Solar PV facility screening study for public and educational facilities on Antigua and Barbuda

UN
Electric

United Nations Electricity Supply Partnership
Technical Report Final Draft 30 Jan 2018

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EXECUTIVE SUMMARY

The Government of Antigua and Barbuda (AB) has developed and is implementing a range of policies to adapt to and mitigate climate change. One small component of the ongoing programme of works is installation of solar photovoltaic and battery power supplies in public sector facilities.

The purpose of this technical study was to support the AB government in final site selection and scoping of the first phase of investment. The focus of the study was on the facility structures and their physical suitability for installation of either rooftop or ground mounted PC arrays and associated power management systems and small battery banks.

A total of 18 sites were inspected, 14 on Antigua and 4 on Barbuda. All were either government facilities or providing some form of public service, such as a school or children's home. The results are summarized in the table below and detailed in this report. Further inspection details and photographs are available online.

Facility	Recommendation summary
Antigua – GEF project	
Bendalls health clinic	Rooftop installation.
Bolans health clinic	Rooftop. Repair-strengthen roof
Fiennes institute – health facility	Ground mount
Good Shepherd Children's Home	Rooftop. Complicated installation
Holbertons Hospital – Children's Wing	Rooftop. Repair-strengthen roof
Holbertons Hospital - Hospice	Rooftop. Repair-strengthen roof
Nyahbinghi Theocracy School	New steel shade structure with rooftop PV
Old Road health clinic	Exclude due to major building structure problems
Parham health clinic	New steel shade structure with rooftop PV
Potters health clinic	Rooftop installation.
Swetes health clinic	Rooftop installation
Victory Centre – educational facility	Rooftop installation
Wilikies health clinic	Rooftop. Repair-strengthen roof
Antigua – future projects	
Clearvue Psychiatric Hospital	Rooftop. Repair-strengthen roof
Barbuda – future projects	
Airport fire station hangar	Rooftop. Check for demand
Codrington fire station	Rooftop – Integrate into rebuild works
Hannah Thomas Hospital	Rooftop – Integrate into rebuild works
Justice Center	Exclude. Building still in early construction stage.

To summarize the overall results, most sites were confirmed as suitable. Concurrent investments in strengthening the roofs and replacing sheet steel roof coverings were recommended in over half of the sites. Implementation of all recommendations in this report will escalate the cost per site beyond the original budget, hence the government may need to prioritize.

Final Draft 30 Jan 2018

1 INTRODUCTION

1.1 The study context

The Government of Antigua and Barbuda (AB) has developed and is implementing a range of policies to adapt to and mitigate climate change. One component of that effort is adaptation of public and public service buildings to climate change. The objectives and scope of the planned investments include:

- Reducing their vulnerability to wind and flood damage, via renovation of the structures and drainage;
- Reducing their reliance on the electrical grid, via installation of autonomous power supplies;
- Reducing their reliance on town water supplies, via installation of rainwater harvesting systems.

In the medium to long term, the AB Government plans to have the majority of key public buildings operating off grid with autonomous renewable energy power supplies and battery storage. These facilities will be in reach of and able to access the grid for back-up, but in general will operate as autonomous units. Grid electricity costs in AB are quite high (approximately US$0.40/kWhr), so this investment will also significantly reduce government operating costs.

The investment in buildings and associated energy systems will occur in phases. In January 2018, the AB government has up to 13 sites proposed for solar PV investment. Competitive procurement of a turn-key contractor is well advanced, based on an initial study in 2017 and an outline design.

The proposed approach to management of the works is to divide the scope into two main streams: a) PV installations and b) general building works, particularly for the roofs, that should precede or complement the PV installations.

The capital works will be financed from two main sources:

- The Global Environmental Facility, via the Inter-American Development Bank and Caribbean Development Bank;
- AB Government in-kind contributions;

There are three main pre-requisites for commencing implementation of this project in 2018:

1. Completing the screening study for final selection of the sites and analysis of any significant installation issues and design alternatives that need to be addressed;

2. Securing the finance for both the capital works and the oversight;
3. Detailed design and costed plan development by the contractor for each screened site and subsequent review and approval of those plans by the AB government.

Note that 18 sites were inspected in total, but only 13 sites on Antigua are proposed for GEF project investment. The other 5 sites will be incorporated into future building upgrade and adaptation projects.

1.2 Purpose and status of this report

This report is designed to fulfil the first pre-requisite listed above: Completing the screening study for final selection of the sites and analysis of any significant installation issues and design alternatives that need to be addressed.

The report is non-confidential and designed for circulation to the Government of Antigua and Barbuda, project donors and contractors. It should be read in conjunction with the main public procurement document for the project: *Bidding document for the design, supply and installation (Solar photovoltaic with battery storage electrical systems and accessories for schools and clinics in Antigua, ICDB no. SEF-ATG-001.*

1.3 UN Electric and CTCN

This study is financed by UN Electric and the Climate Change Technology Centre and Network, (CTCN) in response to a request from the Government of Antigua and Barbuda. It is a small-scale study, undertaken as the first component of a longer-term demand driven technical assistance programme.

UN Electric is the abbreviation for the United Nations Electricity Supply Partnership, which is a new multi-national public-private partnership. UN Electric is designed to support the sustainable development and where relevant the recovery of at least 40 countries, through the timely delivery of grid standard and renewable sourced electricity. In addition, UN Electric delivers a range of subsidized and donated services including local micro grid startup support, private sector capacity building, post-disaster reconstruction and recovery support, energy conservation awareness programmes, national government demand driven technical assistance and access to a new online based global geographic information system (GIS).

