Facility Designers Guide for Tropical Islands

Designing for resilience in a changing climate

November 2022

Facility Designers Guide for Tropical Islands
Designing for Resilience in a Changing Climate

November 2022

Facility Designers Guide for Tropical Islands (FDGTI)

Contents

1 Introduction and Overview 1
- 1.1 Background 1
- 1.2 Purpose and Scope 1
- 1.3 Structure and Use of the FDGTI 1
- 1.4 Environment and Setting 3
  - **1.4.1 Description of Island Areas** 3
  - **1.4.2 Location, Geography and Climate** 4

2 Guidance on Building Project Process 10
- 2.1 Best Practice Approaches to Design Supporting Construction 10
- 2.2 Supporting Long Term Asset Management and Maintenance 10
- 2.3 Planning and Executing a Good Building Project 10
  - **2.3.1 Keys to Quality Building Outcomes** 10
  - **2.3.2 Successful Design Processes** 11
  - **2.3.3 Basis of Design** 12
  - **2.3.4 Design Statement** 13
- 2.4 Implementation Considerations for Building Design 13
  - **2.4.1 Procurement Methods** 13
  - **2.4.2 Local Planning and Regulatory Requirements** 14
  - **2.4.3 Supply Logistics** 14

3 Codes, Standards and Guidelines 16
- 3.1 Minimum Requirements 16
- 3.2 Definitions 16
- 3.3 Available Building Codes 16
- 3.4 Local Building Codes in Each Area 16
- 3.5 Relevant Technical Standards 17
- 3.6 Guidance Where No Local Code Exists, or Departures Are Needed 18
- 3.7 Relevant Building Practice Guidelines 18

4 Building Design for Sustainability and Resilience in Tropical Environments 20
- 4.1 Guidance on Buildings for Tropical Climates 20
- 4.2 Selecting Appropriate Equipment and Materials 21
- 4.3 Tropical Environmental Considerations 21
- 4.4 Environmental Protection and Planning Controls 21
- 4.5 Environmental Protection and Design Considerations for Materials and Construction Methods 22
  - **4.5.1 Solid Waste and Waste Minimization** 22
  - **4.5.2 Hazardous Waste** 23
  - **4.5.3 Material Handling** 23
  - **4.5.4 Safety Data Sheets** 23
  - **4.5.5 Lead Paint and Asbestos Containing Materials** 23
  - **4.5.6 Chemical, Petroleum, Oil, and Lubricant Systems** 24
- 4.6 Historic Preservation 24
- 4.7 Natural Hazards in the Pacific and Atlantic Oceans 24
  - **4.7.1 Rainfall** 24
  - **4.7.2 Wind and Extreme Wind Events** 24
  - **4.7.3 Flooding and Wave Action** 25

4.7.4 **Seismic** 25
4.7.5 **Tsunami** 26
4.7.6 **Volcanic** 26
4.7.7 **Wildfire Risk** 27
4.7.8 **Munitions of Explosive Concern** 27
4.7.9 **Biological Hazards** 27
4.8 Living With and Adapting to a Changing Climate 28
4.8.1 **Forecasting Sea Level Rise and Consideration of the Impacts for the Designer.** 30
4.9 Architectural Considerations for Tropical Environments 34
4.9.1 **Site Location and Planning** 34
4.9.2 **Simulation of Light Energy Performance** 35
4.9.3 **Exploitation of Natural Ventilation.** 35
4.9.4 **Inclusion of Rainwater Harvesting for Treated Use or Irrigation.** 35
4.9.5 **Landscaping and Stormwater Management** 36

5 Building Detailing 40
5.1 General Corrosion Control Measures 40
5.1.1 **Introduction** 40
5.1.2 **Overview of Corrosion Process** 40
5.1.3 **Corrosion Expert Design Input** 41
5.1.4 **Passive Corrosion Control Measures** 41
5.1.5 **Proper Material Selection** 41
5.1.6 **Dissimilar Metal Contact Prevention** 42
5.1.7 **Protective Coating Systems** 44
5.1.8 **Cathodic Protection Systems** 44
5.2 Building Systems and Materials 47
5.2.1 **Concrete and Masonry** 47
5.2.2 **Metals** 47
5.2.3 **Wood and Plastic** 47
5.2.4 **Thermal and Moisture Protection including Roofing** 48
5.2.5 **Doors & Windows** 50
5.2.6 **Finishes/Coatings** 51
5.3 Structural 55
5.3.1 **Design Loading Requirements** 55
5.3.2 **Material Codes and Standards** 61
5.3.3 **Design Best Practice Guidance** 64
5.3.4 **Geotechnical and Foundations Considerations** 70
5.4 Mechanical 75
5.4.1 **Design Approach** 75
5.4.2 **System Selection** 75
5.4.3 **Best Practices** 79
5.5 Plumbing 83
5.5.1 **System Selection** 83
5.5.2 **Best Practices** 84
5.6 Electrical 89
5.6.1 **Design Approach** 89
5.6.2 **System Selection** 89
5.6.3 **Best Practices** 90
5.7 Fire Protection 95
5.7.1 **Best Practices** 95
5.7.2 Required Standards 95
5.7.3 **Sustainable Design Strategies - Fire Protection** 96
5.7.4 **Fire Protection Elements** 96
5.8 Site Infrastructure 98
5.8.1 **Drainage** 98
5.8.2 **Erosion and Sediment Control** 98
5.8.3 **Wastewater** 98
5.8.4 **Water and Reclaimed Water** 99
5.8.5 **Roadways and Driveways** 100

6 Tasks Supporting Design 102
6.1 Gateway/Stage Checklists 102
6.1.1 **Scope Definition and Design Brief** 102
6.1.2 **Preliminary Design** 104

6.1.3 **Design Statement** ... 104
6.2 Construction Cost Estimate ... 105
6.3 Construction Quality Assurance Oversight Plan ... 105
6.4 Asset Management Support ... 106
6.4.1 **Background** ... 106
6.4.2 **Role of Design in Asset Management** ... 106
6.4.3 **Asset Management Plans** ... 106
6.4.4 **Preventative Maintenance** ... 107
7 References ... 108
Appendix – List of Persons Consulted and Contributing ... 112

Abbreviations

Abbreviation	Full Name
A-E	Architect-Engineer
ACI	American Concrete Institute
AISI	American Iron and Steel Institute
AHJ	Authority Having Jurisdiction
ASCE	American Society of Civil Engineers
FDGTI	Facility Designers Guide for Tropical Islands
CNMI	The Commonwealth of the Northern Mariana Islands
DoD	U.S. Department of Defense
DOI	U.S. Department of the Interior
DoR	Designer of Record
DPW	Department of Public Works
ENSO	El Niño – Southern Oscillation
FAS	Freely Associated States
FEMA	Federal Emergency Management Agency
FSM	Federated States of Micronesia
HAZOP	Hazard and Operability Study
HVAC	Heating, Ventilation and Air Conditioning
IBC	International Building Code
ICC	International Code Council
IEBC	International Existing Building Code
IECC	International Energy Conservation Code
IEEE	Institute of Electrical and Electronics Engineers
IPC	International Plumbing Code
IPCC	Intergovernmental Panel on Climate Change
INGO	International Non-Governmental Organization
LED	Light Emitting Diode
NEC	National Electrical Code[1]
NESC	National Electrical Safety Code[2]

[1] Refer to *NEC NFPA 70* for international design applications
[2] Refer to *NESC IEEE C2* for international design applications

Abbreviation	Full Name
NFPA	National Fire Protection Association
NGO	Non-Government Organization
NRTL	Nationally Recognized Testing Laboratory[3]
OIA	Office of Insular Affairs
OSHA	Occupational Safety and Health Administration
PRIF	Pacific Region Infrastructure Facility
RMI	Republic of the Marshall Islands
SoW	Scope of Work
UFC	Unified Facilities Criteria
UL	Underwriters Laboratories[4]
USACE	United States Army Corps of Engineers
USVI	United States Virgin Islands

1.1.1 3 Material testing and certification organization recognized by OSHA and other public agencies

[4] Privately owned/operated NRTL that tests and certifies building materials for safety (e.g., fire and electrical)

Glossary

Term	Definition
Asset Management Program	Asset management programs ensure an organization's assets are used and maintained to achieve the optimum performance and the longest life cycle for the asset. This is based on a plan and record of the maintenance, repair, renewal and financing over the full life cycle of the facility.
Basis of Design	The Basis of Design document describes the technical approach planned for the project.
Design Statement	A design statement is a report that sets out, illustrates and justifies the process that has led to the development proposals.
Organized Unincorporated Territory[5]	Territories of the United States that were both incorporated (part of the United States proper) and organized (having an organized government authorized by an organic act passed by the United States Congress). Residents of these territories are U.S. Citizens. – Guam, CNMI, USVI
Unorganized Unincorporated Territory[5]	An unincorporated United States island area which the federal government of the United States does not have control over as they have their own constitution. This means that the residents of these areas are U.S. Nationals (i.e., not U.S. Citizens) are not obliged by the law to file taxes to the federal government of the United States. – American Samoa
Compacts of Free Association[6]	Or referenced as 'Freely Associated States'. Financial assistance commitments by the United States and administered by the Office of Insular Affairs. - FSM, RMI and Palau
Critical Five	The Critical Five is an international forum, established in 2012, comprising members from government agencies responsible for critical infrastructure protection and resilience in Australia, Canada, New Zealand, the United Kingdom, and the United States. The Critical Five aims to strengthen cooperation between member countries on addressing the threats to critical infrastructure, as well as to share information, practices and ideas on domestic policy and operational approaches to critical infrastructure protection and resilience
Insular Area	A jurisdiction that is neither a part of a state of the United States, nor a federal district. This is the current generic term to refer to any commonwealth, freely associated state, possession, or territory. Unmodified, this term refers not only to a jurisdiction which is under United States sovereignty but also to one which is not (i.e., a freely associated state or a territory/district covered under the 1947-1994 Trust Territory of the Pacific Islands). Typically, the Area's financial matters are administered or supported by the Department of the Interior's Office of Insular Affairs. For the purposes of this guide, the use of "island" is a non-political term for an area that is an island nation located in tropical environments.
Specification	A description of the standard of materials and workmanship required to be used in the building.

[5] OIA (2022). *Island areas* Retrieved on January 31, 2022, from https://www.doi.gov/oia/islands
[6] OIA (2022). *Compacts of Free Association.* Retrieved on January 31, 2022, from https://www.doi.gov/oia/compacts-of-free-association

1 Introduction and Overview

1.1 Background

This Facility Designers Guide for Tropical Islands (FDGTI) has been prepared under the direction of the United States Army Corps of Engineers (USACE) on behalf of the Office of Insular Affairs (OIA).

Design and construction in the islands are very challenging and each jurisdiction has its own unique issues. Typically, the OIA provides grant funding for eligible new construction and repair projects. Poor designs and inappropriate building materials/construction methods have led to premature failure of many facilities. The loss of function and unsafe conditions have degraded the standard of living.

In addition to the normal challenges of designing facilities for existing conditions, recent changes in climate are widespread, rapid and intensifying. Facilities constructed on tropical islands must be designed to accommodate the environmental changes through their expected lifetime so that the investments and users will be protected. This Guide addresses the issues which have historically plagued tropical islands as well as those which are anticipated due to climate change. Building quality into the facilities is part of effective climate risk management. Land use planning and facility siting is beyond the scope of this document but cannot be overlooked.

1.2 Purpose and Scope

The purpose of the FDGTI for the island areas is to provide design guidance for standardizing and improving the quality and long-term performance of building projects (vertical construction) which are critical to the island communities. This Guide sets out the minimum requirements for building projects funded by OIA. The areas included in this project are:

- American Samoa;
- The Commonwealth of the Northern Mariana Islands (CNMI);
- Guam;
- The Federated States of Micronesia (FSM);
- The Republic of Palau (Palau);
- The Republic of the Marshall Islands (RMI);
- The US Virgin Islands (USVI).

Puerto Rico was not within the scope of the study leading to this Guide, but it is expected that the majority of provisions of the FDGTI will also be relevant to Puerto Rico.

The focus of the FDGTI is on sustainable design and construction for the varied and challenging island environments. All seven island areas have high ambient temperatures, humidity, and corrosive, salt laden air. All are subject to changing climate conditions, e.g., drought periods, sea level rise, hurricanes or typhoons, and some are in seismically active areas. All seven island areas are isolated and remote and are therefore dependent upon their critical public facilities for both day-to-day activities and emergencies.

While the FDGTI is tailored to the situation for buildings funded by OIA in the nominated seven island areas, it is also relevant to other building projects in other similar tropical localities.

Cyber security of facilities is not covered by this Guide. Separate guidance should be sought if there are requirements to include measures for cyber security.

The FDGTI contains both requirements and best practices. There are both general (e.g., assess natural hazards) and specific (e.g., dissimilar metal contact) requirements. Best practices are not requirements and both the proponent and the designer need to be made aware that anything identified as a Best Practice is optional and to be considered if the funding and situation allows. For example, Section 5.4.3.5 (Documentation) and prohibition of dissimilar metals are requirements while Section 5.4.2.8 is optional.

1.3 Structure and Use of the FDGTI

The content of this Guide is written for designers (including the Designer of Record - DoR) as an informative document to provide direction on the most suitable approaches and tips for designing installations in island areas. It assumes that the reader is familiar with general building design. The content is intended to assist experienced designers with guidance especially where their experience may be in more temperate and less aggressive environments, or to identify aspects for others where assistance should be sought.

All design and construction projects shall comply with current local codes and International Building Code (IBC) standards. The FDGTI does not provide an exhaustive list of codes and standards but addresses unique requirements that are specific to tropical island environments. In some cases, this Guide provides additional requirements to ensure resilient and sustainable facilities. The use of the words MUST and SHALL indicate additional requirements while MAY or SHOULD indicate desired outcomes but not requirements. Designers and contractors are to verify all applicable requirements and codes during the development and execution of projects.

The contents of the FDGTI are based on consultation with island area authorities and building practitioners. It is structured to cover these main focuses:

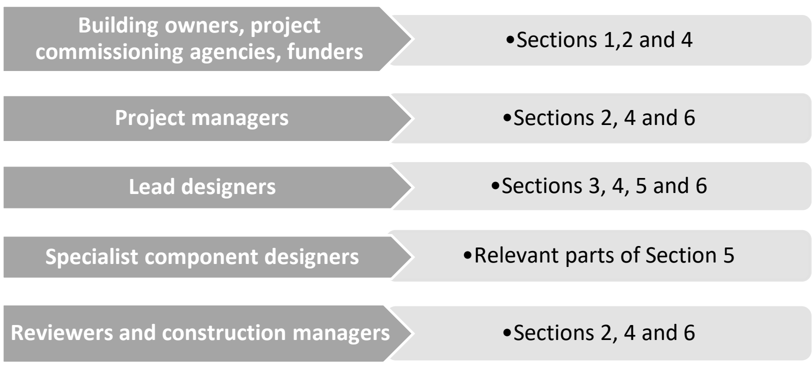
- Design Process Guide
- Code/ Standard/ Guide References
- Planning Maintenance
- Specific Area Requirements
- Best Practice Details and Materials
- Good Tropical Design Practices including Climate Change Adaptation
- Checklists

This information is structured in the FDGTI as follows:

1. Guidance on best practice for design processes and for appropriate design for the island area locations (Sections 1, 2 and 5)
2. Direction to applicable codes and standards for design of buildings (Section 3)
3. Best practice for building details (Section 4 and 5).

Checklists are also provided in Section 6 that may be used to guide building design activities.

The intention is that the FDGTI is used by individuals involved in planning and designing critical building infrastructure. The following graphic guides different parties in the planning and design process on where to look first for the main information needed for their role.



However, all parties should consider the whole Guide for information relevant to them and should understand the project concept and objectives (Section 2) in carrying out their work.

The goal of the FDGTI is to provide a clear, comprehensive approach for designers to establish and maintain sustainable facilities and implement appropriate standards. Furthermore, proper selection of methods and materials of construction is required to reduce repair and maintenance costs.

The following summarizes where to find information relevant to different stages and aspects of the design process:

Step	Guidance
Project Concept Using FDGTI	• **Section 1, 2** • Determine project scope / basis of design against key concepts
Establish the design objectives	• **Section 2, 4** • What are you trying to build? • Where are you going to put it? • How are you going to build it?
Determine the applicable Codes	• **Section 3** • Are there local codes? Then use them and supplement with IBC • If not, then use IBC • Agree on and document codes/standards for both DoR and Checker/Independant Peer Review to avoid conflicting approaches
Read Common Sections Guidance	• **Section 4** • Concept building design • Corrosion Factors • Sustainability and Resilience, including design for climate change
Read Discipline Specific Guidance	• **Section 5** • Corrosion • Building Systems and Materials • Structural • Mechanical • Plumbing • Electrical • Fire
Tasks Supporting Design	• **Section 6** • Checklists • Plans • Asset Management

The FDGTI does not replace nor duplicate official codes and standards. Instead, it is intended to support and direct designers in their reference to the appropriate codes and standards, and to provide guidance on best practice to consider when making decisions during the building planning and design phase to improve the resilience and longevity.

1.4 Environment and Setting

1.4.1 Description of Island Areas

The seven island areas vary in population size and incomes, and therefore vary in resources and capacity to develop and maintain infrastructure and buildings. All the areas are subject to similar natural hazards but to varying extent. Table 1-1 below gives a synopsis of the salient details and hazards when considering design and development of building structures and services.

Table 1-1 Comparison of Salient Background Information of the Island Areas

Island Area	Land type	GDP $USD (per capita)[1] (2019)	Population [2][3] (2020)	Cyclone / Typhoon / Hurricane Hazard [4]	Seismic Hazard [5]	Coastal Flood Hazard [5]
American Samoa	Volcanic. Developed narrow coastal plains with mountain interior	$11,715	49,710	High	High	High
CNMI	Inhabited islands are limestone with development on limestone terraces	$20,659	47,329	High	High	Medium

Island Area	Land type	GDP $USD (per capita)[1] (2019)	Population [2][3] (2020)	Cyclone / Typhoon / Hurricane Hazard [4]	Seismic Hazard [5]	Coastal Flood Hazard [5]
FSM	Multiple high volcanic islands with fringing reefs; atolls	$3,585	113,815	Medium - High	Low	High
Guam	Limestone in the north and volcanic in the south. Most development along shore and on limestone plateau	$38,040	153,836	High	High	High
RMI	Narrow limestone atolls. Average 6ft above sea and some building in the coastal zone	$4,073	~55,000	Medium	Low	High
Palau	Limestone and volcanic islands, main development on coastal plains	$15,232	~18,000	High	Very Low	Medium
USVI	Volcanic and sedimentary rocks overlain in some places with limestone. Hilly with limited flat land	$38,137	87,146	High	High	Medium

Source: [1] World Bank Group. (2022). *GDP per capita (current US$) | Data*. The World Bank. Retrieved January 24, 2022, from https://data.worldbank.org/indicator/NY.GDP.PCAP.CD
[2] U.S. Census Bureau, Wilson, S., Koerber, W., & Brassell, E. (2021, October 28). *2020 Population of U.S. Island Areas Just Under 339,000*. census.gov. Retrieved January 24, 2022, from https://www.census.gov/library/stories/2021/10/first-2020-census-united-states-island-areas-data-released-today.html
[3] Australian Government Department of Foreign Affairs and Trade. (n.d.). *Countries, economies and regions*. Retrieved January 24, 2022, from https://www.dfat.gov.au/geo/countries-economies-and-regions
[4] Global Facility for Disaster Reduction and Recovery & World Bank Group. (n.d.). *Think Hazard*. Retrieved January 24, 2022, from https://thinkhazard.org/en/
[5] Pacific Power Association. (n.d.). *United States of America Insular Areas Energy Assessment Report*.

The population and GDP per capita give a simple picture of the resource base in each area for staffing building projects and for financial capacity to fund building works and maintenance. Designers should take this into account when considering how ongoing maintenance and renewal of the building works can be funded and implemented.

The hazard assessments in Table 1-1 are for comparative reference and are not intended as the primary source of information for design. Other sources of information can define different levels and designers should identify the source and hazard level applicable to the building type, funder/owner, and Code requirements.

1.4.2 Location, Geography and Climate

The island States and territories covered under this guide are located largely in the west to mid Pacific Ocean. One territory is in the Caribbean. All are considered tropical, being on or near the equator. All have relatively small land masses with most or all populated areas within two miles of the ocean.

Figure 1-1: Location of the Island States and Territories

The geographical location of the project will result in typical trends towards adoption of design standards and procurement logistics. For instance, proximity to Australia/New Zealand may result in adoption of AS/NZS standards, or proximity to Asia may result in logistic procurement and support from these countries, rather than increased duration and cost of procuring from mainland United States.

Designers will need to consider these factors and others discussed in greater detail in this guide to produce a design compliant with codes that can be feasibliy delivered in a remote island environment.

The basis of design for any project must consider the local climate conditions as well as any design specific loadings. The impacts of climate change and allowances for these potential changes are becoming increasingly important for longevity and resilience of buildings. Designing buildings that will be fit-for-purpose during their design life, based on forecasted climate, occupancy/usage, and technological changes, while remaining economic to construct and maintain is a challenge to be addressed by the DoR.

The geographical spread of the islands covered by this guide across the equatorial west to central Pacific, and also equatorial Atlantic results in a variation on the tropical environment and potential future impacts of climate change. A visual comparison of the climatic variances in monthly rainfall and temperature (key climate factors) across the geographic spread is shown in Figure 1-2.

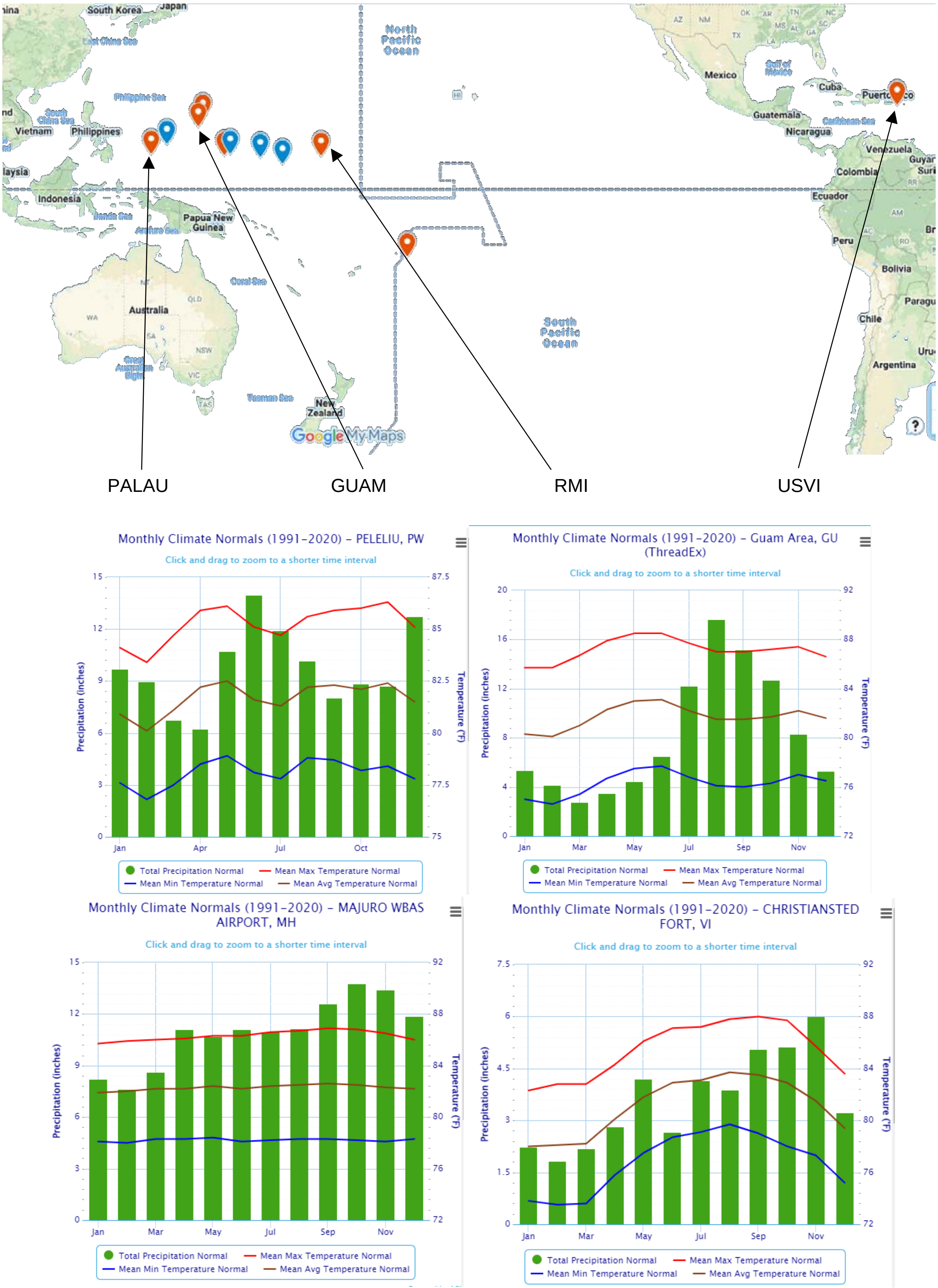


Figure 1-2: Geographical climate comparison of average monthly temperature and rainfall. Climate charts shown for visual reference and comparison only and data should be obtained for site specifics as noted in the following paragraph.

The information in Figure 1-2 is illustrative of the range of conditions. Designers should obtain records specific to the building site. In lieu of local records being available, reference should be made to official United States Government Departments for historical records. The National Oceanic and Atmospheric Administration (NOAA) provide the “National Weather Service”. This includes official forecasting and historical climate data (rainfall and temperature) for US states and territories. The NOAA’s NOWData webpage gives access to datasets (NOAA, 2022).

NOAA's National Weather Service Precipitation Frequency Data Server can produce Point Precipitation Frequency Estimates with Average Recurrence Intervals (years) plotted against Duration for a selected site (NOAA, 2017). This can be used to obtain basis of design information required for stormwater runoff calculations (refer to Section 5.8.1).

Figure 1-3: gives an overview of the area’s covered in “Selected Pacific Islands”. The U.S.Virgin Islands are covered in “PR/VI”. A sample output for GILMAN station on Yap island is then shown in Figure 1-4.

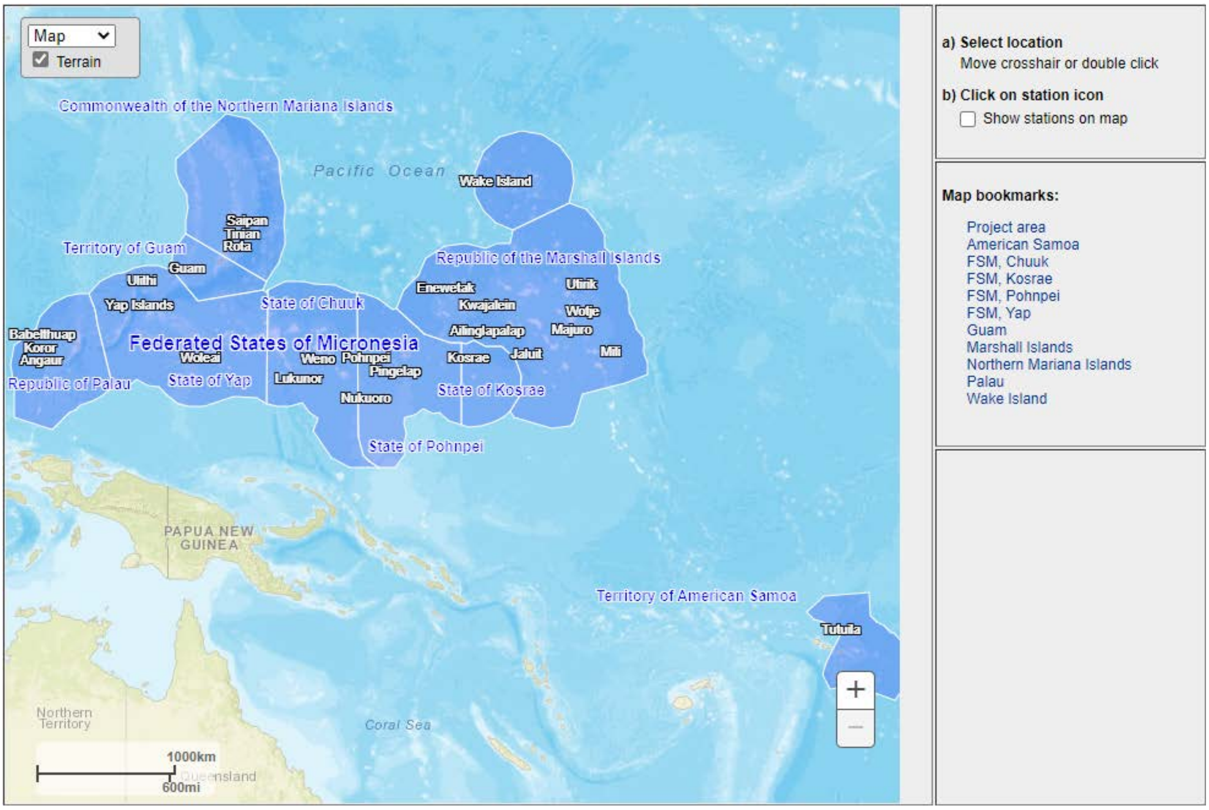
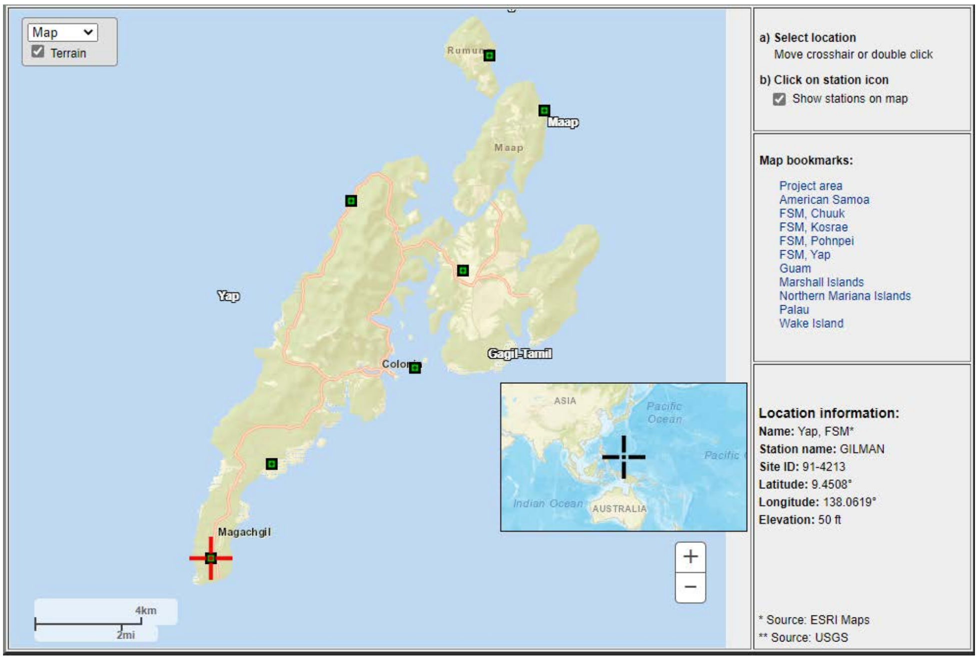


Figure 1-3: NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES - Selected Pacific Islands overview



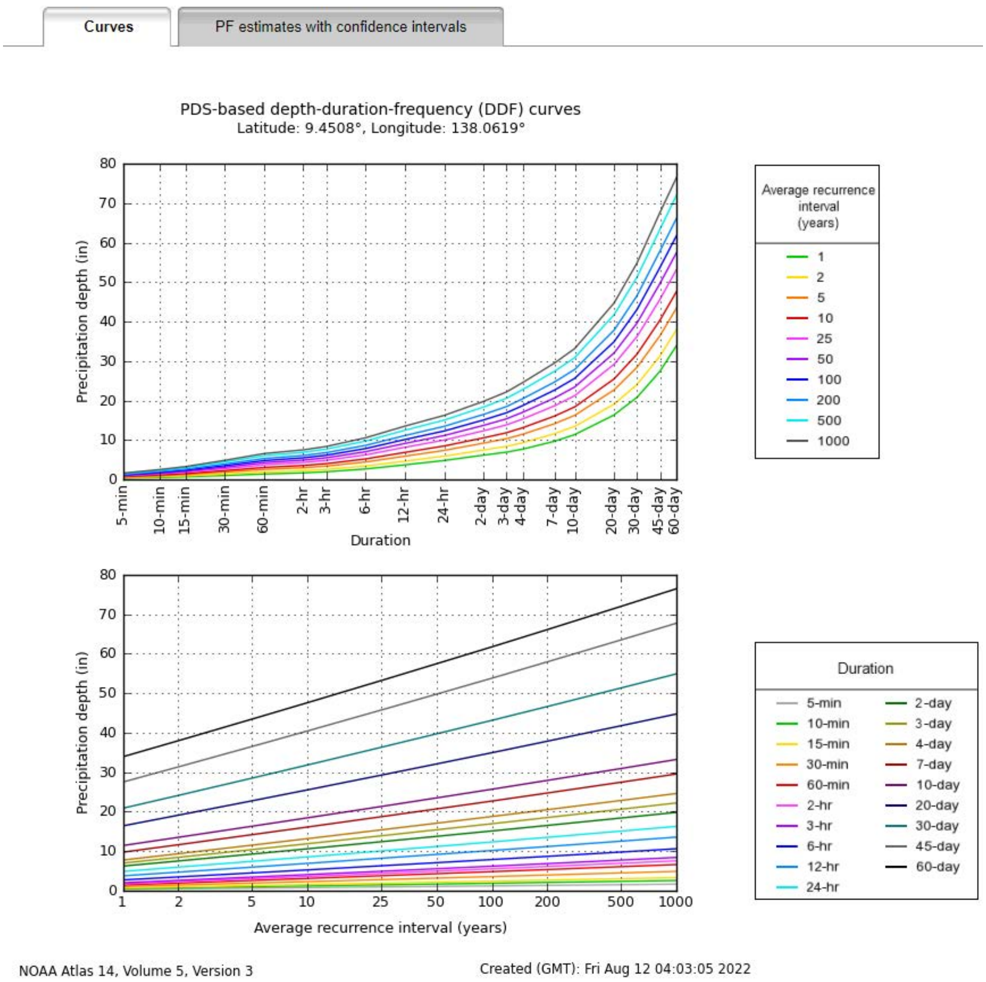


Figure 1-4: NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES - Gilman station, Yap - Graphical Output

Note that the islands can have microclimates with extreme variation in rainfall, soil type, vegetation, wave dynamics etc. Care is required in using data that is not specific to the location.

For the island areas within this guide,Table 1-2 identifies the weather stations that are known to be available for the basis of design reference.

Table 1-2: NOAA weather station data locations (data sets 1991 to 2020)

Island Area	Stations per island
American Samoa	PAGO PAGO WSO AIRPORT (+1 stations)
CNMI	SAIPAN INTLAP (+2 stations)
FSM – Chuuk	CHUUK
FSM – Pohnpei	NWS OFFICE
FSM – Kosrae State	TOFOL
FSM – Yap State	DUGOR (+4 stations) WOLEAI ATOLL
Guam	GUAM INTERNATIONAL AP (+4 stations)
RMI	MAJURO WBAS AIRPORT (+1 station)
Palau	PELELIUNEKKEN FORESTRY
USVI	HENRY E. ROHLSEN AIRPORT (+1 station)

Note – Station names in CAPITAL letters are the main NOAA weather station name for the island area to aid the facilities designer in searching for data if using this resource. (+# Stations) denotes additional geographic locations are available within the NOAA search function for that Island area.

2 Guidance on Building Project Process

2.1 Best Practice Approaches to Design Supporting Construction

The scale and compliance of code enforcement by local authorities varies from project to project in each area. In addition, construction monitoring and code enforcement of projects by the designer and/or a building inspector is not guaranteed, or necessarily undertaken by appropriately qualified staff. The quantum and quality of construction monitoring is also dependent on the available project budget.

The research and interviews gathered opinion and understanding on code adoption, use and compliance for design and subsequent enforcement during construction. While not directly related to the use of building code compliance for design, construction compliance through enforcement is an important part of the project life cycle, ensuring the quality of the construction and reducing the potential for longevity/durability failures for the end user if a lack of compliance occurs in either.

This Guide therefore recommends the following:

- Construction oversight shall be part of the scope of the project and its budget – reliance should not be placed on local agencies for ensuring compliance;
- The building designer should be part of the Quality Assurance (QA) team;
- A construction quality assurance plan to identify the critical elements for verification by construction administration staff should be prepared as part of the design outputs.

