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PV Systems integrated into the Urban Environment to reduce Heat Islands harms Public Health

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A B S T R A C T

Climate change is a global concern that has a significant impact on urban environments. Cities contribute significantly to greenhouse gas emissions, estimated to be 75% of global CO2 emissions. To combat this issue, it's necessary to implement sustainable solutions that promote clean energy & reduce rising temperatures in urban Environment. One such solution involves integrating photovoltaic cells into the urban environment elements to mitigate urban heat islands caused by emissions from cooling systems used for achieving thermal comfort in buildings, the research methodology involves a theoretical analysis of heat islands and explores how PV cell applications currently available in the market can address this issue supported by an analytical study of applied projects that utilize photovoltaic applications, the research findings emphasize the significance of integrating PV cells into the urban environment. This integration serves multiple purposes, including reducing heat islands, decreasing harmful carbon emissions, providing clean energy, and supporting public health.

1. Introduction

Climate change is a global issue affecting urban life, Rising global temperatures lead to various challenges, including rising sea levels, extreme weather events like storms, droughts, floods, and the spread of tropical diseases, These factors can have costly impacts on cities, including damage to basic services, infrastructure, housing, livelihoods, and public health [1], Heat waves are expected to intensify in the twenty-first century due to climate change. This will lead to long periods of high temperatures during the day and night. This extreme heat can have a public health impact and exacerbate the leading global causes of death, including respiratory and cardiovascular diseases, diabetes, and kidney disease. [2], Cities play an important role in climate change, as it is estimated that cities are responsible for 75% of global carbon dioxide emissions, with buildings and transportation being major contributors [3], Therefore, rethinking urban planning and design with a sustainable vision is important to reduce rising temperatures and create a healthy, friendly environment for residents, One effective solution involves integrating photovoltaic

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applications, which are advancing rapidly technologically, to reduce costs and meet the diverse design of urban environment, These Technological advances have led to the development of PV paving materials as a sustainable alternative to paving vehicle and pedestrian paths. In addition to using photovoltaic modules to build rooftops, awnings, skylights, PV facade systems, and urban furniture to generate clean energy, reduce heat islands, achieve thermal comfort, and enhance public health, The research methodology involved a theoretical study on heat islands and how photovoltaic cell applications available in the market can address this issue. The study was further supported by presenting various applied examples from international companies in this field, illustrating the impact of photovoltaic cell applications on public health. As a result, the research provides a set of recommendations to expand the use of photovoltaic cell applications in the urban environment, whether at the level of buildings or open spaces

Urban Heat Island and its Effects on Public Health

The Urban Heat Island (UHI) is a significant challenge impacting residents' quality of life and health in cities Fig.1 [4]. It results from unintended climate alterations due to land surface modifications, primarily driven by urbanization and human activities Fig.2. These modifications include the replacement of open spaces and vegetation with buildings and roads. Tall buildings and narrow streets can trap air and reduce airflow [5], exacerbating heat retention. Dark, impervious surfaces (Asphalt, concrete, etc.) cover a substantial portion of cities, absorbing solar radiation and contributing to heat islands [4]. As a result, heat islands are less noticeable in smaller cities, but in large cities with one million people, the average temperature can be 1°C to 12°C warmer than the surrounding area [6].

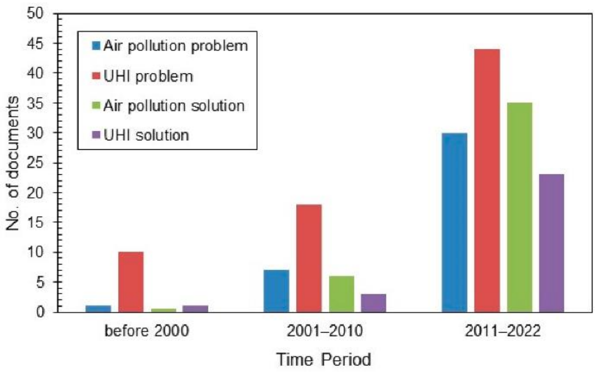

Fig.1. (Left**),** A chart shows the increase in heat islands compared to air pollution in cities, but interest in combating them is less despite their danger Source [4].