The CTCN provides technical assistance in response to requests submitted by developing countries via their nationally-selected focal points, or National Designated Entities (NDEs). Upon receipt of such requests, the Centre quickly mobilizes its global Network of climate technology experts to design and deliver a customized solution tailored to local needs. The CTCN delivers five main types of technical support on climate technologies:

- Technical assessments, including technical expertise and recommendations related to specific technology needs, identification of technologies, technology barriers, technology efficiency, as well as piloting and deployment of technologies.
- Technical support for policy and planning documents, include strategies and policies, roadmaps and action plans, regulations and legal measures
- Trainings
- Tools and methodologies
- Implementation plans

1.4 The study sites

A total of 18 sites were inspected, 14 on Antigua and 4 on Barbuda. All were either government facilities or providing some form of public service, such as a school or children's home. The majority were occupied and fully operational at the time of the inspection.

Facility
Antigua – GEF project
Bendals health clinic
Bolans health clinic
Fiennes institute – health facility
Good Shepherd Children's Home
Holbertons Hospital – Children's Wing
Holbertons Hospital - Hospice
Nyahbinghi Theocracy School
Old Road health clinic
Parham health clinic
Potters health clinic
Swetes health clinic
Victory Centre – educational facility
Wilikies health clinic
Antigua – Other projects
Clearvue Psychiatric Hospital
Barbuda – Other projects
Airport fire station hangar
Codrington fire station
Hannah Thomas Hospital
Justice Center

1.5 Study methodology and report contents

The study is a gap filling exercise for an ongoing project and so both the scope and the report are pragmatic and succinct.

The principal activity of the study was brief physical inspections of the proposed facilities over the period 9-12 January 2018. This entailed a walkaround of the buildings and their surrounds, internal inspections where needed and rooftop inspections in most cases. Two buildings visited were two storey and the remainder were one-storey. The roofs of all buildings were accessed by ladder. Facility staff were queried on selected issues.

The inspection protocol was based on a template for assessing site suitability. This template briefly covered the following issues:

- Roof structure and roof covering;
- Building structure;
- Access;
- Wind exposure;
- Shading;
- Tilt;
- Security
- Site flooding.

Antigua was not affected by the 2017 hurricane season whilst Barbuda was badly damaged. The older building methods and standards are near identical on the two islands, particularly for smaller structures. Hence an inspection of the hurricane damage and building failure modes on Barbuda provides an accurate picture of how many buildings in Antigua will perform in a hurricane.

he completed inspection notes for all of the sites is provided as a separate Excel spreadsheet. In addition, the photographs taken were stored in individually named folders. All these files have been uploaded to the Government of Antigua online Dropbox.

The study results are summarized in the remainder of the report and presented in two chapters:

- Crosscutting issues and recommendations that apply to all sites;

- Site specific findings and recommendations, to be added to the generic recommendations.

2 GENERAL RESULTS AND RECOMMENDATIONS

2.1 Detailed design, costing and final site and scope selection

Detailed design, costing and final selection of the systems has yet to be done and is clearly needed. This screening study is input into that process and not a substitute.

The detailed work will be iterative and can only be completed after appointment of the turn-key contractor. This will exposure the AB Government to post-award negotiations, cost escalation and/or a scope reduction at a late stage. The scale of this financial exposure can however be controlled through careful contract management, so no major change in the general procurement process is considered necessary.

One alternative reviewed was developing an independent detailed design, and then repeating the procurement process with a much tighter and effectively fixed scope of work. This alternative however is **not** recommended, for the following reasons:

- The significant cost of such design work and the transaction cost and lost time associated with the process;
- Tightly specifying the detailed design does not make the best use of the contractor's own expertise and flexibility to address detailed but routine issues as they are presented.
- With a fixed budget, the final site list and scope cannot be determined prior to combining the detailed designs and the contractors' unit rates into a near-final costing. Once this near-final costing is provided, the scope can then be re-adjusted (either up or down) to fit the actual fixed budget.

The recommended way forward is as follows:

- Complete the competitive selection and pre-award negotiations, integrating input from this study to the extent feasible at the pre-award stage;
- Instruct the contractor to develop the detailed designs and associated final costs for each site;
- Review the designs, clarify and negotiate on the fine details and modify the scope to fit the available budget.

It is likely that incorporation of all the recommendations of this report will raise the average cost per site beyond that budgeted. To resolve this, it is recommended to prioritize and reduce the number of sites, to ensure robust installations that are both fully fit for purpose and will remain in service up to 20 years.

Note that the tender document specification demands compliance with several standards. These standards are useful for controlling quality issues on the component materials, panel and inverter performance and electrical safety. They do not however guarantee adequate whole system design or structural solutions.

The noted tender document requirements in Section 10 roof specifications are comprehensive but generic. In some cases, they may be physically impossible or technically very difficult to achieve and/or assess or enforce. In particular, it is not possible to fully warrant the structural and wind resistance performance of PV panels installed on old timber roofs with concealed structures - without fully disassembling and rebuilding the roof structure and roof-wall connections.

The following sections provide recommendations that will influence the detailed designs for all sites.

2.2 Shading and obstructions

A minority of sites are affected by potential shading from trees and other buildings. This will influence the precise preferred location of the installations and the maximum viable installation. One site was affected by overhead obstructions, specifically badly installed powerlines.

Recommendations A detailed analysis of the shading issues, where present, should be conducted on-site, using a Solar Pathfinder or one of many newer software-based instruments. This equipment will confirm and quantify any shading issues and enable on site design modifications. Note that these modifications may include trimming or cutting down trees in exceptional cases, but this is not always advisable or feasible (for example very tall trees and trees on neighboring properties).

Note that horizontal PV strings should be specified wherever shading is a potential issue. This approach limits the energy losses when shade strikes the lowest panels.