2.2 Supporting Long Term Asset Management and Maintenance

Infrastructure maintenance has long been recognized as a challenge, with inadequate maintenance resulting in loss of service to communities and additional costs. There is common agreement that maintenance is being avoided within the 'build-neglect-rebuild' paradigm (*PRIF report "Infrastructure Maintenance in The Pacific*"). This is not an effective strategy for long term sustainable facilities. It is better to consider the full life cycle of the facility in the planning and design phase and design it for achievable maintenance objectives that will extend the service life of the facility. The information and processes for the long-term management, maintenance and renewal of infrastructure should form part of the design and construction phases and, where applicable, be consistent with the facility owner's practices. This is discussed further in Section 6.

2.3 Planning and Executing a Good Building Project

It is apparent that there is inconsistency in the use of Codes and Standards for building design and construction, which is driven by several factors, including:

- Requirements and direction of project sponsors;
- Preference and stipulation by the client procurement team for design and for construction;
- Available resources e.g. water supply;
- Preference and knowledge of building designers, sometimes defaulting to Codes, Standards and practices with which they are most familiar;
- Independent reviewers following different Codes and Standards to those adopted by the designer or client;
- Limited quality checks on construction for compliance with Codes and Standards.

Stakeholders report both over-specification (specifying better than needed facilities or materials) and under-specification (specifying inadequate facilities or materials) in some cases. The former has led to overly expensive facilities that are difficult to maintain while the latter as led to unsuitable buildings or early deterioration.

During the initial planning or scoping process, the key features needed and the right materials for the situation should be considered, and then determined any variations to official Codes.

2.3.1 Keys to Quality Building Outcomes

Examples of successful practice highlights the following seven keys to achieving an appropriate building for the situation:

1. Design it right – put in place a process from project commencement that will achieve the right design through scoping, expertise, and review.
2. Be thoughtful about where to build; choose a safe location. Consider sea level rise, flooding, storm surges and wind exposure when selecting sites and building configurations. Also consider environmental impacts and permitting requirements (local jurisdiction requirements may apply)

3. Only build what is needed – Identify the current and future uses and space requirements for the facility. Design to those requirements since larger or more elaborate buildings cost more to build and more to maintain.
4. Match the available services and infrastructure - Evaluate available services and infrastructure during design. Water, sewer, and electricity are all scarce and expensive resources and shall be addressed through design efficiencies. For example, avoid high water demand features where there is limited water supply, adopt passive design to avoid reliance on air conditioning where power costs are high and will not be operated correctly.
5. Match materials / equipment to local capability for construction and maintenance. Evaluate the available construction resources, equipment and technical capabilities of the island and adapt the design accordingly.
6. Balance higher quality contractors and materials that may cost more versus lower quality contractors and cheaper materials. Identify risks to construction and maintenance to justify material and design selections. Higher quality (more specialized) contractors and materials may cost more than lower quality contractors and cheaper materials but result in better long-term performance or lower maintenance. Assess the whole-of-life costs of materials and equipment, including availability of maintenance capability and its cost. Verify compliance of materials with relevant Codes.
7. Include requirements for the construction contractor to have an experienced site supervisor and a quality control inspector to oversee the work (this also reduces reliance on inspections for critical quality control).

Not all of these are design activities, but all shall be considered in the decisions made in planning and design for the implementation of the building project.

Figure 2-1: Building cyclone-resistant buildings on remote site using available skills

2.3.2 Successful Design Processes

Successful projects for the island areas have shown that designers should consider the following while designing:

1. What can we achieve in this environment and how?

This includes consideration and agreement of the applicable dispensations or variances to Building Codes prior to beginning design. Previous building design, practice, and performance in the same area may offer guidance on both successful and unsuccessful practices.

2. What resources are available in this environment?

Designers for tropical island projects must not assume that resources easily available in large population centers will be standard in these small islands. Consider the resources available to deliver the project and the skills and capability to enforce them: How will the required design and construction expertise be provided? Are the chosen materials and equipment practical and give the intended quality to the environment? Is the supply chain in place for the chosen materials and equipment? How will the quality of design and of construction be checked and verified?

3. How are we going to be able to maintain it in this environment?

Skilled and specialized tradespeople are difficult to retain on the smaller island areas. As a result, preventative maintenance suffers significantly regardless of design. Design the project so that maintenance will be simplified and reduced to enable non-specialized staff to carry out preventative maintenance tasks whenever possible. Design with equipment and materials that require lower or less frequent maintenance where appropriate. Include the first year of maintenance in the construction contract if budget allows for it. Avoid the use of “state of the art” concepts that may be costly or difficult to maintain. One successful process is to interview current maintenance staff to help clarify requirements

4. What is the design lifespan?

The design lifespan is the approximate total amount of time the structure/utility/part is to remain in service. Design with a minimum lifespan expectation of 40 years or longer for structures with a sustainable solution. Determine whether local materials and labor forces will be able to achieve this and at what cost. Factor in the whole life costing for the project in decision making - Planning, Design, Construction, Maintenance, Recapitalization. Consider likely repairs that may extend facility operations and consider costs of relocation or decommissioning where appropriate. Maintenance (or lack of) has a real impact on a lifespan of a buildings function and performance, and the designer may wish to consider over specification to achieve a longer design life to reduce whole life costs and environmental impacts of refurbishment and maintenance. These should be highlighted to the client and identified at basis of design stage.

The Designer should be aware of the particular challenges within island areas relating to:

- End user priorities and importance of basis of design review;
- Capability and capacity of project management;
- Capability and capacity of contractors and skilled labor;
- Limitations to whole life design (due to lack of maintenance budgets);
- Simplifying design drawings, specifications, and proposed construction methods.

These points, and others, are addressed in subsequent sections of this guide.

2.3.3 Basis of Design

A Basis of Design document shall be prepared and agreed to at the project commencement. This document outlines the criteria and rationale to inform the design, and to guide subsequent reviews.

The Basis of Design should be prepared by the Designer of Record (DOR) with inputs from design component specialists, and in consultation with the project proponents (e.g., client, resource sponsor, project manager) in accordance with Section 6.1.3.

As a minimum, the Basis of Design shall include:

- **Project background:** A briefing of the project including description and previous work;
- **Project Scope:** This section includes the overall scope of the project in detail, and separate scopes of each discipline involved in that project as applicable;
- **Information Sources:** all the design information or assumptions for each discipline;
- **Technical Assurance Review:** Requirements and processes to ensure the safety and quality of the project by performing various quality reviews like Design Review and HAZOP study;
- **Design Criteria:** various basis for design decisions and calculations; for example, design life, level of service or sizing criteria, environmental requirements;
- **Project Cost Estimates:** Budgets for design and construction, including permitting and management;
- **Codes and Standards:** all the relevant codes and standards listed along with their editions;
- Government Laws and regulations: as and when applicable (consider local requirements);
- **References and Appendices:** All the references and appendices to substantiate the above-mentioned decisions.

An approved basis of design for each stage of the project is critical to a project’s success. Early engagement with all stakeholders (which may include regulators, building users, as well as project proponents) to define and agree on the scope, design, permitting requirements, governing Codes and Standards is essential.

While some designers may continue the Basis of Design through the end of the design process with updates, this Guide deliberately specifies separate documents – Basis of Design to define the design outcomes needed, and Design Statement to record the design information.

2.3.4 Design Statement

On completion of the design, the Designer of Record shall complete a Design Statement in accordance with Section 6.1 to record the design information.

This shall include a design report, including narratives, calculations, and other supporting features (e.g., sketches and diagrams), to document the development and evaluation of the design for this project and how the requirements of the Basis of Design have been achieved. The DoR shall prepare the report for record and review to identify assumptions and support decisions made during the design process. The design report is developed in coordination with the project proponents and end users.

2.4 Implementation Considerations for Building Design

The FDGTI is intended for use by the design team, project proponents (e.g., client, resource sponsor, project manager) and project reviewers at all stages affected by design. This includes preparing for and managing the construction and commissioning of a building.

The design team; being designer, independent peer reviewer, and contractor (if Design-Build, Early Contractor Engagement, or Engineer-Procure-Construct contracts are used) will likely make significant project implementation decisions during development of the scope/performance requirements and design/specification that will have an impact on the longevity and resilience of the building and thus affect the end user over the lifetime of the building.

The client and subsequently the design team should take the following into account when preparing a Request for Proposal (RFP) for design works.

2.4.1 Procurement Methods

Typically, in these island areas, OIA-funded project procurement, including the design and construction, are overseen by the local project management office. The Department (or Ministry) of Public Works (DPW) for an area generally overseeing all horizontal and vertical government infrastructure projects.

Open solicitations are most frequently used for larger capital projects. Single contract source selection is done through either a single- or multi-stage (selection of most qualified designers first, then selection of the best proposal) process depending on project value, complexity and commercial risk. Closed tender (i.e., direct appointment or sole-source selection) is sometimes used on lower commercial risk projects, but national government procurement requirements may restrict this method. The procurement strategy is usually determined by the sponsor prior to any solicitation. It is not expected the design team will be able to influence the procurement method but should be aware of the implications and risk associated with the procurement approach. The design team should communicate to the procurement agency and sponsor any specialized expertise or experience that will be required so the source selection team can include in the source selection criteria.

Construction is typically delivered via either:

- Build Contract
  - Client provides the design as part of the RFP (which may include small elements of low-risk contractor design). The client carries the design and longevity risk, and the contractor is limited to construction risks.
  - The design team will need to ensure the design is fit for purpose and considers location specific requirements to avoid excessive construction costs or poor performance / lack of spares during the O&M period.
  - The advantage of Design – Bid – Build process is that owner specified requirements and features are included in the design and bid accordingly by all offerors. A disadvantage is that the process requires two contracts and procurements.
- Design-Build Contract (or Engineer-Procure-Construct or turnkey)
  - Client provides functional and technical performance requirements for the project. These can require an extensive set of documents to make sure the contractor's end product meets the client's expectations. These types of contracts tend to place significant commercial risk on the contractor, both during construction and afterwards if the project fails to meet the performance requirements during the operation and maintenance period.
  - Can include development – the client provides a reference design or proof of concept to accompany the D&B functional performance requirements to give greater cost certainty during tendering on Clients preferred solution.

- The clients procurement source selection team will need to ensure the performance requirements are fit for purpose and represent the clients' intentions for the project to avoid failed project procurement due to lack of interest, over-designing, and unnecessary cost.
- Advantages of Design-Build processes are faster product delivery and better teaming between the designer and the constructor. The disadvantage is that the owner must clearly identify all requirements and quality expectations in the RFP. Requirements identified after the Design-Build award can result in very costly and time-consuming changes.

Design and Construction supervision and enforcement may be defined by the client to gain assurances that the construction meets the design and specification procured under the contract.

2.4.2 Local Planning and Regulatory Requirements

Requests for dispensations and variances should be very rare, designers should make every effort to find designers should make every effort to find design solutions which meet the Code.

The designer shall comply with all national and local regulations. Section 4.4 Environmental Protection and Planning Controls contains further information.

2.4.3 Supply Logistics

The designer should be aware of the remote locations of some parts of the Pacific and construction logistics and supply of equipment and materials being the major challenges to construction.

Figure 2-2: Material supply on remote island

Some OIA-funded projects will have the US mainland as a prerequisite for supply of materials and equipment for the project, so the designer will have to specify items as such. If no preconditions are set, the respective project and/or program manager for each area will be able to give preference for supply (US East Coast, Australia/New Zealand, Asia).

The designer shall consider and address the following constraints when specifying materials and/or equipment, or construction methods specific to a design:

- Transport routes - Land/sea/air freight dependency. Expect and plan for long shipping times and infrequent departures. Ask about the local shipping schedules and sailing times from the continental US or other sources of long lead items;
- Design workforce (local vs expat) – capability and capacity. Designers on most islands have only a limited expertise at best and do not have specialties (e.g., medical);

- Construction workforce / labor supply (local vs expat) – capability and capacity. Inquire about the capacity and capabilities. Many islands have only a few general contractors and these are subject to surges in workload. Availability of local specialty subcontractors is variable and may need to be imported;
- Supply chain availability for construction materials;
- Supply chain availability for operation and maintenance spare parts. Specified equipment must be serviceable after the facility is put in operation. Procurement and shipping delays should be expected, so equipment which is locally available and serviceable is preferred over equipment which will require parts and maintenance from remote locations;
- Local utilities to support project delivery and maintenance;
- Appropriate units (imperial versus metric) and Standards depending on expected source of materials. The default should be to imperial units in these localities. If materials are expected to be supplied from outside USA territories, then metric units should be used. Appropriate standard sizes should be used depending on the expected source of materials (e.g. timber or steel section dimensions). Another consideration is whether the construction workforce will be familiar with the units of measure. In some situations, both imperial and metric units may be relevant. The designer shall consult with the project sponsor to determine appropriate units prior to commencing design activities.

Key Strategies for Building Project Processes
1. Best practice approaches to design supporting construction • Construction oversight shall be part of the scope of the project and its budget – reliance should not be placed on local agencies responsible for building compliance • The building designer shall be part of the Quality Assurance (QA) team • A construction quality assurance plan shall form part of the design outputs
2. Supporting long term asset management and maintenance The information and processes for the long-term management, maintenance and renewal of infrastructure should form part of the design and construction phases.
3. Planning and Executing a Good Building Project Designers should consider the following while designing: • What can we achieve in this environment and how? • What resources are available in this environment? • How are we going to be able to maintain it in this environment? • What is the design lifespan? A Basis of Design document shall be prepared and agreed at the project commencement. This document outlines the criteria and rationale to inform the design, and to guide subsequent reviews. On completion of the design, the Designer of Record shall complete a Design Statement to record the design information.
4. Implementation Considerations for Building Design The client and subsequently the design team should take the following into account when preparing a Request for Proposal (RFP) for design works: • Procurement methods • Local planning and regulatory requirements • Supply Logistics

3 Codes, Standards and Guidelines

3.1 Minimum Requirements

For new build design and construction, Facilities designers shall follow the latest edition of IBC or the local building code, whichever is the more stringent, for building works. For alterations of existing buildings, the facilities designer shall follow the latest edition of the IEBC or the local building code, whichever is more stringent.

Other information on relevant Codes, Standards and Guidelines is below.

3.2 Definitions

To assist with use of this design guide, the following ‘lay-person’ descriptions are given for:

- A **Regulation** is a legal document that incorporates codes (and/or standards) to give legal requirement for a building to comply with. i.e., *“**the legal minimum requirements for health, safety and consumer protection**”;*
- A **Code** is a regulatory document that identifies the minimum performance requirements that a design must comply with. i.e., *“**rules of what you need to do**”;*
- A **Standard** is a technical guideline developed by an industry body for promoting safety, reliability, productivity, and efficiency in design, supply, and installation. A Standard may be directly referenced in a code to demonstrate compliance or adopted by the designer (when no specific standard is referenced). Producing a design in accordance with the methods defined within a Standard would in turn, demonstrate compliance with a code. i.e., *“**the how-to of achieving the rules**”;*
- A **Dispensation** or **Variance** is a record of deviation from a requirement of a Code or Standard. Any dispensations should be clearly identified by the designer and identified to the Client, as a peer review may be required to gain agreement on the scope of the dispensation and subsequent impact on building performance. Dispensations (and the background discussion) shall be noted in the Basis of Design.

3.3 Available Building Codes

The scope of this design guide is based on USACE’s direction for overarching compliance with the International Building Code (IBC) as a minimum benchmark for consistency in design approach. The IBC is prepared by the International Code Council (ICC) (International Code Council, 2021), with the latest version being 2021 at time of preparation of this guide. The scope of this design guide does not cover compliance with other publications of the ICC (such as the Residential Code); however, designers may choose to reference or use ICC publications as a recognized standard of international design requirements.

The IBC, being based around mainland United States of America, may not have specific performance requirements specific to the island areas or tropical environments. Where possible, this guide will identify or recommend alternative sources of basis of design information or design approaches.

Many of the island areas have established, or are looking to develop or update, national/local building codes for country-specific use. These usually sit at the regulatory level as a legal requirement to meet minimum health, safety, and welfare requirements for protection of occupants from hazards and define the quality requirements for longevity of the building structure and services. Where a country-specific code does not exist, or is considered out of date by the designer, they may choose to adopt the IBC.

The FDGTI is intended to cover non-military buildings that do not require compliance with the Department of Defense (DOD) requirements for whole building design. However, the unified facilities criteria (UFC) provide useful reference and basis of design information for planning, design, construction, sustainment, restoration, and modernization criteria for locations where the DOD has installations, including many locations across the Pacific Ocean (including or adjacent to island areas). The DoR should be aware that the DoD building Code (UFC 1-200-01) is based upon the provisions of the 2018 IBC (Department of Defense, 2019), so would need to cross reference requirements with the latest version of the IBC to demonstrate compliance.

The International Existing Building Code (IEBC) may also provide a useful reference, although it has not been adopted in any of the island territories covered by this Guide.

3.4 Local Building Codes in Each Area

A synopsis of the findings on code adoption, use and enforcement at the time of writing this FDGTI is shown below in Table 3-1.

Table 3-1: Code adoption, use and enforcement in the island areas as of 2022

Island Area	Current Building Code	Current Regulations	Comments
American Samoa	Uniform Building Code, 1964 Edition, Volume I – approved by the International Conference of Building Officials ASHRAE Standard 90-75 – lighting, equipment, thermal efficiency standards No energy code for private sector	Source - 26.1001 Adoption of code-Exceptions. - American Samoa Bar Associations (asbar.org)	Use of ASCE standards common
CNMI	IBC 2018 (Public Law 21-14, Code T155-10.1) The Model Tropical Energy Code 2014 (equivalent to IECC)		Local variations exist FEMA P-2177
FSM	No official local code FSM specific local code under development Not formally adopted International Building Code		Government projects follow IBC, NEC, AISC, NFPA
Guam	Unified Facilities Criteria (UFC) for US Federal Military projects IBC 2009, IECC 2009 (commercial), IRC 2009 (residential)		Guam Code – Chapter 67 Building Code
RMI	1987 Local Building Code Not formally adopted International Building Code		New Building Code awaiting ratification by local govt and ICC review
Palau	No official code Not formally adopted International Building Code		Some regulations and guidelines to IBC
USVI	IBC 2018	USVI Construction for Stronger Homes 4th Edition	Supported by guide for stronger homes

3.5 Relevant Technical Standards

For ease of compliance with the IBC, design work should be undertaken using "imperial-unit based" standards, such as American Society of Civil Engineers (ASCE) and Structural Engineering Institute (SEI).

For buildings, the IBC references ASCE/SEI 7 "Minimum Design Loads and Associated Criteria for Building and Other Structures" as the adopted Standard. The IBC revision generally adopts the version of ASCE 7 current at the time, so the DoR should be aware that IBC 2021 adopts ASCE 7-16 (latest version at the time). As ASCE 7-22 has now been issued, the DoR should comply with this, as the latest version that will be adopted in the next IBC, otherwise the buildings will constantly be to outdated standards.

For natural hazard design guidance, FEMA Building Science Branch and Earthquake Wind Programs Branch at Headquarters provide publications on flood resistance, tsunami and seismic resilience provide detailed direction to the designer on specifics of the design code implementation and compliance.

Facility designers shall use either the local building code or the international building code, whichever is more stringent. The FDGTI shall be used to supplement and strengthen those requirements to provide for additional resiliance and sustainability. Best practices identified by this FDGTI are not mandatory but are to be included as appropriate and practical for the project.

3.6 Guidance Where No Local Code Exists, or Departures Are Needed

The process for adoption of a code is usually directed by a country's government at a legislative level (government act), regulatory level (subsidiary legislation on how the act should be implemented) and technical level (standard or approved code of practice on design and construction to achieve specific requirements for safety and longevity).

From desktop research and interviews, it has been determined that applicability, adoption, use and enforcement of the IBC or area specific building codes (BC) use for design and implementation varies widely across the island areas.

The process for obtaining a dispensation varies between jurisdictions and it is the responsibility of the designer to identify the applicable process and apply for the dispensation in a timely manner. If no formal process exists, it is recommended that the designer maintains a log of dispensation requests required by the design and request a written response from the AHJ or the relevant party (e.g. PMO) to document the decision. The documentation shall be included as an appendix to the design submission (basis of design and/or detail design).

It is important for the design team to document the adopted code/s and standard/s followed through the design and reasons for deviations or decisions made in the design process (in the Basis of Design and Design Statement). This facilitates a background explanation for any peer review, where economic / resilience decisions have been made that lead to under-/over-designing a building, instead of direct code compliance.

3.7 Relevant Building Practice Guidelines

Codes and Standards set the minimum standard for prevention of harm to persons and minimize the impact of external forces (such as hurricanes) on the building performance. Compliance with criteria set within should ensure a minimum performance of the building during these events and minimize the potential for serviceability and ultimate damage.

However, in the tropical environment, detailing is often key to providing longevity in building performance for both extreme design events and minimizing maintenance requirements.

The following is a list of guidance documents that the DoR should be aware of to supplement codes and standards for tropical island buildings including but not limited to:

- PRIF Guidance
  - Regional Diagnostic Study on the Application of Building Codes in the Pacific
- FEMA Guidance

  FEMA P-787 - Catalogue of FEMA building science branch publications, 5th Edition (FEMA, 2022) Including the following reference publications:

  - FEMA P-55 Coastal Construction Manual
  - FEMA P-83 Seismic Considerations for Communities at Risk
  - FEMA P-424 Design guide for school safety in earthquake, floods, and high winds
  - FEMA P-543 Design guide for improving critical facility safety from flooding and high winds
  - FEMA P-577 Design guide for improving hospital safety in earthquake, floods, and high winds
  - FEMA P-646 Guidelines for design of structures for the vertical evacuation from tsunamis
  - FEMA P-804 Wind Retrofit Guide for Residential Buildings
  - FEMA P-936 Floodproofing Non-residential Buildings
  - FEMA P-1019 Emergency Power Systems for Critical Facilities,
  - FEMA P-2082 EHRP Recommended Seismic Provisions for New Buildings and Other Structures
  - FEMA P-2181 Hurricane and Flood Mitigation Handbook for Public Facilities.
  - Technical Bulletin 8 - Corrosion Protection for Metal Connectors in Coastal Areas
  - IBC 2021: A Compilation of Wind Resistant Provisions.
  - FEMA P-2177 Codes, Standards, and Permitting Mitigation Assessment Team Summary Report and Recommendations CNMI [7]

[7] https://opd.gov.mp/library/reports/codes-standards-and-permitting-fema-p-2177/codes-standards-and-permitting-fema-p-2177.pdf

Key Strategies Codes, Standards and Guidelines

1. Minimum Requirements

- For new builds follow latest edition of the International Building Code (IBC) or the local building code whichever is the more stringent
- For alterations follow latest edition of International Existing Building Code (IEBC) or the local building code, whichever is more stringent

2. Local Building Codes

Table 3.1 lists local building codes for specific regions.

3. Relevant Technical Standards

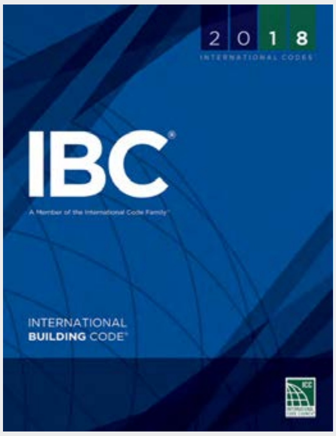
- Design should be undertaken using “imperial-unit based” standards, such as American Society of Civil Engineers (ASCE) and Structural Engineering Institute (SEI)
- For buildings IBC references ASCE/SEI 7 “Minimum Design Loads and Associated Criteria for Building and Other Structures”
- For natural hazard design guidance, refer FEMA Building Science Branch and Earthquake Wind Programs Branch
- FDGTI shall be used to supplement and strengthen requirements of IBC and local building codes

4. Guidance where no local code exists, or departures are needed

- It is the responsibility of the designer to identify the dispensation applicable process and apply for dispensation
- Where no process exists designers should maintain a log of dispensation requests required by the design and request a written response The document shall be included as an appendix to design submission
- The design team must document the adopted code/s and standards and reasons for deviations or decisions made during the design process

5. Relevant Building Practice Guidelines

- PRIF – Regional Diagnostic Study on the Application of Building Codes in the Pacific
- FEMA P787 – Catalogue of FEMA building science branch publications, 5th Edition. Refer section 3.7 for complete list of FEMA P787 publications



New builds to follow latest edition of IBC or local building code

4 Building Design for Sustainability and Resilience in Tropical Environments

4.1 Guidance on Buildings for Tropical Climates

The following Table 4-1 is a list of guidance documents that the DoR should be aware of for tropical island buildings, including but not limited to:

Table 4-1: Design Guides for Tropical Buildings

Guide	Author	Salient Features
Sustainable Tropical Building Design, Guidelines for Commercial Buildings	(Cairns Regional Council, 2011) https://www.cairns.qld.gov.au/__data/assets/pdf_file/0003/45642/BuildingDesign.pdf	• Guidance on passive design, energy and emissions reduction, water and waste water management, indoor environment and construction materials for tropical environments
Sustainable Building Design for Tropical Climates	(United Nations, 2015) https://unhabitat.org/sustainable-building-design-for-tropical-climates	• Design guide for multiple tropical environments, including hot/humid islands. • Supported by technical note 10: key strategies for sustainable building design
Design Guidelines for Queensland Public Cyclone Shelters	Department of Public Works, 2006 https://www.hpw.qld.gov.au/__data/assets/pdf_file/0023/5558/designguidelinesqueenslandpubliccycloneshelters.pdf .	Information on cyclone shelter design and dual purposing of structures
Key Strategies for Sustainable Building Design in the Tropics	UN-Habitat, 2015 https://unhabitat.org/sustainable-building-design-for-tropical-climates	
Homeowners Handbook to Prepare for Natural Hazards	Republic of Marshall Islands. 2015 https://repository.library.noaa.gov/view/noaa/36094	
Construction information for a Stronger Home, 4th Edition	DPNR, USVI, 2018 http://www.vitema.vi.gov/docs/default-source/response-recovery-documents/(1)-construction-information-for-a-stronger-home-4th-edition.pdf?sfvrsn=c52995d_2	
Guidance Manual for Smart, Safe Growth	CNMI, 2018 http://www.opd.gov.mp/assets/cnmi-ssg-guidance-manual-final-2018-11-14.pdf	Development strategies focused on improving the resiliency of the built environment.
Guide for Resilient Energy Systems in Hot and Humid Climates	USACE	Recent USACE publication

4.2 Selecting Appropriate Equipment and Materials

The DoR shall consider the following principles for appropriate equipment and material selection in tropical environments and address them in the Basis of Design:

- Availability of supply
- Availability of spares
- Expertise to maintain
- Durability
- Environmental sustainability including obsolescence and disposal
- Standard factors *of cost and effectiveness.*

Further guidance is given in Section 5, Building Detailing.

4.3 Tropical Environmental Considerations

The design team shall address the following environmental points when designing and detailing a building in the tropical environment:

- Aspect and topography;
- Ground conditions;
- Humidity;
- Saline atmosphere / sea spray;
- UV exposure;
- Biological attack;
- Climate change on environmental loading.

Refer to Section 4.7, Natural Hazards and Section 4.8, Living With and Adapting to a Changing Climate of this guide for further details

4.4 Environmental Protection and Planning Controls

Environmental and land use rules are set by legislation and planning rules, and not by Building Codes. These rules vary between each region. Implementing planning controls is difficult in some Pacific states because of complex communal ownerships and rights. District Zoning plans are not common practice across every island area. Further, low-risk land for building is scarce in some areas such as Marshall Islands, which results in building on land close to coast or other hazardous areas. A zoning guide and associated enforcement would help mitigate risk of building on hazardous areas. Nevertheless, in the absence of stipulated zoning guidance can be given on best practice and the important factors to consider.

The design team should be aware of the following local government departments and current permitting requirements and consider engagement with the relevant officials early in the design process to encourage collaboration and support for the design decisions. Table 4-2 gives a synopsis of the area, regulations, and links to relevant resources (this information is correct at the time of writing but may change as a result of government actions).

Table 4-2: Protection and Planning Regulations

Island Area	Planning Regulations	Website Links
American Samoa	• PNRS (Project Notification and Review System) and Land Use Application	• Department of Commerce • Department of Public Works • Environmental Protection Agency
Northern Mariana Islands (CNMI)	• CNMI Planning and Development Act of 2017 (Public Law 20-20)	• Office Of Planning and Development • Coastal Resources Management • DCRM Regulations • Commonwealth Zoning Board
Federated States of Micronesia (FSM)	• Chuuk - Chuuk State Environmental Protection Act (Article 11, Section 1 of the Chuuk State Constitution)	• Legal Information System

Island Area	Planning Regulations	Website Links
	• Kosrae – Resource Management Regulations (Title 7, Chapter 4 of the Kosrae Code). • Pohnpei – Resource Management Regulations (Chapter 1 of Title 41 of the Pohnpei State - Pohnpei Land Use Planning and Zoning Act of 1993) • YAP - Title II - Environmental Impact Assessment (Environmental Quality Protection Act)	
Guam	• Guam Code Title 21, Chapter 61 Zoning Law	• Development Requirements on Guam (Bureau of Statistics, Government of Guam, 2005) – no link available
Palau	No official planning or zoning regulations, local state requirements may apply	• Palau Sustainable Land Management Policy (Government of the Republic of Palau, 2012)
Republic of Marshall Islands (RMI)	No official planning or zoning regulations, local state requirements may apply.	• Refer to local building code 1987.
U.S. Virgin Islands (USVI)	• Title 29, Section 228 of the Virgin Islands Code	• Department of Planning and Natural Resources: Comprehensive and Coastal Zone Planning

4.5 Environmental Protection and Design Considerations for Materials and Construction Methods

Building designers shall minimize project impacts on the natural and built environment.

The limited land mass of the island areas requires that all materials and waste which may pose a threat to the environment be critically evaluated as to their procurement, use, and ultimate disposition. Every effort shall be made to identify and use materials which are non-hazardous and/or non-toxic.

When this is not possible, the design analysis for each project shall explain how the use of hazardous and/or toxic materials will be controlled and how spent, waste, or surplus material will be collected and ultimately disposed. Hazardous materials and wastes must be managed in accordance with applicable local and federal regulations for proper handling, storage, labeling, sampling, containerizing, and transporting. Special attention should be paid to coatings that must comply with applicable volatile organic compound (VOC) content requirements.

A formal environmental plan shall be developed as part of the design scope, to guide both the design and construction activities. In accordance with local requirements which, at minimum will identify permits, restrictions, hazardous materials (for repairs and renovations) and other issues as identified below.

4.5.1 Solid Waste and Waste Minimization

The reduction of solid waste and its safe disposal is a common problem for all the island countries. Geographical isolation and small local markets make it more difficult to recycle materials economically and therefore imported goods and products are most likely disposed of at a dumpsite, which is made more difficult by limited land area. Waste dumping into lagoons and coastal areas is a major threat to clean environments. Even on high islands, improperly managed dumpsites pose serious risks to public health.

The largest waste stream generated by construction is combustible and non-combustible solid waste. Designers shall adopt practices to reduce wastes and to recycle materials whenever possible and practical.

Designers shall consider the pathways for eventual disposal of construction materials in selection of materials and equipment and identify areas where waste materials can be reduced, propose less hazardous or recycled alternatives.

Where demolition or site clearance is required, solid waste such as ferrous and non-ferrous metal, roofing materials, sheetrock, cement, porcelain, rubber, vehicles, etc. shall be identified, segregated, and processed.

4.5.2 Hazardous Waste

A hazardous waste may cause or contribute to an increase in mortality or an increase in serious or incapacitating illness, or cause or contribute to adverse health effects in people or other organisms.

Hazardous waste is defined in the Code of Federal Regulations (40 CFR 261) as a waste or combination of wastes that exhibit one or more of the following criteria:

- Ignitability: A flash point less than 140º F;
- Corrosivity: A pH less than or equal to 2 (acidic) or greater than 12.5 (basic);
- Reactivity: Various characteristics including Reacts violently with water, may generate toxic gas, may detonate, oxidizers;
- Toxicity: Concentration limits for organics, metals and pesticides;
- Listed Waste: A waste may be deemed hazardous if it is used in a specific process (i.e. degreasing) or contains ingredients that are individually regulated.

Non-hazardous and non-toxic materials should be used wherever possible. When hazardous or toxic materials are used, the design information shall include how the hazardous or toxic materials will be controlled and how waste will be collected and disposed of.

All hazardous wastes must be managed and disposed of in accordance with the recommended practice for the substance including electrical and electronic waste.

4.5.3 Material Handling

The designer shall include requirements in the construction documentation for the construction contractors to handle materials so that adverse impacts are minimized. This shall include, as a minimum:

- Minimize the amount of material wastage;
- Safely dispose of all waste material from the site;
- Ensure hazardous and non-hazardous wastes are segregated. Code of Federal Regulations 40 CFR 261.3 states that when a hazardous waste is co-mingled with non-hazardous waste, the resultant mixture is a hazardous waste and must be handled as such;
- Ship and dispose of hazardous and regulated waste (polychlorinated biphenyl [PCB], asbestos, etc.) in accordance with local and federal regulations. Copies of shipping documents (manifests) and disposal records/certificates of destruction shall be retained as permanent records for the project.

4.5.4 Safety Data Sheets

Safety Data Sheets (SDS) are required for all construction materials. These should be considered during design to determine the occupational and environmental hazards associated with the material. The SDS should be made available to the building owner, the construction contractor and any agency implementing the building work or maintaining the building.

4.5.5 Lead Paint and Asbestos Containing Materials

This section is applicable to building modifications. Lead paint and asbestos containing materials (ACM) shall not be used in new construction.

When interfacing with existing facilities, the DoR shall require an existing condition report to be provided for hazardous substances to advise on the design and removal requirements.

Before paint removal is specified, the designer shall verify that all affected existing coating/painting systems have been tested for possible lead content. Appropriate guidance is contained in OSHA 29 CFR 1926.62, Lead in Construction Regulation and Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing by United States Department of Housing and Urban Development (HUD).

Before buildings are demolished, they shall be assessed by a qualified person to identify whether there is potential for ACM. Asbestos has been used in the past in a variety of building construction materials. The most likely to be encountered are:

- Attic and wall insulation;
- Vinyl floor tiles and the backing on vinyl sheet flooring and adhesives;
- Roofing and siding shingles;

- Textured paint and patching compounds used on walls and ceilings;
- Hot water and steam pipes coated with asbestos material or covered with an asbestos blanket or tape;
- Electrical panel insulation, back boards, and fuse components.
- If ACM is identified, it should only be removed or handled by a qualified specialist contractor.

4.5.6 Chemical, Petroleum, Oil, and Lubricant Systems

Spill containment and clean-up methods shall be included in above ground systems for storage and transfer of fuel, oil, lubricants, or chemicals.

4.6 Historic Preservation

Design and construction shall comply with the applicable local requirements. Projects in the Territories shall comply with the National Historic Preservation Act (NPHA) and the Archaeological Historic Preservation Act (APHA) and any local legislation and practices. Islands in the other states have developed their own rules, regulations, and processes to ensure that the appropriate permits are obtained and that the design and construction will be compliant. A person knowledgeable on local cultural history and practice should be part of the project implementation team.

4.7 Natural Hazards in the Pacific and Atlantic Oceans

Designers shall assess the existence and extent of natural hazards for the building site including those which will be exacerbated from a changing climate and rising sea level.

The following list includes, but is not limited to, natural hazards known to occur in the tropical environment that should be considered during the design and detailing of buildings. Natural hazards may interact with each other and create compounded problems that need to be addressed in tandem rather than in sequence.

Standard State Mitigation Plans include area-specific hazards analysis that can further inform this assessment component.

If the facility is intended to be used as a shelter during storm events, then specific references should be consulted. This includes storm shelter/safe room provisions that provide near absolute protection. Criteria for a safe room are provided in FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms* (FEMA, 2021). Basic safe room information and construction drawings for site-built safe rooms are provided in FEMA P-320, *Taking Shelter from the Storm: Building or Installing a Safe Room for Your Home* (FEMA, 2021).

4.7.1 Rainfall

The tropical environment in these island areas is prone to periodic events of high rainfall. This rainfall is not always associated with other environmental phenomena including high winds. Also, some of these areas have distinct dry and rainy seasons with most of the annual rainfall occurring within a limited number of months. Designing for this fluctuation is important.

Rainwater harvesting shall be considered. In locations that do not require the collection of rainwater reliable sources of fresh water are not always available and collecting this on-site for re-use provides a more long-term sustainable solution in these environments. Roofs should be designed to effectively divert rainwater into a collection device or otherwise away from the building walls and foundations. Sizing of gutters and downspouts should also be properly calculated to prevent these from backing up and flooding in torrential situations.

