**Construction and energy aspects of affordable housing developments for formal settlements**

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# Abstract:

Nearly one quarter of the world’s urban population lives in informal settlements or encampments, most in developing countries but increasingly also in the most affluent countries. Many residents live in overcrowded, insecure dwellings, without water and sanitation, fearful of eviction and subject to preventable life-threatening illnesses. UN Sustainable Development Goal 11: “Make cities and human settlements inclusive, safe, resilient and sustainable” is committed to ensure access for all to adequate, safe and affordable housing and upgrade slums by 2030. There is therefore an urgent need for more affordable and permanent housing to be developed. This paper presents a review of the construction and energy aspects of affordable housing developments for informal settlement dwellers. The conditions of existing informal settlements in Global South countries have been researched and various case studies of informal settlement upgrading programmes are presented. The potentials of solar energy technologies in development of green affordable houses in case study countries Uganda and Indonesia are assessed.

# 1. Introduction

An estimated 330 million households worldwide were living in inadequate housing or struggling to meet housing costs in 2014, while 880 million people were living in slums in developing countries (UN Habitat, 2015). Figure 1 shows that global population growth continues to manifest itself in urban areas and is particularly prevalent in developing Global South countries (UN Department of Economic and Social Affairs, 2018), which are also most vulnerable to the effects of climate change (Stern, 2007). Inadequate housing leads to many issues ranging from economic stagnancy to severe public health problems. Providing adequate and affordable housing at a local level acts as a development multiplier by stimulating housing construction and finance industries, creating jobs and reducing poverty. Low-cost housing also has vast potential to contribute to global sustainability across multiple dimensions; environmental, economic, social and cultural. This paper will focus on populations living in informal settlements. The conditions of existing informal settlements in Global South countries have been researched and various case studies of informal settlement upgrading programmes are presented. The potentials of green energy technologies in development of formal settlements in two case study countries of Uganda and Indonesia are investigated.



**Figure 1:** World total, urban\* and rural populations 1950-2015 with projections for 2015-2050.

\*More developed regions = Europe, North America, Australia, New Zealand, Japan

Less developed regions = Africa, Asia (excl. China and Japan), Latin America & the Caribbean, Melanesia, Micronesia and Polynesia

# 2. Global population growth and urbanisation

## 2.1 Global context

The combination of natural population growth and migration from rural to urban regions results in rapidly growing urban populations in the world’s cities. By 2030, 60% of the world’s population will live in cities and 90% of urban growth will occur in Global South countries (UN Department of Economic and Social Affairs, 2018) (Seto, et al., 2011). Urban population increase is most prevalent in developing countries, while rates of urbanisation are slowing in more developed regions such as Europe and North America. Asia and Africa are home to the largest and most rapidly growing urban populations, with the highest proportion of slum-dwellers, as indicated by Figures 2 and 3. Sub-Saharan Africa has consistently had the highest urban growth rate in the world since 1970, and in 2018, 56.2% of the urban population lived in slums (UN Habitat Urban Indicators Database, 2020). However, there is already a significant housing deficit in most cities, and the rate of house building cannot keep up with the rate of urban growth. Consequently, the lack of affordable, adequate housing intensifies, which leads to a rise in numbers of informal settlements and slums. Figure 4 shows that the number of people living in slums worldwide was estimated to be more than 880 million in 2015. However, despite the increase in the absolute number of people living in slums, the relative proportion compared to the total urban population decreased consistently over 25 years (UN Habitat, 2015) (UN Habitat Urban Indicators Database, 2020).



**Figure 2:** Urban population of the 6 major contingents 1950-2015 with projections for 2015-2050.



**Figure 3:** Percentage of urban population of different regions living in slums in 2018.



**Figure 4:** Number and proportion of global urban residents living in slums 1990-2015.

## 2.2 Uganda and Indonesia context

The 2020 population of Uganda and Indonesia is 45.7 million and 273.5 million, respectively. 25% of Ugandans live in urban areas compared to 57% in Indonesia (UN Department of Economic and Social Affairs, 2018). Figures 5 and 6 illustrate that in both countries the urban population growth rate continues to exceed the total population growth rate. In 2016, Uganda faced a housing backlog of 1.6 million units, increasing by 140,000 each year (MLHUD, 2016). In 2013, the housing deficit in Indonesia was 11.8 million, increasing by around 300,000 annually (The World Bank, 2016).