Shading from trees impacting the potential ground mount site at Fiennes Institute

Powerlines lying on the roof of Parhams clinic

2.3 Facing and tilt analysis

The majority of buildings assessed had pitched roofs with at least 2 faces. In some cases, the buildings had up to 10 faces. Hence the detailed design needs to include selection of the one or more faces for installation. In several sites the optimum (south facing) orientation was either unavailable or space limited.

Swetes clinic – A complex roof requiring tilt and shade analysis

Recommendations For hurricane risk management and cost reasons only flush (flat lying) roof installations are recommended (see below). This increases the importance of maximizing the use of south facings and undertaking a tilt analysis to accurately forecast the average annual energy production. In some cases, the reduction in energy anticipated from flush installations should be rebalanced by increasing the number of panels.

2.4 Roof safety offset and work safety plans

The procurement documents specify a 2m safety offset from the roof edge for the PV installations. This is a standard term presenting best general practice, mainly for flat and low angle pitched roofs.

In practice however, tight application of this offset will effectively halve the potential size of south facing installations and make other sites non-viable. It is not considered critical for 1st and 2nd storey roofs that can be effectively accessed by ladders. It is also not a substitute for a general work safety plan, which needs to be included along with the detailed designs.

Recommendations Repeal the 2m offset requirement, but require the submission and approval of a works safety plan.

2.5 Roof load capacity and condition

The majority of buildings assessed had a traditional Antiguan wood and sheet metal roof, with ages ranging from 5 - 40+ years. The typical design consists of the following layers, from bottom to top:

1. **Wall support and fixings** Perimeter support for the timber consisting of insets in the masonry wall of the building. In most cases the timber beams are held in these insets only by friction and gravity. The masonry itself is laid in simple rows of blocks with limited or no interconnecting reinforcing steel in the older buildings. The very oldest buildings inspected had stonework in place of masonry.

2. **Interior ceilings** Most buildings noted had interior ceilings concealing all or part of the roof structure. The ceilings were typically either plywood, planking or plasterboard. In the smaller and older buildings, the ceilings were pitched and connected directly to the rafters. Flat/false ceilings were noted in the larger buildings.

3. **Roof structure** The roof structure typically consists of a timber framework of rafters, typically softwood (pine) and typically 50mm wide and 200 - 250mm deep and up to 3m long. The spacing, length, age and condition of the beams varies widely. Beam spacings of 550 - 800mm were noted. Transverse battens or beams are installed on the larger roofs. In many buildings the structures are partially or fully concealed and can only be inferred by nail spacings. Roof ridge boards were inferred but rarely visible.

4. **Roof deck** The rafters are topped by a layer (roof deck or sheathing) of either thin pine planking or plywood. This layer is also commonly concealed by interior ceilings. Some utility buildings and verandah sections did not have a roof deck.

5. **Roof surface** Sheet metal is laid on top of the top planks/ply and fixed onto the beams, through the top layer. Modern building standards specify the use of roof screws rather than nails. In practice, the roofs are of variable age and both screws and nails were noted. One building inspected had a plastic composite imitation tile surface, which will be complicated for rooftop PV installation.

6. **Roof eaves and edges** The standard three-layer roof structure was generally finished at the lower edge with a horizontal set wooden fascia board. A minority of buildings also had gutters, but these were commonly broken. The length of the eaves ranged from 150 - 500mm. Longer eaves are highly vulnerable to uplift in high winds.

7. **Penetrations and rooftop structures** The roofs in general are simple and rarely penetrated by rooftop structures, such as chimneys, vents, water pipes and skylights.

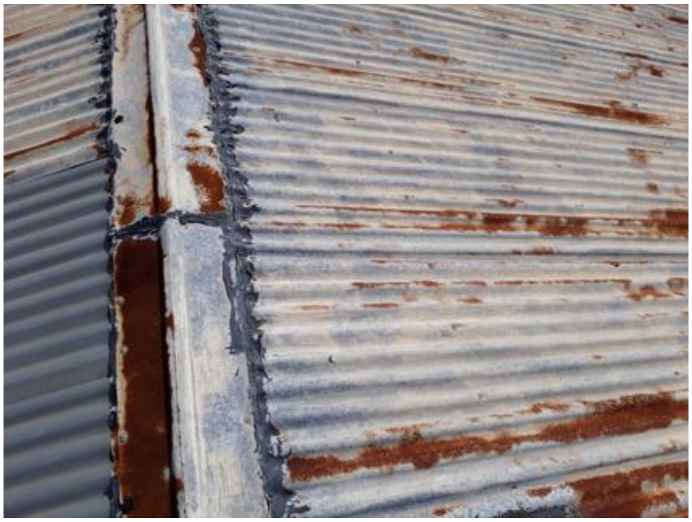
Such features were noted however in a minority of roofs. The penetrated sheet metal was typically waterproofed with basic flashing and bitumen-based resin caulking.

Wilikies clinic – A sheet metal roof in moderate condition but fixed with nails. Also a window shutter suitable for storm protection. Note the stonework on the oldest buildings appears stronger than some new build masonry.

Victory Centre – Recent build showing traverse rafters, ply deck and extended eaves

Good Shepherd home for children – A plastic roof on a plastic clad structure: the structure is fully concealed and visible only through partial dismantling.

Bendalls clinic – A recently replaced metal roof with roof screws, fixed into battens or traverse rafters and only limited fixings into the pitched rafters. Roof integrity is controlled by the rafters.



Holberton Hospital Childrens Wing – A degraded roof with weak fixings, degraded caulking and replacement sheets of different ages.

Bolans clinic interior – The absence of an internal ceiling enables a view of the rafters and roof deck planks. Note the rafter inserts into the masonry wall top and the absence of straps and metal fixings at rafter junctions.

With respect to rooftop PV installations, such roofs have four very specific vulnerabilities. These are discussed in turn below, including generic recommendations for the detailed design and installation planning.