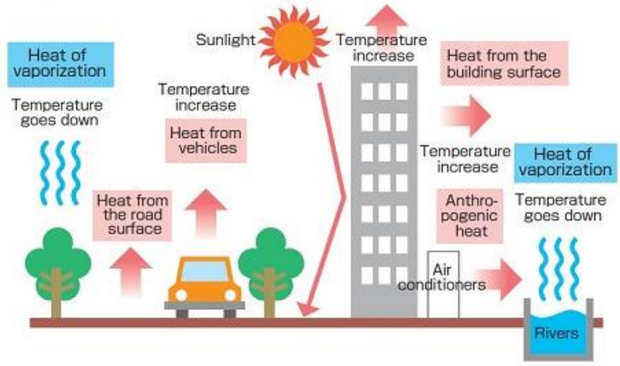

Fig. 2. (Right**),** How the Heat Island phenomenon occurs. Source [6].

Heat islands have detrimental effects on public health, including higher daytime temperatures, reduced nighttime cooling, and increased air pollution. These factors contribute to heat-related illnesses & discomfort, such as respiratory difficulties, heat cramps, heat exhaustion, and non-fatal heat stroke [7]. Additionally, heat islands negatively impact economic development in the region and the well-being of its inhabitants [8], Addressing this issue requires attention and the implementation of applications that improve the urban environment and enhance public health.

2. Sustainable Applications to mitigate the Heat Island phenomenon.

Sustainable applications play a role in mitigating the adverse effects of heat islands (Fig. 3). These applications include [9]:

- Green infrastructure integration: Incorporating water features or vegetation components into buildings or outdoors.

- Sustainable materials: Utilizing innovative streets, pavement systems, and various coating materials (light-colored materials, phase-change materials, color-changing materials, or fluorescence materials).

- Energy-efficient appliances: Implementing PV applications to generate clean energy and combat heat islands. These applications will be further explored in detail within the context of this research.

Fig. 3 Shows different sustainable applications in an Urban Environment that can help reduce Heat. Source(pinterest.com)

3. Integration of PV systems into Urban Environment.

Integrating solar energy into planning and designing urban environment elements is crucial. This approach ensures that future cities consume and locally produce energy through solar power. The transition to clean energy within cities is essential to address the ongoing climate crisis. By 2050, harnessing more than half of the global solar capacity presents significant opportunities for low-carbon energy production [10], Integrating PV systems into urban environments can lead to several benefits. As decreasing heat islands, achieving thermal comfort both indoors and outdoors without relying on energy-intensive ventilation, there are two primary photovoltaic systems based on installation techniques [11]:

- BAPV (Building Applied Photovoltaics): These systems are attached to buildings using mounting structures and rails, most importantly it has no direct impact on the building's structure.

- BIPV (Building Integrated Photovoltaics): refers to the integration of PV technology into building structures as a component of the building. By combining photovoltaic products with building materials, traditional materials like glass, stone, and tile can be replaced. BIPV contributes to sustainable energy production and enhances the urban environment.

4. Some applications for integrating photovoltaic cells into the urban environment.

*4.1 **Pitched Roofs** (Discontinuous roofs):*

Typically consists of small elements (slates, tiles, shingles, etc.) with the primary function of water drainage [12]. Due to their size, ease of installation, and favorable inclination and orientation toward the sun, photovoltaic (PV) modules can replace the traditional tiling layer. Categories within this application area include solar glazing, in-roof mounting systems, full roof solutions, large tiles small tiles, & metal panels [13], The installation methods involve mounting the solar panels directly onto the roof or using rail-based mounting systems Fig.4. These rails or brackets, typically made of corrosion-resistant materials like stainless steel or Aluminium to provide stability & withstand environmental conditions [14].

Fig.4. Examples of PV mounting systems on pitched roofs.

4.2 Flat & curved Roofs (Continuous roofs):

Characterized by large, uninterrupted layers designed for water resistance. Typically, membranes serve as water barriers [12]. Within this application area, several categories include solar glazing, metal panels, & PV thin films Fig.5. which are directly fixed on the roof [13]. the solar panels are mounted on flat roofs by Ballasted Mounting Systems using materials like concrete or blocks Fig.6, This system is ideal when drilling into the roof is not feasible. [14].

Fig.5. PV membrane installation on the roof directly without mounting system

Fig.6. examples of Ballasted mounting systems

4.3 Atrium/Skylight:

They are typically (semi)transparent for daylighting purposes, with additional thermal, acoustic, and/or waterproofing functions when protecting an indoor environment. This system covers all or a part of the roof Fig.7, fixed or openable, and retractable is typically part of the glazed layer, applying both crystalline or thin-film PV technologies, and with various possibilities for transparency degrees and visual appearance [12].