Finally, buildings should be placed to avoid locating structures in areas that may also serve as natural swales or other similar features that allow for rainwater to flow across the natural topography of the island.

Figure 4-1: Wide gutter located in Pohnpei. Photo supplied by USACE

4.7.2 Wind and Extreme Wind Events

Wind load is often the dominant structural loading for vertical buildings. The IBC Chapter 16, Section 1609 makes reference to use of ASCE 7, chapter 26 to 30 for derivation of the minimum wind loading for the building to withstand.

Extreme wind event is a term used to cover storm winds that have geographical specific names that will be referenced as; Cyclones, Typhoons, Hurricanes, Tropical Depressions.

The Design team should refer to section 5.3.1.4 of this guide for further details and island area specific considerations.

4.7.3 Flooding and Wave Action

Being islands, mitigating the effects of flooding and wave action need to be considered during site appraisal (if able to be influenced during project planning phase) or considered during the design. The DoR shall address the following when determining the base flood elevation:

- Siting factors (geology, topography, foreshore development, floodplain mapping) and their potential to increase the impacts of wave action, storm surge and inundation flooding;
- Individual storm events (duration to peak wave height or storm surge);
- Long-term impacts (coastal erosion and sea level rise).

Guidance provided in FEMA P-55 Coastal Construction Manual gives practical design steps for compliance with IBC Appendix G and ASCE 24-05 Flood Resistant Design and Construction.

Designs should increase resiliency by increasing the elevation of the structure's functional levels (i.e., "ground floor") to be above the base flood elevation, being the minimum IBC compliance (G103.3). Additional elevation (freeboard) will decrease the likelihood of flood damage to the structure and will vary in accordance with the Designer's classification of the structures use and occupancy (ASCE 24-14, Table 1-1). FEMA has released a guidance document to assist in decision making and design in accordance with ASCE 24-14[8]. This, combined with consideration to building detailing as listed below, will contribute to longevity of the structure and decreased risk:

- Water-resistant flooring finishes (e.g., sealed concrete);
- Wall detailing (i.e., plaster instead of plasterboard / non-porous foam insulation);
- Electrical equipment location and wiring ingress protection (IP) ratings.

Further guidance is given in Section 5.3.1.5 of this Guide.

4.7.4 Seismic

The Pacific Rim, commonly known as the "ring of fire", is seismically active due to tectonic plate boundaries of the Pacific Plate with Australian-Indian, Philippines and North American plate and potential seismic events that will likely affect building structures. The USVI is located on the boundary of the Caribbean and North American plates and is also likely to be affected by seismic events.

As such, the design team should be aware of the seismic hazards that need to be considered during the design process.

The quantity, quality and availability of geological records, fault locations and values for horizontal and vertical peak ground accelerations (PGAs) are dependent on location. The Design team should look to identify, and agree on chosen PGAs, amplification factors and if necessary, interpolation/estimation of basis of design values.

A Comparative table between the commonly used instrumental intensity (Mercalli scale) and PGAs is provided by the United States Geological Survey (USGS) (USGS, United States Geological Survey, 2003)

USGS provides an open-source reference for past seismic events through their online Atlas (USGS, 2022). An example of the search function showing seismic events above magnitude 7.0 since 2005 is shown below in Figure 4-2 (plate boundaries in red).

[8] HIGHLIGHTS OF ASCE 24-14 Flood Resistant Design and Construction (fema.gov)

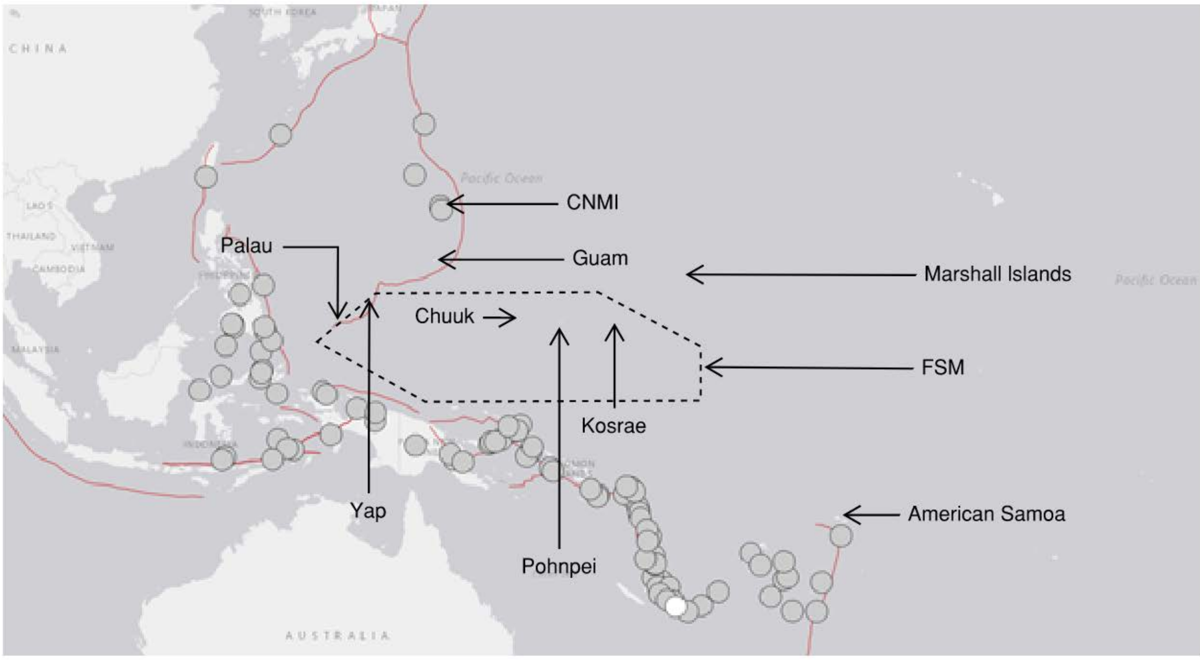


Figure 4-2: USGS Pacific Atlas

In lieu of other information on background geology, the USGS provides further guidance through publications (U.S. Geological Survey Publications Warehouse)

For design of new buildings, the design team should refer to section 5.3.1.3 of this Guide.

Should the project scope include for re-purposing and retrofitting of existing structures, the design team may look to consider the guidance within FEMA P-154 (FEMA, 2015) as the basis for assessment and subsequent design.

4.7.5 Tsunami

Accompanying the land-based hazard of seismic activity, tsunami hazards created by seismic activity and coastal topography may exist both from seismic events at the site location, or remotely across the Indo/Pacific and Atlantic oceans.

The design team should appraise the risks of the project site location and basis of design decisions for the building structure accordingly.

FEMA P-646 provides comprehensive guidance on the planning and siting appraisal to minimize the impacts of tsunami hazards and subsequent assessment and design to ASCE/SEI 7-22 (chapter 6) and onwards compliance with IBC Chapter 16, Section 1615. (FEMA, 2019).

Further guidance is given in Section 5.3.1.5 of this Guide.

4.7.6 Volcanic

While there are currently no active volcanoes near the island territories, this hazard may be encountered in other localities or may become applicable if volcanic activity increases.

Should the intended use of the building be a refuge or other life preserving function (typically IBC chapter 16, section 1604, risk category IV), the design team should appraise the criticality of the building, and this should be taken into consideration with regards to site location as it would unlikely be economic to design resilience against volcanic explosion impacts.

Consideration should be given to the roof loadings (ash deposition) and serviceability aspects of ash-fall on emergency response plant and equipment (water supply, solar panel “back-up” for communications needing cleaning and abrasive dust particles on exposed mechanical plant)

The USGS provides guidance to the design team on the impacts of volcanic ash and gases on buildings and other infrastructure associated with buildings (USGS, 2019).

Further guidance is given in Section 5.3.1.6 of this Guide.

4.7.7 Wildfire Risk

Wildfires occur during the dry season in some locations, even on an annual basis. Designers shall review the history of wildfires in the vicinity of the building site and the island and determine whether any consideration is needed in the building or landscape design to reduce the risk of damage from wildfires.

If this is a relevant risk, then guidance on this risk and possible design responses is available from these sources:

- The National Oceanic and Atmospheric Administration's (NOAA) Regional Integrated Sciences and Assessments (RISA) website (NOAA, 2022).
- The Pacific Fire Exchange website (Pacific Fire Exchange, 2022).
- FEMA P-754 Wildfire Hazard Mitigation Handbook for Public Facilities, 2008.
- FEMA P-737 Home Builder's Guide to Construction in Wildfire Zones, 2008.

4.7.8 Munitions of Explosive Concern

The Pacific Island areas are subject to the historical impacts of World War II, with Munitions of Explosive Concern (MEC), also referred to as Unexploded Ordnance (UXO), potentially to be found during site clearance and excavation works. Designers shall inquire if the site is a former battleground and whether MEC has been found nearby. If so, risk assessment and investigation shall be undertaken by MEC experts. Monitoring and reporting requirements shall be identified in the plans and specifications.

US State Department, Office of Weapons and Removal and Abatement (U.S Department of State, 2022) has active MEC disposal programs across the Pacific and can be contacted for advice on planning for and removal of MEC.

Figure 4-3: Unexploded Ordnance (source: USACE)

4.7.9 Biological Hazards

In some regions, such as Guam, there are also biological hazards to consider, like the brown tree snake. Climate change may alter the ranges of these species and thus the sphere of their impacts. In places where brown tree snakes are present electrical systems need to be secured.

Designers should seek local advice on relevant risks.

4.8 Living With and Adapting to a Changing Climate

The impacts of climate change on weather events are becoming more apparent and the designer can make key decisions that affect the longevity, resilience and ultimately the success of a project for future use.

Location-specific design considerations on intensity and frequency of meteorological events (for example, rainfall, wind, wave impact, sea level rise) are available from various sources and are subject to regular revision. For instance, the Intergovernmental Panel on Climate Change produces assessment reports every 6-7 years and Assessment Report 6 (AR6) publications are currently being progressively released. Similarly, applicable data on seismic design loads is available in published sources and is updated from time to time, although much less frequently than climate data. Guidance is therefore best linked to these published sources. Designers should refer to the most current version of each information source.

The Pacific Islands Regional Climate Assessment (PIRCA) developed a report on climate change indicators and considerations for key sectors focused on CNMI (Grecni, Derrington, Greene, Miles, & Keener, 2021). While this report was drafted based on input from CNMI and other Pacific Island Nations, much of the report's findings are applicable to all tropical islands, including USVI. A synopsis of these findings and key issues are provided below. in Figure 4-2: Key climate issues for CNMI and other tropical islands.

.

Changing air temperatures — Hot days have increased, while the frequency of cool nights has decreased in the CNMI. Air temper-atures will continue to rise under all future warming scenarios.

Stronger tropical storms and typhoons — Tropical cyclone intensity is expected to increase. While tropical cyclones are expected to decrease in number in the future, those that do form are more likely to be intense (higher category), delivering higher wind speeds and more rainfall. The CNMI experienced profound impacts to the economy, infrastructure, and public health from recent typhoons.

Threats to natural areas and infrastructure from sea level rise — Sea level is rising in the CNMI and is expected to become damaging by exacerbating high tide and wave flooding, storm surge, and coastal erosion. More frequent and intense coastal flooding and erosion are anticipated to affect properties and infrastructure in the coming decades as sea level rise accelerates.

Human health and safety — More extreme storms and heatwaves, increased risk of wildfire, transmission of disease, and declining ecosystems all threaten human health and safety. Local preparedness and global action to significantly cut greenhouse gas emissions can greatly reduce these health impacts.

Equity considerations — Climate change is expected to disrupt many aspects of life in the CNMI, and some groups will be affected disproportionately. Those who are already vulnerable, such as children, elderly people, people with pre-existing medical conditions, and low-income communities, are at greater risk from extreme weather and climate events.

Coral reef bleaching and loss — Oceans are warming, causing coral reef bleaching that is already severe. Coral reefs and ocean ecosystems contribute more than $100 million annually to the CNMI's economy. In the next few decades, more frequent coral bleaching events and ocean acidification will combine with existing stressors to threaten widespread mortality for coral reefs.

Uncertain total rainfall amounts — Global and regional climate model outputs available for the Mariana Islands region show a range of possible future precipitation changes, from as much as 7% lower to as much as 20% higher in the CNMI overall in the long term.

Risks to fresh water — Hotter temperatures increase the demand for water and decrease the supply of fresh water available. The combination of possible increased pumping and sea level rise threaten to bring saltwater contamination into wells that supply drinking water.

Threats to ecosystems and biodiversity — Changes in temperature, rainfall, and tropical cyclone characteristics promote the spread of invasive species and reduce the ability of terrestrial habitats to support rare and protected species. Measures that enhance biodiversity and improve ecosystem resilience can support communities in adapting to climate variability and change.

Figure 4-4: Key climate issues for CNMI and other tropical islands (Grecni, Derrington, Greene, Miles, & Keener, 2021)

The Designer shall consider the following impacts of climate change in the basis of design values determined for the project specific location:

- Ocean changes
  - addressing sea level rise (SLR) - avoid (i.e., setback and elevate) or engineer (e.g., build a sea wall)
  - temperature, acidity – coral reef protection decreasing due to bleaching events and SLR
- Climate oscillation
  - ENSO – strong El Nino, strong La Nina
  - other oscillations and cycles with regional variation in effects
- Intensity and duration of rainfall invents
  - increase - inundation and flooding
  - decrease - drought and salination
- Storm frequency reoccurrence / changes to patterns
  - warming seas may lead to a greater frequency in storm occurrence resulting in decreased return periods
- Intensity and frequency of extreme wind events
  - cyclone wind intensity increase, and thus storm surge effects, due to increased sea and air temperatures

Other resilience and sustainability considerations the DoR should consider are:

- Aspect and topography
  - increasing saline atmosphere / sea spray
  - wave run-up and wind accelerations and modifications due to topography
- Change in air temperature and humidity
  - less clouds, more sun results in increased UV degradation
  - less diurnal variation results in higher night-time temperatures requiring increased periods of building cooling / increased humidity
- Drinking water availability
  - saline ingress / aquifer depletion due to SLR / wave overtopping
  - decreases in rainfall or increased evaporation of rainwater collection systems
- Alternative power systems
  - solar, thermal, battery backup (redundancy in emergency power supplies)
- Low energy design
  - passive buildings / detailing, HVAC selection

4.8.1 Forecasting Sea Level Rise and Consideration of the Impacts for the Designer.

Most coastal areas of the Pacific Islands are exposed to the potential impacts of a SLR. The nature of many islands is that they only have flat and accessible land that are only a couple of meters above sea level. This leaves them exposed to the direct impacts of SLR (i.e., the increase in mean high-water level) and indirect impacts, such as:

- Overtopping of existing beach protection
  - Natural - dunes, cliffs
  - Man-made - revetment, sea walls, reclaimed land
- Increased saline ingress of island groundwater due to overtopping
- Increased run up / inundation and decreased resilience to storm surge
  - Reduced protection from seaward coral reef and coastal vegetation (mangroves)
- Re-zoning of land due to changing hazards for compliance

It is essential that builders look beyond static SLR estimations for planning. SLR is only one component of coastal dynamics - even without SLR there can be significant coastal impacts related to changing tidal intensities, storm driven flooding, etc. and SLR should be considered only a part of planning building accommodations for coastal dynamics under climate change. The DoR should also consider how or whether the design may be adapted in the future if SLR (or other evolving coastal dynamics) exceeds the chosen design scenario (i.e., are there design decisions now that may make it easier to adapt in the future if necessary).

Foundation elevations in coastal areas must consider the impacts of storm surges and sea level rise for the life of the facility. USACE has identified the following calculation that combines these factors, to determine the minimum acceptable elevation for facilities:

A + B + C = acceptable foundation elevation

Where:

A = Elevation of 1% Annual Exceedance Probability (AEP) from nearest location with long-term water level records OR maximum recorded storm surge for the area, whichever is higher

B = Relative sea level change for site using USACE intermediate probability in 50 years or high probability curve for critical facilities

C = ASCE 24 Table 2-1 Freeboard(refer to FEMA guidance document in Section 4.7.3 of this Guide)

To assist in forecasting sea level changes, NOAA and USACE have developed a “Sea Level Change Curve Calculator” that estimates current, intermediate, and high rates of increase in sea level rise. The DoR may consider adopting an intermediate or high rate of rise for their design basis depending on the criticality and location of the building.

The calculator includes data assessments for the following relevant areas:

- Pago Pago (American Samoa);
- Chuuk – Caroline Islands (FSM);
- Guam, Marianas Islands (CNMI);
- Kwajalein (RMI);
- Charlotte Amalie (Virgin Islands).

Palau is not currently covered by the calculator; however, the DoR may look to consider interpolation from Guam / Chuuk as the nearest geographical sources. Similarly, eastern FSM (Pohnpei/Kosrae) are not covered, however the DoR may look to consider interpolation from Kwajalein (RMI) as the nearest geographical sources

Extracts from the calculator for the above areas are shown for reference below in Figure 4-3 through Figure 4-. The DoR shall use the online tool to ensure the most up-to-date information is obtained for the basis of design.

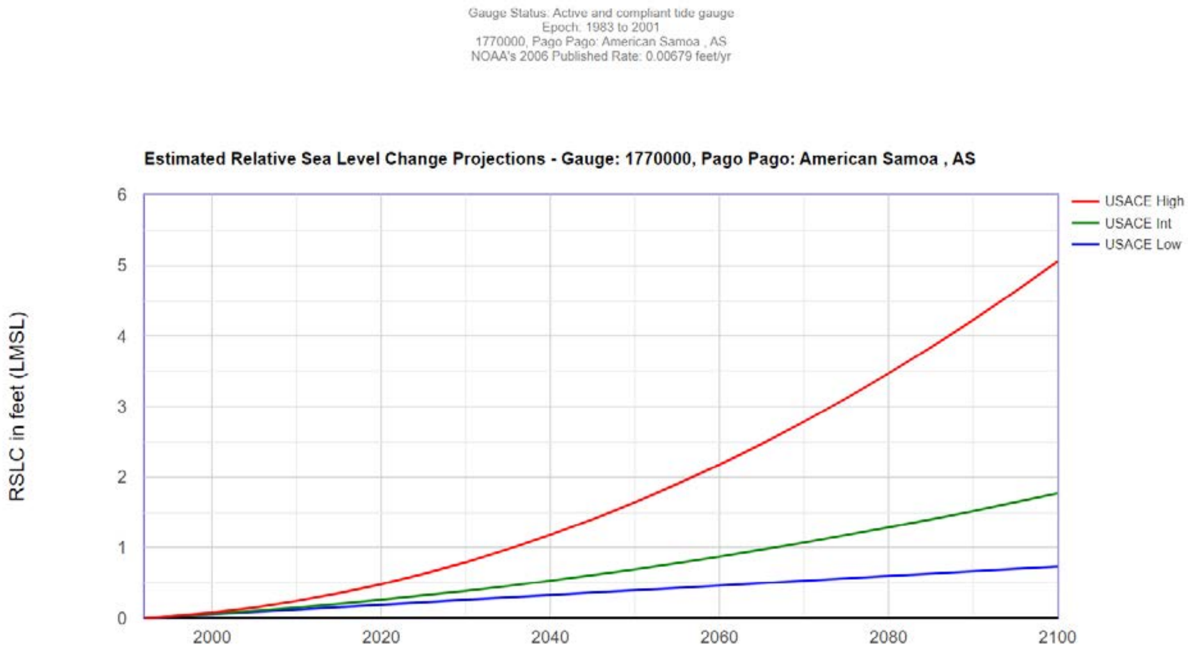


Figure 4-5: Sea Level Rise Forecast - American Samoa[9]
*The RSLR rate from NOAA used as input is based on the rate prior to the 2009 earthquake. The rate is much faster now due to subsidence. Please revisit rate prior to using.

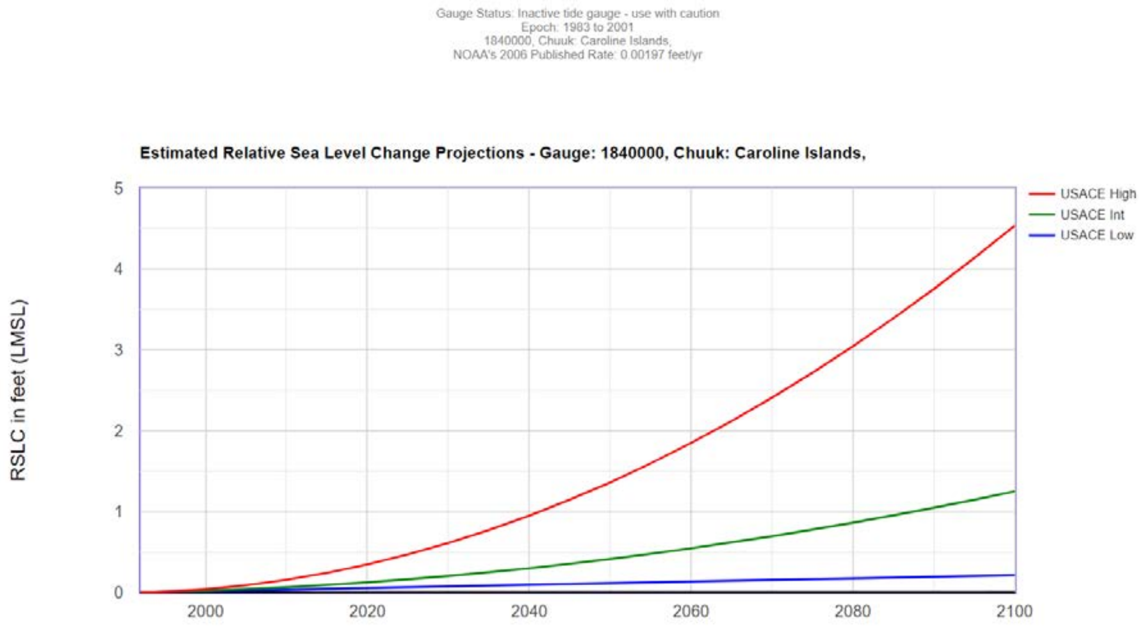


Figure 4-6: Sea Level Rise Forecast - FSM, Chuuk

[9] The RSLR rate from NOAA used as input is based on the rate prior to the 2009 earthquake. The rate is much faster now due to subsidence. Please revisit rate prior to using.

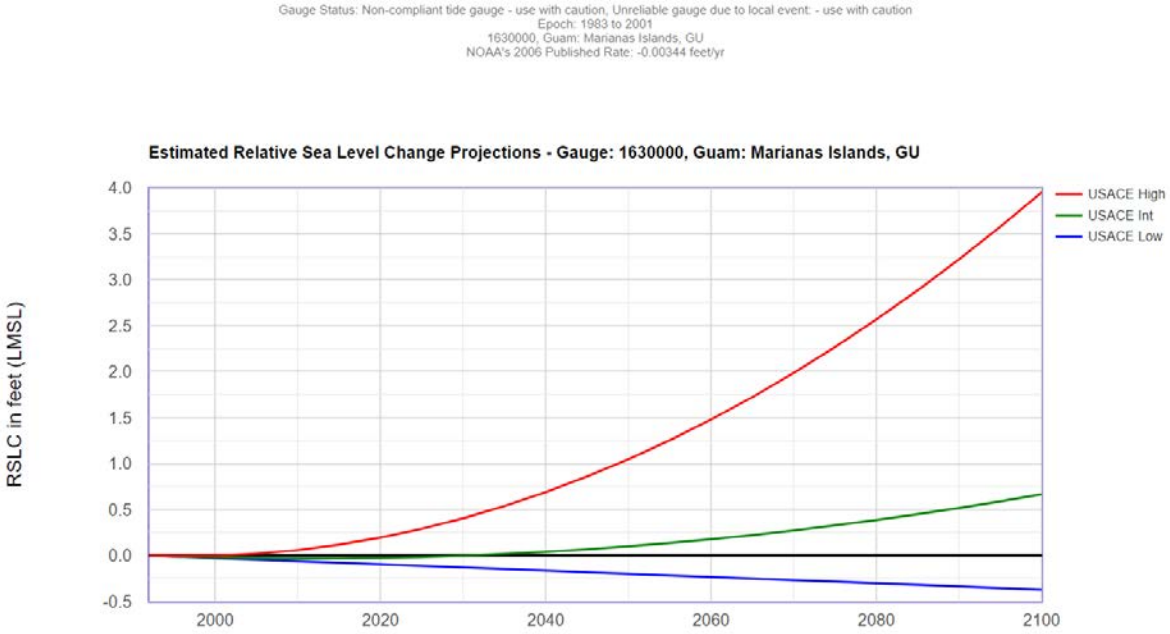


Figure 4-7: Sea Level Rise Forecast - Guam / CNMI

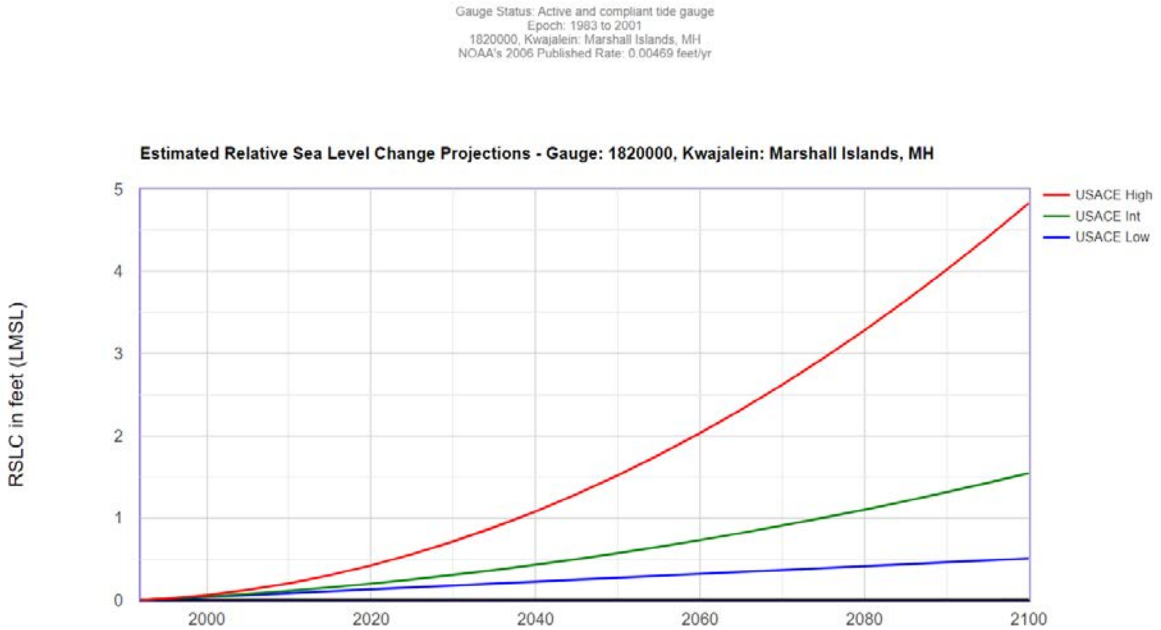


Figure 4-8: Sea Level Rise Forecast - RMI

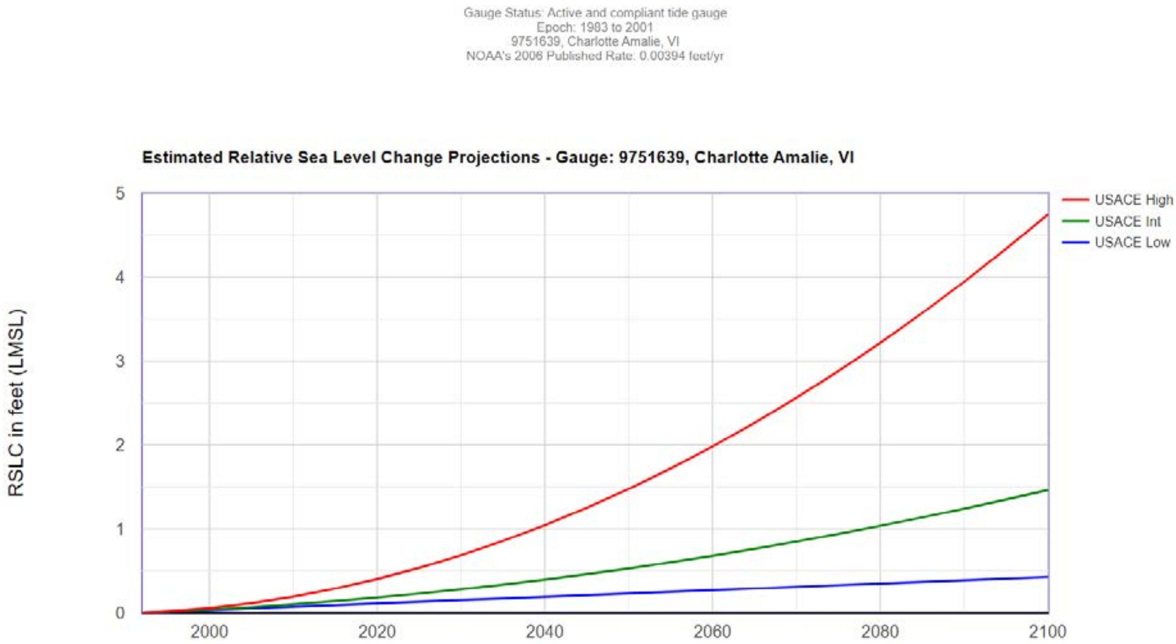


Figure 4-9: Sea Level Rise Forecast - USVI

The background datasets available in the “Sea Level Change Curve Calculator” are not current for some areas so interpolation and engineering judgement will need to be applied by the DoR and peer review team.

In lieu of any other industry available design guidance, the DoR can refer to USACE Engineer Technical Letter (ETL) 1100-2-1 Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaption (USACE, 2014) when considering SLR and the Basis of Design.

The rate and allowance for SLR and which indirect impacts of SLR that will be considered should be agreed in the Basis of Design; as decisions made will have an impact on the level of resilience that will be included in the design (see Section 4.7.3 **Flooding and Wave** for further guidance).

Links to the SLR calculators are below:

- Sea Level Change Curve Calculator (NOAA, 2021)
- Sea-Level Curve Calculator (U.S. Army Corps of Engineers, 2022)

4.9 Architectural Considerations for Tropical Environments

The design team should consider the following when undertaking building design:

- Site location;
- Building form / shape, footprint and orientation for passive design;
- Roof and wall materials for low thermal mass and insulation;
- Opening placement, size and type for airtightness and ventilation;
- Use of natural light, natural shade and prevailing winds;
- Location of mechanical and electrical equipment for operation and maintenance;
- Low maintenance / corrosion-resistant finishes.

Good practice documents are available for reference as noted in Section 4.1, Guidance on Buildings for Tropical Climates. The below paragraphs provide additional explanation to some select aspects of the above list.

4.9.1 Site Location and Planning

Buildings should be located on sites exposed to sea breezes; avoid sheltered sites. Trees should be used for shading if PV collectors are not used.

In rural areas, layouts should be open, so buildings should be widely spaced to allow maximum ventilation in and around buildings, which should be spaced at 7 times their height if facing each other; closer if staggered.

At high urban densities, building height should be increased in preference to an increase in ground coverage.

4.9.2 Simulation of Light Energy Performance

For new facilities, use the sun path chart to identify how the sun and shade exposure will affect the building and Photovoltaic performance (if applicable). If landscaping is part of the facility, incorporate variations in landscaping to minimize the energy footprint.
Example tool: [SunEarthTools, 2022]

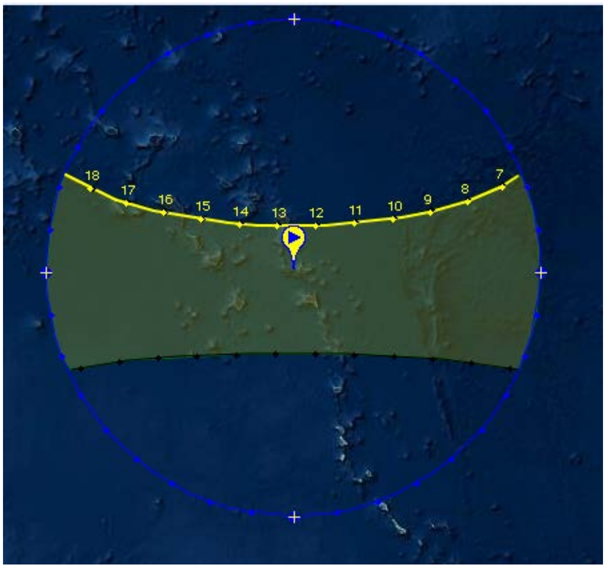


Figure 4-10: Sun-path for Majuro, RMI

Maximize the use of daylight through windows, lightwells, light ducts, shades, light shelves and reflectors.

4.9.3 Exploitation of Natural Ventilation.

Orient the building to maximize surface exposure to prevailing winds. However, a building does not necessarily need to be oriented perpendicular to the prevailing wind. It may be oriented at any convenient angle between 0 – 30 degrees without losing any beneficial aspects of the breeze.

- Consider, in the orientation of the building and in sizing the windows, the different needs according to the climate: day ventilation in a hot, humid climate; moderate ventilation in a cool, upland climate.
- Avoid positioning the building directly across the wind as this can create hot still air zones in the wind shadow.
- Raising the building on stilts is an advantage: it catches more wind as well as allowing better access to below floor utilities.
- Plan landscaping to avoid blocking airflow in key areas. Hedges and shrubs deflect air away from the inlet openings and cause a reduction in the indoor air motion. These should not be planted inside about 8 yards from the building because the induced air motion is reduced to a minimum in that case. However, air motion in the leeward part of the building can be enhanced by planting low hedges at 2 yards from the building.
- An effective cross-ventilation design starts with limiting the depth of the building to facilitate inward air flow from one facade and outward flow from the other. Architectural elements can be used to harness prevailing winds: architectural features like wing walls and parapets can be used to create positive and negative pressure areas to induce cross ventilation. For mechanically ventilated and cooled buildings, sufficient air tightness of the building envelope must be achieved to minimize unwanted moisture movement. Refer to Section 5.4.3.1.

4.9.4 Inclusion of Rainwater Harvesting for Treated Use or Irrigation.

Evaluate whether the project is appropriate for rainwater harvesting. Rainwater may be collected from the roof or roof-like surface and redirected into a tank, cistern, deep pit (well, shaft, or borehole), aquifer, or a reservoir with percolation. The collected water can then be treated and used for drinking water consumption, cooking, and personal hygiene purposes. Untreated, harvested “grey water” serves many useful purposes such as toilet flushing, emergency firefighting, or vegetation irrigation where it seeps down through the soil to restore the ground water.

See Section 5.2.4.4 for special considerations for construction methods and materials for roofs intended for rainwater harvesting.

Figure 4-11: Rainwater harvesting tanks on new building in Rarotonga

4.9.5 Landscaping and Stormwater Management

The design team should consider the function of the external works of the building and the impact they can have on sustainable building practice.

Choice of vegetation and planting can provide shade and protection and manage stormwater. However, tall vegetation should not be near the building structure avoid to damage to the structure in event of extreme winds.

All relative sea level rise calculations should begin with RSLR = 0 from the year 1992 as the mid-point of the current tidal epoch (1983-2001), until the tidal epoch is updated.

Key Strategies Building Design for Sustainability and Resilience in Tropical Environments

1. Guidance on Buildings for Tropical Climates
Refer Table 4.1 for a list of design guides for tropical island buildings

2. Selecting Appropriate Equipment and Materials
Designers should consider the following principals for selection of appropriate equipment and materials:

- Availability of supply
- Availability of spares
- Expertise to maintain
- Durability
- Environmental sustainability including obsolescence and disposal
- Standard factors of cost and effectiveness

Building in coastal environment

3. Tropical Environmental Considerations
Designers should consider the following environmental points when designing and detailing a building:

- Aspect and topography
- Ground conditions
- Humidity
- Saline atmosphere / sea spray
- UV exposure
- Biological attack
- Climate change on environmental loading

4. Environmental Protection and Planning Controls
Environmental and land use rules are set by legislation and planning rules, not by Building Codes. Refer to Table 4.2 for list of regulations for specific locations.