Static-dead load uncertainty Detailed static load assessments are not considered viable for this project and a more pragmatic approach is recommended. Completely quantitative and robust static load assessments are very case specific and require full access, extensive data and engineering time. For the simple Antiguan roofs noted, the cost of analysis and reporting per small pitched roofed face may exceed the value of the timber roof structure of concern.

Flush mounted PV panels on low angle roofs generate a static load of 16-20 kilograms per m2, which is relatively low. If appropriate installed, that weight will be fully transferred onto the roof structure in 4-6 locations. In comparison a typical worker on a roof carrying tools or a panel will weigh 100-120 kg and whilst walking will concentrate that weight on one foot with a surface area of less than 0.03 m2.

Many hundreds of PV panels have been installed to date on traditional Antiguan pitched roofs and all the anecdotal evidence suggests that static load is not a major issue.

Recommendations The recommendation on static load is that the AB government simply tolerates the technical uncertainty on static load and focuses their attention on the following issues.

Seismic load uncertainty Adding PV panels to weak roofs increases the risk of damage and full collapse in earthquakes. The level of uncertainty however on seismic loadings is even greater than for static loads. This is not viable to resolve by modelling for small and complex timber structure roofs.

In mitigation, reinforcement designed for wind loading also generally contributes to protection against seismic loading. It is not viable to design for avoided damage for the building types assessed. It is viable however to design to help avoid catastrophic failure of the entire roof and linked full wall collapse. The critical goal in this case is simply the survival of the occupants during an earthquake, rather than protection of the building. What is needed in this case is reinforcement of timber joints and timber-masonry joints to maintain overall integrity.

Recommendations Investments in the buildings roofs for hurricane resilience should also be regarded as concurrent investments in seismic protection (see below notes on hurricane risk management).

Installation point loads and surface damage Installation point loads and surface damage will be a real issue for this project, with the potential to cause protracted problems and contract disputes if not well managed. To summarize the problem, workers walking and installing the PV panels and associated conduits on the Antiguan style roofs can impose transient loads that exceed the capacity of the corrugated metal sheets or the underlying timber or both. This results in local damage, such as dinted metal sheets, pulled roofing nails, cracked timbers and weakened timber joints. This in turn results in point leaks and weakened roofs, which may become evident to the building occupants only some time later – such as during the next storm.

Recommendations The following precautionary measures are recommended, to control this issue:

- Temporary walkways and boards must be used, to avoid point loading. The safety risk from slipping boards on steep pitches must be managed with temporary cabling.
- The contractors need to present a detailed record of the condition of the precise faces and locations proposed for PV installation. This can be as simple as a set of detailed and referenced photos, with annotated remarks on sheet and fixing conditions.
- Degraded, warped or dented steel sheets should be lifted and replaced prior to PV panel installation. The connections between the sheets and between the sheets and the roof cornice/ridge covering strips should be resealed.

- Substandard fixings, such as simple and old roofing nails and all corroded fixings, should be pulled and replaced with roofing screws prior to PV panel installation. All new roof penetrations (from replaced nails and new screws) need to be well sealed.
- In selected cases, the underlying timber frame will be seen (or heard) to move or break. In such cases the sheet roof needs to be stripped off and the timber frame reinforced, typically with additional parallel and traverse beams and joint reinforcing.

PV racking roof fixings and waterproofing The racking for flush mounted PV panels is almost fully covered by the panels once installed. These racks are typically fixed to the building by drilling through the sheet metal direct into the timber frame and screwing/bolting. These potential leak points are then concealed by the panels.

Recommendations These key potential leak points should all be well sealed, and a subset need to be spot checked by the supervising engineer.

Roof maintenance, degradation and replacement A well maintained PV array has an effective working life of up to 25 years. In comparison, the remaining working life of the aging sheet metal seen ranges from 0-30 years. Some sheeting was already clearly leaking and had been patched. Other sheets were fixed only by corroded roofing nails not screws, and so have only limited resistance to high winds.

Recommendations It is economically not rational for a building owner to permit PV to be installed onto a roof that will shortly need replacement. It is also not viable to expect non-specialist contractors to repair or maintain the areas of roofing concealed under PV panels. In such cases, the sheet roofing should be renewed prior to PV installation.

From the inspections to date, it is anticipated that it would be appropriate to replace 10-20% of the sheets on the roofs of the target buildings as part of the PV installation process. This decision should be made on a case by case basis as part of the detailed design and approval.

2.6 Building condition, space and security

Several of the smaller buildings noted had very limited interior space, in particular fully weatherproof and lockable space. The secure storage of high cost lithium batteries and personnel safety against electrical shock are the key issues noted.

Recommendations This issue needs to be addressed at the detailed design stage. Where building interior space and conditions are not suitable (for otherwise suitable sites) the recommended solution is to install and ground anchor (against wind) a 10-foot shipping container for the battery and inverter. Such a container will no doubt also be useful for the clinic for appropriate storage of higher value items.

2.7 Ground mounts and dedicated structures

Five sites were inspected where rooftop installations would not currently be possible. The reasons for exclusion were varied: 1 unfinished building, 1 site without a building, 1 damaged building, 1 site with power lines lying on the roof and 1 with heavily shaded roofs. It is expected over time that the AB government may wish to invest in many other sites that are also unsuitable for rooftop installations.

The generic and simple alternative to rooftop mounting is ground mounting. The lowest cost design is simple tilted metal racks of one panel height, with the lower edges located 0.3 -1.0m from the ground. However, there are several disadvantages to this approach:

- The array takes significant space, that is not always available
- The low mounted panels are more vulnerable to shading issues than rooftop installations
- The ground mounts are more vulnerable to theft
- The open tilted racks are highly vulnerable to wind damage, particularly on the corners and back facings. Wind gets under the panels, the fixings break and the panels fly loose;
- The low panels are more vulnerable to wind debris strike, with heavy debris bouncing and rolling.
- The space under the panels needs to be maintained, by weeding or mowing, without damaging the electrical lines.

