heavily subsidized lower-income or the higher-income that have the financial resources [9]. The middle-income fall under the category of "Early adopters" as identified by Rogers in his "Diffusion of Innovation theory" (2003) that defined them as "Opinion leaderships but more attached to the local population in their status and level of innovativeness" [10], therefore it is a segment worth investigating.

The paper aims at exploring the untapped context of the middle-income multi-unit residential buildings and assessing the applicability of Agri and PV systems on its rooftops. It formulates a replicable framework for conducting the applicability analysis of these systems in the Cairene context by overlaying different spatial aspects. In addition, it concludes with the applicability percentage on the rooftops of the selected case study blocks.

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2. Case Study Description

Nasr City; one of Cairo's middle-income districts was selected to host the case study blocks. Nasr City was built in the socialist era to host middle-income families in cooperative housing [11]. It has transformed over the years to host a mix of single-family houses and multi-family buildings that reach up to 13 floors in response to the exploding population [11,12]. Two blocks in Nasr city were analyzed; block (A) represents the private multi-unit residential blocks, and block (B) represents the cooperative housing blocks.

3. Methodology

The paper adopts a case study approach to identify the potentials and constraints of the systems' adoption in this specific context. Site visits to the two blocks were conducted to create a profile that covers all spatial aspects. The study used a combination of manual and GIS-based selection methods for data analysis. The manual selection was used by [13,14] to identify rooftops suitable for Agri systems, and by [15,16] for PV systems. According to [19], this method depends on manual identification of the determinant aspects using maps and on-site images then comparing them to literature-based thresholds concluding with the rooftops' suitability to host the systems. The shading analysis used a GIS-based method which was adopted by [3] for Agri-rooftops and by [18,19] for PV rooftops.

4. Spatial Aspects Thresholds and Applicability Results

Each of the theoretically and contextually outlined aspects is analyzed for the two blocks.

4.1. Building Height

For Cairo, usually building height does not add any load on Agri-rooftops [20] or PV rooftops. Wind load is checked against the load-bearing capacity of both systems only for buildings exceeding 10 floors [21]. Block (A) has 3 to 17 floors, while block (B) has 5 floors. The applicability percentage of Agri-rooftops on Block (A) buildings (> 10 floors) is 80% due to the needed wind moderation strategies to overcome the loads at this height (4 times the wind load = 280 Kg/m²) [21]. For PV rooftops, the load-bearing capacity of the panels is 244 kg/m² [23], thus 20 % was also deducted but was compensated by the high sun exposure at this height. Block (B) buildings achieved 100% applicability (< 10 floors).

4.2. Load Bearing Capacity LBC

Agri systems add to the live loads around 20-75 kg/m² according to their type [20,22]. While PV systems add to the dead loads (e.g.: crystalline panels add 14-20 kg/m²) [23,24]. Site visits confirmed that all buildings have concrete skeleton structures and their load-bearing capacity was identified based on the concrete building code. For block (A), rooftop floors withstand a live load of the typical floor (200-300 kg/m²), while block (B) withstand the live load of a usable last floor (200 kg/m²) [25]. Loads added by Agri and PV systems are less than the acceptable ranges outlined above, thus their applicability is confirmed.

4.3. Rooftop Area

For Agri-rooftops, there is no minimum threshold for the area to cover [3,20,26]. The maximum system coverage is 60% of the total area; i.e. Roof Cover Ratio (RCR) is 0.6 for maneuvering [13,14]. For PV rooftops, the minimum area for having an efficient system is 50 m² for residential uses (5 kWp/month) [24]. The RCR, in this case, is between 0.6 to 0.9 leaving room for the panels' spacing [23,27]. Block (A) and (B) have areas of 335 m² and 760 m². After applying the Roof Cover Ratio (RCR) for both systems, the remaining available areas are more than the minimum, so the applicability percentage is 100% for all.

4.4. Obstructions and Materials

The obstructions include clutter and competing functions existing on the roof such as poultry rearing, livestock or dogs raising, and Satellite dishes [23,28]. Finishing materials vary in Cairo where the most important is the waterproofing membrane [23].

For both blocks, the rooftops were finished with tiles and waterproofing membranes. The obstructions were classified based on their level to slightly obstructed (obstructed area $\leq 40\%$ of roof area) having 100% applicability, moderately obstructed (obstructed area = 40% to 70%) having 90% and 70% applicability for Agri and PV systems respectively, or highly obstructed (the obstructed area $\geq 70\%$) having 70% and 50% respectively. Block (A) rooftops had more structural obstructions than block (B) due to the elevator and stairs rooms. Satellite dishes and clutter were the most common functions on both blocks.

4.5. Rooftop Accessibility and Safety

The easiness and safety of accessibility are more critical to Agri-rooftops to ensure the farmers' access and transporting of materials and equipment [29]. For PV rooftops, accessibility is mainly needed for system mounting and occasional panels' cleaning. Accessibility was classified into three categories: easy accessibility through elevator/stairs having 100% applicability for both systems. Medium accessibility bound to caretaker approval and having 90% for both systems. Difficult accessibility through a vertical stair having 0% and 90% for Agri and PV systems respectively. 75% of block (A) buildings have easy accessibility, while 89% of block (B) are difficult to access due to vertical stairs.

4.6. Utilities Provision on the Rooftop

The identified utilities include water access, drainage point, and electricity access. Water access is necessary to water plants [29], and to clean the PV panels [27]. With water usage, a drainage point is needed to avoid any leakage risks [28]. Electricity is needed to power Agri systems components. 80% of block (A) buildings have a full provision of the three utilities, while 94% of block (B) buildings have no access to any of them. Utilities' provision is of extreme significance to Agri-rooftop thus the roofs with no access were discarded and those with one utility get 30% applicability but get 70% for PV systems.

4.7. Shadow Analysis

Shadow impact on both systems is very critical, so a shadow analysis was conducted on 4 days (in the 4 seasons) at 3 times (9 AM, 12 PM, 3 PM) using Google SketchUp shadow tools. Shadow levels were categorized into slightly shaded (shaded area $\leq 40\%$ of rooftop area) having 100% applicability for both systems, moderately shaded (shaded area = 40% to 70%) having 80% and 60% for Agri and PV systems respectively, and highly shaded (shaded area $\geq 70\%$) having 60% and 0% for the Agri and PV systems. Block (B) buildings have 100% applicability for both systems since no shadows exist due to equal heights.

5. Conclusion

By overlapping these results and percentages, a conclusion about the applicability potential of Agri and PV rooftops can be reached as shown in Figure 1. PV rooftops are more applicable in both blocks where it is applicable on 85% of block (A) and 100% of block (B). While Agri-rooftops are applicable on 75% and 10% of block (A) and (B) respectively. The main barriers facing the Agri systems were the lack of accessibility, followed by the lack of utilities' provision and the negative impact of casted shadows. Shadows were also the main barrier facing PV systems. The replicability potential of block (A) typology is very high in Nasr City. Thus, the generalization of this block's results is possible. For block (B), the generalization potential is limited since some characteristics are specific to this type of cooperative housing. However, this particular block was not the target, but identifying the unfavorable block conditions is the added value of the conducted analysis.

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Figure 1. Agri-rooftop and PV rooftop Applicability Results for Block (A) and (B). Source: Author

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