5. Environmental Protection and Design Considerations for Materials and Construction Methods
Designers shall consider the following:

- Minimize project impacts on the natural and built environment
- Every effort shall be made to use non-hazardous and/or non-toxic materials
- Hazardous materials and wastes must be managed in accordance with applicable local and federal regulations for proper handling, storage, labelling, sampling, containerizing, and transporting
- A formal environmental plan shall be developed as part of the design scope
- Designers shall adopt practices to reduce waste and to recycle materials whenever possible. Also consider the pathways for eventual disposal of construction materials
- All hazardous waste as defined in the Code of Federal Regulations (40 CFR 261) must be managed and disposed of in accordance with the recommended practice for the substance including electrical and electronic waste
- Hazardous and non-hazardous wastes shall be segregated
- Safely dispose of all waste materials from the site
- Safety Data Sheets (SDS) are required for all construction materials
- Lead paint and asbestos containing materials shall not be used in new construction
- Before paint removal is specified on existing facilities the designer shall verify that all affected

Key Strategies Building Design for Sustainability and Resilience in Tropical Environments

- costing/painting systems have been tested for lead content
- Before buildings are demolished, they shall be assessed by an experienced person to identify whether there is a potential for asbestos containing materials
- Asbestos containing materials should only be removed or handled by an experienced specialist contractor
- Spill containment and clean-up methods shall be included in above ground systems for storage and transfer of fuel, oil, lubricants, or chemicals

6. Historic Preservation

- Design and construction shall comply with applicable local requirements
- Projects in the territories shall comply with the National Historic Preservation Act (NPHA) and the Archaeological Historic Preservation Act (APHA) and any local legislation and practices

Hurricane straps on rooftop equipment

7. Natural Hazards in the Pacific and Atlantic Oceans

The following list includes natural hazards known to occur in the tropical environment that should be considered during the design and detailing of buildings:

- Rainfall – tropical environments are prone to periodic events of high rainfall. Consider rainwater harvesting
- Wind and Extreme Wind Events – wind load is often the dominant loading for vertical buildings – refer 5.3 for further guidance
- Flooding and wave action – Increase resiliency by increasing the elevation of the structure's functional levels - refer section 5.3 for further guidance
- Seismic – the design team should be aware of the seismic hazards that need to be considered - refer to section 5.3 for further guidance
- Tsunami – refer section 5.3 for further guidance
- Volcanic – refer section 5.3 for further guidance
- Wildfire risk – review history of wildfires in the vicinity of the site and island to determine if any consideration is needed
- Munitions of Explosive Concern (MEC) – enquire if the site is a former battleground and whether unexploded ordinance has been found nearby
- Biological Hazards – Seek local advice

Unexploded ordnance (USACE)

8. Living with and Adapting to a Changing Climate

The designer should consider the following impacts of climate change in the basis of design values:

- Ocean changes – sea level rise, temperature, acidity
- Climate oscillation
- Intensity and duration of rainfall invents
- Storm frequency reoccurrence / changes to patterns
- Intensity of extreme wind events

Other resilience and sustainability considerations:

- Aspect and topography
- Change in air temperature and humidity
- Drinking water availability
- Alternative power systems
- Low energy design

Key Strategies Building Design for Sustainability and Resilience in Tropical Environments	
9. Architectural Considerations for Tropical Environments The design team should consider the following when • Building form/shape, footprint, and orientation for passive design • Opening placement, size and type for air tightness and • Use of natural light, natural shade, and prevailing • Location of mechanical and electrical equipment for operation and maintenance • Low maintenance / corrosion resistance finishes	 *30-year-old 316 stainless steel faring well in tropical conditions*

5 Building Detailing

5.1 General Corrosion Control Measures

5.1.1 Introduction

Sites on tropical islands are extremely corrosive whether close to the coast or more distant. This is due to frequent precipitation, high salt content, warm temperatures, high relative humidity, and persistent wind. In this environment, metallic materials experience high corrosion rates that result in reduced service life, increased operating cost and deteriorated appearance. Corrosion is prevalent in infrastructure across the island areas, including buildings, services, equipment, and ancillary structures.

Specific corrosion rates are dependent on the material, location, environment, and applied control measures. It is imperative that appropriate material and equipment selection is made and that corrosion control measures are incorporated into designs, specifications, construction plans, and maintenance programs.

This section is intended to be a general guideline to understanding the causes and impacts of corrosion on buildings and implement measures to reduce corrosion. Specific corrosion control measures are also addressed in the specific discipline sections following.

5.1.2 Overview of Corrosion Process

Corrosion of metallic building materials is a natural process which progresses with time. It is an electrochemical process which requires the presence of water, typically from humid air, and oxygen from the air. A chemical reaction takes place at the surface of the building material and is accelerated by the presence of water and particularly by salt water or water containing other chemicals such as chlorine or sulfur. Corrosion can also occur by direct reaction with other chemicals such as sulfur or sulfur containing chemicals such as hydrogen sulfide.

For steel, the corrosion product is rust, which is a hydrated iron oxide $Fe_2O_3.3(H_2O)$ although the number 3 is not fixed and may be much larger. Initially a thin layer is formed, but as the corrosion progresses a thick layer is formed and this tends to peel off, exposing the underlying metal to more corrosion. Stainless steels tend to form a hard layer of corrosion product which stays attached to the parent metal and protects it to some extent.

Stainless steel should be protected from contamination by regular steel, for example from steel tools. Any regular steel particles embedded in the stainless steel will cause local corrosion.

For aluminum, the corrosion product is aluminum oxide Al_2O_3 or a more complicated hydrated aluminum oxide such as $Al(OH)_3$. Aluminum oxide is a hard compound and may provide protection against further corrosion, but the hydrated compounds typically do not provide such protection. A hard oxide layer may form directly on the surface, but a more porous and less protective hydrated oxide will form above that.

Reinforced concrete may suffer corrosion in the reinforcing steel. The alkaline nature of the concrete does offer some protection but good quality concrete and sufficient cover over the steel are necessary. More information is provided Section 5.2.1 Concrete and Concrete Masonry. The concrete itself may be attacked by acid soil and specialized methods such as tanking (a protective membrane) may be necessary.

Items which are buried or submerged in water suffer similar chemical corrosion, but the process may be hindered by the lack of oxygen for buried items or accelerated by the water. For example, steel piles in the ground may not corrode at all except near the ground surface. On the other hand, if there is water flow through the ground, corrosion may occur at normal rates.

The electrochemical process (galvanic corrosion) is responsible for the well-known effects when dissimilar metals are put in contact: the more reactive (less noble) material corrodes, and the less reactive (more noble) material does not. For example, when mild steel and zinc are in contact, the zinc corrodes preferentially. See below for information on galvanic corrosion.

Only surface corrosion is considered here. There are other forms, such as intergranular corrosion, stress corrosion, dezincification, and biological corrosion to name a few. These are not generally relevant to building infrastructure.

Non-metals such as plastic are not considered here. They may also degrade by chemical reactions with the atmosphere but are more likely to suffer degradation by sunlight (UV radiation).

Wood is not considered here as it is not considered to degrade by corrosion, but usually by decomposition, biological (rotting) or animal/insect (termites or ants) attack.

5.1.3 Corrosion Expert Design Input

Due to the significant impact of corrosion on critical building infrastructure, a Corrosion Expert shall be engaged as part of the design delivery team for each project funded by OIA to provide input and guidance for overall corrosion control measures including material selection, dissimilar metal contact prevention, protective coatings, and cathodic protection.

A Corrosion Expert means a person, by reason of thorough knowledge of the physical sciences and the principles of engineering and mathematics acquired through a professional education, is qualified to engage in the practice of corrosion control engineering and is accredited or certified as being a specialist in their field of practice (Corrosion Specialist, Cathodic Protection Specialist, Protective Coating Specialist or Level 3 Coating Inspector) by the National Association of Corrosion Engineers (NACE) or is a registered Professional Engineer (PE) with at least 10 continual years of direct experience in corrosion control engineering.

5.1.4 Passive Corrosion Control Measures

While corrosion is most severe closest to the sea, most buildable areas in the islands are close enough to suffer the effects of salt air corrosion. Designers must understand that materials which are suitable for arid or continental sites may not perform well in the islands.

Surfaces which are washed by rain will also corrode more slowly. This can be seen under verandahs and similar structures where the corrosion may be more severe than on the more exposed surfaces. This will only apply if the rain does not contain a significant amount of salt, as might happen in stormy conditions near the sea.

Equipment in areas sheltered from the weather will generally corrode more slowly. Thus, location of plant (such as external HVAC units) should be in sheltered locations away from the prevailing weather side of a building where possible.

5.1.5 Proper Material Selection

Material selection should be made with consideration of the corrosion protection systems to be adopted. For example, structural steel may be satisfactory in a coastal environment if a high-quality surface protection is applied. Conversely, some alloys of stainless steel are not suitable for exposure to corrosive environments, so the alloy should be selected appropriately. Similar comments apply to aluminum alloys.

Traditional, off the shelf construction materials do not perform adequately in the highly corrosive environment of the island areas. All materials need to be carefully selected for the intended applications which are defined as “exterior”, “non-conditioned interior”, and “conditioned interior”. In many applications, specialty materials that exhibit superior corrosion resistance in marine environments are required and can exceed the minimum requirements of the IBC. For guidance on material selection for specific systems, refer to the applicable discipline sections in the FDGTI. General guidelines for material selection are listed below:

- A Corrosion Expert shall review engineering designs, specifications, construction plans, and maintenance programs for proper material selection.
- Non-metallic materials shall be used instead of metallic materials if design conditions permit.
- 316 or 316L stainless steel and marine grade aluminum (5052, 5083, 6061, etc.) are the
- preferred metals of choice and shall be used if design conditions permit.
- 304 stainless steel shall NOT be substituted for 316 or 316L stainless steel.
- 316 or 316L stainless steel fasteners (bolts, nuts, washers, rivets, etc.) shall be used for exterior and non-conditioned interior applications unless dissimilar metal contact requires the use of marine grade aluminum fasteners.
- Steel and galvanized steel fasteners shall NOT be used for exterior and non-conditioned interior applications unless provided with a protective coating system and specifically approved by a Corrosion Expert.
- Aluminum shall not be embedded in concrete. If aluminum is in contact with concrete, the aluminum surface shall be protected.
- The location of the island areas limits the availability of specialty materials, as delivery times can be up to 3-4 months. When performance has been proven by past use, commonly available material types and sizes shall be specified to maximize the availability of replacement materials.
- Metallic materials for conditioned interior applications shall be stored in air-conditioned building to prevent atmospheric corrosion prior to installation.

5.1.6 Dissimilar Metal Contact Prevention

When two different types of metal are in electrical contact, galvanic corrosion can occur in the presence of moisture. A comprehensive review of materials, equipment, and construction methods is required to prevent dissimilar metal contact. General guidelines for prevention of dissimilar metal contact are listed below:

- Dissimilar metal contact shall not be permitted unless specifically approved by a Corrosion Expert.
- Fastener type shall be matched to the material type to be joined unless specifically approved by a Corrosion Expert on a case-by-case basis.
- All equipment enclosures for exterior and non-conditioned interior applications shall be evaluated for incidental dissimilar metal contact from the manufacturer. Attention shall be given to joining methods and equipment fasteners including nuts, bolts, washers, and rivets. For example, a commercial air handling unit with a 316 stainless steel housing shall use 316 stainless steel fasteners.
- If approved by a Corrosion Expert, dielectric insulators may be used to electrically isolate dissimilar material(s).

Figure 5-1: Example of corrosion of dissimilar metal fastener

Dissimilar metals should not be in contact with each other. To avoid this, non-conducting washers and sleeves should be used.

5.1.6.1 Galvanic Corrosion

The table below shows the galvanic series of metals and alloys. In general, materials close to each other in the table will cause less corrosion than those far apart when in contact.

Table 5-1: Galvanic Series of Metals and Alloys

Corroded end (anodic, or least noble)
Magnesium
Magnesium alloys
Zinc
Aluminum alloys
Aluminium
Alclad
Cadmium
Mild steel
Cast iron
Ni-Resist
13% chromium stainless (active)
50-50 lead-tin solder
18-8 stainless type 304 (active)
18-8-3 stainless type 316 (active)
Lead
Tin
Muntz Metal
Naval brass
Nickel (active)
Inconel 600 (active)
Yellow brass
Admiralty brass
Aluminium bronze
Red brass
Copper
Silicon bronze
70-30 cupronickel
Nickel (passive)
Inconel 600 (passive)
Monel 400
18-8 stainless type 304 (passive)
18-8-3 stainless type 316 (passive)
Silver
Graphite
Gold
Platinum
Protected end (cathodic, or most noble)

The rate of corrosion of dissimilar metals in contact is greatly affected by the surface area of each. For example, if zinc and steel are in contact, and the zinc component is small compared to the steel one, the zinc will corrode rapidly, and the steel may not corrode at all.

5.1.7 Protective Coating Systems

Coating systems protect metallic structures from corrosion and are an integral part of corrosion control. Proper coating selection, application, inspection, and maintenance are critical steps to the performance of all coating systems. For guidance on protective coatings for specific systems, refer to the applicable discipline sections in this guide. General guidelines for the use of protective coatings are listed below.

- Each facility, system, and structure shall be evaluated for application of a high performance industrial protective coating system.
- If design conditions require the use of steel other than 316 stainless steel, marine grade aluminum, or non-metallic materials, all steel structures shall have a high-performance industrial protection coating system that is specifically designed to withstand the characteristics of the environment to which it will be subjected.
- Protective coating systems shall be specified by a Corrosion Expert with a NACE Level 3 Coating Inspector certification in accordance with Unified Facilities Guide Specifications (UFGS) 09 90 00.
- Protective coating systems shall be factory-applied to the maximum extent possible. Factory-coated materials shall be properly stored and carefully transported to protect the protective coating system from damage, including UV degradation.
- Shop and field application of protective coating systems shall be performed by a qualified and experienced industrial coating contractor in strict accordance with the manufacturer’s instructions and applicable project coating specifications. The coating contractor shall have a minimum of five (5) years of experience applying similar high-performance industrial coatings.
- A NACE Certified Level 3 Coating Inspector shall provide on-site inspection and testing for all shop and field coating applications for high-performance industrial coating systems. The coating inspector shall have a minimum of five (5) years of experience inspecting similar high-performance industrial coatings.
- For each new facility, system, and structure that is provided with a protective coating system, specific maintenance requirements shall be specified for the protective coating system.

5.1.8 Cathodic Protection Systems

Cathodic protection (CP) systems protect buried, above grade or submerged metallic structures from corrosion. This is not generally applicable to buildings, but brief information is included here for completeness. Cathodic protection systems are required for multiple types of facilities including, but not limited to petroleum, oil, and lubricant pipelines; new waterfront structures; fire protection storage tanks and piping; and water/wastewater distribution piping and storage tanks. For guidance on cathodic protection application, refer to the applicable discipline sections in the FDGTI. General guidelines for cathodic protection are listed below.

- Buried or submerged metallic structures shall be avoided to eliminate the need for cathodic protection systems, if design conditions permit. For example, buried piping shall be constructed of non-metallic materials or, if metallic materials are required, piping shall be routed above-ground or within conduits to prevent soil contact.
- Each facility and/or system with buried or submerged metallic structures shall be evaluated for installation of cathodic protection systems in accordance with the IBC
- Cathodic protection systems shall be designed by a Corrosion Expert with a NACE CP Specialist certification in accordance with the IBC.
- Galvanic anode cathodic protection systems are preferred over impressed current cathodic protection systems due to fewer maintenance requirements if design conditions permit.
- Consider the use of sacrificial anodes in reinforced concrete construction and repair.
- Cathodic protection systems shall be operated, inspected, and maintained in accordance with the IBC.

Key Strategies for Sustainable Corrosion Control Measures in the Tropics

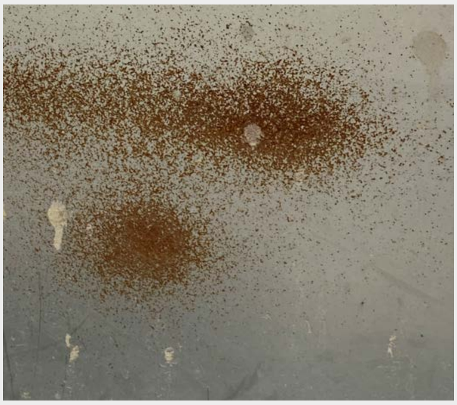
1. Overview of Corrosion Processes

- Corrosion of metallic building materials is an electrochemical process which requires the presence of water, typically from humid air, and oxygen from the air.
- For (carbon) steel, the corrosion product is rust. As the corrosion progresses a thick layer is formed and this tends to peel off, exposing the underlying metal to more corrosion.
- Stainless steels tend to form a hard layer of corrosion product which stays attached to the parent metal and protects it to some extent.
- Stainless steel should be protected from contamination by (carbon) steel, for example from steel tools. Any steel particles embedded in the stainless steel will cause local corrosion.
- For aluminium, the corrosion product is aluminium oxide Al_2O_3 or a hydrated aluminium oxide such as $Al(OH)_3$. Aluminium oxide is a hard compound, but the more porous and less protective hydrated oxide will form above that.

Rust on a painted surface

2. Specialist Corrosion Design Input

- A Corrosion Expert shall be engaged as part of the design delivery team for each project funded by OIA to provide input and guidance for overall corrosion control measures including material selection, dissimilar metal contract prevention, protective coatings, and cathodic protection.



Corrosion on stainless steel caused by contamination with carbon steel particles.

3. Passive Corrosion Control Measures

- Most buildable areas in the islands are close enough to the sea to suffer the effects of salt air corrosion. Designers must understand that materials which are suitable for arid or continental sites may not perform well in the islands.
- Location of plant (such as external HVAC units) should be in sheltered locations away from the prevailing weather side of a building where possible.

4. Proper Material Selection

- Material selection should be made with consideration of the corrosion protection systems to be adopted. For example, structural steel may be satisfactory in a coastal environment if a high-quality surface protection is applied. Conversely, some alloys of stainless steel are not suitable for exposure to corrosive environments, so the alloy should be selected appropriately. Similar comments apply to aluminum alloys.
- For guidance on material selection for specific systems, refer to the applicable discipline sections in the FDGTI.

5. Dissimilar Metal Contact Prevention

- When two different types of metal are in electrical contact, galvanic corrosion can occur in the presence of moisture.
- Dissimilar metal contact shall not be permitted unless specifically approved by a Corrosion Expert.
- Fastener type shall be matched to the material type to be joined unless specifically approved by a Corrosion Expert on a case-by-case basis.

Galvanic corrosion on fastener. Note that the stainless-steel lug is not corroded.

6. Galvanic Corrosion

Key Strategies for Sustainable Corrosion Control Measures in the Tropics	
• The table below shows the galvanic series of metals and alloys. In general, materials close to each other will cause less corrosion than those far apart when in contact. A more comprehensive list is provided in Table 5-1.	

Corroded end (anodic, or least noble)
Magnesium
Magnesium alloys
Zinc
Aluminum alloys
Aluminium
Mild steel
18-8-3 stainless type 316 (active)
Copper
18-8-3 stainless type 316 (passive)
Protected end (cathodic, or most noble)

5.2 Building Systems and Materials

5.2.1 Concrete and Masonry

The use of concrete and concrete masonry units (CMU) is prevalent in these locations. These materials have proven to be relatively cost effective, durable, and maintainable over the lifespan of their installations assuming that care is taken when installing and detailing these elements.

As noted in the Section 5.3 below, special care must be taken in the specification of the components and handling of materials. The environment in which these materials are installed is inherently aggressive to concrete applications if certain protective measures are not taken. Intense moisture, in the form of humidity and sea-breezes, is often compounded by adding salinity-laden products and associated accessories during the placement and curing timeframes of cast in place concrete as well as other mortars and other cement-based products.

The costs to repair spalling concrete can be overwhelming, and in some cases requires complete replacement of those elements which can place an undue burden on a facility or property owner. It has been determined and explained in other sections of this Guide, that spalling concrete is caused primarily by a few key factors:

1. Inappropriate materials;
2. Inadequate concrete cover;
3. Moisture intrusion.

The use of an admixture as noted above can mitigate item 3 above and help to protect reinforcing steel in the event that that there is inadequate cover, or some minor use of inappropriate materials as noted in items 1 and 2.

5.2.2 Metals

In some instances, the use of metals is for primary load-bearing structural purposes, and in others the use is limited for other functional or even decorative intents. Regardless of their intended use, it is critical to engage the opinions of a certified Corrosion Specialist as noted above.

Metals can be found in virtually every type of building component whether they are structural or not. It is imperative that any interface between these components and adjacent elements are treated appropriately. Even in circumstances where the elements are not part of the primary structural frame of a building, the potential for deterioration of structural or adjacent non-structural elements is great if proper detailing, material specification and installation is not applied. Recent documentation and reports suggest that “rust” accounts for $400 billion in renovation/reconstruction costs in the U.S. annually, which exceeds the total cost or recovery of all other natural disasters combined. For this reason, it is imperative that the design includes the required coatings that may be applied for additional protection of metals.

The type of protective coating to be used is largely dependent on the location and use of the component. In addition to Code requirements, it is suggested to require extended warranties for manufacturers products used in these locations.

5.2.3 Wood and Plastic

5.2.3.1 Wood

The use of wood as a primary structural building element has been a common practice in these hot and humid climates. The relatively cheap cost and local availability, coupled with the ability to construct things with wood by local labor forces without specialized tools or expertise made the use of wood commonplace. Historically, this has also coincided with the generally infrequent use of air conditioning systems. Prior to the widespread availability and use of AC, these structures were also highly ventilated and designed to encourage maximum air circulation caused by local trade winds. The open nature of these structures and resultant air flow in and around the wood structural components, prevented any significant accumulation of moisture within the cavities and did not cause situations where mold or rot enhancing conditions could occur. Once the use of AC systems became more prominent, the need to keep moisture out of the structural cavities and enclosed spaces became more of an issue. That, plus the lack of quality design detailing and installation techniques have made the use of wood as primary structural elements problematic.

It is possible to properly detail and construct buildings using wood as a primary structural element, but special attention should be made to the entire assembly that includes the wood. This would include the location of vapor retarders, air barriers, drainage planes, flashing, and other similar elements that prevent the accumulation of water and moisture within these cavities. Other considerations would include placing wood framing on concrete curbs to prevent the possibility of any standing water coming into contact with the sill of these walls. Additionally, due to the likelihood of termite and other pests, it is also acceptable to use engineered wood products as well since some natural species of not pest resistant. Care must be taken in selecting these as some chemicals used in the treatment process can be problematic. Other engineered wood products, such as Oriented Strand Board (OSB) are used for non-structural elements of projects such as millwork, cabinetry, and other furnishings. Care must be taken with these materials to prevent the intrusion of moisture. These types of products can pick up moisture and cause swelling and damage to the actual material which could ultimately cause failure. The use of marine-grade plywood and other hardwoods are acceptable, but these can present issues regarding sustainability and sourcing. Consider specifying Forest Stewardship Council-certified [or suitable alternative] products if wood is desired.

5.2.3.2 Plastics

Plastics used as part of the primary structural systems are rare although there are instances where Fiber Reinforced Polymer (FRP) or other fiberglass type products are used. These products are suitable for the harsh environments likely to be encountered but usually come with a high initial cost, and any future repairs or maintenance efforts are challenging due to the general unfamiliarity with the materials. If those issues can be overcome, these products are acceptable, but care should be given to the potential for UV-degradation in some products if used in an exposed exterior location.

5.2.4 Thermal and Moisture Protection including Roofing

5.2.4.1 General

Thermal and moisture protection of buildings is critical in hot, humid climates. The thermal comfort of occupants is important for the promotion of general well-being which can also increase productivity. In these locations, thermal comfort is generally associated with the cooling of spaces as heating is not typically necessary.

In addition to the occupants of the building, temperature sensitive equipment and materials also benefit from thermally regulated spaces. The building envelope contributes to this system by keeping the cool air in and the warm, humid air out. This can be reasonably expected to be accomplished by the proper installation of thermal insulation, in the form of batts or rigid insulation products. Most codes as well as sustainability standards address the requirements for these components in wall and roof assemblies. Following those guidelines would be generally sufficient to achieve the desired thermal performance of a building.

The need to prevent moisture intrusion is a bit more complicated as many different components and assemblies are used and they all perform differently. There are basically 4 different sources of moisture intrusion in buildings

1. Rainwater;
2. Moisture-laden air from outside;
3. Moisture generated from inside buildings;
4. Vapor diffusion.

Understanding the potential sources of moisture intrusion is important to provide the necessary means of protection. Also, the proper selection, detailing and installation of these materials is necessary to ensure they perform as expected.

With regards to item 1 above, prevention of moisture intrusion caused by rainwater is primarily related to the detailing of the interface of different materials. Most building materials intended for exterior use have some ability to withstand direct water intrusion if the detailing is appropriate. The exception would be any type of porous materials such as cementitious components and natural stones. These materials rely on a secondary weather barrier, typically installed behind the finish, to divert water back outside the building envelope. The use of rain-screen type assemblies, with air gaps and weather barriers can work well in these instances. The use of an air gap should not be omitted as if moisture does migrate through the exterior layers, this air gap will help dry out the back side of the material and prevent the moisture from staying in that exterior material. For other materials, rainwater intrusion generally occurs at the seams between a given material or at the transitions between different materials. The proper design and installation of flashing and counterflashing is usually critical to the performance in these instances. The criteria for the design shall not only include understanding how the various materials may react if in contact [see need for the Corrosion Expert, Section 5.1.3], but also the potential for differential movement of adjacent elements. The use of sealants helps to contribute to the success of these joints; however, sealants will also generally require some level of periodic maintenance which is often challenging due to the location and quantity of joints. This maintenance effort is therefore often neglected. For that reason, it is imperative that the integrity of the joint does not solely rely on sealants.

Items 2, 3 and 4 are somewhat more challenging since, unlike the visible nature of rainwater, moisture in the air in vapor form is not visible, takes longer for the adverse effects to become apparent, and once these impacts are known, the mitigation methods are generally extensive. In contrast, if a roof or window starts to leak, chances are that you will see this somewhat early, and the impact is relatively localized making the fix a bit less daunting. For this reason, designing to avoid the intrusion of moisture laden air and vapor diffusion is critical. In these hot, humid climates, it is expected that most buildings intended for regular occupancy or housing specialized equipment will have HVAC systems. There may be other buildings that experience less frequent use by personnel or that house non-critical equipment that may not require the need for HVAC systems. The approach to the prevention of moisture intrusion due to these causes will be different depending on whether the building will have HVAC systems or not and the strategies for building component assemblies will possibly be different as a result.

5.2.4.2 Ventilation

If a building is not expected to have any HVAC systems, the most important design consideration is the ability to create or enhance air flow and natural ventilation. Historically, structures in these environments did not have HVAC systems and relied on natural ventilation for the general comfort of the occupants. These traditional methods had roof vents, chimneys and carefully located openings around the perimeter and were often elevated above grade. All these techniques enhanced the natural flow of air. As most of these locations are also relatively close to oceans, there is a consistent breeze that also helped. This constant air flow helped to keep the building components relatively dry, and as the assemblies were not “air-tight” there was little ability for moisture to accumulate in these assemblies and for the resultant impacts of rot and mold to occur. These strategies are still appropriate today, however, with the introduction of modern HVAC systems, there is an expectation that most buildings will utilize those to provide the desired cooling and ventilation for the intended use of the building.

With the increased use and expectation of providing HVAC systems came the need to provide buildings that were designed to keep the cool air in and the hot, humid air out. This is when the issues of rot and mold within building assemblies became more problematic [item 2]. If using HVAC, providing positive pressure within the facility can help to prevent the infiltration of moisture-laden air. Similarly, if properly designed, internally generated moisture can also be mitigated by the HVAC systems [item 3]. However, to avoid issues associated with vapor diffusion [item 4], it is important to know where the dew point occurs within building component assemblies.

Identifying the location of the dew point within any wall, roof, or elevated floor assembly has challenges due to climatic variations, building materials and local conditions. There are many traditional methods that designers can use to determine this, but the most accurate and valuable is using a dew point calculating program that analyzes the heat and moisture transport through various layers of materials, and at various times of day and times of year. This software shows where the dewpoint locations would be and allows designers to place vapor retarders and water/air barriers in the correct locations to prevent moisture from accumulating and getting into materials that may be susceptible to rot and/or mold. One program that does this is WUFI® Oak Ridge National Laboratory/Fraunhofer Institute for Building Physics (WUFI-ORNL/IBP). The use of this or similar software should be considered as a mandatory requirement for new buildings.

Refer to Section 5.4.3.1 for air-tightness requirements for mechanically cooled buildings.

5.2.4.3 Walls

In general terms, walls will likely be comprised of several different layers of materials. The interior finish, likely applied to a wall board such as a cement or gypsum board product, is typical. In certain circumstances, the specification of moisture resistant wall board or even moisture and mold-resistant wall board may be warranted. Some of these products, such as Purple XP® drywall, are proprietary so they may not be appropriate as a single-sourced item, but they are intended to exceed typical gypsum wallboard products with enhanced resistance to moisture intrusion and the resultant growth of mold. Regardless of the product type, it is important to design and install so that there is a slight gap ¼”- ½” between the bottom of the wall board and the floor to prevent migration of any incidental water that may be on the floor up through the wallboard. The introduction of a curb is also recommended if the walls are framed in either metal or wood studs for the same reason. The interior finishes can be a multitude of products, including paints, tile, stone, or wood cladding to name a few. The use of vinyl wall covering is to be avoided due to its ability to trap moisture inside the wall cavity.

Beyond this internal structure, the outer layers of the wall assembly would then typically include a layer of rigid insulation. This is generally required by most model codes and needs to be continuous throughout the perimeter of the structure to comply with those code requirements. Care should be taken to detail this component to avoid thermal bridging that may occur if materials, usually metal components, penetrate this. These can also provide a path for moisture intrusion. Follow manufacturer’s recommendations when installing these as some products have different methods for handling this situation. Depending on the make-up of the wall assembly and the finish materials used on the building, the outer layers of the wall construction will vary. There may be exterior wall board, which if used, should be a glass-mat faced product, not paper-faced. A weather barrier, vapor retarder and/or air barrier will also be necessary. There are several materials available that can meet the needs of any of those 3 components, and others that are able to only provide one of those attributes. The design professional should properly specify these products in conjunction with the other elements of the wall assembly to assure a properly working complete system. The use of the WUFI® software as noted above can help validate the selection of the intended materials and products in this regard. Those products typically come in 2 types - sheet (or membrane) products and liquid-applied products. The sheet products are typically easier to install and require a less-skilled labor force and no special tools. It is important to provide specifications and inspections during the installation process to ensure that seams are properly treated and overlapped, no tears or gaps exist, and the terminations/transitions at door, window and other penetrations are properly done. Those are typically where failures in this component occur. If using a liquid-applied system, those transitions are a bit easier to handle but the installation should be done only be qualified installers using the proper equipment and assurance that the mil thickness specified is being met.

The weather barrier, vapor retarder and/or air barrier represents the last point in the wall cavities that moisture is expected to exist. It is important that at the bottom of these cavities, a weep system is introduced that allows any moisture that accumulates to drain out of the cavity. As much as there is a need to allow moisture to drain out, it is also important to design these weeps to also prevent termites or other small pests from getting into the cavity. There are a variety of screen-type products that are effective in this regard.

5.2.4.4 Roofs

The WUFI® analysis is similarly helpful when designing the roof assembly. One important consideration when selecting a finished roof material is whether any rainwater is intended to be collected. The intended use is also a factor as use for irrigation is different than use for potable purposes. Some materials used for roofing and roof accessories such as gutters and downspouts can leach unwanted and harmful chemicals into the collected water. Certain wood products, such as cedar shingles, as well as asphalt shingles, copper, terne-coated metals, lead flashing, cement and terra cotta tiles are all problematic and contain contaminants and should not be used if rainwater collection is intended. Depending on the intended use and the desired material, some of these products might be suitable, however testing the water regularly for contaminants is required. This may not always be possible, so it is best to avoid them. Rubber coatings, aluminum and polyvinylidene fluoride (PVDF) coated steel roof products are generally acceptable for any of these uses. For roofs not intending to be used for rainwater harvesting, some of the other material types noted above, as well as some other membrane systems for flat roofs can be considered.

For all roofs, sloped options are better at shedding water. Gutters should be used to conduct water away from the walls into cisterns or drainage features. Extending eaves to protect the walls and windows from the constant rainfall and humidity can be a great benefit to the structure. Eaves provide shade and help prevent additional solar heat gains to the walls and at window locations. When designing sloped roofs in areas prone to high winds, the designer shall ensure that overhanging eaves are designed to withstand the potentially significant uplift issues that may occur during high-wind storm events and shall consider limited overhangs [+/- 2’ max] to reduce potentially significant uplift issues that may occur during high-wind storm events. Longer cantilevered roofs shall be considered with associated structural engineering considerations and costs.

Figure 5-2: Moisture damage without adequate eaves, gutters or site drainage (USACE 2019)

If flat roofs are desired, the use of internal drains is likely and can be a potential source of water intrusion if not designed, installed, and maintained properly. Some available membranes for these uses do not perform as well as others in high UV and high salinity environments so care should be taken to specify these materials properly. Whether using flat or sloped roofs, it is important to note that regular maintenance is required to clear out gutters, downspouts, roof drains and secondary overflow drains or scuppers.

Where air conditioning is to be used and passive ventilation is not required, avoid high-pitched roofs in high wind areas.

5.2.5 Doors & Windows

The most common type of exterior door and window systems in commercial structures in these locations are composed of metal components. These systems have been proven to perform better as they are integral and complete systems including frames, panels, glazing, sealants, etc. especially when compared to more traditional wood systems. As noted above, the use of wood in exterior conditions is potentially problematic anyway. For doors, metal frame and hollow metal doors are acceptable products. Type 316 stainless steel should be specified for both doors and frames for maximum protection and longevity. Care should be taken to specify proper finishes/coating for these elements and plan for regular upkeep and maintenance to ensure that the system will be less prone to deterioration from high salinity in the air. Further protection can be afforded if these doors are located on the leeward side of structures, although this is not always possible.

Primary entrances should be covered and serve as a transition from exterior to interior spaces, and large enough to accommodate reasonable queuing.

Window systems are primarily factory finished aluminum framed systems with PVDF (e.g., Kynar®) finish. Stainless steel and UV-stabilized vinyl are also acceptable alternatives. Select products that have integral water-drainage components and weep holes and be careful not to obstruct the positive flow of water out of the system with adjacent materials or sealants. It is not uncommon for some installers to incorrectly seal the weepholes during construction which will lead to water build up and ultimately failure of the system.

5.2.5.1 Glazing

Glazing used in either doors or windows should be specified to limit heat gain inside the structures which will decrease the need for internal cooling. Some structures are not as critical with regards to internal UV degradation, but care should be taken to limit solar transmittance while still achieving the maximum visible light transmittance. This is often a balancing act between extremely high performing glazing units and cost so all stakeholders should be part of the discussions relative to this material. Insulated glazing units will perform best in most situations and will likely be required by most codes. Where possible, use non-metal framing to avoid corrosion issues.

One of the biggest concerns for both doors and windows is their ability to withstand high wind pressures and wind-borne debris impact caused by storms. If impact-resistant glazing is not specified, then other means of providing protection of these openings should be considered. Manufactured, and engineered shutter systems exist and are very effective although upper stories and other building configurations and the surrounding topography may complicate their installation. Automatic, and permanently installed options for shutters are available but come with a cost. However, in circumstances where it is difficult to install shutters in a timely and effective manner, these may be unavoidable.

Glass selection needs to match wind speeds in the area. This may include laminated glass to achieve the required impact resistance.

5.2.5.2 Hardware

The hardware required for the exterior door and window systems should be selected with input from and approved by the Corrosion Expert to avoid situations where dissimilar metals contact each other. At a minimum, commercial grade, heavy duty hardware types should be specified. Where possible, avoid installing hardware in exposed exterior locations. An example would be any door closers. If needed, specify door closers that are not exposed-mounted on the exterior, and instead, select concealed closers that will not be as likely to deteriorate due to the constant exposure to the environment. Also, in locations where doors or windows are not regularly used, it is important to regularly check the operation of these devices and clean/maintain operable parts as suggested by the manufacturer to prevent salt build-up and potential rust.

Gaskets, sweeps and protective sills should also be specified at doors to help prevent moisture and pest intrusion.

5.2.6 Finishes/Coatings

5.2.6.1 Finishes

Finishes selected for use on the exterior of the building should consider the following criteria:

1. Expected life-span – products with warranties for this use are preferred as they have demonstrated effectiveness in these locations;
2. Maintenance requirements – all materials and building components require some level of maintenance and the frequency of this activity and the need for any specialized labor force to implement this should be carefully evaluated as it may have an impact on any warranties, extended or otherwise;
3. Ability to be repaired – incidental damage by natural or man-made causes are inevitable. Some products are easier to repair than others, some require specialized labor and/or tools, and some may require attic stock of additional materials to be used for this purpose.