Recommendations The routine use of standard PV ground mounted arrays for Antigua and Barbuda is not recommended on the grounds of investment risk and disaster resilience. They are simply too vulnerable to theft and wind damage and have some other disadvantages. The likelihood of a standard ground mount surviving the normal design life of 20 years is considered low. Fencing provides negligible protection against theft.

Instead, three specific alternatives are recommended, which should be selected on a case by case basis:

A. Low level ground mounted arrays need to include specific design features to reduce hurricane vulnerability, such as:

   - Highest standard and additional panel fixings.
   - Boxing in panel and array back and side faces, either with specialized molded racking or bespoke metal paneling fixed to the mounts and the ground.

- A surrounding mesh fence to catch debris (this requires a strong build and post foundations).
- Reducing the tilt, if possible to flush with the ground.

B. The panels are mounted flush to a new build fabricated steel shade structure, open sided with a 2.2m minimum ceiling clearance. Roofs are pitched to the south to enable flush mounted panels and metal back and side panels extend from the roof to the minimum clearance. Such structures need to be designed for each site, based on a generic standard. Whilst not fully hurricane resistant, they can be built both strong and simple to repair. The extra return on investment in such structures is that the site users and the community benefit from a functional shade and rain shelter.

C. If no options appear to work or the costs become prohibitive, do not install PV and redirect the investment to other rooftop installations to achieve a better return.

2.8 Hurricane risk management

Both PV panels and the typical Antiguan timber and metal roof are fundamentally vulnerable to damage and destruction from the very high winds and flying debris generated by hurricanes. Good design, extra investment and special pre-event precautionary actions can greatly reduce the risk of damage but cannot guarantee full protection.

Increasing the hurricane resilience of PV installations is expensive and in some cases, reduces the functionality. Some potential measures, such as protecting or removing rooftop panels before a storm, even increase the personnel safety risk. The period immediately before a hurricane strikes is typically chaotic and stressful, and people will correctly place the security of government assets such as PV panels low on their urgent to do lists. The approach also should vary by client and site: the sites inspected have limited potential for pre-hurricane interventions, compared to say a large scale commercial PV array with dedicated operational staff.

Hence all measures to increase hurricane resilience require a trade-off between the risk and return and a pragmatic analysis of their feasibility.

Barbuda Codrington Fire station – Showing all 4 modes of roof failure from hurricane winds. 1. Metal sheet separation from the ply roof deck. 2 Ply roof deck separation from the rafters. 3. Rafters breaking off with sections of roof deck & sheet. 4 Rafters torn out of the walls and pulling out masonry in the process. Note the horizontal reinforcing bar laid in the concrete top of the masonry wall failed in sections - due to a lack of vertical strapping.

Final Draft 30 Jan 2018

Codrington Power station 100kWp solar array – The hurricane destroyed 95% of the ground mounted panels

Codrington array – The alloy fixings between the PV panels and the racks can be the weakest point for wind vulnerability

Codrington power station – The generator house was deroofed. Critical infrastructure such as this should be strongly hardened against hurricane winds

Codrington Hospital – Parts of the hospital had flat concrete roofs, which were not affected by the hurricane

Recommendations The following design, planning and operational procedures should be integrated into the detailed designs:

- All rooftop PV mountings should be flush to the roof and low profile, with an air gap of ideally not more than 50mm.

- All fixtures, both from rack to roof and from rack to panel, should be increased in density 50% above the standard recommended density. Fixing are the most common failure points and it is simple and cheap to use more fixings.
- Existing weak roof pitches should be reinforced prior to the PV installations. Dependent upon the issues noted for the specific face, these measures could include:
  - Lifting and replacing nails and corroded screws with new screws and sheet metal
  - Reinforcing key timber frame joints and installing hurricane straps, ties and clips whilst they are exposed for other works.
- Install bespoke hurricane straps to connect the rafters to the masonry walls in selected accessible sites and within the project budget. These straps should extend vertically down at least the height of 2 masonry block rows (to compensate for the lack of reinforcing in the older masonry walls). To control costs, such installations should focus on outside corner rafters.
- The weatherproofing of the control and battery room needs to be addressed. Water infiltrating these systems can cause major damage and/or a complete loss and potentially an electrical fire in worse cases. If there is significant doubt on the quality of the roof, then it should be repaired.

No specific actions are recommended for hurricane preparation of the PV arrays other than turning off the power at the control panel before vacating the site. Essentially, once all the design precautions and associated investments have been made, the residual risk of damage and destruction simply needs to be accepted.

2.9 Theft risk management

Most of the sites visited are assessed as easily accessible by trespassers/thieves. None of them have fully adequate 24/7 site security. Most of the roof inspected are accessible by a 2-3m ladder. Hence the default designs for both the PV and the inverters and batteries needs to assume a high risk of component theft.

Theft protection works should be regarded as a mandatory part of the project – to install expensive and easily removed equipment on unsupervised sites is to invite heavy losses. Due to the interconnected nature of PV systems, even small losses and damages can result in a 100% loss of use.

Extensive experience in PV theft problems has resulted in the development of a wide array of solutions including specialized fittings, welded frames, extra high mounts, cages, containers and alarm systems. Only a subset of these options would be viable for the assessed sites.

Recommendations The following specific theft protection measures should be incorporated into the detailed designs:

- The panels should be protected against theft by careful post-installation modification-damaging of the fixtures. The targets for modification are the fixing bolts and screws that need to be undone to remove the panel. The modifications are fixing specific but are of two types:
    - Bolt heads are rounded off, to stop removal by spanners
    - The heads of hex and star head bolts and screws are drilled out to stop removal by hex keys and screwdrivers.