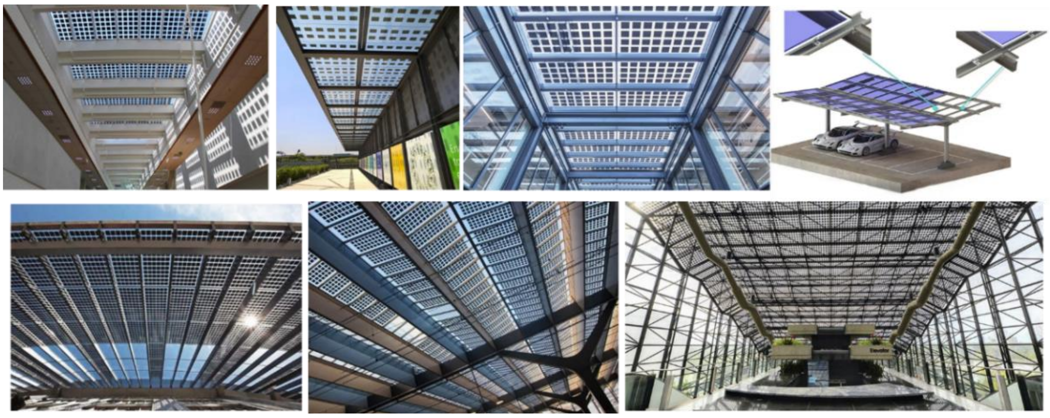

Fig.7.Examples of Atrium & Skylight

4.4 Spare Ground:

PV Panels are mounted a direct application in road structures Fig.8 and the PV panels may be installed at the optimal orientation like their conventional applications in PV power plants, such spare ground includes medians of roads, slopes along expressways, disused highways, & open ground among interchanges [15]. Used Bifacial PV Panels have solar cells installed on both sides with vertical east-west mounting of BPV providing two production peaks per day one in the morning and one in the evening [16].

4.5 Electrical Collector Pavement:

Creating movement paths for pedestrians or vehicles using photovoltaic cells has become possible Fig.9, The PV panels are made of specifically formulated tempered glass, which can support the weight of pedestrians, bicycles, or semi-trucks, The solar panels LEDs are controlled via microprocessors which display information on the surface of the pavement and are centrally controlled. [17], However, some road paving projects that implemented this system showed problems affecting the efficiency of the system in generating the required energy and compensating for the high application costs, such as insufficient lighting, difficulty seeing LED lights during the day, efficiency affected by shading or elements of the surrounding environment, difficulty in ventilation and cooling of the units, and difficulty in maintenance.

The units are subject to damage or theft [18]. This requires consideration to develop the system to be more effective in the future.

Fig 8. PV mounted in spare Ground

Fig .9. P V integrated into vehicles' road

4.6 PV Pavers*:*

PV Pavers offer a variety of anti-slip options for outdoor pavements or building rooftops. These pavers come in various colors and differ in PV cell type, power output per square meter, panel efficiency, maximum loads, and installation techniques such as:

- Onyx Solar Company: PV pavers using both amorphous silicon & crystalline silicon (withstand up to 400 kg /point load). Additionally, they can be combined with a backlit system for courtesy lighting and improved landscape design. Installation is like any technical raised flooring system using PVC pedestals, wood, or metal framing Fig.10 [19].

- Platio Company: They offer solar tiles in two versions: Polycrystalline (a nominal power of 158 W/ m², efficiency of 18.6%), and Monocrystalline (Power output of 186 W / m², 22.0% cell efficiency). These tiles can operate at safe low voltages and support a walkable load of 8.6 kg [20].

- Erthos Company: They've developed a novel approach to installing solar power plants directly on the ground (Fig. 11). This method requires fewer cables and trenches, significantly reducing installation costs by at least 20%. [21].

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Fig.10. PV pavers used in building rooftops (Onyx Solar)

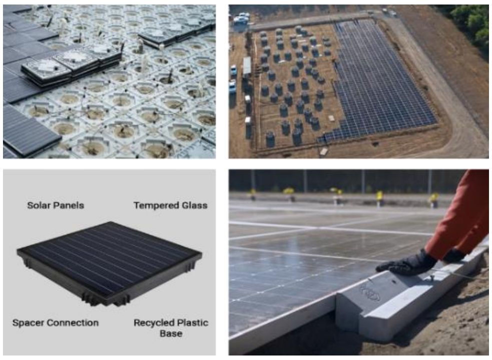

Fig.11 Examples of PV pavement (Ertho Co).