|  |  |
| --- | --- |
|  |  |
| **Figure 5:** Uganda total and urban population growth rates 1950-2015 with projections for 2015-2050. | **Figure 6:** Indonesia total and urban population growth rates 1950-2015 with projections for 2015-2050. |

# 3. Defining adequate and affordable housing

## 3.1 Overview

The Universal Declaration of Human Rights acknowledges the ‘right to adequate housing’ for all people; not simply a physical structure, this encapsulates the right ‘to live somewhere in security, peace and dignity’ (OHCHR, 2009). The UN Human Settlements Programme defines adequate housing as that which lacks none of 5 key ‘shelter deprivations’ (UN Habitat, 2011a): (1) Durability/structural quality, (2) Sufficient living space, (3) Access to improved water, (4) Access to improved sanitation and (5) Security of tenure. Inadequate or ‘slum’ housing lacks one or more of these shelter deprivations. Furthermore, UN Habitat defines ‘affordable housing’ as that which ‘does not cost so much that it prohibits its occupants meeting other basic living costs or threatens their enjoyment of basic human rights’ (UN Habitat, 2011a). Figure 7 shows the capital and occupational variables that contribute to housing affordability. Various methods exist for measuring housing affordability (Bogdon & Can, 1997), such as price-to-income and rent-to-income ratios. A more specific measure is to represent housing costs as a proportion of household income; a household which spends more than 40% of its income on housing is considered ‘overburdened’ (Urban 20, 2018). (UN Habitat, 2011a) lists five major contributors to the cost of housing: land, materials, labour, infrastructure and finance. The availability and cost of these components directly impacts the affordability of housing produced. The most significant contributors are the high cost of land and lack of affordable finance schemes. There is a chronic shortage of suitable urban land, particularly in Africa. Providing low-cost housing in developing countries is not as straightforward as building physical shelters; it requires long-term government strategies (Chakraborty, 2017) (Sahoo, 2016), a participatory approach (Sadiqi, et al., 2013) (Guevara, 2014) and ongoing evaluation.

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**Figure 7:** Capital and occupational variables contributing to housing affordability

## 3.2 Sustainability

The United Nations Sustainable Development Goals, set in 2015, outline 17 targets towards a more sustainable world by 2030, including ‘access to basic services, ownership and control over land and other forms of property’ (Target 1.4) and ‘access for all to adequate, safe and affordable housing’ (Target 11.1) (UN Department for Economic and Social Affairs, 2015). Sustainability is split into four dimensions: environmental, economic, social and cultural; these dimensions, within the context of low-cost housing in the Global South, are explored hereafter.

### Environmental

One of the key methods of ensuring environmental sustainability is to minimise the embodied energy and embodied carbon of the materials used. Naturally occurring materials such as bamboo, timber, straw, earth and stone require minimal energy to convert into suitable building components. Moreover, they can often be sourced locally to the site of construction, minimising energy consumption and carbon emissions from transportation. However, in many areas, particularly in Africa, deforestation is a serious issue and timber should be avoided as a building material until forests can be restored. Alternative resources such as earth and stone are more abundant, particularly in volcanic regions in East Africa. Additionally, design and construction should aim to integrate national housing and energy systems, ensure adequate location and density of residential areas, and protect local ecosystems by preventing pollution and promoting efficient use of water.

Alongside urban population growth, urban land expansion is increasing rapidly and is just as likely to occur near IUCN Protected Areas as in other locations, threatening valuable ecosystems. (Seto, et al., 2011) predicted an increase in global urban land cover of up to 12.5 million km2 by 2030, with fastest growth occurring in low-elevation coastal zones, which are at increasing risk of flooding due to climate change.

### Economic

### Economic sustainability is a crucial component of low-cost housing schemes, particularly in developing countries; housing programmes must be able to survive financially in the long-term. Institutional frameworks at national, regional and local levels must can regulate land and housing markets to balance supply with demand (Guevara, 2014). Design of community housing schemes should also take into account domestic economic activities and local entrepreneurship; particularly for women, home-based enterprises are an important source of income in developing countries. Housing plays an important role in regional and urban regeneration and should be well-integrated with local employment opportunities (UN Habitat, 2012).