  This work results in a new problem, which is the difficulty of removing the panels if needed for replacement or maintenance. This is unavoidable and considered solvable, by simply ensuring a good stock of spare fixings and forewarning the contractors to bring angle grinders and large bolt cutters to cut off the modified fixings. To minimize this problem but still provide some protection, only 20% of the fixings need to be modified (or at least 2 per panel/rack). Thieves can still use hacksaws and grinders to remove the panels, but this results in either a very slow process or a lot of noise.

- The valuable inverters and lithium batteries also need protection. Three options are proposed:
    - If the building is suitable, the system can be enclosed in a secure room, with upgraded strong doors and door locks and internal window bars.
    - If the building is not suitable, the key components can be enclosed within an internal metal cage bolted to the building wall or floor.
    - If there is insufficient internal space, then a 10-foot shipping container (with a good lock) provides a good level of security and other benefits.

2.10 Site flood risk

In general, the assessed flood risk at the inspected sites was low. The most common source of risk noted is standing water and overflow of open urban stormwater drains during heavy rain periods, in flat and low-lying sites. Catchments are very small and generally have a high percentage of grass and forest cover. Hence the most common type of flooding anticipated is very short term standing water of up to 100mm, from rainfall in the immediate site area.

Many of the buildings inspected are built on top of elevated foundations and slabs and are surrounded by a ring drain.

The generic recommendation to mitigate this level and type of flood risk is to simply ensure the power management system and batteries are wall mounted or placed on racks a minimum of 200mm above floor level.

3 SITE SPECIFIC SUMMARIES AND RECOMMENDATIONS

3.1 Introduction

The following summaries cover all the 13 sites presented in the tender document (in the same order) and 5 others requested by the AB government. Detailed site inspection records and photographs are provided separately.

The advice provided needs to be addressed at both the site and portfolio level. Solutions are possible for virtually all sites, but some sites are more economic and lower risk than others. Hence the AB government will need to prioritize its investment.

Secondly, a crosscutting finding of the assessment is that the AB government will be investing heavily in installing new and expensive equipment onto old, degrading and low strength roofs. Wherever possible, the recommendation is to use this project as an opportunity to also efficiently invest in upgrading the receiving roofs. This will improve overall (PV+building) hurricane resilience and reduce future repair costs. Hence roof repairs are commonly recommended.

3.2 Bendalls Clinic

Bendalls clinic

Summary Bendals clinic is a small freestanding masonry building with 2 storey and 1 sections and a pitched timber and sheet metal roof. Its age is in excess of 20 years and its condition overall is moderate. It is in a flat rural area with low wind exposure. The 2nd storey sheet metal roof is in good condition with roof screws. The flood risk is assessed as moderate to low – the building is on a very gentle slope 2m above a valley floor.

Issues The noted issues are:

- Worker safety issue on access to the 2nd storey, which however has a security benefit.
- Potential minor shading issue from trees, resolved if the installation is on the 2nd storey.

Recommendations Routine rooftop installation.

3.3 Bolans Clinic

Bolans clinic

Summary Bolans clinic is a small freestanding 1 storey masonry building with a pitched timber and sheet metal roof. Its age is in excess of 30 years and its condition overall is fair to poor. It is in a hilly area with moderate wind exposure. The roof sheet metal is in a fair condition with a combination of roof screws and nails. The timber structure is notably aged with widely spaced rafters. The flood risk is assessed as low – the building is on a hilly area with only a very small catchment upstream and adequate drainage.

Issues The noted issues are:

- A weak roof structure with high wind vulnerability;
- Limited internal space;
- Potential minor shading issue from a large tree to the southeast.

Recommendations Rooftop installation. Invest in roof strengthening and sheet replacement.

3.4 Fiennes institute

Fiennes Institute – Proposed ground mount site

Summary Fiennes Institute is a collection of 1 storey buildings in a grassed compound with many trees. All of the buildings have major shading issues and are unsuitable for rooftop installations. A relatively open grassed area is available for a ground mounted array, within the fence, whilst a more open area is noted just uphill to the southeast. The flood risk is assessed as low – the building is on a side of hilly area with only a very small catchment upstream and adequate drainage.

Issues The noted issues are:

- Shading from trees.
- Location of the battery and control room.

Recommendations Ground installation. If possible, move the array location uphill, analyze shade in detail and move the fence and trim/remove trees as needed.

3.5 Good Shepherd Home for Children

Good Shepherd Home for Children – showing the plastic roof tiles

Summary The Good Shepherd site is in the suburbs of St Johns and has two buildings: A church and the home itself. The church has steeply pitched roof with east and west faces and is not very suitable for PV installation.

The home is a 1 storey building with a garden. The structure is unusual and difficult to discern, as it is entirely clad outside in PVC cladding and inside with PVC planking/paneling. It appears to be mainly timber framed with a concrete pad foundation. The pitched roof is covered with PVC-resin imitation tiles, laid in horizontal rows with hidden fixings. The flood risk is assessed as low to moderate to low – the building is a very gentle slope with a small catchment upstream and paved drainage.

Issues The noted issues are:

- The (inferred but concealed) lightweight timber structure, with an inherent high wind vulnerability;
- The need to disassemble the roof tiling to find and access the roof rafters;
- Limited internal space.

Recommendations Rooftop installation. Anticipate complications and potential cost escalations linked to the need to remove and reinstall the roof to fix the PV mounts to the rafters.