4.7 Photovoltaic Facade Systems:

An ideal solution for buildings that lack suitable roofs for conventional rooftop installations or as an addition to existing rooftop PV systems. These systems are typically installed on south-facing walls, either parallel to the wall or with a slight tilt, [22], these systems as Curtain walls, Double Skin Facades, rain screen facades, Solar windows Fig. 12, or buildings that have PV integrated into external integrated devices (balustrade, Canopy, solar shadings. Etc) with transparent PV cells or not with the same mounted to traditional systems [12], Compared to rooftop PV systems, facade systems generally produce less energy but exhibit higher electricity production during winter months. While installation and maintenance are easier, facade systems tend to be more expensive [22].

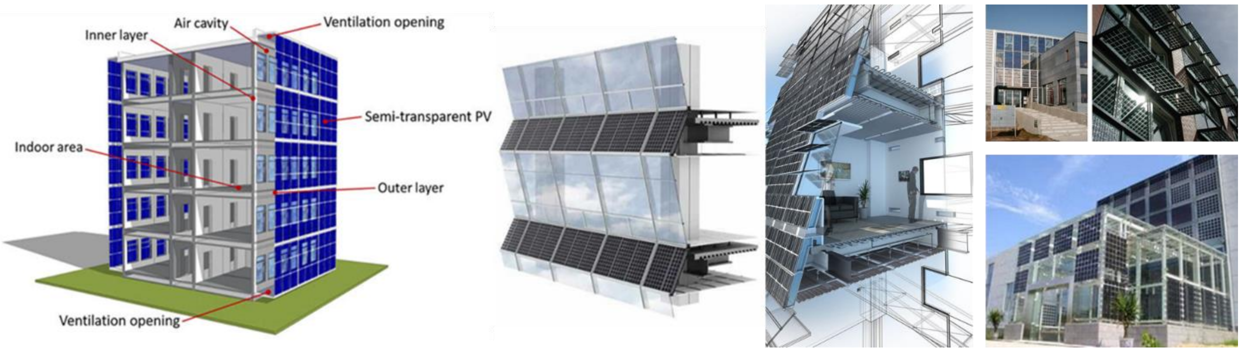

Fig.12. examples and details of PV Facades systems

4.8 Photovoltaic Noise Barrier (PVNB):

An external structure that is aesthetically harmonious with its surrounding urban environment and with a double function, It is designed to be a physical obstruction to lower noise levels between noise sources (highways, Railways, Etc) around populated areas and sensitive receptors such as hospitals, schools, and residential buildings (typically reduce overall Noise levels by 5 to 10 dB/ one ha), and produce clean and free energy thanks to the sun [23], there many of PVNB Solutions Fig.13 to mount PV panels to Noise Barrier as Rear side integrated which PV Noise barrier located to the side south of the road, Top Mount with the flexibility to change the orientation, combination by using bifacial PV cell which Possibility Located to the north side of the road [24], Integrated mount (cassette, Zigzag, Fully-integrated designed), or Artificial or Earthen Berm-mounted),..etc. [23]