### Social and cultural

Effective community housing schemes must promote public participation and social cohesion. Good access to fundamental infrastructure and public spaces is essential to avoid social isolation and fragmentation, particularly of politically marginalised groups (Sahoo, 2016). It is important to understand the history and identity of a community to provide appropriate housing within its local context. Communities, particularly from a rural background, are often wary of contemporary design and materials. While introducing new methods and technologies may be advantageous, it must not risk erasing cultural styles and practices. Therefore, while low-cost housing initiatives should be innovative, they must also be culturally sensitive. This allows a smooth transition for residents into new housing and increases the likelihood of future community involvement in the promotion and growth of such housing programmes. Local knowledge can be a valuable resource, particularly with regard to sustainable materials, energy efficiency and resilient buildings (Mulligan, et al., 2017). Housing projects should work closely with the community to maximise creativity and resourcefulness, particularly when solving local problems.

# 4. Construction of informal settlements and affordable housing initiatives

## 4.1 Construction of existing informal settlements

### Materials

Informal settlements (also known as slums, shanty towns, townships and favelas according to their global location) vary greatly in the materials used to construct them, depending on what is cheap and locally available. Townships in Africa commonly use corrugated iron, plastic crates, timber, straw and mud to form single-storey structures. Conversely, favelasin South America are more likely to include concrete and masonry but are poorly constructed and rarely meet standard engineering requirements. Materials must be small and lightweight enough for manual transportation, particularly among narrow, uneven streets. Buildings often appear mismatched and patchwork-like due to the spontaneous nature of development. Structures lack durability and require frequent maintenance and repairs, using whichever materials are available nearby.

### Size and location

Individual property sizes vary in informal settlements, particularly in different countries. Typical shacks in African townships are approximately 13m2, single room, single-storey structures (Grain of Rice Project, 2020). Sanitation facilities comprise an open toilet shared between around 50 households. Favelas in Rio de Janeiro contain houses that are 3-4 storeys tall. This is due to the incremental nature of construction in which each generation builds a new floor atop the existing family home; the severe shortage of affordable land motivates people to build upwards rather than outwards. The area of each floor is approximately 45m2 (Veysseyre, 2014). Informal settlements develop around city peripheries as populations migrate towards urban centres. Unoccupied land is cheaper on the outskirts of urban areas, but is often difficult to build on, hazardous and disconnected from urban infrastructure. Informal settlements often spread up steep slopes, like in Columbia and Haiti. Alternatively, communities are forced to build on flood plains, where regular flooding causes unstable ground, structural damage and poor sanitation. A lack of proper foundations exacerbates problems. Furthermore, a lack of infrastructure such as public transport connections to the city centres, where education, health and employment opportunities lie, makes informal settlements socially and economically isolated (Mesquita & Kos, 2017). The absence of other vital infrastructure including energy, water supply and drainage adds to the difficulties of living in these areas.

### Land ownership and Health and Safety

In many informal settlements, residents have illegally occupied available land outside cities due to the unaffordability of formal housing within city boundaries. In some settlements, informal rental schemes have developed where local landlords rent out rooms, often at unfair prices. Families often rent out sections of their house to friends and relatives. Due to the lack of formal, legal home ownership, tenure is very uncertain for many residents, and there is a high risk of forced eviction (Potts, 2011) (Khan, 1994). This is most prevalent in urban areas; across Kenya in 2002, 79% households owned their home, but in the capital, Nairobi, this fell to 18% (UN Habitat, 2011a).

Informal settlements are often characterised by poor hygiene due to a lack of adequate sanitation, water, electricity and ventilation (Richards, et al., 2007). Open sewers and rubbish dumps cause heavy pollution and increased fire hazards. Residents in informal settlements are at increased risk of disease, a problem exacerbated by the scarcity of hospital treatment facilities and rapid transmission amongst densely packed communities. High crime rates are also a problem in informal settlements and slums due to a lack of basic policing and infrastructure, and violence against women is distressingly common.