3.6 Holbertons Hospital - Childrens Ward

Holbertons Hospital – Childrens Ward

Summary The Holbertons Hospital Childrens Ward is a large freestanding 1 storey masonry building with a pitched timber and sheet metal roof. Its age is in excess of 30 years and its condition overall is fair. It is on a ridgetop with high wind exposure. The roof sheet metal is in overall poor condition, with extensive corrosion and several replaced sections. The flood risk is assessed as very low – the building is on a ridge

Issues The noted issues are:

- The corroded sheet metal roof covering;
- High wind vulnerability due to its location;
- Potential minor shading on one south pitch.

Recommendations Rooftop installation. Invest in roof sheet replacement and in roof strengthening for wind resistance. Shade analysis for any installation on the south pitch.

3.7 Holbertons Hospital – Hospice

Holbertons Hospital - Hospice

Summary The Holbertons Hospital Hospice is a large freestanding 1 storey masonry building with a pitched timber and sheet metal roof. Its age is more than 30 years and its condition overall is good, due to a recent renovation. It is on a ridgetop with high wind exposure. The sheet metal is in overall good condition. The flood risk is assessed as very low – the building is on a ridge.

Issues The noted issues are:

- High wind vulnerability due to its location.

Recommendations Rooftop installation. Invest in roof strengthening for wind resistance.

3.8 Nyahbinghi Theocracy School

Nyahbinghi – Potential ground mount with tree shading issue

Summary The Nyabinghi Theocracy school site is in a relatively collection of very small buildings in an orchard and market garden setting. All buildings noted have major shading issues and are unsuitable for rooftop PV installation. Any low-level ground mount in the central community space would also be problematic due to tree shading. More open ground is available in the garden area to the south, however this would still have shading constraints, as well as long wiring runs.

To turn a problem into an opportunity, there was also a notable lack of permanent rain shelter in the community area, with a large portable pergola in use for community gatherings.

The flood risk is moderate – the slope is very gentle and within 50m of a river. There are no distinct drains.

Issues The noted issues are:

- Shading from trees.
- No suitable buildings.

Recommendations Construct a new fabricated steel shade structure with rooftop PV, as per the generic recommendation in Section 2.7, option B of this report. Site to maximize community amenity and minimize tree cutting to resolve the remaining shade issues.

Final Draft 30 Jan 2018

3.9 Old Road Clinic

Old Road clinic

Old Road – Cracked concrete column, probably due to reinforcing steel corrosion

Old Road – Detail of reinforcing steel corrosion inside concrete beam and lintels

Summary The Old Road Clinic is a small freestanding 1 storey masonry building with a bespoke and problematic roof. The original roof is fully concealed but was reported by staff to be a concrete flat roof. Due to reported leaks a second pitched roof with a timber structure and sheet metal was installed on top of the original. Inspections indicate that this second roof structure is not well bonded to the original. The secondary roof sheet metal cover is completely corroded and has failed in many places. Evidence of ongoing leaks was noted inside the building.

The root cause of the original leaks and a larger problem for the building is poor design and the very extensive main concrete structure degradation. Large and deep cracking is visible in virtually all supporting columns and beams and particularly pronounced in lintels and door and window frames. The prior internal leak spots are visible as lines of deposited rust from the corroding roof and/or structure.

The inspection indicated the root cause of the cracking is water penetration and extensive corrosion of the main structure reinforcing steel inside the concrete. Corroding steel bars swell and separate from the concrete and thus instigate cracking. Once this becomes pervasive throughout a building it is practically impossible to permanently fix.

A more detailed structural analysis for the building is warranted. It is considered probable that the building could be classed as a structural write-off and not possible to renovate. In such a case the best long-term solution may be demolition and rebuild.

The site is small and has insufficient space for a ground mounted system. The site has moderate to high wind vulnerability due to its seaside location and facing.

Flood risk (from surface flows) is assessed as low. The facility is on the side of a hill with adequate urban drainage

Issues The noted issues are:

- A fully degraded secondary roof;
- A degraded building structure that appears problematic to fix;
- High wind vulnerability due to its location;
- No space for a ground installation.

Recommendations Do not invest in PV installation at this site prior to resolving the problems with the building.

3.10 Parham Clinic

Parham clinic – showing obstructing powerlines

Summary Parhams clinic is a small freestanding 1 storey masonry building with a flat timber and sheet metal roof. Its age is in excess of 20 years and its condition overall is fair. It is in an enclosed valley area with moderate wind exposure. The roof sheet metal is in fair to poor condition.

The principal issue noted for this site is overhead obstructions. Medium and low voltage powerlines from the grid traverse the entire roof. The lowest lines touch the metal roof, in violation of any sensible grid build and safety standard. Rooftop PV installations are not viable unless this is resolved. The flood risk is assessed as moderate, due to the flat site and urban drainage.

There is some limited space available at the southern front of the site, which is currently used for car parking.

Issues The noted issues are:

- Overhead obstructions;
- Limited space for a ground mounted array.

Recommendations Construct a new fabricated steel shade structure with rooftop PV, as per the generic recommendation in Section 2.7, option B of this report. Position the structure on the southern edge of the existing building. Demand resolution of the power line safety issue by the electrical utility.

3.11 Potters Clinic

Potters clinic

Summary Potters clinic is a small freestanding 1 storey masonry building with a pitched timber and sheet metal roof. Its age is in excess of 20 years and its condition overall is moderate. It is in an open semi-rural area with moderate wind exposure. The sheet metal roof is in good condition with roof screws. Flood risk is assessed as very low – the facility is on the side of a hill with adequate drainage.

Issues None noted.

Recommendations Routine rooftop installation.

3.12 Swetes Clinic

Swetes clinic

Summary Swetes clinic is a small freestanding 1 storey stonework building with a complex footprint and a pitched timber and sheet metal roof. Its age is more than 40 years and its condition overall is moderate due to renovation. It is in a residential hilltop area with several large trees and moderate to high wind exposure. The sheet metal roof is in fair condition with roof screws. Flood risk is assessed as low – the facility is on the top of a hill.