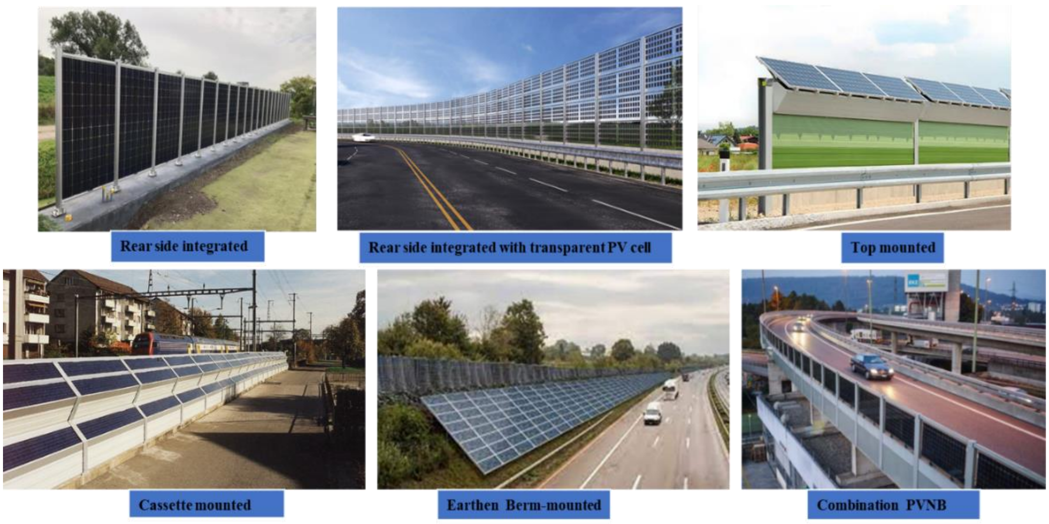

Fig.13 Example of PVNB

4.9 Photovoltaic Urban Furniture:

Including tables, canopies, benches, pergolas, lighting units, and poles, now can harness clean solar energy. This innovative furniture integrates a photovoltaic glass module, which utilizes either crystalline Silicon cells or amorphous Silicon for overcast conditions and electrical equipment needed for the connection of electronic devices via a USB port. It also comes with a battery to store and use electricity whenever needed [25].

Fig.14. Examples of PV Urban Furniture

5. PV projects Examples

In this part of the research, examples of various applied projects on integrating photovoltaic cells in the urban environment were reviewed, such as the photovoltaic floor, PV Canopy, PV Balustrade, PV carport, and PV Noise Barrier, and application importance in Energy generation and reduce Co2 emissions which causes raise in temperature and air pollution which have bad effects on public health.

5.1 Photovoltaic Floor, Mendes Gonçalves building, Portugal.[26]

The Mendes Gonçalves building entrance underwent redevelopment by the Onyx Solar Company. They installed a 21 m² photovoltaic system made of colored Amorphous silicon glass with a non-slip coating on the outdoor flooring of the Main Entrance. The glass panels, measuring 298x600 mm, are backlit with green LED strips. Over 35 years, this application is estimated to generate 50,408 kWh of electricity. Additionally, a total of 99 lighting points will operate for 4 hours per day, resulting in an avoidance of 34 tons of CO_2 emissions. Fig.15

Fig.15. details of PV flooring installation

5.2 Photovoltaic Canopy, Tanjong Pagar, Singapore. [27]

The Tanjong Pagar building in Singapore features a large photovoltaic canopy that has obtained both Designed by Onyx Solar Company, the canopy covers the main entrance and spans 2,624 square meters with a power capacity of 125 kWh, It consists of 858 amorphous silicon photovoltaic glass modules, each measuring 2,456 mm x 1,245 mm, with a transparency grade of 10% (M vision). Over 35 years, this application is estimated to generate 3,654,781 kWh of electricity and provide lighting for 7,169 points operating 4 hours per day. Additionally, it will result in a reduction of 2,449 tons of CO_2 emissions and an 86% reduction in HVAC energy demand. Fig.16

Fig.16. Picture of PV Canopy in Tanjong Pagar Building

5.3 Photovoltaic Balustrade, the Eco-Building Generation office, China.[28]

The Eco-Building Generation office in China features a photovoltaic balustrade with a total area of 340 square meters. The high-transparency amorphous photovoltaic glass, installed by Onyx Solar Company, is estimated to generate 191,048 kWh of electricity over 35 years. Additionally, it will provide lighting for 345 points operating 4 hours per day and result in an avoidance of 128 tons of CO2 emissions Fig 17.

Fig.17. Picture of Balustrade

5.4 PV Carport, Jinan East Service Area Photovoltaic Project, China [29]

Jinan East Service Area's carport represents the first "Zero-carbon service area" The canopy is equipped with N-type bifacial double glass modules with a Capacity of 3.2MW installed by DAS Solar's Company, while the slope will be fitted with lightweight flexible modules. the photovoltaic system generates around 10,000 kWh/day and helps to reduce CO_2 emissions by approximately 850 tons each year, Fig 18.