All the above factors will play a part in the overall life cycle analysis of a finish. It is possible that some finishes may require complete or partial replacement within the lifespan of a building. That is not necessarily a bad thing, but a reality that must be planned for and dealt with prior to these finishes failing to the point where they contribute to other building component and potential structural failures. It is important that the users and operators of these facilities understand this and factor it into their long-range maintenance and budgetary plans.

5.2.6.2 Coatings

With regards to coatings specifically, it is important that the designers reference industry standards, such as the guides and systems recommended by the Master Painter Institute (MPI) for the selection of coatings on specific materials. This, in conjunction with the input of the Corrosion Specialist for finishes on metal substrates, will ensure the highest level of protective coatings are installed. These coating systems have a long-standing performance record. It is important to note, that many consist of a series of primers and secondary coats of multiple products to build up the complete coating specified. This is typically done by trained specialists often in the recommended factory environments. While this represents an ideal condition, packaging, shipping, and transport of these finished products as well as the installation process can cause some damage to these components. Inspection of these prior to installation is important, and if damage is extensive, they should not be installed as the integrity of the system may be in question. In the event the damage is small, or if touch-up is required, it is necessary to have the proper touch-up materials on hand. In remote locations, it is likely that replacement products are not readily available so keeping an attic stock of all specialized coating is necessary to avoid prolonged exposure to damaged areas. Note that some of these products may also need some protected storage space so that high heat and humidity levels do not adversely affect the product. The shelf-life of these stored materials should also be monitored as some will need replacement if not used in a certain period.

Key Strategies for Building Systems and Materials in the Tropics

1. Concrete and Masonry

- Proper storage and handling of materials prior to installation is critical to avoid salinity-laden moisture from accumulating.
- Detail and install components properly to ensure adequate coverage of reinforcement.

2. Metals

- Engage Corrosion Expert during design phases.
- Specify and install coatings on metal products as required for additional protection.
- Where appropriate, write specifications to include extended warranties in coastal environments.

Rusting metal panels due to improper coatings

3. Wood

- Moisture build up in wood stud cavities can cause rot and mold. Proper detailing of entire assembly including placement of vapor barriers and drainage planes are critical in preventing this.
- Specify wood products that are naturally pest resistant.
- Consider specifying FSC-certified wood products.
- Care should be taken when using OSB and other similar products in locations where they are on the ground and can wick-up water.

Full under-slab termite protection layer in high-risk area

4. Plastics

- Some plastics such as FRP and fiberglass are suitable for harsh environments.
- High initial costs for some plastic products are offset by lower long-term maintenance costs.
- Any maintenance that may be required should be done by qualified specialists with expertise with these materials.
- Specifying materials with enhanced UV-protection is important to prevent degradation if exposed.

5. Thermal and Moisture Protection

- Weather barriers, vapor barriers and drainage planes to be detailed and installed properly to divert water intrusion away from the interior spaces.
- Flashing and counterflashing to be detailed and installed properly to prevent reliance on sealants being the primary barrier for water intrusion.
- Understand whether spaces are naturally ventilated vs. Conditioned/dehumidified with mechanical AC systems – details of assemblies will change.
- Recommend doing a dewpoint calculating software such as WUFI®-ORN/IBP to determine dew-point locations in exterior envelope and then detail accordingly.

Mold damage due to moisture intrusion

6. Doors and Windows – Glazing and Hardware

- Metal doors and frames are acceptable, consider specifying Type 316 stainless steel or PVDF [like Kynar®] as appropriate based on base metals.
- Specify windows with integral weep systems.

Key Strategies for Building Systems and Materials in the Tropics	
• If impact resistant glazing is not specified, then other means of protection from high-wind events will be necessary. Automatic shutters may be required in areas with limited access or operational resources required to deploy manual shutters. • Engage Corrosion Expert during design to inform decisions related to metals used for hardware. • Gaskets/sweeps/seals are critical to prevent unwanted moisture and pest intrusion.	 *Swollen OSB due to moisture intrusion*
7. Finishes / Coatings • When selecting coatings, consider lifespan, maintenance, and ability for repairs. Some materials last longer but any repairs should be done by trained specialists with proper materials that may not be readily available. Specifying attic stock for these special materials and storing them properly can help to mitigate this issue. • Rely on advice from Corrosion Expert regarding any required coating due to adjacency of dissimilar materials.	

5.3 Structural

This section is presented in two parts, the first for guidance regarding loadings, and second for guidance regarding assessment of structural capacity and strength.

5.3.1 Design Loading Requirements

Design loading requirements are to be based on structural standards and codes. Additional information for location specific loading resources may be supplementary to the structural standards and codes.

Island areas within U.S. territories should utilize the adopted international design codes with American-based standards for loading and design and location specific data being supplementary.

Island areas which are freely associated states (FAS) should use international-based design codes with American-based standards, codes, and guidelines being supplementary depending on applicability of location-based data and Codes.

Additional design data from International, American, Australian, and New Zealand-based guidelines are given within Table 5-4 and Table 5-5.

5.3.1.1 Code Based Loading Resources

Global loading resources applicable to U.S. territories and associated states include the following hierarchy:

- International Building Code, IBC Chapter 16: Structural Design (International Code Council, 2021);
- American Society of Civil Engineering, ASCE 7: Minimum Design Loads for Buildings and Other Structures (ASCE, 2022);
- Unified Facilities Criteria, UFC 3-301-01: Structural Design (Whole Building Design Guide, February 2022); Federal Emergency Management Agency (FEMA);

To comply with the current latest version of the IBC (2021), the DoR will need to comply with ASCE 7 as the referenced adopted code. Note that the IBC does not call out the use of the latest version of codes and standards. IBC 2021 (Chapter 35) specifically references ASCE 7-16 with Supplement 1.

ASCE 7 is updated every 6 years, with the latest version being ASCE 7-22. The DoR should keep up to date with the latest version of codes and standards, as the latest version generally becomes adopted by the local jurisdiction and thus becomes a legal requirement to comply with. Also, the latest version of ASCE 7 will contain the design loading guidance based on the latest data available.

The IBC covers basic design principles for structural loading covering dead, live, wind, rain, seismic, flood, and tsunami design loading criteria. Exceptions are stated in ASCE 7 for structures under higher risk categories. The UFC 3-301-01 makes alterations to, and adopts criteria, from the IBC and ASCE 7 for structural design in the Department of Defense (DoD). The UFC was developed for areas where DoD sites have been established, as such the designer must take into consideration the proximity of DoD sites relative to their structure when determining structural loadings from this standard. The UFC has also established an online structural loading tool to determine loading data from the Whole Building Design Guide, this includes regions outside of U.S. territories such as:

- Marianas Islands / Guam;
- American Samoa: Pago Pago;
- Marshall Islands: Kwajalein, Wake Island;
- Caroline Islands (FSM): Koror, Palau Islands, Ponape.

Table 5-3 below shows a typical design loading table for the Kwajalein, Marshall Islands from the online structural loading tool (Whole Building Design Guide, February 2022).

BASE / CITY	
Kwajalein	
Latitude / Longitude	8.716667, 167.73333300000002

WIND SPEED (MPH)					WIND SPEED (KM/H)				
RISK CATEGORY					RISK CATEGORY				
I	II	III	IV	V	I	II	III	IV	V
107	132	163	173	233	172	212	262	278	375

SNOW LOADING			
GROUND SNOW (PSF)	FROST PENETRATION (IN)	GROUND SNOW (KPA)	FROST PENETRATION (MM)
Use local data, if available			

SEISMIC DATA		
PGA (%G)	S_S (%G)	S_1 (%G)
14	32	9

Wake Island

Figure 5-3: Design loading data for Marshall Islands (Whole Building Design Guide, 2022)

5.3.1.2 Risk Categories

Risk categories are essential for determining the loading requirements on the structure. Risk categories affect wind, seismic, flood, and tsunami loading. Risk categories are defined in the IBC Section 16 under table 1604.5: Risk categories of buildings and other structures (International Code Council, 2021). Under the IBC risk categories are determined by the risk posed to human life under structural failure and collapse, with higher categories representing increased risk to human life. These categories are summarized below with further definition provided in Figure 5-4:

- Category I: Low risk;
- Category II: Normal risk;
- Category III: High occupancy and critical;
- Category IV: Essential facilities.

Note the UFC document makes specific alterations to the IBC and may affect the loading guidance as specified in the IBC. This is shown in UFC Chapter 2: Modifications to IBC (Whole Building Design Guide, February 2022). The UFC also references an additional risk category, Category V: National Strategic or Military Assets, which is specified for key national defense structures (e.g., missile defense facilities, emergency backup power-generating facilities, etc.).

RISK CATEGORY	NATURE OF OCCUPANCY
I	Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to: • Agricultural facilities. • Certain temporary facilities. • Minor storage facilities.
II	Buildings and other structures except those listed in Risk Categories I, III and IV.
III	Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to: • Buildings and other structures whose primary occupancy is public assembly with an occupant load greater than 300. • Buildings and other structures containing Group E occupancies with an occupant load greater than 250. • Buildings and other structures containing educational occupancies for students above the 12th grade with an occupant load greater than 500. • Group I-2, Condition 1 occupancies with 50 or more care recipients. • Group I-2, Condition 2 occupancies not having emergency surgery or emergency treatment facilities. • Group I-3 occupancies. • Any other occupancy with an occupant load greater than 5,000.[a] • Power-generating stations, water treatment facilities for potable water, wastewater treatment facilities and other public utility facilities not included in Risk Category IV. • Buildings and other structures not included in Risk Category IV containing quantities of toxic or explosive materials that: Exceed maximum allowable quantities per control area as given in Table 307.1(1) or 307.1(2) or per outdoor control area in accordance with the *International Fire Code*; and Are sufficient to pose a threat to the public if released.[b]
IV	Buildings and other structures designated as essential facilities, including but not limited to: • Group I-2, Condition 2 occupancies having emergency surgery or emergency treatment facilities. • Ambulatory care facilities having emergency surgery or emergency treatment facilities. • Fire, rescue, ambulance and police stations and emergency vehicle garages. • Designated earthquake, hurricane or other emergency shelters. • Designated emergency preparedness, communications and operations centers and other facilities required for emergency response. • Power-generating stations and other public utility facilities required as emergency backup facilities for Risk Category IV structures. • Buildings and other structures containing quantities of highly toxic materials that: Exceed maximum allowable quantities per control area as given in Table 307.1(2) or per outdoor control area in accordance with the *International Fire Code*; and Are sufficient to pose a threat to the public if released.[b] • Aviation control towers, air traffic control centers and emergency aircraft hangars. • Buildings and other structures having critical national defense functions. • Water storage facilities and pump structures required to maintain water pressure for fire suppression.

a. For purposes of occupant load calculation, occupancies required by Table 1004.5 to use gross floor area calculations shall be permitted to use net floor areas to determine the total occupant load.

b. Where approved by the building official, the classification of buildings and other structures as Risk Category III or IV based on their quantities of toxic, highly toxic or explosive materials is permitted to be reduced to Risk Category II, provided that it can be demonstrated by a hazard assessment in accordance with Section 1.5.3 of ASCE 7 that a release of the toxic, highly toxic or explosive materials is not sufficient to pose a threat to the public.

Figure 5-4: Risk Category of Buildings and Other Structures Table 1604.5 (International Code Council, 2021)

Table 5-2 shows importance factors determined from the risk category as per ASCE 7. The designer should reference ASCE 7 for further information on the design process for loadings on structures.

Table 5-2: Importance factors (ASCE, 2022).

Risk Category	Importance Factors	
	Wind - Iw	Earthquake - Ie
I	0.87	1.00
II	1.00	1.00
III	1.15	1.25
IV	1.15	1.50

5.3.1.3 Seismic Design

When determining the peak ground acceleration, the designer must use specific loading codes relevant to their respective areas if available. If the area has no code or the code does not determine the peak ground acceleration (PGA), general seismic loading resources can be used to determine seismic risk in an area as identified in Section 5.3.1.7. For structures with a high importance level or high risk to human life, geotechnical investigation may be required to determine an appropriate PGA.

For determining seismic demand on a structure all major national and international codes have dedicated sections specifying the exact process used to determine seismic forces acting on a structure. U.S. territories should use American based design codes as they contain location specific design guidance. Freely Associated States (FAS) without an official code or seismic loading guidance should supplement current building regulations with international codes and regulations.

The International Building Code (IBC) Section 16 discusses structural design with specific guidance on earthquake design data, risk categories, seismic importance factors, and site class coefficients.

One critical section for determining the seismic load is the seismic importance factor. For American based standards this is found in ASCE 7 Section 11. The seismic importance factor is determined through the risk category of the structure. Risk Categories I (low) and II (normal) structures see no amplification of seismic forces, while Risk Categories III (high occupancy) and IV (essential structures) receive a 1.25 and 1.5 importance factor, respectively. This reflects the larger seismic forces the structure must be designed to withstand. The designer is responsible for determining the risk category and applying the correct seismic importance factor (American Society Of Civil Engineers, 2022).

Site class coefficients are dependent on the soil properties, with lower grade (softer, weaker) soils representing a lower grade site class. ASCE 7 Section 11 details specific site coefficients for each soil grade and spectral response acceleration (ASCE, 2022).

Table 5-3 shows the site classifications and definitions as per ASCE 7.

Table 5-3: Site Class Definitions (ASCE, 2022)

Site Class	Site Profile Name
A	Hard Rock
B	Rock
C	Very Dense Soil or Soft Rock
D	Stiff Soil
E	Soft Clay Soil
F	Soil Requires Site Response Analysis

5.3.1.4 Wind Design

Under ASCE 7 all regions in this report are considered cyclone prone wind regions. Areas of high cyclone risk, such as those in the western pacific, are recommended to follow best design practices regarding securing roofs, providing adequate lateral bracing, and ensuring load paths can adequately transfer loads to the foundations. When determining wind speeds the appropriate special wind region maps should be used in conjunction with the corresponding codes. For U.S. territories, ASCE 7-22 should provide appropriate wind speed regions and methods for determining loading on the structure. FAS nations with other or no adopted codes should use appropriate wind speed sources in conjunction with international structural design codes such as the IBC and UFC. The provided region-specific wind resources may not account for cyclone peak wind speeds. In such cases they should be supplemented with general cyclone wind loading guidance and other international design codes for cyclones.

The IBC Section 1603.1.4 provides information required to determine wind loading. This includes determining the basic wind speed, risk category, wind exposure, internal pressure coefficients, and overall design wind pressures. The IBC provides specific loading guidance for the U.S. and associated states such as Guam, American Samoa, and the U.S. Virgin Islands. For FAS nations, the design methodology may be applicable, but studies into specific wind speed and topographic effects may be required for their respective region. The designer is responsible for determining the maximum sustained wind speed and maximum cyclonic wind speed (if applicable). The designer must consider all wind loading effects to determine maximum loading combinations, regardless of if wind is the governing load or not, as positive pressures inside the structure can affect design and construction.

5.3.1.5 Flood, Storm Surge and Tsunami Impact

When determining flood, storm surge and tsunami loads the designer must perform a risk assessment to determine the likelihood and result of each event occurring in the area. Due to climate change raising sea levels, and increasing storm frequency and severity, the designer may need to perform an impact assessment for important structures with a longer design life. Location specific flood and tsunami loading guidance may be limited for structures. General design principles and guidelines from international, American and Australian/New Zealand codes have been referenced for the use of modern tsunami design principles. For structures of high importance and in a high exposure/risk area it is recommended to perform a hydrological study and model potential impacts from floods, storm surges, and tsunamis. For tsunami considerations, structures requiring tsunami design should follow the provisions in ASCE 7-22 Chapter 6, Tsunami Loads and Effects. The IBC Section 1604.5 discusses risk categories with exceptions for tsunami risk categories III and IV to be in accordance with ASCE 7 Section 6.4 (International Code Council, 2021). Flood loads are determined using ASCE 7 Chapter 5 (ASCE, 2022) which references ASCE 24-14 Flood Resistant Design and Construction. Design and construction of Risk Categories III and IV building and structures in the Tsunami Design Zones is discussed on IBC (2018) Section 1615.

Case studies are an effective tool for understanding the effects of flooding, storm surges, and tsunamis. The Hunga Tonga-Hunga Ha'apai volcano eruption in Tonga produced tsunamis that damaged structures across the island nation. From this tsunami, future design considerations have been identified to improve the resilience of the island, not just from a structural perspective but also from a land and natural resources perspective. One example is the use of planting trees around coastal areas. An investigation from Tonga's Ministry for Lands and Natural Resources (MLNR) found that as the tsunami moves through, trees fall and create log dams which reduce the flow energy of the wave. However, broken trees also become large floating debris which result in large impact forces. The log damming against structures also greatly increases the hydrodynamic drag on the structure. The Tohoku tsunami in Japan demonstrated that forests along the shoreline can have negative consequences in a large event when the trees fail. The MLNR's investigation also found that for the tourist resort rebuilds, adopting more of a Mediterranean-style model with the main hotel facilities located further inland with "pop-up" day-use activity hubs set up closer to the beach will help reduce the impacts of future events (BBC, 2022).

The designer should consult with specialized coastal engineers and regional regulatory bodies in the design of sustainable and effective flood, storm surge, and tsunami mitigation systems.

5.3.1.6 Volcanic Ashfall Impact

Volcanic impacts should be considered for island areas in proximity to volcanic activity. Significant volcanic activity can cause seismic events, tsunamis, and pyroclastic events with ashfall. Ashfall is the term used to describe ash falling after volcanic eruptions, layering on structures and roofs up to hundreds of kilometers away after an eruption. Ash from volcanic eruptions is considerably dense (ranging from indicatively 64.3 to 128.6 PCF for dry and wet ash) and can layer on structures to great depths. This poses significant risk to lightweight structures or structures with long spans and low-pitched roofs as the applied load can range from 1 – 5 kPa depending on the saturation and depth of accumulated ashfall (US Geological Survey, 2015). The designer should consider the risk volcanic activity and ashfall poses to structures in the region. This includes the type of and proximity to volcanic activity due to some types of volcanos producing more ash and pyroclastic flows than others. This may require collaboration with geotechnical investigations to determine the risk posed to a critical structure. Existing codes do not account for volcanic ashfall impact on structures however this may be a consideration for structures where wind loading does not govern the design. Further reading on ashfall impacts, loading, and case studies are found from the Volcanic Ashfall Impacts Working Group (Volcanic Ashfall Impacts Working Group, 2015)

5.3.1.7 Global and Local Loading Resources

Following on from the general approach given in Section 4, this section provides general loading advice specific for the seven island areas considered by this document. Table 5-4 provides global loading guidance from internationally recognized scientific, engineering, and governmental bodies. Global loading guidance should be used in conjunction with location specific guidance, or in place of when location specific guidance is not available.

Each location should use the appropriate adopted codes for the region. Areas with very limited information or no codes on loading and risk assessments for wind, seismic, tsunami, and flood loading should use the general loading guidance in conjunction with other international codes.

Table 5-4: Location specific loading data and guidance

Island Area	Wind	Seismic	Tsunami	Flood
American Samoa	**Simulated Historical Climate and Weather Data** (Meteoblue, 2022)	**Structural Load Design Tool for UFC 3-301-01** (Whole Building Design Guide, 2022)	**Evaluating the Effects of Tsunami Loading** (University of Hawaii, December 2014)	**Multi-Hazard Mitigation Plan** (Territory of American Samoa, April 2015)

Island Area	Wind	Seismic	Tsunami	Flood
Northern Mariana Islands (CNMI)	**Mitigation Assessment Team Summary Report and Recommendations** (FEMA, July 2021) **Special Wind Region Maps** (FEMA, October 2020)[10]	**Seismic Hazard Assessment for Guam and the Northern Mariana Islands** (Charles S. Mueller, 2012) **U.S. Seismic Hazard Maps** (USGS, 2019)	**Tsunami Inundation Mapping for At Risk OCONUS DoD Installations** (Whole Building Design Guide, 2019)	-
Federated States of Micronesia (FSM)	**Pacific Catastrophe Risk Assessment and Financing Initiative** (Pacific Catastrophe Risk Insurance Company, September 2011)	**Structural Load Design Tool for UFC 3-301-01** (Whole Building Design Guide, 2022)	-	-
Guam	**Wind Safety of The Building Envelope** (Whole Building Design Guide, 2017)	**Seismic Hazard Assessment for Guam and the Northern Mariana Islands** (Charles S. Mueller, 2012) **UBC Seismic Zone** (AEI Consultants, 1997) **UFC Structural Load Design Tool** (Whole Building Design Guide, 2022) **U.S. Seismic Hazard Maps** (USGS, 2019)	**Tsunami Inundation Mapping for At Risk OCONUS DoD Installations** (Whole Building Design Guide, 2019)	**Guam Comprehensive Flood Study (**USACE, 2020)
Republic of Marshall Islands (RMI)	**Simulated Historical Climate & Weather Data** (Meteoblue, 2022)	**Structural Load Design Tool for UFC 3-301-01** (Whole Building Design Guide, 2022)	**Tsunami Inundation Mapping for At Risk OCONUS DoD Installations** (Whole Building Design Guide, 2019)	-
Palau	**Pacific Catastrophe Risk Assessment and Financing Initiative**	**Pacific Catastrophe Risk Assessment and Financing Initiative**	-	-

[10] *https://opd.gov.mp/library/reports/special-wind-region-swr-maps-for-the-commonwealth-of-the-northern-mariana-islands-cnmi/special-wind-region-swr-maps-for-the-commonwealth-of-the-northern-mariana-islands-cnmi.pdf*

Island Area	Wind	Seismic	Tsunami	Flood
	(Pacific Catastrophe Risk Insurance Company, September 2011)	(Pacific Catastrophe Risk Insurance Company, September 2011) **Structural Load Design Tool for UFC 3-301-01** (Whole Building Design Guide, 2022)		
U.S. Virgin Islands (USVI)	**USVI Special Wind Region Maps** (FEMA, April 2020)	**U.S. Seismic Hazard Maps** (USGS, 2019)	-	**Monitoring Storm Tide, Flooding and Precipitation from Hurricane Maria** (USGS, 2019)

Note: Blank sections are regions where no local specific loading data could be found. Where region specific information is lacking, global loading guidance should be used.

Table 5-5: Global loading data and guidance

Wind	Seismic	Tsunami	Flood	Volcanic Ashfall
Asia Pacific: Tropical Storm Risk **(United Nations OCHA, 2014)** **Last 50 Years Tropical Storms in Asia-Pacific: 1968 - 2018** **(United Nations OCHA, 2019)** **U.S. Seismic and Wind Zones: ASCE 9-75** **(ASCE, November 2015)**	**Asia Pacific Regional Hazard Map** (United Nations OCHA, 2014) **U.S. Seismic and Wind Zones: ASCE 9-75** (ASCE, November 2015)	**Tsunami Loads and Effects: ASCE 7-22** (ASCE, 2022) **Tsunami Loads and Effects on Evacuation Structures** (New Zealand MBIE, May 2020) **Guidelines for Design of Structures for Vertical Evacuation from Tsunamis** (FEMA, 2019)	**Minimum Design Loads for Buildings and Other Structures: ASCE 7-22** (ASCE, 2022) **Flood Resistant Design and Construction: ASCE 24-14** (ASCE, 2014) **Flood Resistance Of The Building Envelope** (Whole Building Design Guide, 2017)	**Volcanic Ashfall Impacts: Roof Loading** (US Geological Survey, 2015)

5.3.2 Material Codes and Standards

5.3.2.1 Concrete Masonry and Reinforced Concrete

The design of concrete structures should follow the American Concrete Institute structural design standards and guidelines. ACI 318: Building Code Requirements for Structural Concrete (American Concrete Institute Committee, 2019) defines key aspects of concrete design, including key aspects to be considered for concrete structures in the island areas:

- Seismic resistant design requirements;
- Steel reinforcement properties, durability, and embedded items;
- Reinforcement details;

- Construction documents and inspections.

For specific concrete masonry design, the designer should follow TMS 402-16 (formerly designated ACI 530.1): Building Code Requirements and Specification for Masonry Structures (American Concrete Institute, 2011). Further information can be found in the Masonry Designers' Guide 9th Edition which is compliant with the latest TMS 402/602 code requirements (Masonry Institute of America, 2016).

Further information regarding best practice for designing reinforced concrete sections in tropical islands is provided in Section 5.3.3.2

5.3.2.2 Steel and Aluminum

Island areas within U.S. territories should follow the American Institute of Steel Construction codes and guidelines for steel design and construction requirements, mainly AISC 303-16: Code of Standard Practice for Steel Buildings and Bridges (American Institute of Steel Construction, 2016). FAS can choose to import steel from Australia or New Zealand depending on material availability. Structures using imported steel products from Australia and New Zealand should follow applicable structural steel codes:

- AS/NZS 1664: Aluminum Structures (Standards New Zealand, 1997);
- NZS 3404: Durability Requirements for Steel Structures (Standards New Zealand, 2018);
- AS 4100: Steel Structures (Australian Standards, 2020);
- AS/NZS 4600: Cold Formed Steel Structures (Standards New Zealand, 2018).

Material traceability and identification is key to ensuring the material properties of the sections match those specified by the designer and what the manufacturer will supply. AISC 303-16 Section 2.1: Material Identification and Traceability dictates the process required for adequate material identification from the manufacturer (American Institute of Steel Construction, 2016). Steel imported from Australia or New Zealand should follow the AS/NZS 5131: Structural steelwork and fabrication code (Standards New Zealand, 2016)

5.3.2.3 Timber

Island areas within U.S. territories should follow American Wood Council (AWC) standards for wood structure design and construction (American Wood Council, 2018). This includes the:

- National Design Specification (NDS) for Wood Structures;
- Wood Frame Construction Manual (WFCM);
- ANSI/AWC Special Design Provisions for Wind and Seismic (SDPWS);
- ANSI/AWC Permanent Wood Foundation Design Specification (PWF);
- Fire Design Specification (FSD) for Wood Construction.

FAS can choose to import timber products from Australia or New Zealand as at times these can be easier to source depending on material availability and code compliance. Australian and New Zealand design standards include:

- AS/NZS 1604: Preservative-treated wood-based products (Standards New Zealand, 2021);
- AS/NZS 2269.0: Plywood – Structural – Part 0 Specifications (Standards New Zealand, 2012);
- AS/NZS 2269.1: Plywood – Structural – Part 1 Determination of structural properties (Standards New Zealand, 2012);
- AS 1648: Residential timber framed construction (Standards Australia, 2010);
- NZS 3602: Timber and wood-based products for use in building (Standards New Zealand, 2003);
- NZS 3603: Timber structures standard (Standards New Zealand, 1993);
- NZS 3604: Timber-framed buildings (Standards New Zealand, 2011);
- NZS 3631: New Zealand timber grading rules (Standards New Zealand, 1988);
- NZS 3640: Chemical preservation of round and sawn timber (Standards New Zealand, 2003).

The designer may wish to import timber products due to treatment requirements improving the lifespan of timber products. NZS 3602 specifies minimum required treatment for different timber products exposed to different conditions following a hazard classification scale (Standards New Zealand, 2021). Table 5-6 shows the minimum timber treatment requirements and Table 5-7 shows the minimum timber grade requirements from NZS 3602 (Standards New Zealand, 2003).

Table 5-6: Minimum timber treatment requirements - NZS 3602 (Stantec, October 2016)

Treatment Grade	Treatment Description	Use
Untreated	Untreated timber.	No timber incorporated in the works shall be untreated.
H1.2	Timber protected from the weather but still at risk of moisture exposure.	Minimum requirement for timber treatment. Internal framing and framing not directly exposed to weather.
H3.1	Timber used outdoors above ground, exposed to the weather, generally non-structural applications.	All cladding, all ply lining, all exposed timber excluding piles.
H3.2	Timber used outdoors above ground, exposed to the weather but at risk of water entrapment.	All exposed joists and rafters.
H5	Timber used for severe decay hazard risks, such as ground contact with continuous wetting.	All piles, poles, retaining walls, crib walling.
H6	Timber used for marine environments, regularly immersed in seawater.	Wharf piles, marine and jetty components.

Table 5-7: Minimum timber grade requirement – NZS 3602 (Stantec, October 2016)

Use	Timber grade
Framing	Minimum requirement no.1 framing grade or higher as may be required by specific design
Ply	CD face grade, C grade face exposed, H3 treated, marine bonded
Weather boards	H3.1 treated pinus raidata
Flooring	H3 treated marine grade ply, or macrocarpa T&G, or H3 treated pinus raidata

Further guidance on New Zealand treatment grades and applications can be found in the NZ Building Magazine and other publications with diagrams and further grade guidance (BRANZ, 2012).

5.3.2.4 General Material Guidance

The following summarizes additional resources available for material guidance for island regions. The designer should use this information as supplementary to design standards and codes. Table 5-8 summarizes island material guidance. Note that use of coral aggregate is banned in Kosrae.

Table 5-8: Island area material guidance

Materials	Material Guidance	Comments
Concrete	(Wen Zhou, 2020)	Advances in the design of concrete using coral aggregate. An economical and environmentally friendly construction material. A research paper focused on the physical and mechanical properties of coral aggregate.
	(Taylor and Francis Group, 2020)	The effects of seawater for mixing and curing of structural concrete. How chloride contamination can affect short and long term strength of concete.
	(U.S. Department of the Interior Bureau of	Alternative reinforcment for concrete in corrosive environments. A study into alternative options for steel or hybrid reinforcement in high performance reinforced concrete in highly corrosive environments.

Materials	Material Guidance	Comments
	Reclamation, September 2016)	
Steel	(J.T. Pérez-Quiroz, 2008)	Assessment of stainless steel reinforcement for concrete stuctures rehabilitation. Improving the service life of reinforced concrete structures.
Timber	(Pacific Island Projects, 2018)	Mechanical properties of processed wood timber species from Papua New Guinea. Locally sourced timber species used for timber construction.

5.3.3 Design Best Practice Guidance

The following is recommended best practice for designing structures in tropical islands areas. The designer is required to follow structural design standards and codes, with the information here being supplementary to the design and construction process.

5.3.3.1 Wind Design

Specific design guidelines and technical construction sheets for cyclone resistant housing and shelters are available from the Queensland and Western Australia government. The Western Australia Cyclone Preparedness Guide provides specific wind loading, failure mechanisms, and remedial methods for housing and light commercial structures (Department of Fire & Emergency Services, 2022).

ASCE-7 Outlines wind exposure categories based upon surface topography, vegetation, and existing structures. The three defined exposure categories are B, C and D. Category B is urban and suburban, wooded, and other areas with closely spaced obstructions. Category C is open terrain with scattered obstructions with heights less than 30ft tall. Category D is flat, unobstructed areas and water surfaces. The correct classification is critical in determining wind forces acting on the structure. From high winds the risk of light structures and vegetation being stripped away from the landscape is high, therefore it may be appropriate to design a building to exposure category C even if category B may apply, accounting for the potential change in structure/vegetation shielding.

Figure 5-5: Failure of roof fasteners due to corrosion (Department of Fire & Emergency Services, 2022)

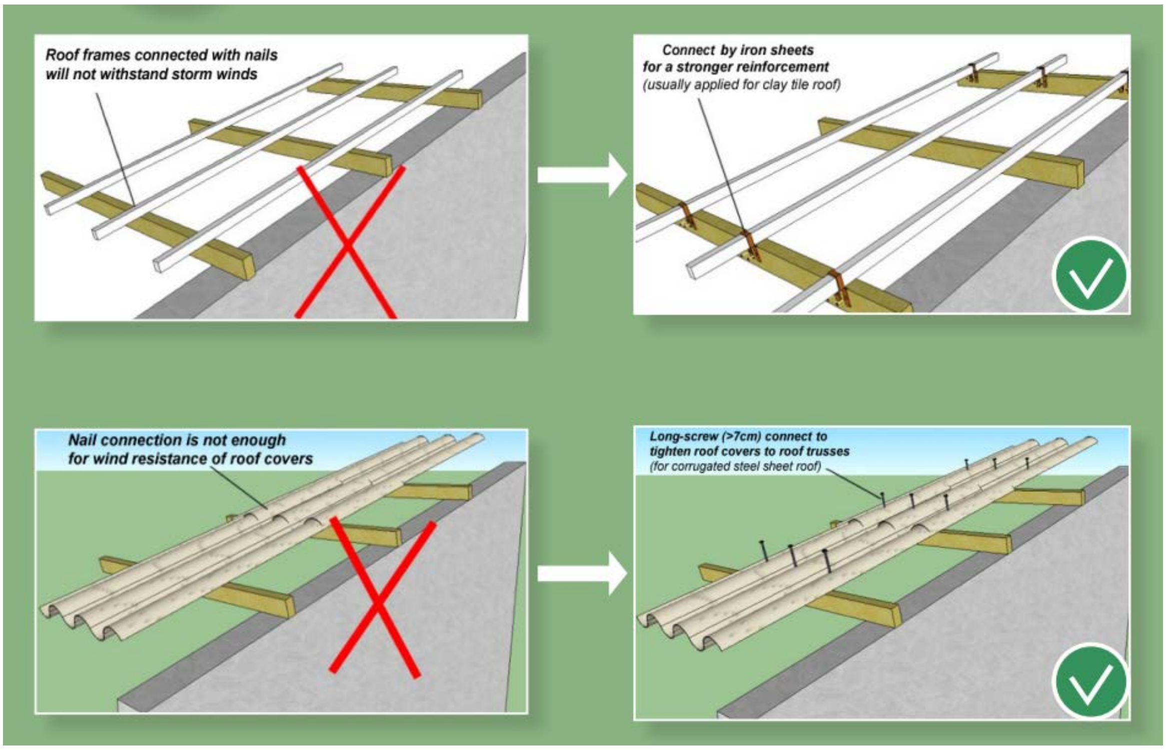


Figure 5-6: Connection design example for roof tie-downs (Da Nang Department of Construction, 2017)

Mean and maximum wind speeds are given from the five-category cyclone rating system. The document outlines typical damage seen from extreme wind, storm tides and storm surges. Note this document may not be relevant for essential and critical infrastructure. The designer should coordinate with specialists around detailed design for critical infrastructure and ensuring constructability and risk management criteria are meet. The Design Guidelines for Queensland Public Cyclone Shelters offers both concept design and detailed design guidance for cyclone and storm shelters (Mullins Consulting, 2006). The document refers to specific Australian design codes which the designer must be able to understand, interpret, and apply to best design practice.

5.3.3.2 Concrete Masonry and Reinforced Concrete

The design guidelines highlighted here should act to supplement design codes and standards.

Masonry solutions are generally weak for seismic performance, and as such a hybrid system with moment carrying members should be considered when designing a masonry wall. Figure 5- shows reinforced masonry design for tsunami loading from the American Samoa Tsunami Study Working Report #06 (American Samoa Government, 2011) although there are limitations in resisting face loads. The designer should refer to the Masonry Designers' Guide 9th Edition for specific masonry construction detailing (Masonry Institute of America, 2016). Alternatively, the New Zealand Concrete Masonry Manual offers specific design guidance and construction details for reinforced masonry structures (New Zealand Concrete Masonry Association Inc, 2018).

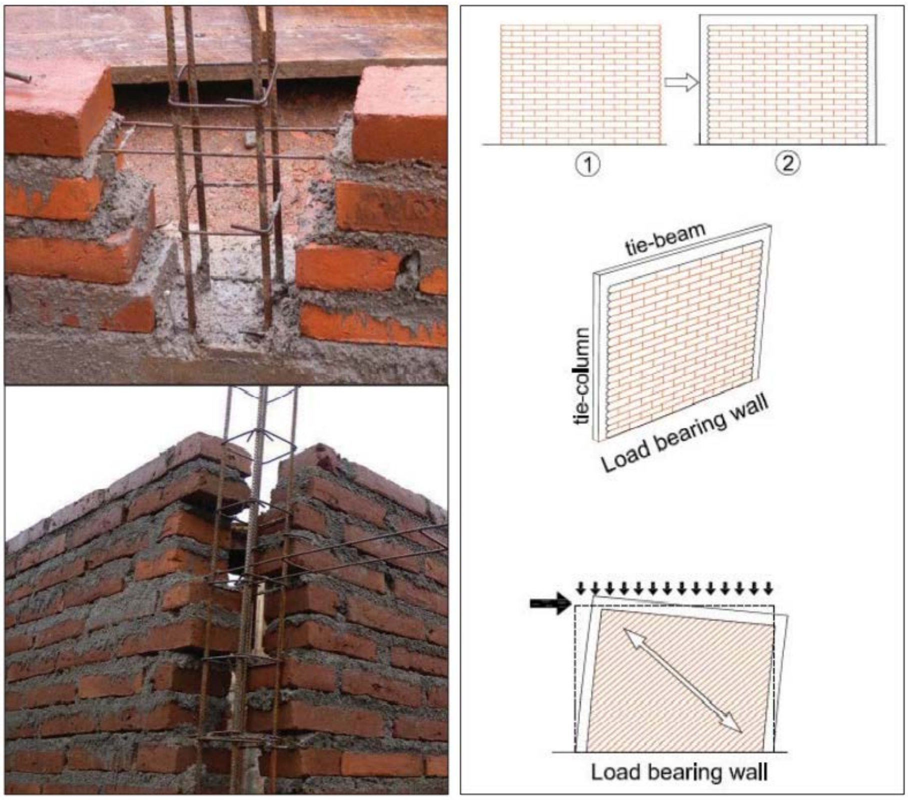


Figure 5-7: Tsunami and Seismic resistant masonry wall design (American Samoa Government, 2011)

The design of steel reinforcement is critical to structural performance of reinforced concrete sections, especially under seismic loading. The designer is responsible for defining the concrete design and durability properties, along with specifying provisions for the durability and detailing of steel reinforcement.