Issues The noted issues are:

- Shading;
- Limited space for a ground mounted array.

Recommendations Routine rooftop installation with shade analysis.

3.13 Victory Centre

Victory Centre

Summary The Victory Centre is a small freestanding 1 storey masonry building and a pitched timber and sheet metal roof. Its age is reported at 5 years and its condition is very good. It is in a residential and recreational flat area with and moderate wind exposure. Trees are noted to the east and south. Flood risk is moderate, due to the flat site.

Issues The noted issues are:

- Shading, from trees;

Recommendations Routine rooftop installation with shade analysis.

3.14 Wilikies Clinic

Wilikies clinic

Summary The Wilikies Clinic is a small freestanding 1 storey stonework building and a pitched timber and painted sheet metal roof. The building age appears to be more than 40 years. The site is a hillside with high wind exposure. The sheet metal roof is in good condition but fixed mainly by nails. One nearby tree is noted to the west. The flood risk is assessed as low – the site is on the side of a hill.

Issues The noted issues are:

- Shading, from trees;
- High wind vulnerability

Recommendations Rooftop installation with shade analysis. Invest in rooftop strengthening for wind resistance.

Final Draft 30 Jan 2018

3.15 Clearvue Psychiatric Hospital

Clearvue – Female Ward

Clearvue – Male 2 storey ward, showing industrial sheet metal roof

Summary The Clearvue Psychiatric Hospital is a collection of 1 and 2 storey buildings in a grassed and walled compound with many trees. Many of the buildings have major shading issues and are unsuitable for rooftop installations. Ground mounted arrays are not viable due to the special purpose of the facility. Two buildings do appear viable for a rooftop array.

The Female Ward is a large single storey masonry building, with a pitched timber and sheet metal roof. The building and roof are in good to fair condition. Nearby trees indicate a minor shading issue.

The Male Ward is a large 2 storey stonework building, with a steeply pitched timber and sheet metal roof. The building is over 50 years old and its interior is very basic and in poor condition, however the roof is more recent and in fair to good condition. The flood risk is low – the centre is on a gentle slope with urban drainage.

Issues The noted issues are:

- Shading from trees, for the Female Ward
- The need for general renovation of the Male Ward building.

Recommendations Rooftop installations. Invest in rooftop strengthening for wind resistance.

3.16 Barbuda Airport fire station hangar

Barbuda Codrington Airport fire station hangar

Summary The Barbuda Airport fire station hangar is a bespoke industrial hangar for the airport and island fire engine. It is a very solid concrete and steel structure that showed no major damage from the hurricane. In general it is ideal for a rooftop installation, except for the unfavorable pitch of the roof at 5 degrees north. A flush installation on this roof would sacrifice up to 30% of potential energy compared to an optimum south facing.

The question of use of the generated power is also open, as the only neighboring building is the small airport terminal office, which is not in full time use. The Codrington fire station itself is some 600m distant and so too far to connect. The flood risk is moderate due to the flat site.

Issues The noted issues are:

- The unfavorable roof pitch;
- Query on the demand for the generated power.

Recommendations Rooftop installation, if designed to support the airport terminal office.

3.17 Codrington Fire station

Codrington fire station

Summary The Codrington fire station hangar is a 1 storey masonry building located in residential Codrington. It was badly damaged in the hurricane and provides useful evidence of the uplift failure modes of the Antiguan roof design. The following damage was noted:

- The roof covering of sheet metal and wood roof deck was 60% removed
- The timber frame was also ripped out in 25% of the footprint.
- The displaced timbers in turn were set in the upper row of masonry, which was also ripped out. The masonry included a reinforced beam, which was also lifted.
- Windows and doors were broken and the interiors rainsoaked.

The flood risk is moderate, due to the flat site.

Issues The noted issues are:

- The building needs complete renovation, reroofing and strengthening

Recommendations Rooftop installation, integrated into the rebuild and strengthening works.

3.18 Hanna Thomas hospital

Barbuda Hannah Thomas Hospital

Summary The Hanna Thomas Hospital is a collection of 1 storey masonry building on an open site on the edge of Codrington. It was badly damaged in the hurricane but is now partly operational. The steel roofed sections were effectively completely deroofed. In contrast, as expected, the flat concrete roofed sections remained intact apart from broken windows.

The flood risk is moderate, due to the flat site.

Issues The noted issues are:

- Some buildings need renovation, reroofing and strengthening

Recommendations Rooftop installation on the concrete sections, integrated into the overall rebuild works.

3.19 Barbuda justice center

Barbuda Justice Center construction site

Summary The Barbuda justice center is located next to the council building in central Codrington. It is however only partly built as of January 2018 and work has halted due to the hurricane. There is space for a ground mount however ongoing building works put any such installation at risk. There is also obviously no electricity demand from the center itself, however the council building would be a logical customer for any electricity.

The flood risk is moderate, due to the flat site.

Issues The central issue is the absence of a completed building and a tenant to use the electricity.

Recommendations Postpone installation of any kind, excluding the site from the current project if needed.

4 CONCLUSIONS

To summarize the overall results of the study, most of the 18 sites were confirmed as suitable. Concurrent investments in strengthening the roofs and replacing sheet steel roof coverings were recommended in over half of the sites. Implementation of all recommendations in this report will escalate the cost per site beyond the original budget, hence the government will need to prioritize.

It is recommended that the AB government undertake a post-installation review of the results of the first phase and then refine both the strategy and the detailed approach for future phases. This should improve cost forecasting, lower the final installed costs per kilowatt and reduce the risks of contract disputes and installation and longer-term performance issues.