Fig .18. PV Canopy of Jinan East Service Area

5.5 PV thermal noise barrier, Gyeryong, South Korea [30]

The Korea Institute of Energy Research has created a 3kW solar noise barrier in Gyeryong, South Korea. This innovative barrier combines PV modules, solar-thermal collectors, and airflow to optimize energy production. Excess heat from the PV panels is efficiently transferred to the solar collectors, reducing the PV system's operating temperature. The system also incorporates sound-absorbing material, achieving a sound absorption performance of 0.83 (compared to 0.7 in standard noise barriers). Additionally, the system's sound insulation performance at 1000 Hz is 37.1 decibels (dB), significantly better than conventional systems (around 30 dB). Overall, the PV system generates approximately 6% more electricity and produces 400Wt per square meter of heat for heating and ventilation purposes. Fig 19.

Fig.19. Picture of PV thermal Noise barrier details

The analytical part can be summarized in the following table.

Table 1. A comparison between selected applied projects in terms of electricity production and reducing carbon dioxide emissions

Project	PV Application	Electricity production	Co2 emission avoid
Mendes Gonçalves building	flooring pavers	50,408 kWh through35Y	34 tons / 35 Y
The Tanjong Pagar	Canopy	3,654,781 kWh through35Y	2,449 tons /35Y
the Eco-Building Generation office	balustrade	191,048 kWh through35Y	128 tons /35Y
Jinan East Service Area	PV carport	10,000 kWh/day	850 tons/ year
Gyeryong city	Noise barrier	40 Watt/ m²	unknown

6. Results Effects of Photovoltaic Applications on Public Health

The integration of photovoltaic cells into the urban environment has several positive impacts on public health:

- ✓ **Reducing Heat Islands**: Photovoltaic applications absorb solar radiation, helping to mitigate heat islands. This reduction in high temperatures positively affects thermal comfort and human activity.
- ✓ **Noise Reduction**: PV noise barriers along motorized transportation routes decrease noise levels. This reduction in noise exposure contributes to better health outcomes by preventing issues such as hearing loss, lack of concentration, and increased stress for residents and workers near busy roads.
- ✓ **Visual Connection and Mood Improvement**: Building-integrated photovoltaics (BIPV), such as transparent facades, atriums, skylights, and PV rooftops, visually connect internal spaces with the surrounding environment. This enhances thermal comfort and improves mood.
- ✓ **Supporting Walkability**: BIPV pedestrian paths promote walking, which positively impacts mood, cognition, memory, sleep, balance, and coordination. These paths are an alternative to asphalt and concrete, which contribute to heat islands.
- ✓ **Reducing Carbon Emissions**: Photovoltaic applications help reduce carbon emissions, which are linked to respiratory and nervous system diseases.
- ✓ **Financial Benefits**: Photovoltaic cell applications reduce building operating costs and improve income for individuals. These financial benefits positively impact mental health and overall quality of life.

7. Recommendations for expanding the use of PV in the Urban Environment

The integration of **photovoltaic cells** into the urban environment has several positive impacts on public health. To enhance opportunities for these applications in both existing and future cities, consider the following proposals:

- ✓ **Building Licensing Requirements**: Make it a requirement for building licensing in investment projects to partially or entirely rely on photovoltaic cell applications to meet the energy needs of the building.
- ✓ **Sponsorship Agreements**: Collaborate with sponsors to cover the costs of installing photovoltaic cell systems in urban areas. In return, offer free advertising for their companies for a duration proportional to their financial contribution to the installation costs. Alternatively, consider tax deductions for sponsors.
- ✓ **Charitable Initiatives**: Encourage charitable organizations to invest in installing photovoltaic cells in places of worship and low-income residential areas. This not only promotes clean energy but also benefits the communities they serve.
- ✓ **Community Awareness**: Local authorities should actively raise awareness about the importance of photovoltaic cell applications for generating clean energy. Additionally, they should facilitate support and provide necessary facilities to specialized companies offering highly efficient products that can be easily purchased.

By implementing these proposals, we can create a more sustainable and health-conscious urban environment.

8. Conclusion

The integration of photovoltaic cells into the urban environment has several positive impacts on public health. These applications, whether at the building level (such as PV facades, roofs, and external devices) or in open spaces (such as urban furniture, flooring pavers, and noise barriers), offer benefits such as Reducing Heat Islands, Noise Reduction, Visual Connection and Mood Improvement, Supporting Walkability, Reducing Carbon Emissions and Financial Benefits, the research suggested some recommendation to enhance opportunities for these applications in both existing and future cities such as cooperations between local authorities and sponsors or charitable initiatives for investment in PV applications, Making concessions for the population to rely on solar energy to provide energy, and working to produce more efficient cells at an economical price

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