The main risk of reinforcement corrosion and subsequent concrete degradation in each of the island areas comes from chloride penetration and contamination in the reinforced concrete section. However, there are a variety of potential factors including one or more of the following:

- Saline conditions penetrating the concrete;
- Saline-contaminated aggregate used for concrete;
- Saline-contaminated water used for concrete;
- Deterioration of reinforcing from saline conditions during shipping or storage prior to being concreted;
- Inadequate cover depth leading to cracking due to solar expansion or stress concentration, and subsequently to corrosion of reinforcing;
- Improper compaction of the concrete;
- Improper water content affecting concrete durability;
- Rough surface finishes accumulate more water on the surface and should be avoided.

Figure 5-8: Reinforcement corrosion due to lack of cover

Saline environments such as coastal areas are high risk environments and precautions should be taken to ensure proper corrosion protection as stated above. The risk of chloride contaminated water and aggregate in construction may be high depending on how the materials are sourced and used. If chloride contamination is possible then additives which increase the alkalinity of the mixture and reduce the effects of chloride ions are recommended. If chloride contamination is within the aggregate, then washing may be required along with additives. If chloride contamination is unavoidable in reinforced concrete structures due to sourcing, transport, and/or cost limitations, then stainless-steel reinforcement is highly recommended. Where possible, locally sourced coral aggregate can be used with specific design guidance as shown in Table 5-8 (Wen Zhou, 2020). The presence of chloride containing materials, salt water and beach sand, can adversely affect the long-term strength of concrete (Qingyong Guo, 2018).

For reinforced concrete design ensuring corrosion protection of the steel reinforcement is critical for long term strength and durability. For regions in contact with or close to water, especially chloride containing water, special consideration for detailing of corrosion protection is required. The International Building Code (International Code Council, 2021) has specific provisions for concrete reinforcement protection and references the American Concrete Institute (ACI) 318: Concrete Structures Code (American Concrete Institute Committee, 2019). Other regions also have specific reinforced concrete design codes (e.g., NZS 3101.1&2:2006).

The following are general design and protection guidelines for reinforced concrete. Each of these guidelines aims to increase the long-term strength, durability, and corrosion protection of reinforced concrete structures:

- Specify more concrete cover in highly corrosive environments. Each concrete structures code will have specific requirements for minimum levels of concrete cover given different exposure risk levels/categories. ACI 318-19 dictates up to 3 inches of cover for the maximum exposure category (American Concrete Institute Committee, 2019).
- UFC 3-301-01, paragraph 2-7.3 provides guidance on additional cover for high exposure facilities.
- For highly corrosive environments with contact to chloride-containing water or ground, galvanized or stainless-steel rebar is recommended due to the high corrosive resistance of each material. FRP rebar may also be considered. Stainless steel can be bent, cut, and welded while retaining the high corrosive resistant properties (U.S. Department of the Interior Bureau of Reclamation, September 2016). The designer must consider the appropriate reinforcement selection given performance, time, cost, and constructability constraints.
- Epoxy coated rebar is not recommended due to the highly fragile nature of the system. Mishandling during transport or construction will result in the scratching and removal of the epoxy. Studies have shown that as little as 0.5% of exposed surface area on epoxy coated reinforcement will result in corrosion like that of plain steel reinforcement (U.S. Department of the Interior Bureau of Reclamation, September 2016). Epoxy coated reinforcement should only be used under high levels of construction monitoring and quality checks.

Figure 5-9: Epoxy-coated reinforcing with damage to coating and corrosion

- The use of sacrificial anodes should be considered for infrastructure where long term strength and durability are critical for the operation of the structure.
- Controlling the porosity of the concrete will help reduce the rate of water and chloride penetration into the concrete. This may reduce the rate of corrosion within the section and help keep the steel reinforcement in a passive state.
- Consider using additives to increase the alkalinity of concrete and reduce the effects of any chloride contamination from water or aggregate. High levels of alkalinity form a passivating layer over the reinforcement which creates a corrosion resistant film.
- Do not use chloride containing water or aggregate for the construction of reinforced concrete sections. ACI 318-14 concrete code states requirements for maximum percentage by weight of water-soluble chloride ions (American Concrete Institute Committee, 2019). These limits should not be exceeded to ensure satisfactory corrosion protection.
- On site mixing is the most likely form of concrete construction, and as such construction monitoring will be key to ensure no additional chloride containing material is added (such as unwashed aggregate, beach sand, and salt water)
- Ensure placement, compaction, and curing is properly executed.

Figure 5-10: Spalling of reinforced concrete due to lack of concrete cover causing corrosion in the steel reinforcement

The designer is also responsible for considering other measures during the structural design phase.

- Crack control measures should be in place to reduce water intrusion. Exterior finishings will reduce the likelihood of intrusion and corrosion. Sealants and waterproof coatings are also recommended to limit water intrusion.
- Transportation may be critical during the construction phase to ensure the rebar is not damaged. This is especially important for coated or glass fiber systems which may be susceptible to scratching, bending and breakage.

One final consideration is the economics of reinforcement options. Alternative reinforcement options (e.g., stainless, glass fiber, carbon fiber, basalt fiber, etc.) may be multiple times more expensive than plain steel reinforcement. Alternative reinforcement may also require specialty training and labor to construct the structure, adding to the overall build cost. However, superior structural performance and corrosion resistance can reduce overall life cycle costs by minimizing maintenance and repair cost and increasing the total useable lifespan of the structure (U.S. Department of the Interior Bureau of Reclamation, September 2016).

Overall, the designer is advised to take a conservative, robust approach to concrete design, particularly when construction supervision may be limited or not present. Using additional cover, galvanized or stainless-steel reinforcement, and uncontaminated aggregate can increase the durability and longevity of concrete structures.

5.3.3.3 Structural Steel and Aluminum

The design guidelines highlighted here should act to supplement design codes and standards. For structural steel design a critical aspect is the specification of corrosion control systems for high exposure areas. External members exposed to highly corrosive environments will require a high-performance protective system. These include the use of galvanizing, zinc coatings, protective epoxy/urethane coatings, and sacrificial anodes. The designer should perform optioneering to determine the appropriate corrosion control system for a given structure type, exposure setting, and risk category. The coating system should be sufficiently designed to withstand the characteristics of the environment that it will be subject to. The designer is responsible for determining the correct application of corrosion protection system relative to time, cost, risk of damage, and availability constraints.

5.3.3.4 Timber

The design guidelines highlighted here should act to supplement design codes and standards. The designer should follow design codes and standards applicable to the region, with materials sourced accordingly. However, material may be sourced from outside the region if supply of material within the region is insufficient and/or inadequate. When sourcing locally supplied timber, the designer must ensure adequate testing of the timber products is carried out for quality assurance and determining the strength of the timber.

For sawn timber products the designer shall consider treatment options for high exposure areas. This is to ensure long-term durability of the timber in high exposure environments. Timber treatment is highly recommended for residential housing applications to limit degradation and pests. If timber treatment is not available, engineered wood products are an acceptable alternative, otherwise the use of untreated timber is advised against. Figure 5- shows the rotting of untreated timber in a high exposure environment.

Figure 5-11: Rotting of untreated, unprotected timber (Department of Fire & Emergency Services, 2022)

For high importance or high-risk structures, the designer should consider the use for engineered timber such as plywood, glulam and LVL timber products. Engineered timber products have superior physical and mechanical properties such as strength, ductility, and fire performance, along with much larger sizing options. For engineered timber products, specific design codes need to be used where applicable. Additional strengthening for roof and wind support design may also be required, this includes the following:

- Double roof trusses;
- Double and triple top plates and bottom plates;

- Extensive strapping from top/bottom plates to studs;
- Threaded steel tie rods, particularly for high-risk category buildings;
- Stainless steel bolting to piles;
- Extra heavy foundation pads with rebar through the pile engaging in the concrete.

For optimal fire performance, specific design requirements need to be met to ensure adequate fire protection and long-term serviceability. Consultation with a fire engineer or specialized engineering timber supplier is recommended. Suppliers of engineered wood products will provide physical and mechanical property charts for design purposes. Additional detailing guides, such as connection detailing, should be supplements to the design process. For external applications of plywood, marine grade is advised to be used underneath appropriate finishings.

5.3.3.5 General Construction Guidance

The following list additional infrastructure and structural guidance for construction within Pacific areas. Table 5-9 summarizes island area design and construction guidance.

Table 5-9: Island area design and construction guidance

Specifc Designs	Design and Construction Resources	Comments
Coastal Protection	(Pacific Region Infrastructure Facility, November 2017)	Guidance for the design and construction of coastal protection works in island countries. Covering the assessment, design, and construction of coastal protection systems.
Structures/ Buildings	(Tasman Insulation New Zealand Ltd, 2022)	Insulation design guide with specific design considerations for tropical climates
	(Pacific Region Infrastructure Facility, August 2021)	A diagnostic study on the application of building codes in the Pacific. The utilization of building standards for Pacific countries.
	(Timber Queensland, June 2016)	A technical data sheet for the design and construction of wind tie-down connections for high cyclone risk areas.
Pavement/ Roads	(Transport Global Practice World Bank Group, September 2019)	The design of climate resilient low-volume concrete paved roads for Pacific island countries. A guide for improving the longevity of concrete paved road surfaces.
	(Horsley Witten Group, 2021)	Unpaved road standards for Caribbean and Pacific countries. A guide for improving the longevity of unpaved road surfaces.
	(Pacific Region Infrastructure Facility, January 2016)	Specific design guidance for concrete and pavement for Pacific island countries. Design, specification, and standard recommendations for island countries.

Note: Pavements and Roads are outside the scope of the FDGTI, but references are included here to assist designers for related site works.

5.3.4 Geotechnical and Foundations Considerations

The geological and geotechnical conditions of a site should be considered during the planning, designing and construction of engineering projects.

Site-specific geotechnical investigation and recommendations shall be obtained for each project. For low-risk projects where site conditions are known or not critical to design (say of small structures), waiving the requirements of site-specific geotechnical investigation and adopting presumptive values listed under Chapter 18 of the 2021 International Building Code (IBC) to develop geotechnical recommendations may be considered but requires approval by the Client representative and/or contracting officer.

The following steps are normally undertaken for a basic geotechnical assessment and are discussed further in the following sections.

- Desk Study and conceptual ground model including preliminary risk assessment. The desk study should include review of published geological mapping and existing ground related information (where available) as

well as an engineering geological walkover of the site. The walkover should include a site slope stability assessment.
- Ground Investigation based on desk study, access and availability of equipment and the site's risk profile.
- Design considerations including update to the risk assessment.

5.3.4.1 Geology of Islands

The island territories covered under this guide are located largely in the Pacific Ocean, as well the USVI, located in the Caribbean.

The Islands of the Pacific are represented predominately by four lithological types: 1. Volcanic (igneous), 2. Limestone (calcareous and non-volcanic sedimentary), 3. Composite (both volcanic and limestone) and 4. Reef islands (unconsolidated sediment) (Patrick D. Nunn, 2016). A single island may have multiple lithological types, with limestone near the coast and other types inland. Soil horizons and lithologic layers may be very thin and vary within a relatively small site.

The lithological types can be further distinguished by elevation, whereby islands that rise to an elevation of at least 100 feet above msl can be described as 'high islands' and those below as 'low islands'. These two variables - lithology and elevation - reflect the dominant controls on key diagnostic characteristics of Pacific islands including their relief, drainage (surface and subsurface) erodibility and resistance, and their landscapes and landscape processes (Patrick D. Nunn, 2015).

Most of the US Virgin Islands rise only to a few hundred feet above sea level and are composed of metamorphosed igneous and sedimentary rocks overlain in parts by limestone and alluvium.

5.3.4.2 Engineering Geology Considerations

Understanding a site's geological conditions and history can help identify potential geological hazards and characterize the ground conditions to inform planning, design, and construction of projects.

Factors such as location, topography, geological conditions, climate/weather, natural structures, and previous land use can influence the following:

- Material properties;
- Foundation types;
- Potential settlement;
- Landslide risk and slope stability;
- Flooding and erosion;
- Seismic and liquefaction hazard;
- Excavation stability and dewatering requirements.

Seismic and liquefaction investigation and assessment should be undertaken in accordance with local government requirements.

Volcanics:

- High islands characterized by high, mountainous terrain;
- Variable deposits of volcanic rocks, breccia, tuff, conglomerate, sandstone and weathered clays;
- Rock and soils likely to be suitable for bearing;
- Tropical residual soils weathering in-situ (i.e., decomposing from rock to soil);
- Where forming slopes may be prone to instability, particularly where water is concentrated or in areas of high rainfall.

Limestone:

- Chemical weathering;
- Karst;
- Sink holes, may have shallow soil horizon.

Includes reef islands/alluvial areas:

- Recent soft/loose and unconsolidated soils;
- High groundwater;
- Variable in soil type and engineering properties.

5.3.4.3 Recommended Investigations

Geotechnical ground investigation should be appropriate for the anticipated ground conditions, nature of the proposed structure and available equipment.

Recommended ground investigation for lightweight single-story structures involving pads, strip footings or shallow piles includes the following:

- Hand augering (minimum 2 inch dia.) or mechanical auger with recovered soil logged to an international engineering standard. Not suitable for rock or gravelly soils;
- Test pitting using a mechanical excavator.

Spacing and number or investigation shall be dependent upon the size of the structure and should normally include at least 2 investigation locations.

In-situ testing should be undertaken at each investigation location as a minimum consisting of:

- Handheld or mechanical Dynamic Cone Penetration (DCP) or Scala Penetrometer recording blow counts, typically in 4-inch increments, over at least the full depth of the hand auger or test pit;
- Where available, calibrated handheld shear vanes for cohesive soils (silts and clays) recording peak and residual shear strength. Testing recommended in 1 to 2 feet increments.

Alternative ground investigation can include rotary or percussive boreholes or Cone Penetration Testing (CPT) where locally available.

Key Strategies for Sustainable Structural Design in the Tropics

1. Code Based Loading Resources

- Island areas within U.S. territories should utilize American based standards with international design codes and location specific data being supplementary.
- Freely Associated states (FAS) Islands should utilize international codes with American standards and codes being supplementary.

2. Risk Categories

- Risk categories are defined in the IBC Section 16 under Table 1604.5: Risk categories of buildings and other structures

Failure of roof fasteners due to corrosion

3. Global and Local Loading Data and Guidance

- Table 5-5 provides global loading guidance from internationally recognized scientific, engineering, and governmental bodies. Global loading guidance should be used in conjunction with location specific guidance, or in place of when location specific guidance is not available.

4. Seismic Design

- When determining the peak ground acceleration (PGA), the designer must use specific loading codes relevant to their respective areas
- For structures with a high importance level or high risk to human life, geotechnical investigation may be required to determine an appropriate PGA.

Dissimilar metal corrosion on roof fasteners

5. Wind Design

- Under ASCE 7 all regions in this report are considered cyclone prone wind regions. The appropriate wind region maps should be used in conjunction with the corresponding code when determining wind speeds.

6. Flood, Storm Surge and Tsunami Impact

- Designers should perform a risk assessment to determine the likelihood and result of flood, storm surge and tsunami events in the area for critical structures.
- For tsunami considerations all structures should follow IBC Appendix M **(International Code Council, 2021)**
- Flood loads are determined using ASCE 7 Chapter 5 **(ASCE, 2022)**

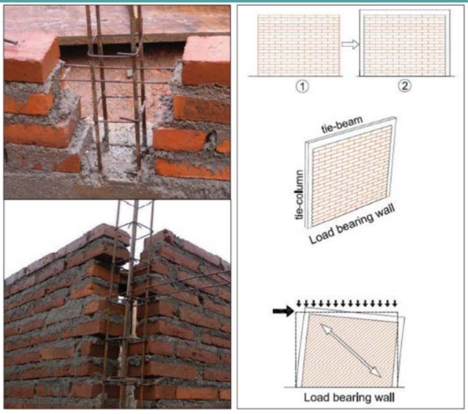
7. Volcanic Ashfall Impact

- Volcanic impacts should be considered for island areas in proximity to volcanic activity. The impacts from Volcanic ashfall are greater than equivalent snow loading due to the higher density of ash.

8. Masonry and Reinforced Concrete

Key Strategies for Sustainable Structural Design in the Tropics

- The design of concrete structures should follow the American Concrete Institute (ACI) structural design standards and guidelines ACI 318.
- The design of concrete masonry should follow ACI 530.1.
- Galvanised or stainless-steel reinforcement is highly recommended over alternatives such as epoxy coated reinforcement due to durability and construction monitoring concerns.
- Concrete cover is essential for durability, the designer must ensure adequate cover is maintained.



Tsunami and Seismic resistant masonry wall design

9. Steel and Aluminum

- Island areas within U.S. territories should follow the American Institute of Steel Construction codes and guidelines for steel design and construction requirements, mainly AISC 303-16.
- The design of steel structures should be in accordance with the Area’s regional standards and codes.
- External members exposed to highly corrosive environments will require a high-performance protective system.


Spalling of reinforced concrete due to lack of cover leading to corrosion of the steel reinforcement

10. Timber

- Island areas within U.S. territories should follow American Wood Council (AWC) standards for wood structure design and construction.
- The designer should consider local versus imported timber species with regards to quality control, treatment options, sizing, strength, and costing.
- The use of untreated timber is advised against. Importing timber from Australia or New Zealand will follow specific and strict treatment grades for uses in different environments.


Rotting of untreated, unprotected timber

5.4 Mechanical

5.4.1 Design Approach

Important Note: This Guide is intended for experienced HVAC Engineers as an informative document to provide background as to the most suitable approaches and tips for designing installations in island areas. It assumes that the reader is familiar with general HVAC design especially those in more temperate and less aggressive environments.

Refer to Section 2 for an overview of the design process. This provides references the standards and regulations in each Island Area, and what codes are suggested to supplement these where needed.

Section 2 provides an initial scoping and performance objective identification for the project.

Section 4.1 provides an overview of key initial decisions in the project (for example how to cope with rising sea water levels, and what materials are appropriate for the local environment.) Section 5.1 provides general information on corrosion controls and material selection.

The following sections describe the remaining stages of the design process. These are:

- High-level design decisions relating to system and material selection;
- Best practices and design tips to aid the more detailed parts of the design to help ensure it is compatible with the local environment, construction, and maintenance conditions.

5.4.2 System Selection

This section provides guidance on the initial design selections for the system and overall system design approach.

5.4.2.1 System Selection – Ambient Design Conditions

Designers should refer to the ASHRAE Climatic Design Information. Some of the key information is summarized below in Table 5-10. The key points to note are:

- The difference between the 0.4% and 2.0% exceedance dry bulb temperature is generally less than 2°F Similarly the corresponding wet bulb difference is generally less than 1°F. This means that there is little difference between systems designed for comfort applications and semi-critical applications. Table 5-10 should not be used for "mission-critical" systems;
- The design conditions all have a relative humidity of approximately 65%. This means that latent cooling loads will be significant and will be a significant portion of the cooling load. Cooling outside air from 90°F DB / 80°F WB to 75°F DB and 55% RH gives a latent cooling load that is three times the sensible load;
- The average daily temperature ranges during the hottest months are in the range of 7-10°F. This means that building precooling overnight is limited;
- All locations are close to the equator, this means that peak temperatures correspond generally to a sun location that is directly overhead;
- Although minimum temperatures are not presented below the 99.6% heating temperature is between 73 and 77°F for the pacific area and 67-70°F for the USVI. Therefore, as a general rule, heating for comfort purposes is not necessary.

Table 5-10: Area Climatic Design Temperatures Specific To Mechanical Design

Island Area	Location	Latitude	Elevation (ft)	Annual Avg Temp (°F)	0.4% Exceedance		2% Exceedance		Hottest Month Dry Bulb Daily Range (F)	MCWS (mph)	PCWD
					Dry Bulb (°F)	MCWB (°F)	Dry Bulb (°F)	MCWB (°F)			
American Samoa	Pago Pago Int. Airport	14° S	12	82.2	90.7	80.9	89.0	80.4	9.5	11.2	90°
CNMI	Saipan Int. Airport	15° N	215	81.9	89.8	80.2	88.2	79.4	8.8	12.0	70°
Guam	Int. Airport	13° N	254	81.8	89.4	78.1	88.1	77.9	9.3	12.8	90°
	Anderson AFB	14° N	612	80.6	87.8	78.7	86.3	78.4	8.3	11.9	80°

Island Area	Location	Latitude	Elevation (ft)	Annual Avg Temp (°F)	0.4% Exceedance		2% Exceedance		Hottest Month Dry Bulb Daily Range (F)	MCWS (mph)	PCWD
					Dry Bulb (°F)	MCWB (°F)	Dry Bulb (°F)	MCWB (°F)			
FSM	Chuuk Int. Airport	7° N	5	82.5	89.3	80.3	88.0	79.9	8.0	4.4	40°
	Pohnpei	7° N	151	81.5	90.0	80.5	88.3	79.8	9.9	3.3	50°
	Yap Int. Airport	9° N	44	82.2	91.4	81.0	89.1	80.1	10.4	4.2	100°
Palau	Koror	7° N	176	82.3	89.7	80.0	88.3	79.5	9.8	8.4	90°
RMI	Bucholz AFB	9° N	7	82.6	88.2	78.9	87.5	78.7	7.4	5.0	70°
	Majuro Island	7° N	13	82.9	89.0	79.8	87.9	79.8	7.1	4.2	70°
USVI	Cyril E King Airport	18° N	20	80.9	89.5	77.9	87.9	77.8	8.7	14.0	90°
	Henry E Rohlsen Airport	18° N	61	80.5	89.5	78.2	88.1	77.9	9.8	16.0	110°

MCWB Mean Coincident Wet Bulb temperature °F WB
MCWS Mean Coincident Wind speed (relative to 0.4% exceedance)
PCWD Prevailing Coincident Wind Direction (0°=north, 90°=east) (relative to 0.4% exceedance)
(extracted from ASHRAE Climatic Data Tables, from ASHRAE Handbook - Fundamentals)

The ambient environment is quite aggressive towards HVAC equipment due to the combination of hot temperatures, high moisture content, salt content, high ultra-violet levels and wind containing salt spray and in many cases fine coral sand.

5.4.2.2 System Selection – Location Factors

The location of many of the island areas also means that systems need to be carefully designed to ensure a long operating life. The key factors to be aware of are:

- A skilled workforce (for operations and maintenance tasks) is limited. This is mainly due to the low population on the islands. The total population in each area is between 18,000 and 150,000;
- The low population also means that spare parts and equipment spares are rarely held locally. Those parts that are held would typically be for air conditioners typically found in residential houses and complexes;
- Spare parts and replacement parts must come from major cities in other countries that may be up to 2,000 miles away. Even Miami is 1,000 miles away from USVI. As a result, air freight is expensive. Shipping is also limited due to the small population served.

The closest analogy is designing for a small city on a mainland country that has the nearest major city a long distance away. Therefore, limited specialized skills exist and all major materials and repair staff (except for day-to-day tasks must be brought in (at significant expense and with significant forward planning). As many of these areas have a small population, they will never be major HVAC markets

All significant materials must be imported on a project-by-project basis.

The small population also means that craneage may also be limited. The designer shall enquire as to the availability of cranes and other heavy equipment when developing the design. A construction company may bring cranes to site for the project construction, but once built that crane is no longer available for maintenance tasks. So, equipment locations must be selected for the maintenance equipment normally available in the area.

5.4.2.3 System Selection – Resilient System Design

For the reasons above, the HVAC systems must be primarily for a long operating life through:

- Selection of materials that will last in the aggressive environment;
- Selection of technologies that are appropriate for a small population area;

- Selection of design conditions (temperature and relative humidity / dew point) that is appropriate for the building occupant needs and can be maintained under all normal operating conditions so that mold and mildew does not occur (typically this is below 60°F dew point);
- Selection of the equipment locations that can be maintained with the facilities normally available (limited specialist tools, limited craneage, limited proprietary equipment skills and long periods between diagnosing a faulty part and receiving a replacement one;
- Modular design to allow separate components to be replaced with industry standard units with minimal modifications to connections etc.
- Avoidance of complex interlinked systems that are reliant on the whole system operating or on specific proprietary communication or controls;
- Construction contracts should include a complete set of maintenance and servicing tools and, say 2 years supply of normal consumables.

The designers shall confirm the types of HVAC available in the local area and where the service technicians are located. Having a local agent with a communication channel to the manufacturer (or an agent in a major city) will provide a first line of factory support and troubleshooting and may be able to source compatible replacement equipment in the future.

5.4.2.4 System Selection – Modular Design

The environments are particularly corrosive on most materials commonly used in HVAC components. Based on past evidence that despite the system designers' best efforts to select the best materials and the manufacturers best endeavors, it is likely that that HVAC equipment will have a relatively short life compared with other global locations.

Many of the construction projects will have adequate construction budgets but may not have adequate operational and maintenance budgets. These may not reflect the difference between the costs of parts and specialist staff visiting when compared with mainland installations. The projects are very unlikely to have mid-life updates scheduled into the building lives to upgrade controls systems, replace chillers or pumps based on age. It is likely that most buildings will operate on a run-it-until-it-fails approach. This means that equipment will need replacing relatively urgently, without the availability of direct factory substitution of parts.

Therefore, the system design should be as simple as possible with a minimum amount of proprietary or specialized interconnections. The design should allow various components to be changed as there become unserviceable. These replacement components could be from other manufacturers. So, it is important to document the key performance requirements (pump flows and pressures, air conditioner cooling sensible and latent performance, etc.).

The objective is to allow the maintenance staff to replace equipment with minimal effort and downtime, from an alternative supplier that provides very similar performance and functionality as the original part.

Therefore, a series of equipment modules with limited non-proprietary interfaces is preferred.

5.4.2.5 System Selection – Sustainable Design Strategies

The preceding sections support a design that appears to go against the current mainland HVAC codes relating to energy efficiency. Codes have evolved from initially "getting the fundamentals correct" to a current point where energy efficiency is the main design driver. As a result, the systems become complex with much monitoring and communication between the various components to further achieve those efficiency gains. Designs for the island areas must primarily operate and stay operational for as long as possible, even at the expense of highest efficiency. Basic efficiency should be inherent in the HVAC system selection and overall design.

When a building or space is selected to be air conditioned (cooled) then this triggers a significant approach to building design (not just the HVAC). When a space is selected to be cooled the following occurs.

- The space must be sealed as far as possible from the outside environment. Warm moist salt carrying air from outside will condense on cooler surfaces. With an outdoor air condition of 90°F DB and 80°F WB, the dew point is 77°F. Thus, any surfaces cooler than this will cause condensation to form along with salt.
- The building sealing should cover all construction joints.
- Realistically, no buildings are absolutely airtight, and the air tightness will reduce as the building ages. To counter this, excess conditioned outdoor air should be supplied to the space to ensure air flow through the gaps is outwards. This must occur even when the space is not occupied.

An initial system scoping should be completed to identify which spaces are fully air conditioned (with the consequential requirements listed above), and which spaces can be ventilated and not cooled. The latter requires much simpler HVAC equipment, but all equipment and fittings must be selected as if they are installed outside.

Life cycle cost analysis (LCCA) can be carried out to assess differing systems that all meet the corrosion and resilient design requirements. It is important that all the systems assessed are equal, or at least above the minimum level of system resilience, reliability and availability of spare parts or consumables. No specific LCCA software is recommended, however it is important that the assumptions on equipment life, costs, etc. are agreed by the team members and stakeholders.

Refrigerant selection based on primarily local availability and then on phase-out expectations.

Consider carbon dioxide sensors where it affects operating costs and prolongs the life of equipment. The control system should be programmed to default to an acceptable fallback strategy should the reading from the sensor be unavailable or out of range.

Do not use cooling towers as water supplies are generally limited and ambient relative humidity's are relatively high.

5.4.2.6 System Selection – DOAS

At a minimum, unit casing and coils should be precoated to provide greater resilience to the harsh environment and is recommended that the Dedicated Outdoor Air Systems (DOAS) should be used wherever possible, especially in larger buildings. This means that the design effort and monetary investment can be targeted at the systems that handle the hot humid and chloride containing air.

"In marine environments, the size of salt aerosol particles can vary widely based on proximity to the coast, wind speed, irradiation, and local air pollution, but salt aerosols typically range from 0.05-0.5 microns. MERV 14 and higher filters can be used to effectively reduce (not eliminate) the amount of salt being introduced into HVAC systems. This can extend the lifetime of HVAC systems by reducing corrosion associated with salt deposition on cooling coils, fans, casings, and other metallic equipment." Extract from "Guide for Resilient Energy Systems Design in Hot and Humid Climates" (US Army Corps of Engineers, 2022)

It is recommended that unit casing and cooling coils pass an ASTM B117 5000-hour salt spray test. For a tightly sealed building, most of the latent loads comes from outside air. A DOAS can cater for much of the sensible cooling loads in a well-insulated building with shaded windows. This results in the remainder of the HVAC system being smaller.

5.4.2.7 System Selection – Refrigerant versus Chilled Water

For smaller buildings, package split system or similar refrigerant systems are the logical system choice. For larger buildings, consideration should be given to central (or distributed) chilled water systems, where there are already similar systems in the area and there is a proven capacity to maintain and operate these systems. Chilled water systems can provide the following benefits.

- Design effort and monetary expenditure can be targeted at the air-cooled chiller as a critical component. It can be replaced at the end of its life with another unit (possibly from a different supplier) without changes to the remainder of the system.
- Larger buildings would also allow the co-location of main exhausts and heat recovery opportunities. Heat pipe heat recovery should be considered for systems with high outdoor air flow rates.
- When combined with a DOAS, the remainder of the air systems should experience a longer life. Generally, the equipment should be located within the air-conditioned building envelope to further prolong the equipment life.
- Energy transfer and transport (by chilled water) can utilize plastic pipework that will not corrode and is unaffected by imperfect pipe insulation and vapor barriers.
- For buildings where relative humidity control is critical (not comfort applications), the DOAS should provide air with a sufficiently low dewpoint to avoid the need for local fan coil units or air handlers needing to provide both temperature and humidity control which adds significantly to the system and control complexity. The DOAS may need to reheat some of the air for specialized applications where the dewpoint requirements are very low.
- Using chilled water fan coils in each space can also de-couple the outdoor air and building pressurization requirements from the space cooling requirements. VAV boxes may not allow this.
- Chilled water coils shall not be used alone on DOAS where the cooling load varies and the possibility of laminar flow occurring with the resulting reduction of latent capacity. Reheat using waste heat is an option. Alternatively direct expansion (DX) coils shall be used with suitable latent capacity control (hot gas reheat, digital compressor control, etc.)

In buildings where the DOAS is critical to the building operation, consideration should be given to a backup unit or spread the duty over multiple DOAS modules. The remoteness of some of these locations combined with a potentially restricted maintenance and/or replacement budget may lead to very long repair or replacement times.

In large buildings with reasonable domestic hot water loads, consideration could be given to using waste refrigerant heat for water preheating. Care should be taken to keep the system design simple. The system could be a small water-water chiller/heat pump to preheat the domestic water. This would work in parallel to the main chiller plant. The supplementary water heating system must be sized to cope with the waste heat from the chillers not being available. As with the design of most systems, the equipment modules should be as simple as possible and not be reliant on other modules.

5.4.2.8 System Selection - Equipment Location

External Equipment:

- Avoid the seaward side of the buildings where possible;
- Avoid the prevailing wind direction. Refer to Table 5-10

Internal Equipment:

- Avoid built-in equipment. All equipment, ductwork and pipework should all be accessible for inspection and replacement without major dismantling of the building.

All Equipment:

- Craneage is also generally limited – locate as much equipment at ground level wherever possible.

5.4.2.9 System Selection – Pipework

Consider PPR (Polypropylene Random Copolymer plastic) pipework, where permitted by codes, in place of carbon steel pipework. This avoids external corrosion issues especially for chilled water systems where condensation will be a major issue; irrespective of how well the vapor barriers are initially installed. Maintenance activities may not fully reinstate the vapor barrier.

Stainless steel cladding or jacketing shall be provided in external locations or in mechanical rooms.

If underground piping is selected as the most suitable for transporting heat between buildings, then pre-insulated piping is preferred over site fabricated to minimize workmanship issues. In general, above ground pipework is preferred as is it less susceptible to physical damage and ease of access for inspection and maintenance.

5.4.3 Best Practices

This section provides some best practices and, in some cases, mandatory requirements (to maximize the longevity of the systems). As stated at the start of this section, it is assumed that the reader is an experienced HVAC designer.

5.4.3.1 Best Practices – Building Air Tightness

In air-conditioned buildings, achieving a high level of air tightness is important to avoid condensation on indoor surfaces and to control the indoor moisture content and therefore minimize mold growth. Two steps are important:

- Detailing and specifying construction details to provide air tightness; adopting building air tightness (0.15 cfm/ft² at 75Pa) to reduce energy consumption, increase resilience and reduce the risk of mold.
- Specifying the compliance tests to be achieved during construction. The actions needed must be specified if the tests do not show compliance (remediation and subsequent air tightness re-testing until the required performance is achieved).

5.4.3.2 Best Practices – Detailed Material Selection

The warm, moist environment combined with chlorides from the salt combines to create a highly corrosive environment to steel and aluminum commonly used in HVAC systems. Wherever possible choose materials that are inherently inert to this environment such as plastics.

- Condensate trays and drains shall be selected to account for salt from the air entering the condensate tray and drains. Select appropriate materials for this duty.
- Avoid galvanized ducting wherever possible, especially outdoors.
- Fasteners shall be selected to avoid galvanic corrosion.
- If selecting metal, 316, 316L stainless steel, or marine grade aluminum (5052, 5083, 6061.) shall be used. Note that 304 stainless steel is not a substitute for 316 stainless steels.
- The usage of outside ductwork should be minimized. Where installed it shall be fabricated from corrosion resistant material as indicated in Section 5.1 (stainless steel, PVC or fiberglass, and with UV protection where needed for longevity.)

5.4.3.3 Best Practices – Control Systems and Occupancy

- To avoid internal condensation and salt ingress, keep the buildings slightly pressurized even outside normal occupancy periods.
- The amount of controls automation and communication between various HVAC components needs to be carefully considered. Wherever possible, this should be limited to industry standard communications methods (for example BACnet) and data transfer (simple setpoint resetting). The key requirement is to allow the system to continue operation when one item has been replaced with a very similar unit from a different manufacturer.
- All control strategies that rely on communicated information must be provided with an automatic workable backup strategy should the communicated data not be available.

5.4.3.4 Best Practices – Mandatory Documentation

- Provide full operating and maintenance manuals for all equipment. Include all manufacturers IOM (Installation, Operating and Maintenance), Material Safety Datasheets, Troubleshooting guides etc.
- Performance requirements air flow rates, cooling capacities etc. shall be clearly identified to aid future equipment replacements.
- As-built drawings shall be provided.

5.4.3.5 Best Practices – Commissioning

- Detailed commissioning requirements must be specified. These can be done by an independent organization.
- Building air tightness testing should be specified including repeated testing until compliance.

5.4.3.6 Best Practices – Spare Parts and Consumables

- Any specialized tools for maintenance or troubleshooting should be included in the project scope.
- At least 2 years or regular consumables should be included in the project scope.

5.4.3.7 Miscellaneous Items

- Transported equipment must be sealed to avoid internal corrosion. Storage warehousing is limited on most sites, so transported equipment needs to be weatherproof, and UV protected.

Key Strategies for Sustainable Mechanical Design in the Tropics

1. Ambient Design Conditions

- Designers should refer to the ASHRAE Climatic Design Information.
- Relative humidity is approximately 65%.
- Average daily temperature ranges during the hottest months are in the range of 7-10°F.