## 4.2 Case studies of formal settlement development initiatives

### Unsuccessful case studies

#### Brazil ‘Minha Casa, Minha Vida’

The Brazilian government began the ‘My House, My Life’ housing programme in 2009 which aimed to provide homes for low-income families and create financial incentives for further housing construction. By 2016, approximately 4 million housing units had been created for low-income families earning up to 10 national minimum wages. Despite being the largest affordable housing scheme in the country’s history, the programme was widely criticised. Houses were poorly located on the urban periphery, where land was cheap but lacked basic services such as transport, health, education and employment, and was also prone to flooding. According to one article, 53 percent of the units in Rio de Janeiro were built 50 km from the city centre, ‘up to four hours and multiple transfer fees away from areas of employment and from the centres of urban resources’ (Linke, 2018). Furthermore, financial incentives and subsidies were given to the developers rather than the potential homeowners, who used cheap land and poor-quality construction to maximise their profits. The end-users had no influence on the design, which resulted in inflexible, repetitive prefabricated units that were poorly suited to a range of family requirements and ill-suited to varying terrain profiles (Mesquita & Kos, 2017).

#### Ethiopia Condominiums

Launched in 2005, the Ethiopian Integrated Housing Development Programme aimed to reduce slum areas in the capital of Addis Ababa by 50%, as well as in 9 other regions of the country. 400,000 units were planned, yet less than half had been built by 2011 (UN Habitat, 2011b). The programme marked a shift from state-owned rental housing to private homeownership but had limited success. The buildings were multi-storey condominiums with communal indoor and outdoor spaces. Each household owned a unit in a condominium block, and all residents shared ownership of the communal areas. The programme highlighted the importance of cultural requirements and community preference; residents were used to living in detached bungalows which promoted open flow and interaction within the community, particularly regarding domestic enterprises operating on doorsteps. They disliked the new vertical apartment blocks which were regarded as an eye-sore, and many programmes outside the capital were abandoned. Affordability was also an issue, as many low-income houses could not afford to purchase a unit or were forced to rent it out to maintain mortgage payments once they bought it. In Hawassa in the south, more than 60% of households in a 2015 survey of condominium housing spent more than 30% of their income on housing expenses and were thus ‘shelter poor’ (Regassa & Regassa, 2015). Like with similar programmes, communities were located on the periphery of cities, with poor access to public services.

#### Ghana low-cost government housing

This case study demonstrates that it is not always a physical lack of housing that causes growth of informal settlements; lack of affordability and realistic finance schemes are a huge problem. A typical low-cost government-built house in Ghana costs at least 9,000 USD. On a minimum wage equivalent to 0.87 USD/day, it would take a family four years to afford the deposit for the house, and a further 34 years to pay off the remainder based on a costly 50% income contribution (UN Habitat, 2011a).

### Successful case studies

#### Smart Havens Africa, Uganda

Smart Havens Africa is a highly successful social enterprise, established in Uganda in 2015 to provide low-cost, environmentally sustainable homes for low-income families, particularly female-headed households. The business operates a rent-to-buy scheme where families can aim for full legal ownership of their property within 3-5 years. Houses cost 17,500 Ugandan Shillings a day (less than US$5) and families are guaranteed to not spend more than 30% of their income on paying for their houses (SHA, 2020). The units range from 2 to 4-bedroom houses, with two toilets and a small garden. They are fully serviced with water and energy and are in areas with education and employment opportunities. Families are offered property and financial management training to help them manage their household finances and make the most of their homeownership. The scheme lifts families out of poverty, providing them with safe and healthy homes and financial security. By 2020, SHA had built more than 80 homes, benefitting 400 people. The programme aims to build a thousand homes a year and spread into neighbouring African countries. Furthermore, the programme aims to involve more women in civil engineering and construction, through training programmes and employment. Construction of a single house creates 25 jobs both directly and indirectly, boosting the local economy. The programme is closely aligned with the UN Sustainable Development Goals and pioneers the use of interlocking stabilised soil bricks (ISSBs).