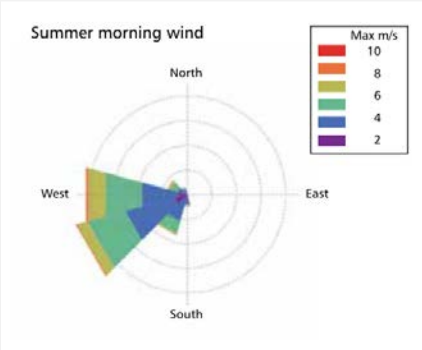
Corrosion on HVAC equipment located at seaward side of the building

2. Location Factors

- Local skilled workforce (for operations and maintenance tasks) is limited.
- All significant materials must be imported on a project-by-project basis.
- Craneage is generally limited particularly for future maintenance.

3. Resilient System Design

- The designers shall specify types of HVAC that are locally available with local service technicians.
- Avoid the seaward side of the buildings and prevailing wind directions where possible.
- Design conditions shall be selected appropriate for the building occupant needs.
- Select equipment locations that can be maintained with the facilities normally available locally.
- Use modular designs wherever possible.
- Avoid complex interlinked systems.
- Refrigerant selection shall be based on local availability and phase-out expectations.
- Do not use cooling towers as water supplies are generally limited and ambient relative humidity is relatively high.
- Dedicated Outdoor Air Systems (DOAS) should be used wherever possible, especially in larger buildings.



Understand the predominant wind direction and shelter the key equipment from this.

Taken from CIBSE TM04 2017 Building for Extreme Environments – Tropical

4. Refrigerant versus Chilled Water

- For small buildings package split system or similar refrigerant systems are preferred.
- For large buildings consider central (or distributed) chilled water systems, particularly where there are already systems in the area.
- Energy transfer and transport (by chilled water) can utilize plastic pipework that will not corrode.
- For buildings where relative humidity control is critical the DOAS should provide air with a sufficiently low dewpoint to avoid the need for local fan coil units or air handlers.
- In buildings where the DOAS is critical to the building operation, consider a backup unit.
- In large buildings with reasonable domestic hot water loads, consideration could be given to using waste refrigerant heat for water preheating.

Key Strategies for Sustainable Mechanical Design in the Tropics

5. Pipework

- Consider PPR (Polypropylene Random Copolymer plastic) pipework where permitted by codes in place of carbon steel pipework.

6. Building Air Tightness

- Detail and specify construction details to provide air tightness.
- Specify the compliance tests to be achieved during construction.

7. Detailed Material Selection

- Wherever possible select materials that are inherently inert in the coastal marine environment.
- Avoid galvanized ducting.
- Fasteners shall be selected to avoid galvanic corrosion.

8. Control Systems and Occupancy

- Keep buildings slightly pressurized to avoid internal condensation and salt ingress.
- All control strategies that rely on communicated information must be provided with an automatic workable backup strategy.

9. Documentation

- Operating and maintenance manuals shall be provided for all equipment. Clearly identify performance requirements for all equipment.
- As-built drawings shall be provided.

10. Commissioning

- Detailed commissioning requirements must be specified.

11. Spare Parts and Consumables

- Spare parts and equipment spares are rarely held locally.
- Any specialized tools for maintenance or troubleshooting should be included in the project scope.
- At least 2 years of regular consumables should be included in the project scope.

All cold water or refrigerant pipes must be insulated to avoid condensation and degradation of pipework.
Picture taken from Assessment of Health Cre Infrastructure and Services, Appendix F, Mechanical LBJ TMC, American Samoa.

5.5 Plumbing

5.5.1 System Selection

5.5.1.1 System Selection – Location Factors

The location of many of the island areas also means that systems need to be carefully designed to ensure a long operating life. The key factors to be aware of are:

- A skilled workforce (for operations and maintenance tasks) is limited. This is mainly due to the low population on the islands.
- The low population also means that spare parts and equipment spares are rarely held locally. Those parts that are held would typically be for plumbing components typically found in residential houses and complexes.
- The factors above may result in less efficient but locally available systems being proposed. These must be discussed in the Basis of Design document and agreed by the stakeholders.
- Some locations, especially in the RMI, utilize dual water systems with fresh water for drinking and washing and sea water for toilets and waste.
- The mineral content in potable water varies widely throughout the regions. Some islands rely on rainwater, which is highly corrosive while others use groundwater which may be high in carbonates. The designer must enquire about the water quality to specify appropriate fixtures and fittings.

5.5.1.2 System Selection – Resilient System Design

For the reasons above, the Plumbing systems must be designed primarily for a long operating life through:

- Selection of materials that will last in the aggressive environment.
- Selection of the equipment locations that can be maintained with the facilities normally available (limited specialist tools, limited craneage, limited proprietary equipment skills and long periods between diagnosing a faulty part and receiving a replacement one.
- Smaller multiple system modules or sub-systems that better match other systems on the island. Refer to the next section for a wider discussion.
- Avoidance of complex interlinked systems that are reliant on the whole system operating or on specific proprietary communication or controls.
- Construction contracts should include a complete set of maintenance and servicing tools and, say 2 years supply of normal consumables.

5.5.1.3 System Selection – Smaller Modular Design

In a large building project, it may be desirable to break down the water systems, and hot water systems to a series of smaller sub-systems. These systems may not have the efficiency benefits of larger, more complex, and sophisticated ones, but the simplicity may result in a longer operational life.

If possible, the size of the individual hot water sub-systems should reflect the size and scale of buildings elsewhere in the locality (probably larger residential complexes or small commercial buildings). This provides an increased overlap of spare parts and components or replacement equipment (of different brands).

Therefore, the system design should be as simple as possible with a minimum amount of proprietary or specialized interconnections. The design should allow various components to be changed as they become unserviceable. These replacement components could be from other manufacturers. Therefore, it is important to document the key performance requirements (pump flows and pressures, electric element capacities, etc.).

The objective is to allow the maintenance staff to replace equipment with minimal effort and downtime, from an alternative supplier that provides very similar performance and functionality as the original part.

5.5.1.4 System Selection – Sustainable Design Strategies

All seven island areas are near the equator and have a high number of annual sunshine hours. In addition, there is very little difference between summer and winter. Therefore, solar heated hot water is very beneficial to minimizing supplementary heating energy costs. Refer to the latest ASHRAE weather guides for solar radiation. But as a guide, the average daily all sky solar radiation varies from 1,400-1,900 Btu/ft^2 by month to 1,600-2,100 Btu/ft^2 depending on the Island Area. Refer to the section below on solar water heating for more detail.

Because of the high availability of solar water heating, consideration can be given to high temperature disinfection cycle rather than UV lamps.

For smaller projects with limited water demand, electrically heated storage heaters or point-of-use may be more appropriate. The rationale for system selection is to be discussed in the Basis of Design document.

5.5.1.5 System Selection – Service Water Heating

The suggested general approach to service water heating has been outlined in the preceding sections; use solar water heating where practicable and provide multiple smaller systems that reflect the scale of other installations in the area.

The primary heating source should be solar with electrical elements for backup and boosting during disinfection cycles. As a result, on-demand or tankless water heaters are not suitable. Storage capacities are to be sized to cater for the water usage overnight (when solar energy is unavailable). The electric heating elements also need to be sized for a significant loss of solar heating. For smaller systems it may be practical to provide 100% electric backup to solar. Larger systems may have a lower level of backup.

Another less obvious advantage of separate groups of heaters serving different areas, is that a failure stops service to that area and maintenance staff will be alerted by the occupants. The loss of service will also hasten repairs. A partial failure in a large system may go unnoticed for a long period and then may not be repaired with urgency.

Solar heating panels should be installed in groups with separate outdoor supporting frames and pipework. This ensures that any panel failures of partial damage during storms do not affect the entire system. After a major storm event, having basic sanitation facilities cannot be overstated. Separate groups of panels will allow individual assemblies to be replaced during the life of the building.

The high availability of solar heating energy means that dissipating excess heat needs to be carefully considered. Potable water supplies are generally limited, so draining off excess hot water is not acceptable. A variety of systems are possible such as using and intermediate fluid with drain back on high temperature or nighttime cooling using the panels. Careful consideration of steam-based approaches is needed from a health and safety perspective. During the life of the building, the systems may be maintained by personnel unfamiliar with systems used in mainland areas and are not aware of the safety issues.

The frequency of storms mean that every construction project should include spare solar collector panels, frames and other external components that are at risk of storm damage.

5.5.1.6 System Selection - Equipment Location

External Equipment:

- Avoid the seaward side of the buildings where possible. This also reduces salt build up on solar panels;
- Avoid the prevailing wind direction. Refer to Table 5-10 (in section 5.4.2.1).

Internal Equipment:

- Avoid built-in equipment. All equipment and pipework should all be accessible for inspection and replacement without major dismantling of the building.

All Equipment:

- Craneage is also generally limited – locate as much equipment at ground level wherever possible.

5.5.1.7 System Selection – Pipework

As the environment is very corrosive consider plastic pipes for water services. Care is needed in hot service water heating systems where solar water heating is used as the high availability of solar heat means that overheating can be a regular occurrence so the pipework selection must be suitable for the temperature protective measures employed. These measures must be reliable and preferably fail to a safe condition. Regular and skilled maintenance cannot be relied upon over the entire life of the building.

5.5.2 Best Practices

This section provides some best practices. As stated at the start of this section, it is assumed that the reader is an experienced Plumbing designer.

5.5.2.1 Best Practices – Cold Water Storage Tanks

Where (smaller) water storage tanks are provided on a project, these should be installed indoors to minimize solar gain and minimize possible damage from cyclones and wind. However, the tanks must still be able to be removed and replaced without major building works.

Tanks should be provided with insect proof vents and overflows. Inspection openings in the top should be provided to allow the tank and water condition to be regularly checked. Provide a ladder and access platform if needed. Tanks shall have seismic restraints.

5.5.2.2 Best Practices – Detailed Material Selection

The warm moist environment combined with chlorides from the salt combines to create a highly corrosive environment to steel and aluminum commonly used on external surfaces of plant and equipment. Wherever possible choose materials that are inherently inert to this environment such as plastics.

- Choose fasteners carefully to avoid galvanic corrosion.
- 316 or 316L stainless steel and marine grade aluminum (5052, 5083, 6061.) are preferred metals. Note that 304 stainless steel is not a substitute for 316 stainless steels.

5.5.2.3 Best Practices – Equipment Standardization

- To minimize the number of spare parts to be held and to simplify the ordering of replacement parts, the type of different models of equipment should be reduced to a minimum. It is acknowledged that this may result in some items being oversized, which is acceptable provided performance and operation is not affected.

5.5.2.4 Best Practices – Pipework Jointing and Location

- Equipment connections should have flanged or screwed connections. Any item that requires pipework dismantling for equipment replacement should have reusable joints. Proprietary connections requiring specialized tools should be avoided as it is likely that those specialized tools will not be available in the locality after the construction project has been completed. This does not prevent using proprietary permanent pipe jointing in distribution pipework through the building where the pipework is not expected to change over the life of the building or require removal for maintenance.

5.5.2.5 Best Practices – Water Supply Pipework Isolation Valves

- Provide sufficient isolating valves throughout the pipe distribution system to allow areas to be isolated and equipment maintained without shutting down the entire system.
- Provide stainless steel flexible hoses and isolating valves on lavatory cisterns, sinks and basins to allow maintenance tasks to be carried out quickly and entire units to be simply replaced with slightly different models during the life of the building.

5.5.2.6 Best Practices – Water Conservation

- Low-flow and other water-efficient shower heads, toilets and hand wash basins should be selected to minimize water use while providing acceptable service for users. Water supplies are limited in most, if not all, of the seven island areas covered under this Guide. Refer to the International Plumbing Code for maximum water consumption rates.

5.5.2.7 Best Practices – Documentation

- Provide full operating and maintenance manuals for all equipment. Include all manufacturers IOM (Installation, Operating and Maintenance), Material Safety Datasheets, Troubleshooting guides etc.
- Performance requirements: heating capacities, pump duties, etc. must be clearly identified to aid future equipment replacements.
- As-built drawings should be provided.

5.5.2.8 Best Practices – Maintenance Signage

- Strainers and water filters must be able to be cleaned easily. Provide signs above each with the suggested cleaning frequency. Visible signs are more likely to prompt maintenance, than schedules written in the maintenance manuals. These manuals are often filed away in an office and only referred to when there is a problem.

Figure 5-12: Sample signage beside equipment to prompt maintenance tasks

- Any specialized tools should be included in the project scope.
- At least 2 years or regular consumables should be included in the project scope.
- Additional solar panels, tubes and support frames should be included as spares to assist when equipment is damaged in storms.

5.5.2.9 Best Practices – Buried Pipework

- Ensure that minimum cover over buried pipes is stated on the drawings and constructed to achieve this.

5.5.2.10 Best Practices – Floor Drain Priming

- Provide floor drain taps to charge floor drains when required. Provide these is a location where it can also be used for floor washing and other cleaning tasks.

5.5.2.11 Best Practices – Insulation of Water Supply Pipework

- Hot water pipework shall be insulated to reduce heat losses.
- Cold water pipework shall be insulated to prevent condensation unless it can be demonstrated that condensation will not occur. With an outdoor air condition of 90°F DB and 80°F WB, the dew point is 77°F. Thus, any surfaces cooler than this will cause condensation to form.

5.5.2.12 Miscellaneous Items

- Transported equipment must be sealed to avoid internal corrosion. Storage warehousing is limited on most sites, so transported equipment needs to be weatherproof, and UV protected.

Key Strategies for Plumbing design in the Tropics

1. Location Factors

- Local skilled workforce (for operations and maintenance tasks) is limited.
- Spare parts are rarely held locally.

2. Resilient System Design

- Select materials that will last in the aggressive coastal environment.
- Select equipment locations that can be maintained with the facilities normally available locally.
- Avoid complex interlinked systems that are reliant on the whole system operating. Consider multiple small systems that match other systems on the island.
- Any specialized tools should be included in the project scope.
- At least 2 years of spares and regular consumables should be included in the project scope.
- Avoid the seaward side of the buildings and prevailing wind directions where possible for external equipment.
- Avoid built in internal equipment.
- Use plastic pipes for water services where possible.

3. Service Water Heating

- Primary heating source should be solar with electrical elements for backup and boosting.
- Install solar heating panels in groups so that partial damage during a storm does not affect the entire system.
- Careful consideration needs to be given to dissipation of excess heat.
- Consider the risk of overheating of pipework in hot water service when selecting materials.
- Hot water pipework shall be insulated to reduce heat losses.

4. Cold Water Storage Tanks

- Small water storage tanks where specified should be installed indoors.
- Tanks shall be provided with the following:
    - Insect proof vents and overflows
    - Inspection openings on the top
    - Ladder and access platform if needed
    - Seismic restraints
- Cold water pipework shall be insulated to prevent condensation unless it can be demonstrated that condensation will not occur.

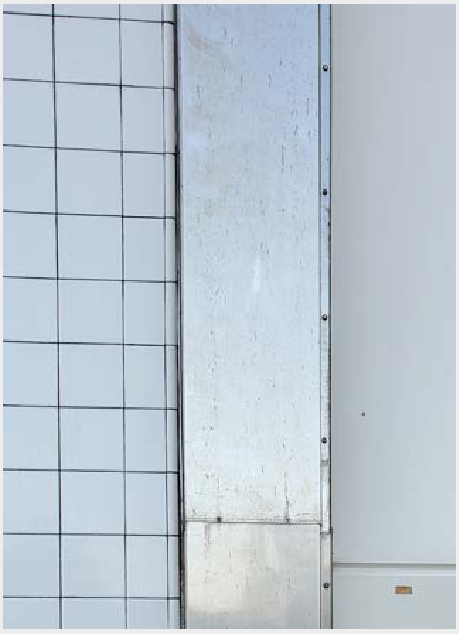
5. Detailed Material Selection

- Fasteners shall be selected to avoid galvanic corrosion.
- 316 or 316L stainless steel and marine grade aluminum (5052, 5083, 6061.) are preferred metals.

6. Equipment Standardization

- Different models of equipment shall be reduced to a minimum to minimize spare parts.

7. Pipework Jointing and Location



30-year-old 316 Stainless steel faring well in tropical conditions.

<table>
<tr><th colspan="2">Key Strategies for Plumbing design in the Tropics</th></tr>
<tr><td>

- Equipment connections shall be flanged or screwed connections.
- Avoid proprietary connections that require specialized

</td><td rowspan="4">

All cold-water pipes must be insulated to avoid condensation and degradation of pipework.

</td></tr>
<tr><td>

8. Water Supply Pipework Isolation Valves

- Provide sufficient isolation valves throughout the system to allow local areas to be isolated for maintenance.
- Provide stainless steel flexible hoses and isolation valve on lavatory cisterns, sinks and basins to allow maintenance.

</td></tr>
<tr><td>

9. Water Conservation

- Shower heads, lavatories and wash hand basins should be selected to minimize water use. Refer to the International Plumbing Code for maximum water consumption rates.

</td></tr>
<tr><td>

10. Documentation

- Operating and maintenance manuals shall be provided for all equipment. Clearly identify performance requirements for all equipment.
- As-built drawings shall be provided.

</td></tr>
</table>

5.6 Electrical

5.6.1 Design Approach

Important Note: This Guide is intended for experienced Electrical Engineers as an informative document to provide background as to the most suitable approaches and tips for designing installations in island areas. It assumes that the reader is familiar with general Electrical design especially those in more temperate and less aggressive environments.

Projects which include demolition and disposal of existing electrical equipment shall include verification if the equipment contains polychlorinated biphenyl (PCB) dielectric fluid or contamination. PCB contaminated fluids and devices shall be specified to be handled and disposed of in accordance with the local regulations.

Refer to section 2 for an overview of the design process. This provides references to the standards and regulations in each Island Area, and what codes are suggested to supplement these where needed.

Section 2 provides an initial scoping and performance objective identification for the project.

Section 4.1 provides an overview of key initial decisions in the project (for example how to cope with rising sea water levels, and what materials are appropriate for the local environment).

The following sections describe the remaining stages of the design process. There are:

- High-level design decisions relating to system and material selection.
- Best practices and design tips to aid the more detailed parts of the design to help ensure it is compatible with the local environment, construction, and maintenance conditions.
- Where possible you are encouraged to fulfill full compliance in accordance with the NFPA 70, National Electrical Code (NEC), the National Electric Safety Code (NESC).
- The design of electrical equipment should be in accordance with the designer's regional standards (UL, NRTL, etc.) and codes (NEC, etc.).
- Power system calculations, studies and drawings shall be prepared under the supervision of a United States registered professional electrical engineer.

5.6.2 System Selection

This section provides guidance on the initial design selections for the system and overall system design approach.

5.6.2.1 System Selections – General Electrical Equipment

New equipment shall be fully compatible with existing on-site equipment to the extent possible.

- If photovoltaic or other alternative energy source is to be included in the facility, the designer shall begin coordination with the local electric utility at the beginning of design. Requirements for interconnection or impact studies and permitting vary by jurisdiction and may cause delays.
- All raceways, fittings, enclosures (junction or pull boxes, safety switches, panelboards, motor starters, circuit breakers, etc.), and other equipment enclosures installed on the exterior of buildings, otherwise exposed to the weather, or located indoors and subjected to condensing humidity shall be listed as NEMA 4X and constructed of Type 316 stainless steel, UV-resistant PVC, UV-resistant fiberglass, or other approved material.
- Provide surge protective device with visual indicators at the service entrance of each building, downstream of each transformer feeding a panelboard, and as required by the IBC. Maximum lead length shall be 12 inches.
- Provide a test portal with voltage indicators downstream of the service entrance disconnect of each building to allow for a preliminary verification of the absence of voltage before performing the code required test of the conductors or busses with portable test instruments.
- Thermal magnetic type circuit breakers shall be used instead of fused switches for feeder or branch circuits to minimize stocking of spare fuses and increase personnel safety.
- Raceways containing only grounding or ground bonding conductors shall not be metallic which creates an impedance choke during fault current conditions.
- Where PVC or RMC conduit is stubbed up from a concrete encasement, provide a plastic-coated RMC elbow and section.
- Conduit shall emerge from the concrete in a direction perpendicular to the surface whenever possible. The portion of the conduit that emerges from the concrete is subject to accelerated corrosion. The interior corners of elbows are subject to damage as the wires are pulled through.

- For all exterior buried conduits and duct banks, provide continuous lengths of underground warning tapes located 12 inches below grade, above and parallel to the duct banks. Provide tape consisting of not less than 3-inch-wide red polyethylene film, imprinted with "CAUTION - ELECTRIC UTILITIES BELOW" with a non-ferrous metal foil conductor sandwiched in the tape for detection purposes.

5.6.2.2 System Selections - Lighting Systems

Lighting system calculations, studies and drawings shall be prepared under the supervision of a United States registered professional electrical engineer.

All light fixtures shall be energy efficient, low-maintenance, self-contained type with highly efficient, high brightness light emitting diode (LED) arrays, suitable for installation in various facilities areas.

All luminaires shall be UL/NRTL listed for the intended application and have the necessary certifications related to intended installation.

Where panelboard or branch circuit surge protective devices cannot be installed provide all LED light fixtures with a surge protection module.

5.6.2.3 System Selections - Telecommunications Systems

Protect fiber optic cable strands by using patch panels, etc. that full enclose the cables, and not open racks. Similarly provide enclosures for telephone punch blocks, etc. rather than open boards.

5.6.3 Best Practices

This section provides some best practices. As stated at the start of this section, it is assumed that the reader is an experienced Electrical designer.

5.6.3.1 Best Practices – General Electrical Equipment

- Where the electrical distribution system for a facility is being renovated, upgraded or is being provided new, provisions shall be made for the future additions of renewable energy systems such as solar photovoltaic or wind power systems.
- Main switchboards should be placed within conditioned spaces to minimize the effects of high humidity and salt on the breakers and busbars.
- Where possible use a stand-alone circuit breaker enclosure for the service entrance device as this allows the downstream transfer switch or main distribution panel to be completely de-energized for maintenance
- Balance loads on panelboards, etc. to the extent possible to minimize current and voltage imbalance which reduces motor and generator life.
- Provide isolation or mitigation for significant non-linear loads in the branch or feeder circuit to minimize impacts on the rest of the system. For systems with many smaller non-linear loads that create a significant impact a system-wide solution should be implemented such as use of active harmonic filter(s) at the buss level.
- Where Variable Frequency Drive (VFD) bypasses are installed ensure that the load equipment is provided with a means to throttle the output where needed for operational needs. Ensure equipment and process safety systems account for both Uninterrupted Power Supply (UPS) and non-UPS operation.

Figure 5-13: Condensation in fire alarm caused by improper sealing of enclosure

- Check that the transformer specifications limit the acceptable impedance to a range that is suitable to the intended usage. If vendors supply unusually low impedance transformers, they will allow high downstream fault current which can exceed the rating of the downstream equipment. If the transformer upstream of large motors has too high of an impedance the motors may have difficulty starting, depending on the driven equipment.
- Verify with maintenance staff requirements/desire for optional safety switches near motors where not required by Code. If the upstream starter is not properly tagged out, unintended closing of the switch can present a hazard to workers.
- All raceway penetrations to the building envelope need to be detailed to prevent insects/rodents etc. from entering via the electrical system and allow drainage of wind driven rain. Openings to the exterior of the building should also be designed to prevent insects, rodents, etc. from entering through the conduits. Duct

sealant and geometry can prevent or minimize water intrusion. It is recommended that all raceways entering buildings be duct sealed, whether used or not. A box or fitting should be installed immediately on the interior with a drain hole or device, and the cables should not exit to the building interior via the bottom of the box or fitting. A bad example would be to route raceways out the top of a panelboard, up the wall and then directly through an exterior wall.

- Do not provide multiple voltage outlets in a facility unless specifically requested (110V and 220V adjacent each other). If this is required, provide permanent engraved labels on receptacles nameplates.

5.6.3.2 Best Practices - Emergency Power Back-Up

- Automatic transfer switches (ATSs) should have a Withstand/Closing Rating (WCR) based on a specific time duration and not on a specific upstream over-current protective device (OCPD) trip. Specific OCPD requirements can create conflicts coordinating with other branch OCPDs in their branch as required by NEC.
- All UPSs shall ride through prolonged voltage sags (brown outs) without the need to switch to the battery. UPSs for critical equipment should at a minimum be the double conversion type, have zero transfer time and continuously filter incoming and outgoing power.
- Specifying standby or emergency power systems as a performance-based package system that allows use of parallel generators in lieu of a single large generator allows the contractor and suppliers more flexibility during the bidding process. Some modern generators can be provided with controllers and circuit breakers that allow them to directly parallel with each other without the need for expensive paralleling switchgear.
- Permanently installed load banks are recommended for all new diesel generator systems and retrofits. It is preferrable that the load bank controls automatically connect and disconnect it to the generator based on the generator operating mode so that it is exercised with sufficient load.
- ATSs shall monitor all phases of the normal and emergency source power. Monitoring of a single phase of either source does not provide protection from problems with a single phase.

5.6.3.3 Best Practices - Lighting Systems

- Clearly mark light fixtures, in a location not visible after installation, with manufacturer's name and catalog number, voltage, acceptable lamp type (where applicable), and maximum wattage.
- Specifying lighting systems as a performance-based package that allows use of differing technologies and controls to achieve the desired results in lieu of a specification written around a single technology allows the contractor and suppliers more flexibility during the bidding process.
- All exterior light fixtures shall have corrosion resistant housings and hardware (e.g., type 316 stainless steel).
- Practical example: For medical facilities – where special luminaires are difficult to procure, it is recommended to use standard LED luminaires in majority of the spaces. Provision of medical grade luminaires is only required in operating theatres and examinations rooms.

5.6.3.4 Best Practices - Telecommunication Services

- Locate telecommunications equipment in a separate, lockable room from the normal electrical distribution equipment in accordance with ANSI/TIA standards.
- Early in the design, verify the number and size of rooms for telecommunications equipment, CATV, CCTV, fire alarm and electronic security systems, etc. as they may or may not be collocated in the same room.

5.6.3.5 Best Practices - Detailed Material Selection

- The warm moist environment combined with chlorides from the salt combines to create a highly corrosive environment to steel and aluminum commonly used in electrical systems. Wherever possible choose materials that are inherently inert to this environment such as plastics and fiber reinforced plastics.
- All raceways, fittings, enclosures (e.g., junction or pull boxes, safety switches, panelboards, motor starters, circuit breakers, etc.), and other equipment enclosures installed on the exterior of buildings, otherwise exposed to the weather, or located indoors and subjected to condensing humidity shall be listed as NEMA 4X and constructed of Type 316 stainless steel, UV-resistant PVC, UV-resistant fiberglass, or other approved material.

5.6.3.6 Best Practices - Control Systems and Occupancy

- Simple automation systems are the best. Where possible, limit or provide manual override of system automation. Lighting control systems that rely on daylight sensors, etc. should be able to switch to a clock driven mode if the sensors fail.
- Control panels and control systems should be designed to eliminate or minimize worker exposure to OSHA defined high voltages (50 volts or more, AC or DC) during routine maintenance, troubleshooting and testing. Methods can include separation of power distribution and control components by barriers or use of separate enclosures.

- Ensure equipment and system controls account for component/device failures and allow operators to keep systems running even if in a less efficient/precise mode. Control system programming particularly allows fully automatic systems to automatically switch to a lesser semi-automatic mode, and then if additional component/devices fail to switch automatically to a manual mode. If automatic mode switching is unsafe or impractical, allow the operator to manually select a non-automatic mode of operation.

5.6.3.7 Best Practices – Documentation

As-built drawings should be provided in electronic pdf and native file format of the appropriate Computer Aided Design (CAD) software files with the following completed:

- Single line diagrams for the entire system (in CAD format);
- Design documents shall be prepared in U.S. Standard units;
- Calculations of available short circuit currents at transformers, panel boards and circuit breakers;
- Loads on all transformers and feeders;
- Voltage drops on secondary service, feeders and branch circuits;
- Cable reticulation containment drawings.

Provide full operating and maintenance manuals for all equipment. Include all manufacturers IOM (Installation, Operating and Maintenance), Material Safety Datasheets, Troubleshooting guides etc.

5.6.3.8 Best Practices – Commissioning

- Ensure the Commissioning Plan submittal is reviewed by everyone who will participate in or sign off on the paperwork.
- Ensure the testing procedures include checking the system operation and functionality when sensors and other components fail.

5.6.3.9 Best Practices – Spare Parts and Consumables

- Adjust quantities listed in bid specifications to match packaging sizes and recommendations from the equipment manufacturers. For generic light fittings, sensors, receptacles etc., it is preferrable and economical to have units as on the shelf spares as it is unlikely that they can be field repaired.
- Ensure that spares are provided for optional accessories, communications cards, etc. for power and control equipment.

Key Strategies for Electrical Design in the Tropics

1. Code Compliances

- Where possible you are encouraged to fulfil full compliance in accordance with the NFPA 70, National Electrical Code (NEC), the National Electric Safety Code (NESC).
- The design of electrical equipment should be in accordance with the Area's regional standards (UL, NRTL, etc.) and codes (NEC, etc.).
- Power system calculations, studies and drawings shall be prepared under the supervision of a United States registered professional electrical engineer.

2. General Electrical Equipment

- New equipment to be fully compatible with existing on-site equipment as possible.
- All exterior raceways, fittings, enclosures shall be listed as NEMA 4X and constructed of Type 316 stainless steel, UV-resistant fiberglass.
- Provide provisions for renewable energy systems - solar photovoltaic or wind power systems at every opportunity.
- Balance loads on panel boards.
- Provide surge protective device with visual indicators.

3. Emergency Back-Up

- ATSs to have WCR based on specific time duration.
- All UPSs to ride through prolonged brown outs without need to switch to battery.
- Specify standby/emergency power systems as a performance-based package system – allows use of parallel generators.

4. Lighting Systems

- Specify performance-based package that allows flexibility of differing technologies and product procurement.
- All light fixtures to be energy-efficient, low-maintenance, self-contained type with highly efficient LED arrays.
- All exterior light fixtures shall have corrosion resistant housings and hardware, type 316 stainless steel, etc.
- Practical example: For medical facilities – where supply of equipment is scarce, it is recommended to use standard LED fittings in majority of the spaces. Provision of medical grade fittings is only required in operating theatres and examination rooms.

5. Telecommunication Systems

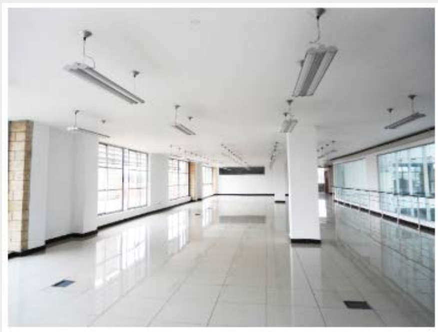
- Protective fiber optic cables by using patch panels that fully enclose the cables and not open racks.
- Locate comms equipment in a separate lockable room to electrical equipment.

6. Controls and Occupancy

- Design with simple automation systems. Where possible, limit or provide manual override of system automation.
- Lighting control systems that rely on sensors should be able to switch to clock drive mode if sensors fail.

NEMA 4X for exterior receptacles

Photovoltaic arrays on building roof



Light color interior finishes to enhance daylight

Key Strategies for Electrical Design in the Tropics	
• Control panel and control systems should be designed to eliminate worker exposure to high voltages (50V or more, AC or DC) during routine maintenance, troubleshooting and testing.	 *Temporary Diesel Generator* Taken from Appendix C, Electrical LBJ TMC,
7. Documentation • As-builts drawings in electronic pdf and native format (of the appropriate CAD software). • Single line diagrams for the entire system. • Design documentation in U.S. Standard units of measure. panel boards and circuit breakers. • Voltage drops on secondary services, feeders, and branch • O&M Manuals for all equipment and include all manufacturers' datasheets for specific installed equipment.	
8. Commissioning • Ensure commissioning plan submittal is reviewed by everyone who will sign off paperwork. • Ensure the testing procedures include checking the system operation and functionality when sensors and other components fail.	
9. Spare Parts and Consumables • Have commonly used light fittings, sensors, and receptacles as 'on the shelf' spares.	

5.7 Fire Protection

Fire protection systems shall be designed stamped, signed, and installed in accordance with Section 9 of the IBC.

It is recommended that the Designer engages with the local fire authority (or similar) to ensure the protection system is compatible with local jurisdictional requirements. Note that in some areas there is no fire authority.

The designer may also find additional guidance in Fire Protection Engineering for Facilities UFC.

Selection of materials shall be based on the following considerations:

- Life Cycle Cost Analysis;
- Maintainability and availability of spare parts due to the installation's remote location;
- Corrosion control due to the island's extreme corrosive environment.

Figure 5-14: Cyclone Corroded fire protection system. Taken from Guam School Assessment, USACE, 2021

5.7.1 Best Practices

Pre-Action fire suppression systems should not be installed due to their high upfront design/install cost, high maintenance cost, and high failure rate.

Consider the use of curb boxed gate valves with T-handles in lieu of fire suppression post indicator valves (PIVs). PIVs are prone to premature failure due to the highly corrosive atmosphere.

Main (2-inch dia.) drains and inspector test connection valve drains should be provided within the building / structure. No fire sprinkler drains should be on the exterior of the building/ structure. Adequate floor drains should be sized and provided for all fire sprinkler drains (e.g., main drains, auxiliary drains, test drains).

Fire Department Connections (FDCs) should be properly sleeved and coated with mastic upon installation. FDCs are to be provided with 2½-inch brass plugs. Plastic FDC caps are not to be used.

All wet pipe fire sprinkler risers require system side FDCs. FDCs are not to be connected to supply side of systems, FDCs are not to supply multiple structures without appropriate signage indicating such design basis.

When automatic sprinkler protection is required, a wet pipe sprinkler system is to be provided, unless environmental concerns indicate otherwise. Wet pipe sprinkler systems provide superior protection with little maintenance.

All fire sprinkler risers and associated equipment including backflow preventers should be installed in conditioned areas to the greatest extent possible to prevent accelerated corrosion on fire sprinkler riser components.

Canopy construction should feature only non-combustible materials.

Fire sprinkler heads should be corrosion resistance Electroless Nickel (ENT) Polytetrafluoroethylene (PTFE) plated.

At minimum, fire alarm system shall consist of 120-volt smoke and/or heat detectors installed in public spaces.

Avoid extension of all fire alarm and fire sprinkler components outside air-conditioned spaces, to the extent allowable by code requirements.

Fire alarm or fire sprinkler devices should be installed on the interior of structures due to the extreme corrosion issues in most island areas.

5.7.2 Required Standards

Subject to project requirements and specific local conditions, standards applicable to the design of fire protection systems may include: * International Building Code (IBC)

- NFPA 3 Standard for Commissioning of Fire Protection and Life Safety Systems
- NFPA 4 Standard for Integrated Fire Protection and Life Safety System Testing
- NFPA 13 Standard for the Installation of Sprinkler Systems

- NFPA 14 Standard for the Installation of Standpipe and Hose Systems
- NFPA 15 Standard for Water Spray Fixed Systems for Fire Protection
- NFPA 16 Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems
- NFPA 17 Standard for Dry Chemical Extinguishing Systems
- NFPA 17A Standard for Wet Chemical Extinguishing Systems
- NFPA 20 Standard for the Installation of Stationary Pumps for Fire Protection
- NFPA 22 Standard for Water Tanks for Private Fire Protection
- NFPA 24 Standard for the Installation of Private Fire Service Mains and Their Appurtenances
- NFPA 25 Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems
- NFPA 72® National Fire Alarm and Signaling Code®
- NFPA 75 Standard for the Fire Protection of Information Technology Equipment
- NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems
- NFPA 2010 Standard for Fixed Aerosol Fire-Extinguishing Systems

5.7.3 Sustainable Design Strategies - Fire Protection

The following shall be considered for sustainable practices in the design and implementation of fire protection systems:

- As far as possible adopt passive fire protection systems to prevent or delay the spread of fire and/or smoke to different parts of the building, including compartmentalization and egress, to meet required standards. Public fire services may be remote or not available in some localities, and mechanical suppression systems are potentially unreliable without good maintenance;
- If allowable and feasible, use reclaimed water in lieu of potable water for fire suppression supply to conserve potable water;
- Use non-ozone depleting products in the fire suppression system.

5.7.4 Fire Protection Elements

Fire protection elements may include fire rated compartments including fire rated doors in fire rated walls, fire alarm and detection systems (including pumps, and fire suppression systems).

The following additional criteria should be considered and addressed in the design process.

System design and materials specifications must account for the corrosive conditions created by very humid climates and airborne salt from the nearby marine environment. Specific attention should be paid to selection of materials for reduced susceptibility to corrosion such as:

- Non-ferrous metals like stainless steel;
- Non-metallic materials such as PVC, fiberglass, and similar materials;
- Special coatings for corrosion resistance such as hot-dip or electroplated zinc, epoxy-based coatings, cold galvanizing paint, and other corrosion inhibiting coating as may be appropriate for any specific application.