Soil stabilisation is the process of improving the strength, durability and density of earth bricks via physical or chemical methods, such as compaction or addition of cement, to meet specific engineering requirements (Venkatarama Reddy, 2012). Compressed stabilised earth bricks (CSEBs) can be made easily and rapidly on site, using local raw materials and manual or hydraulic machines, which reduces transport costs and emissions. CSEBs have good thermal, acoustic and fire-resistance properties. The embodied energy of CSEBs is 550-700MJ/m3 compared to 2200MJ/m3 for traditional burnt clay bricks (Venkatarama Reddy, 2012). The soil mixture can be varied according to the soil type and availability of stabilisers; natural additives such as plant fibres, resin, sand or gravel can be used as an alternative to cement. ISSBs are a type of CSEB made with an interlocking edge which require significantly less mortar and allow for rapid wall construction. ISSBs are a low-cost, sustainable and easy to manufacture building material that provides an ideal solution for self-build community housing. Furthermore, SHA has protected local, endangered forests by using ISSBs, which do not require firing in a wood-fired kiln.

#### *UN Sustainable housing reconstruction in Eastern DRC*

Following years of civil unrest in the Democratic Republic of Congo, UN Habitat led a programme of sustainable and disaster-resilient housing reconstruction (UN Habitat, 2016). Earthen architecture was chosen as the most suitable approach as the materials are widely available, cheap and relatively simple to manufacture. Timber was avoided due to deforestation issues in the region. Due to the active Nyiragongo volcano in the DRC, lava stone is an abundant local material in some areas, well-suited to foundation and wall construction. A combination of stone, adobe and CSEBs with 5% cement reinforcement were used in construction of these houses. CSEBs were used in the most critical areas which required extra strength. In areas where lava stone was more available, the bottom portion of the walls was constructed from stone instead. A demonstration house was first constructed to show the local community what the new houses would look and feel like. This played a significant role in convincing the residents to support the new project and embrace the training provided. The construction was incremental; a main core of 11.2m2 is built comprising a kitchen, main room and roof, with the option of adding two extra rooms up to a total 24.5m2. The large, overhanging roof is built first to provide shelter and protection from rain. The outside terrace allows for safe, sheltered cooking whilst maintaining safe air quality inside the building.

#### *SAFE Bangladesh*

Simple Action for the Environment (SAFE) built 10 affordable and sustainable houses in Dinajpur in Eastern Bangladesh. Made from bamboo, earth, CSEBs and corrugated steel, house types included a detached single storey house, with a floor area of approximately 28m2, and a two-storey semi-detached house with a floor area of 23m2 (Arnold, 2013). Bamboo is treated with a borax solution to prevent it rotting. Innovative bamboo cross bracing with bolted connections was tested and used in the houses to demonstrate more stable design and construction, with guidance leaflets published in both English and Bangla. A wattle-and-daub approach was used for the walls by applying cement-stabilised earth to a bamboo lattice frame. Cement-stabilised earth was also used to construct durable foundation plinths for the houses, which are raised to protect against flooding. A review of these construction materials and methods in Bangladesh concluded they have vast potential as cost-efficient, low carbon and sustainable housing solutions, but must be made more affordable and accessible in order for this potential to be realised (Haque, et al., 2020).

#### KDI, Kenya

Kounkuey Design Initiative is a non-profit design and build organisation that has worked to upgrade community buildings in Kibera, Africa’s largest slum, since 2006 (KDI, 2020). Through a series of interactive workshops with the community, appropriate designs for public spaces are produced whilst also providing training in business and project management skills. The projects emphasise self-sufficiency and sustainability; by engaging residents from the outset, they ensure a participatory approach to design and construction, which enables a more effective response to ‘community concerns and capacity’ (Mullgian, et al., 2020). Focus is given to women and youth to provide a platform for enterprise and income generation. This enables future self-driven development within communities, demonstrating economic, social and cultural sustainability. KDI’s projects include schools, community centres, sanitation blocks, offices and flood resilience measures. Buildings utilise a mixture of wattle and daub construction, corrugated iron, concrete foundations, timber roofs and compressed stabilised earth bricks (CSEBs) to replicate the vernacular style of Kibera’s buildings in an environmentally and structurally stable way. Gabions and proper drainage systems were installed to protect against flooding. As a result of KDI’s ongoing work, hundreds of students have benefitted from new schools; pedestrian links have been improved between Kibera and the wider city via bridges; an interactive web portal using GIS technology allows residents to access local water and sewage infrastructure; and public space remediation projects have served tens of thousands of residents and established a network of over 250 community leaders. This has improved the safety, sanitation and economic prospects of the community and has informed climate-resilient settlement upgrading policies in Kenya and other African countries (KDI, 2020).

# 5. Green energy use in formal settlements

## 5.1 Energy efficiency technologies

Energy efficiency is the one of the main goals when developing low-cost sustainable housing. Based on the definition given by (Yang & X. Yu, 2015) “energy-efficient technologies refer to technologies that reduce the consumption of energy required to provide goods and services”. With technologies like energy-efficient lighting, window, HVAC system, household appliances (e.g., energy‐efficient refrigerators, dryers, and washers), renewable energy systems (e.g., wind turbines, solar panels, and ground source [geothermal] heat pumps), building orientation and configuration, and natural ventilation an energy efficient home can be built. Table 1 summarizes the architectural, mechanical and electrical parameters than need to be considered for design of energy efficient houses.

**Table 1:** Energy efficient parameter at design stage (Roufechaei, et al., 2014)

|  |  |
| --- | --- |
| Architectural | Application of passive solar (take advantage of climate conditions) |
| Use energy efficiency and renewable energy sources |
| Use wooden logs to provide structure and insulation |
| Optimization building orientation and configuration |
| Application of green roof technology |
| Optimization building envelope thermal performance |
| Insulation (roofs, windows, floors, walls and exterior doors) |
| Application of natural ventilation |
| Ample ventilation for pollutant and thermal control |
| Mechanical | Cooling and heating system (environmentally friendly materials for HVAC system) |
| Application of ground source heat pump |
| Application of efficient water heating |
| Application of solar water heater |
| Insulation tank and pipes |
| Demand tank less water heater |
| Application of thermostats, ducts and metres |
| Electrical | Making clean electricity (application of solar system technology) |
| Application of lighting choices to save energy |
| Application of lighting product |
| Application of artificial lighting |
| Use of efficient type of lighting (lighting output and colour) |
| Integrative use of natural lighting (day lighting) with electric lighting system |

## 5.2. Integrated Photovoltaic Systems (BIPV) for formal settlements in Uganda and Indonesia

The feasibility of the use of Building Integrated Photovoltaic Systems (BIPV) as a green energy technology solution in the development of affordable houses in two case study countries of Uganda and Indonesia were assessed. The summary of the key assumptions and the findings in terms of the predicted monthly energy production and the regional economic and environmental benefits of using the PV systems are presented in this paper. The conducted modelling study determined the technical sizing of the roof PV modules for two considered locations Bantul, Yogyakarta, Indonesia and Bukalango, Kampala, Uganda – these are the locations of low-cost houses. The objective of the technical sizing was to ensure maximum output i.e. energy production of the system. The technical sizing parameters included the size and the number of inverter panels that were optimised to give maximum energy production. In the design process, the necessary local rules and requirements, e.g. from fire department and building codes, related to the case study locations were considered. For both locations, the PV cells used for this simulation were monocrystalline module with a nominal power of 330 W. The details of the designed PV systems for both locations are presented in Table 2.

Figures 8 and 9 show the monthly energy production for Bantul, Yogyakarta, Indonesia and Bukalango, Kampala, Uganda, respectively. For Bantul, the annual production of energy is 12.67 MWh and the highest production of energy is observed during the months of May and August at 1200 kWh. For Bukalango, the annual production of energy is 11.14 MWh and the highest production of energy is observed during March which is 1005 kWh. The cost of electricity generation for the optimised PV designs were estimated using the Levelized Cost of Electricity (LCOE) method (PVsyst 7 Help). The Feed-in-Tariff for Indonesia is $0.114/kWh and for Uganda is $0.372/kWh. The payback period for Indonesia is 12.5 years with an LCOE of $0.025/kWh. For Uganda, the yearly cost is $0.06/Wp/year and the payback period for the PV systems for the residential area in Uganda is 11.8 years with an LCOE of $0.041/kWh. Installing residential PV systems can benefit the environment in terms of reducing carbon footprints. The carbon reduction is calculated based on Lifecycle emission (LCE) calculation in PVsyst hich represents the emissions of CO2 related to a certain component of the technology and the amount of energy produced. The carbon balance tool proves that the electricity produced by PV cells produce a lower carbon footprint compared to that produced by grid electricity. For the installation of PV systems on rooftops in Uganda, the amount of CO2 emission can be reduced by 128.902 tonnes per year for each home In Indonesia’s case, the amount of CO2 can be reduced by 110.867 tonnes per year for each home. The installation of residential PV systems benefits the users and the environment greatly and therefore is a sustainable option in the long run.

**Table 2:** Specifications of PV system designs for Bantul, Yogyakarta and Bukalango, Kampala

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Parameter** | **Bantul, Yogyakarta** | | **Bukalango, Kampala** | | |
| **Specifications of PV Designs** | | | | |
| Performance Ratio | 75.5 % | | 77.0 % | | |
| Irradiance | kWh/m2 | | kWh/m2 | | |
| Energy | kWh | | kWh | | |
| Racking | Flush Mount | | Flush Mount | | |
| DC/AC ratio | 1.02 | | 0.92 | | |
| Weather Dataset | TMY, 10 km Grid, meteonorm | | TMY, 10 km Grid, meteonorm | | |
| Solar Angle Location | Meteo Lat/Lng | | Meteo Lat/Lng | | |
| Transposition Model | Perez Model | | Perez Model | | |
| Temperature Model | Sandia Model | | Sandia Model | | |
| Soiling | 2 % | | 2 % | | |
| Irradiance Variance | 5 % | | 5 % | | |
| Cell Temperature Spread | 4°C | | 4°C | | |
| Module Binning Range | -2.5% to 2.5% | | -2.5% to 2.5% | | |
| AC System Derate | 0.50% | | 0.50 % | | |
| **Parameter** | **System Components** | | | | |
| **Name** | **Count** | | **Name** | **Count** |
| Modules | Hanwa, Q. PEAK DUO-G7-330 | 30 (9.9kW) | | Hanwa, Q. PEAK DUO-G7-330 | 25 (8.25 kW) |
| Inverters | AE5.0 (277 V) | 2 (9.66 kW) | | AE5.0 (208 V) | 2 (8.94 kW) |
| String Wiring | 10 AWG (Copper) | 3 (23.7m) | | 10 AWG (Copper) | 3 (16.7m) |
| Optimizers | V750-13.5 | 3 (28.5 kW) | | V750-13.5 | 2 (19.0 kW) |
| Cells per String | 8-13 | - | | 10-14 |  |
| AC Home Runs | 12 AWG (Copper) | 1(10.6 m) | | - | - |
| AC Home Runs | 500 mm2 (Copper) | 3(23.7 m) | | - | - |
| AC Panels | 2 input AC Panel | 1 | | - | - |



1. Bantul, Yogyakarta, Indonesia



1. Bukalango, Kampala, Uganda

Figure 8: Monthly Energy Production for (a) Bantul, Yogyakarta, Indonesia and (b) Bukalango, Kampala, Uganda

# 6. Conclusions

This paper presented a review of the affordable housing development initiatives for populations living in informal settlements with a focus on the construction and energy aspects. The conditions of existing informal settlements in Global South countries were researched and various case studies of informal settlement upgrading programmes were presented. The presented upgrading scheme case studies indicated that providing low-cost housing in developing countries is not as straightforward as building physical shelters, and to work effectively, it requires long-term national and local government strategies and ongoing involvement. Affordability is a key factor and must be considered both in terms of the capital purchase cost of the house and the ongoing ability to finance it. From a construction point of view, case studies have shown that low-cost housing construction schemes are more successful when there is greater collaboration between developers and homeowners early in the design process. Furthermore, alongside the provision of housing there must be sufficient infrastructure providing access to education, healthcare and employment, to prevent isolation of poorer urban communities. The choice of materials plays a key role in determining affordability and sustainability of housing. Cement-stabilised earth construction has shown to be very effective in Africa and Asia. Continued innovation and refinement, such as the development of interlocking bricks, has improved the knowledge and application of this type of construction. However, further testing of the bricks is required in order to produce engineering guidance and standards that will allow CSEBs and ISSBs to be implemented at a greater scale worldwide. The potentials of green energy technologies, in particular solar energy, in development of green affordable houses were presented. The benefits of using solar energy PV systems in two case study countries of Uganda and Indonesia were assessed, and it was shown that substantial economic and environmental cost savings may be achieved by investing in such technologies in the development of affordable houses.

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