The availability of highly skilled labor and well-trained technicians may be very limited. Where practicable, system design complexity should be kept to the minimum needed to meet code and other project requirements

Installation and maintenance of systems like fire pumps, compressors, and control equipment will be complicated by the generally limited pool of available skilled labor on-island. Consider the availability of local manufacturer's support services when designing systems.

Almost all materials will have to be shipped to the island from mainland sources. Consider the cost and availability of materials, systems, and equipment before finalizing specifications.

The capacity of municipal water systems on the islands is often limited, particularly about higher demands for fire flows. The use of on-site storage tanks should be considered to ensure an adequate water supply for fire suppression systems. In addition to water storage, the use of alternative sources of water such as rainwater collection systems or wells, that could supplement a municipal system and be used for fire suppression should also be considered if determined that any materials, chemicals, or contaminants in the water will not be detrimental to the components of the sprinkler system.

.

Key Strategies for Fire Protection Design in the Tropics	
1. Best Practices • Pre-Action fire suppression systems should not be installed due to their high costs and failure rates. • Consider the use of curb boxed gate valves with t-handles in lieu of fire suppression post indicator valves (PIVs). • Main 2-inch drains and inspector test connection valve drains should be provided within the building/structure. • No fire sprinkler drains should be on the exterior of the building/ structure. • Fire Department Connections (FDCs) should be properly sleeved and coated with mastic upon installation. • All wet pipe fire sprinkler risers require system side FDCs. • Fire sprinkler heads should be corrosion resistance Electroless Nickel (ENT) Polytetrafluoroethylene (PTFE) plated. • At minimum, fire alarm system shall consist of 120 V smoke and/or heat detectors installed in public spaces.	 *Cyclone corroded fire protection system. Taken from Guam School Assessment, USACE, 2021*
2. Fire Protection • As far as possible adopt passive fire protection systems to prevent or delay spread of fire/smoke. • Include compartmentalization and egress to meet the standards. • Use reclaimed water in lieu of potable water for fire suppression supply to conserve potable water. • Use non-ozone depleting products in fire suppression system.	
3. Materials Consideration • Specific attention should be paid to the selection of materials for reduced susceptibly to corrosion such as stainless steel, PVC, and fiberglass.	

5.8 Site Infrastructure

5.8.1 Drainage

The primary objective of a drainage system is to manage storm surface water run-off, to minimize storm related health risks, flood damage, flood nuisance and adverse effects on the environment.

Heavy rainfall often results in ponding stormwater and flooding of some buildings. Many sites and roads have deficient or no drainage infrastructure. New projects should mitigate stormwater runoff from the developed site to existing runoff flows and volumes or less. Utilize local data for stormwater runoff calculations or utilize NOAA's National Weather Service Precipitation Frequency Data Server as noted in Section 1.4.2. Renovations of existing buildings should consider flood proofing for the lowest floors to minimize damage from these conditions. The bottom finished floor of new buildings should be located above flood levels.

New inland drainage systems should be constructed of high-density polyethylene (HDPE) pipe. Drainage systems should transition to reinforced concrete pipe (RCP) at the last inland manhole before the sections leading to the ocean or lagoon outfalls. The RCP sections should also be jacketed with reinforced concrete to anchor the outfall and protect the pipe joints.

The following materials should be specified for projects.

- Below ground drain lines should be HDPE;
- Marine storm drain lines should be concrete encased reinforced concrete pipe;
- Trash racks should be Marine Grade aluminum (5052, 5083, 6061) or 316 stainless steel;
- Outfall structures should incorporate “duckbill” or WaStop® or similar flap gates as these have been successful at protecting from the backwater effects of high tides. Fasteners for flap gates shall be 316 stainless steel;
- Inlet frames and grates for should be cast iron for general use. However, specify 316 stainless steel or 5052/5083 aluminum if high corrosion resistance is warranted, such as locations with direct seawater contact;
- All new manholes and drainage structures in roadways should be H-20 rated.

5.8.1.1 Low Impact Development

Implement Low Impact Development (LID), a stormwater management strategy designed to maintain site hydrology and mitigate the adverse impacts of stormwater runoff and nonpoint source pollution, to the maximum extent practicable. Infiltration of stormwater as a LID strategy provides great benefit however, infiltration designs must ensure that groundwater resources are not adversely affected, especially in areas where groundwater is a source of non-potable and drinking water. Areas that have a high potential for polluted stormwater runoff should consider mechanical treatment devices, oil water separators, and at grade, LID Best Management Practices (BMPs) that treat stormwater prior to infiltration.

5.8.2 Erosion and Sediment Control

Implement stormwater management controls for all construction activities, and construction activities that involve soil disturbance to prevent polluted runoff during construction activities. Sediment and erosion controls (compost filter socks, silt fences, gravel construction entrance/exit, etc.) shall be shown on construction plans and implemented to prevent polluted runoff during construction activities.

Large construction activities (where disturbance is equal to or greater than 5 acres of land) require additional soil erosion and sediment controls and periodic inspections. Keep in mind that tropical islands are subject to sudden torrential downpours as well as periods of sustained intense rainfall; fast moving water on bare soil can quickly lead to site damage.

For small construction or demolition activities (i.e., projects that would disturb less than 5 acres), stormwater controls consist of minimizing the area of disturbance, preserving vegetation where practical, good housekeeping, spill prevention, dust control, waste management, erosion, and sediment controls, and stabilizing disturbed areas.

Landfill capacity is limited in all islands. Temporary construction stormwater controls such as filter socks should be 100 percent biodegradable to minimize landfill disposal space and reduce the chances of the control becoming pollution itself.

5.8.3 Wastewater

The wastewater collection system for the islands varies and may include septic systems, gravity lines, pump stations, and force mains leading to a wastewater treatment plant. Connection to existing municipal systems should be made where possible.

In locations where there is no wastewater collection system, install individual on-site wastewater treatment systems. Site conditions and need to minimize environmental impact shall first be assessed before determining the treatment and disposal method.

At a minimum, treatment and disposal should consist of a septic tank and leach field to treat and dispose wastewater. Size leach fields based on the design wastewater flows from the building(s) and the soil percolation rate at the location of the leach field in accordance with relevant technical guidance. As sea level rises the effectiveness of these systems in low lying areas are being affected. Advanced systems may be required to deal with poor soil conditions, high water table, or to protect high-risk adjacent environments. Advanced systems may include raised beds, sand filters, aerated soakage trenches, or aerated treatment tanks. Cesspools for wastewater disposal should not be used due to the harmful impacts on the environment.

New systems should be designed based on the current IBC guidance documents. The following materials should be specified for projects:

- Gravity mains should be ASTM D3034 SDR 26 or SDR 35 PVC pipe;
- Force mains should be ASTM D2241 solvent welded PVC pipe;
- Inlet frames and grates for should be cast iron for general use. However, specify 316 stainless steel or 5052/5083 aluminum if high corrosion resistance is warranted, such as locations with direct seawater contact;
- All manholes, sewer structures, lift stations, and holding tanks shall be coated with appropriate coatings to protect concrete surfaces from chemical attack (should that be a risk);
- All manholes and cleanouts in roadways shall be H-20 rated.

Pipes adjacent to existing buildings and structures shall be located clear of the ‘zone of influence’ of the building foundations. If this is not possible, a specific design shall be undertaken to cover the following:

- Protection of the pipeline;
- Long term maintenance access for the pipeline;
- Protection of the existing structure or building.

5.8.4 Water and Reclaimed Water

5.8.4.1 Water Supply

The water systems on all Islands are highly dependent on basal groundwater while some also use rainwater catchment systems and reverse osmosis. Existing water systems in islands vary and may include a combination of systems placed over a long period of time.

Water systems for buildings should be designed based on assessment of local conditions and available options. Water supply to buildings may include:

- Connection to an existing water system.
- Rainwater capture
- Groundwater supply from on-site well
- On-site tank storage for firefighting reserve.

Higher technologies for water supply such as desalination or condensation are unlikely to be relevant to individual building projects.

On-site treatment of water for potable use may be required even if connection is made to a communal supply. Separate guidance should be sought on this.

Size rainwater catchment systems to provide water throughout the year. Conduct a water mass balance analysis to size the rainwater storage tanks based on the water demands for the project and the rainwater at the site. See 1.4.2 for information on historical rainfall data.

5.8.4.2 Water Pipes

The following materials should be specified for projects:

- New waterlines should be C900 PVC, DR18 minimum.
- Below ground water services should be Schedule 80 PVC.
- Above ground water services should be 316 Stainless Steel.
- Below ground valves should be epoxy coated ductile iron.
- Ductile Iron backflow preventers, post indicator valves, and fire hydrants and associated piping above ground with a protective coating system specified by a Corrosion Expert.

- 2-inch and smaller domestic service reduced pressure principal backflow preventers should be bronze, lead free, on the University of Southern California Foundation for Cross-Connection Control and Hydraulic Research, List of Approved Backflow Prevention Assemblies.
- Couplings, tapping sleeves, and repair sleeves, bolts, nuts, and washers should be 316 stainless steel.
- Boxes should be reinforced concrete raised 4 inches above grade with aluminum checker plate lids or concrete lids painted yellow for potable or red for non-potable as appropriate.
- All manholes, handholes, and valve boxes in roadways should be H-20 rated.

A protective coating and/or cathodic protection system should be considered for any buried metallic component of the water distribution system.

5.8.5 Roadways and Driveways

Roadways and driveways are a challenge to maintain on remote islands. As a result, projects may be required to restore damage resulting from construction while equipment and materials have been mobilized. The construction contractor shall document the roadway and driveway condition prior to construction, and upon completion of work, make repairs resulting from construction damage.

5.8.5.1 Asphalt Concrete Roadways and Driveways

Hot mix asphalt production may be unavailable. Contractors are required to coordinate asphalt plant, equipment, materials, stockpiles, and production areas required for asphalt paving. Repairs of existing asphalt concrete roadways should be with concrete pavement when hot mix asphalt pavement is not readily available on island. Design asphalt concrete pavement based on the design vehicle loading of the site and the underlying soil properties.

5.8.5.2 Gravel Roads and Driveways

Perimeter and other gravel roads and driveways are typically constructed of locally sourced coralline aggregates. The minimum aggregate section shall be 6 inches. The aggregate section shall consist of 1-inch minus, well-graded granular materials.

5.8.5.3 Concrete Roadways and Driveways

Concrete roads and driveways provide a permanent stabilized surface and can be constructed in locations where there is no asphalt plant. Design concrete pavement based on the design vehicle loading for the site and the underlying soil properties. Concrete pavements can either be steel reinforced or unreinforced, based on the design.

Key Strategies for Site Infrastructure Design in the Tropics

1. Drainage

- Drainage systems are needed to manage storm surface water run-off from building sites to minimize flood related health risks, flood damage, and adverse effects on the environment.
- New projects should mitigate stormwater runoff from the developed site to existing runoff flows and volumes or less.
- Infiltration designs must ensure that groundwater resources are not adversely affected, especially in areas where groundwater is a source of potable drinking water.

New building flooded from poor site drainage.

2. Erosion and Sediment Control

- Implement stormwater management controls for all construction activities to prevent polluted runoff during construction activities.
- Stormwater controls should minimize the area of disturbance; preserve vegetation where practical; include spill prevention, dust control, waste management, erosion, and sediment controls; and stabilize disturbed areas.

3. Sewer

- Connection to existing municipal systems should be made where this is possible.
- In locations where there is no wastewater system, install on-site wastewater treatment systems.
- A septic tank and leach field is the minimum for on-site treatment and disposal. Advanced systems may be required to deal with poor soil conditions, high water table, or to protect high-risk environments.

Wastewater Advanced Aeration Bed pipework.

4. Water and Reclaimed Water

- Water supply may be connection to existing supply, rainwater capture, groundwater supply from on-site well.
- On-site treatment for potable use may be required even if connection is made to a communal supply.
- Pipes and fittings shall be located to allow easy access for repairs and maintenance.

5. Roadways

- Repair of construction damage may be needed.
- Gravel roads and driveways are typically constructed of locally sourced coralline aggregates.
- Repairs of existing asphalt concrete roadways should be with concrete pavement when hot mix asphalt pavement is not readily available.
- Concrete roads and driveways provide a permanent stabilized surface and can be constructed in locations where there is no asphalt plant.

Road repairs and trench reinstatement

6 Tasks Supporting Design

6.1 Gateway/Stage Checklists

The following checklists are intended to provide guidance assist the design team. Other tasks may need to be added to suit the building project and situation.

6.1.1 Scope Definition and Design Brief

The checklist in Table 6-1 will help the project proponents (Client, Funder, Project Manager) prepare a Design Brief/Scope Statement that is comprehensive without setting excessive constraints on the design team. The process of developing the Design Brief should give the information necessary to define the role of the designers. The Design Brief may also be further developed and finalized in conjunction with the DoR once they are engaged.

This checklist does not form a Design Brief but presents common areas to consider ensuring the brief covers the key requirements.

Further development of a Design Brief can form the Basis of Design referred to in Section 2.3.3.

Table 6-1: Design Brief Checklist

Scope Definition and Design Brief Checklist		
Item	**Check**	**Notes**
PROJECT BACKGROUND		
Briefing on the project purpose and development		
FINANCIAL		
Budget for the Project and key stages		
SITE		
Description of the site – including location, features, land tenure, access, available services		
Known information on the history of the site – including existing and previous land use, history of hazards, any previous reports or assessments of the site, flooding, archaeological sites, burial sites, endangered/protected plants, and animals		
Inputs and other information to be provided to the designer by other parties		
Availability of utilities (water, wastewater, electrical, communications) and roads		
OUTCOMES		
Purpose and use of the building		
Requirements for building use – including accessibility, durability, technology, aesthetics, adaptation to changing needs, emergency purposes if any		
Design Criteria – including design life, level of service or sizing criteria, environmental outcomes		
Requirements for build quality for structure and services elements		
Quantitative and qualitative functionality requirements - including size, facilities, occupancy, layout or connectivity		
Visual requirements – including form, style and preferred materials		
Sustainability considerations – including sustainable materials, water recycling, energy efficiency		
Requirements for Climate Change Adaption – any specific information known or required, e.g., minimum clearance for coast or sea level		
PERFORMANCE		
Quantify performance targets in relation to aspects such as temperature control, water, and energy use		
Particular Codes or Standards to be used, or specified deviations from these		
Requirements for quality assurance reviews, health and safety, HAZOP etc.		
PROCUREMENT		
Expectations of construction procurement plan that may affect design decisions e.g., contract form, preferred suppliers		
TIMING		
What Deliverables are required – e.g., drawings, calculations, specifications, construction contract conditions, reports		
Targets for completion of finished project, stages, and key activities and decision points		
APPROVALS		
Approvals required to be obtained – including building authority consents, client review and approval		
OTHER		
This item is included to encourage thinking of any other special project needs		

6.1.2 Preliminary Design

The requirements for documenting and reporting on Preliminary Design will depend on the choices of the client, funder and project manager for intermediate outputs and reviews. A template for Preliminary Design is therefore not provided here but can be adapted for the Design Brief (Section 6.1.1) and Design Statement (Section 6.1.3) templates to suit.

6.1.3 Design Statement

The checklist in Table 6-2: Design Statement Checklist will help the design team prepare a Design Statement as referred to in Section 6.1.2 that is comprehensive without setting excessive constraints on the design team. The process of developing the Design Brief should give the information necessary to document the adopted design and the reasons for this.

This shall include a design analysis (DA), including narratives, calculations, and other supporting features (e.g., sketches and diagrams), in accordance with this section to document the development and evaluation of the design for the particular project. The DOR shall prepare the DA for record and review to identify assumptions and support decisions made during the design process. The design analysis is developed in coordination with the project proponents and end users.

This checklist covers the key requirements. It does not form a Design Statement but presents common areas to consider when preparing the statement.

Table 6-2: Design Statement Checklist

Design Statement Checklist		
Item	**Check**	**Notes**
DESIGN BRIEF		
Relevant information from the Design Brief – including the Outcomes and Performance requirements, design criteria (noting any changes made during the design process)		
PROJECT BACKGROUND		
Briefing on the project purpose and development		
FINANCIAL		
Project Budget and Estimated Construction Cost, noting any changes made as the design progressed		
DESIGN ANALYSIS		
Assemble the design analysis as a single document with the following information included, as relevant to the project: • Table of Contents • Design Quality Control Plan • Site Design Narrative (including Landscaping) • Architectural Narrative • Interior Design Narrative • Structural Design Narrative • Mechanical Design Narrative • Electrical Design Narrative • Telecommunications Design Narrative • Fire Protection/Life Safety Code Design Narrative • Civil Narrative • Sustainability Goals Reached (LEED) • Geotechnical Report • Civil Calculations (including all site works) • Structural Calculations • Plumbing Calculations • Mechanical Calculations • Electrical Calculations • Telecommunications Calculations • Complete Energy Calculations per ASHRAE 90.1-App G and EPAct05 requirements (for		

larger buildings or complexes and where considered that it informs future operating cost decisions) • Meeting Minutes and Official Correspondence • All Annotated Review Comments (those received in previous reviews).		
PROCUREMENT PLAN		
Matters to be taken account of in the construction procurement for the design to be fully realized – including expertise and experience required by the builders		
CONSTRUCTION QUALITY ASSURANCE OVERSIGHT PLAN		
Key construction aspects to be verified		
Tasks, roles, and responsibilities for construction quality control – including for Construction Contractor, Designer, any independent construction review contractor, and building control agencies (if available) – Refer also Section 6.2		
OTHER		
This item is included to encourage thinking of any other special project needs, including information for ongoing asset management.		

In the narratives, provide a complete explanation of the basis for design including a scope of work, applicable criteria, floor area analysis. Include gross and net areas compared to the scope of work, seismic analysis, economic, social, technological and maintenance factors influencing system choices, results of field investigations, operation and maintenance requirements, and any other items that warrant special attention.

Compute design calculations and check by separate individuals. Include names of designer and checker with firm name on calculations. Show all design loads and conditions. List the source of loading conditions, formulas, and references. Explain assumptions and conclusions.

As a separate part or section of the Design Analysis (where appropriate, to larger complexes), demonstrate compliance with ASHRAE Standard 90.1 - Energy Standard for Buildings and EPAct05. Use calculations, vendor literature, equipment catalog sheets, compliance forms, worksheets, and narrative descriptions of the building envelope, HVAC systems, service water heating, electrical power, lighting, and other equipment, and systems to demonstrate compliance. Note that the requirements for reliability and system simplicity may not provide energy efficiency compliance with the latest versions of 90.1. High efficiency often leads to complexities and specialized systems.

6.2 Construction Cost Estimate

A construction cost estimate shall be prepared based on the design drawings and specifications at each submittal. This will allow the project team to identify issues early which will impact the feasibility of the design.

Where appropriate, in addition to a breakdown schedule and pricing of the works, interim and final designs may:

- Include all backup information in the estimate including detailed quantity takeoffs;
- Provide quantity takeoffs and wastage assumptions;
- Provide labor manhours including labor burden;
- Have travel costs and lodging/subsistence included for specialty subcontractors who are not on the project island.

6.3 Construction Quality Assurance Oversight Plan

The success of a building project depends on how the good design is implemented.

Requirements for construction quality assurance and oversight (enforcement) should be documented as part of the design to ensure sufficient resources are made available for this and to ensure that not critical matters are overlooked. This is to include: determining critical components for QA testing and inspection; determining plan for staff and processes for quality assurance including requirements on builder and oversight by designer/project manager/regulatory authority; resourcing for quality assurance inspections.

6.4 Asset Management Support

6.4.1 Background

The functional life of a building project depends on how well the facility is maintained as well as the quality of design and construction:

- To ensure the asset keeps delivering service;
- To ensure the asset lasts for its intended life;
- To ensure costs and revenue are controlled;
- To avoid the donate – deteriorate – re-donate cycle.

Asset management is the tasks required to keep an asset functioning and delivering the service intend by it for the duration intended. It includes:

- Understanding the purpose of the asset; what services does it provide;
- Understanding the asset; what you have and what condition it is in;
- Understanding asset lifecycle; when / how it's created, renewed, ended;
- Operating and maintaining the asset;
- Understanding risks; what can go wrong, how to manage;
- Understanding the finances; what it costs, how costs are funded.

The main elements of asset management comprise:

- Strategic Goals; a statement about the purpose of the asset;
- Levels of Service; specifics about what the users of the asset get;
- Demand; specifics about capacity and use;
- Asset Information; a register of what exists and its condition;
- Asset Lifecycle; creation, renewal, life, end;
- Operations and Maintenance; day to day running;
- Risk Management; identifying and mitigating risk;
- Financial plan; costs, revenue, capital expense and funding.

6.4.2 Role of Design in Asset Management

The information and processes for the long-term management, maintenance and renewal of infrastructure needs to form part of the design and construction phases. Full guidance on asset management practices is beyond the scope of this design guide but the notes here provide guidance to designers on what to include in design documentation and construction completion documentation. This should best include:

- Definition of the levels of service and demand to be met - this includes availability, capacity and quantity, and should be defined at the start of any design;
- Listing maintenance and renewal tasks over the life of the building and providing a schedule for the timing of these;
- An initial financial plan (budget over time) for maintenance and renewal tasks over the life of the building;
- Equipment and material manuals and maintenance instructions.

Defining each of these is a fundamental of asset management and is first determined in design. With this information the building owner can then engage the people needed for maintenance and operation, budget and fund the future spending for maintenance, operation, and replacement.

6.4.3 Asset Management Plans

Asset management plans (AMPs) consolidate the data and information needed to make effective decisions on maintenance and renewal to maximize the useful life of a building. The design and construction processes should provide the core information as noted above. An initial draft of the formal Asset Management Plan could form part of the design engagement.

6.4.4 Preventative Maintenance

An important element of asset management is maintenance, which involves activities designed to prolong the useful life of an asset. Maintenance is primarily about service provision: organizations maintain their asset base to ensure that they can continue to provide a service or good. The maintenance of infrastructure assets is a critical, given that poor maintenance has adversely affected infrastructure performance and sustainability in the Pacific. There are various types of maintenance:

- Routine – small-scale regular actions designed to reduce wear and tear and to maintain assets in good condition;
- Periodic – larger scale infrequent works to ensure continuing operation, which might involve specialized technical expertise and equipment;
- Urgent repairs – in response to failures, most commonly resulting from an absence of Routine and Periodic maintenance;
- Rehabilitation – not so much maintenance as renewal, involving major work to upgrade components that reach the end of their expected life, as an alternative to replacement of an asset. Routine and Periodic maintenance can delay or avoid the need for Rehabilitation.

The requirements for Routine and Periodic maintenance should be defined as part of design and construction completion tasks.

7 References

AEI Consultants. (1997). *UBC Seismic Zone Map.*
American Concrete Institute. (2011). *ACI 530-11: Building Code Requirements and Specification for Masonry Structures.* American Concrete Institute.
American Concrete Institute Committee. (2019). *ACI 318-14: Building Code Requirements for Structural Concrete.* American Concrete Institute.
American Institute of Steel Construction. (2016). *AISC 303-16: Code of Standard Practice for Steel Buildings and Bridges.* American Institute of Steel Construction.
American Samoa Government. (2011). *American Samoa Tsunami Study, Working Report #06.* American Samoa Government.
American Society Of Civil Engineers. (2022). *ASCE 7-22: Minimum Design Loads And Associated Criteria For Buildings And Other Structures.* American Society Of Civil Engineers.
American Wood Council. (2018). *National Design Specification for Wood Construction.* American Wood Council.
ASCE. (2014). *Flood Resistant Design and Construction: ASCE 24-14.* ASCE.
ASCE. (2022). *Minimum Design Loads for Buildings and Other Structures: ASCE 7-22.* ASCE.
ASCE. (2022). *Tsunami Loads and Effects: ASCE 7-22.* ASCE.
ASCE. (November 2015). *U.S. Seismic and Wind Zones: ASCE 9-75.*
Australian Government Department of Foreign Affairs and Trade. (n.d.). *Countries, economies and regions*, populations of FSM, RMI and Palau. Retrieved January 24, 2022, from dfat.gov.au: https://www.dfat.gov.au/geo/countries-economies-and-regions
Australian Standards. (2020). *AS 4100: Steel Structures.* Australian Standards.
BBC. (2022, May 25th). *Immense Crater Hole Created In Tonga Volcano*. Retrieved from https://www.bbc.com/news/science-environment-61567521
BRANZ. (2012, February). *Timber Treatment*. Retrieved from Building Magazine NZ: https://www.buildmagazine.org.nz/index.php/articles/show/timber-treatment
Bureau of Statistics, Government of Guam. (2005). *Development Requirements on Guam.* Retrieved from EPA.gov: https://19january2017snapshot.epa.gov/www3/region9/islands/guam-workshop-2011/pdf/BspGuidebook-DevReqs-Guam1.pdf
Cairns Regional Council. (2011, December). *Sustainable Tropical Building Design, Guidelines for Commerical Buildings.* Retrieved from Cairns Regional Council: https://www.cairns.qld.gov.au/__data/assets/pdf_file/0003/45642/BuildingDesign.pdf
Charles S. Mueller, K. M. (2012). *Seismic Hazard Assessment For Guam and the Northern Mariana Islands.* U.S. Geological Survey.
Code Status: US Territories. (2022, April). Retrieved from Building Codes Assistance Project: http://bcapcodes.org/code-status/state/us-territories/
Da Nang Department of Construction. (2017). *Design, Construction and Renovation of Typhoon Resillient Low-Income Housing.* Da Nang Department of Construction.
Department of Defense. (2019, 08 10). *UFC 1-200-01 DoD Building Code.* Retrieved from Whole Building Design Guide: https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-1-200-01
Department of Fire & Emergency Services. (2022). *Western Australia Cyclone Preparedness Guide.* Government Of Western Australia.
FEMA. (2015, January). *P-154, Rapid visual screening of buildings for potential seismic hazards.* Retrieved from FEMA: https://www.fema.gov/sites/default/files/2020-07/fema_earthquakes_rapid-visual-screening-of-buildings-for-potential-seismic-hazards-a-handbook-third-edition-fema-p-154.pdf
FEMA. (2019, August). *P-646, Guidelines for Design of Structures for Vertical Evacuation from Tsunamis.* Retrieved from https://www.fema.gov/sites/default/files/2020-08/fema_earthquakes_guidelines-for-design-of-structures-for-vertical-evacuation-from-tsunamis-fema-p-646.pdf
FEMA. (2019, August). *P-646, Guidelines for Design of Structures for Vertical Evacuation from Tsunamis.* Retrieved from Fema.gov: https://www.fema.gov/sites/default/files/2020-08/fema_earthquakes_guidelines-for-design-of-structures-for-vertical-evacuation-from-tsunamis-fema-p-646.pdf
FEMA. (2021, Mar). *P-320, Taking Shelter from the Storm.* Retrieved September 12, 2022, from Fema.gov: https://www.fema.gov/sites/default/files/documents/fema_taking-shelter-from-the-storm_p-320.pdf
FEMA. (2021, April). *P-361, Safe Rooms for Tornados and Hurricanes.* Retrieved from Fema.gov: https://www.fema.gov/sites/default/files/documents/fema_safe-rooms-for-tornadoes-and-hurricanes_p-361.pdf
FEMA. (2022, January). *P-787, Catalogue of FEMA building science branch publications, 5th Edition.* Retrieved from FEMA: https://www.fema.gov/sites/default/files/documents/fema_building-science-catalog_12-29-21.pdf
FEMA. (April 2020). *USVI Special Wind Region Maps.* FEMA, Department of Planning and Natural Resources.
FEMA. (July 2021). *Mitigation Assessment Team Summary Report and Recommendations, Super Typhoon Yutu.* FEMA.

FEMA. (October 2020). *Special Wind Region Maps for the Commonwealth of the Northern Mariana Islands (CNMI).* FEMA.
GNS Science. (2022, 04 24). *Tectonic Plates and Palte Boundaries.* Retrieved from GNS Science: https://www.gns.cri.nz/Home/Learning/Science-Topics/Earthquakes/Earthquakes-at-a-Plate-Boundary/Tectonic-Plates-and-Plate-Boundaries
Government of the Republic of Palau. (2012, 04 17). *Sustainable Land Management Policy of The Republic of Palau .* Retrieved from Palau Climate Change Portal: http://climatechange.palaugov.pw/sites/default/files/documents/Palau%20SLM%20Policy-Final_President.pdf
Grecni, Z., Derrington, E. M., Greene, R., Miles, W., & Keener, V. (2021). *Climate Change in the Commonwealth of the Northern Mariana Islands: Indicators and Considerations for Key Sectors.* Honolulu: East-West Center. doi:10.5281/zenodo.4426942
Horsley Witten Group. (2021). *Unpaved Road Standards for Caribbean and Pacific Islands.* NOAA Coral Reef Conservation Program .
ICC. (2014, December). *2014 ICC 500/NSSA Standard for the Design and Construction of Storm Shelters.* Retrieved from ICC: https://codes.iccsafe.org/content/ICC5002014
International Code Council. (2021, 09). *2021 International Building Code (IBC).* Retrieved from https://codes.iccsafe.org/content/IBC2021P2
J.T. Pérez-Quiroz, J. T. (2008). Assessment of stainless steel reinforcement for concrete structures rehabilitation. *Journal of Constructional Steel Research*.
Masonry Institute of America. (2016). *Masonry Designers' Guide 2016.* Masonry Institute of America.
Meteoblue. (2022). *Simulated Historical Climate & Weather Data for Marshall Islands International Airport*. Retrieved from https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/marshall-islands-international-airport_marshall-islands_4040398
Meteoblue. (2022). *Simulated Historical Climate and Weather Data for the National Park of American Samoa*. Retrieved from https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/national-park-of-american-samoa_american-samoa_5881525
Mullins Consulting. (2006). *Design Guidelines for Queensland Public Cyclone Shelters.* Department of Public Works, Queensland Government, Australia.
New Zealand Concrete Masonry Association Inc. (2018). *New Zealand Concrete Masonry Manual.* New Zealand Concrete Masonry Association Inc.
New Zealand MBIE. (May 2020). *Tsunami Loads and Effects on Vertical Evacuation Structures.*
NOAA. (2017, April). *Percipitation Frequency Data Server (PFDS)*. Retrieved from Hydrometerological Design Studies Center: https://hdsc.nws.noaa.gov/hdsc/pfds/index.html
NOAA. (2022). *NOWData*. Retrieved from National Weather Service: https://www.weather.gov/wrh/Climate?wfo=gum
NOAA. (2022). *Pacific RISA*. Retrieved from Pacific RISA: https://www.pacificrisa.org/
NZ Government Procurement. (2019, October). *Construction Procurement Guidelines.* Retrieved from Construction Procurement Guidelines: https://www.procurement.govt.nz/assets/procurement-property/documents/setting-up-for-project-success-construction-procurement.pdf
Pacific Catastrophe Risk Insurance Company. (September 2011). *Pacific Catastrophe Risk Assessment And Financing Initiative: Federated States of Micronesia.* Pacific Catastrophe Risk Insurance Company.
Pacific Catastrophe Risk Insurance Company. (September 2011). *Pacific Catastrophe Risk Assessment and Financing Initiative: Palau.* Pacific Catastrophe Risk Insurance Company.
Pacific Fire Exchange. (2022). *JFSP Fire Science Exchange Network*. Retrieved from Pacific Fire Exchange: https://www.pacificfireexchange.org/
Pacific Island Projects. (2018, December). *Innovative Wood Based Products*. Retrieved from Pacific Island Projects: https://www.pip.com.pg/resources/wood-processors/wood-species-a-properties/181-testing-wood-properties.html
Pacific Region Infrastructure Facility. (August 2021). *Regional Diagnostic Study on the Application of Building Codes in the Pacific.* Pacific Region Infrastructure Facility.
Pacific Region Infrastructure Facility. (January 2016). *Road Pavement Design for the Pacific Region.* Pacific Region Infrastructure Facility.
Pacific Region Infrastructure Facility. (November 2017). *Guidance for coastal protection works in Pacific island countries.* Pacific Region Infrastructure Facility.
Patrick D. Nunn, L. K. (2015). *Regional coastal susceptibility assessment for the Pacific Islands: Technical Report.* Unversity of Sunshine Coast.
Patrick D. Nunn, L. K. (2016). Classifying Pacific Islands. *Geoscience Letters*, 1-19.
Qingyong Guo, L. C. (2018). The Effect of Mixing and Curing Sea Water on Concrete Strength at Different Ages. *MATEC Web of Conferences*.
Standards Australia. (2010). *AS 1648: Residential timber framed construction.* Standards Australia.
Standards Australia/New Zealand. (2002). *AS/NZS 1170.0:2002: Structural Design Actions PArt 0: General Principles.* Standards Australia/New Zealand.
Standards New Zealand. (1988). *NZS 3631: New Zealand timber grading rules.* Standards New Zealand.
Standards New Zealand. (1993). *NZS 3603: Timber structures standard.* Standards New Zealand.

Standards New Zealand. (1997). *AS/NZS 1664: Aluminium Structures.* Standards New Zealand.
Standards New Zealand. (2003). *NZS 3602: Timber and wood-based products for use in building.* Standards New Zealand.
Standards New Zealand. (2003). *NZS 3640: Chemical preservation of round and sawn timber.* Standards New Zealand.
Standards New Zealand. (2011). *NZS 3604: Timber-frames buildings.* Standards New Zealand.
Standards New Zealand. (2012). *AS/NZS 2269.0: Plywood - Structural - Part 0 Specifications.* Standards New Zealand.
Standards New Zealand. (2012). *AS/NZS 2269.1: Plywood - Structural - Part 1 Determination of structural properties.* Standards New Zealand.
Standards New Zealand. (2016). *AS/NZS 5131: Structural Steelwork and Fabrication Code.* Standards New Zealand.
Standards New Zealand. (2018). *AS/NZS 4600: Cold Formed Steel Structures.* Standards New Zealand.
Standards New Zealand. (2018). *NZS 3404: Durability requirements for steel structures .* Standards New Zealand.
Standards New Zealand. (2021). *AS/NZS 1604: Preservative-treated wood-based products.* Standards New Zealand.
Stantec. (Mar 2022). *CIDG Study Report.*
Stantec. (October 2016). *Tropical Cyclone Winston Recovery - Repair and Reconstruction in Northern Lau Group, Fiji.* Stantec.
Tasman Insulation New Zealand Ltd. (2022). *Insulation Design Guide for Tropical Conditions.* Tasman Insulation New Zealand Ltd.
Taylor and Francis Group. (2020, October). Effects of seawater for mixing and curing on structural concrete. *The IES Journal Part A: Civil & Structural Engineering*.
Territory of American Samoa. (April 2015). *Multi-Hazard Mitigation Plan.* American Samoa Governor's Office.
Timber Queensland. (June 2016). *Wind Tie-Down Connections - Getting It Right.* Timber Queensland.
Transport Global Practice World Bank Group. (September 2019). *Concrete Pavements for Climate Resillient Low-Volume Roads in Pacific Island Countries.* Transport Global Pracitce World Bank Group.
U.S Department of State. (2022). *Office of Weapons Removal and Abatement*. Retrieved from Office of Weapons Removal and Abatement: https://www.state.gov/bureaus-offices/under-secretary-for-arms-control-and-international-security-affairs/bureau-of-political-military-affairs/office-of-weapons-removal-and-abatement/#:~:text=The%20Office%20of%20Weapons%20Removal,used%20conventional%20wea
U.S. Department of the Interior Bureau of Reclamation. (September 2016). *Alternative Reinforcement for Concrete in Corrosive Environments.* U.S. Department of the Interior Bureau of Relamation Research and Development Office.
United Nations. (2015). *Sustainable Building Design for Tropical Climates .* Retrieved from UN Habitat: https://unhabitat.org/sites/default/files/download-manager-files/Sustainable%20Building%20Design%20for%20Tropical%20Climates_1.pdf
United Nations. (2015). *Technical Note 10: key strategies for sustainable building design in the tropics.* Retrieved from UN Habitat: https://unhabitat.org/urban-energy-technical-note-10-key-strategies-for-sustainable-building-design-in-the-tropics
United Nations OCHA. (2014, December 31st). *Asia Pacific Regional Hazard Map: Natural Hazard Risk.* Retrieved from https://reliefweb.int/map/world/asia-pacific-regional-hazard-map-natural-hazard-risk
United Nations OCHA. (2014, December 31st). *Asia Pacific: Tropical Storm Risk.* Retrieved from https://reliefweb.int/map/world/asia-pacific-regional-hazard-map-tropical-storm-risk
United Nations OCHA. (2019, March 14th). *Last 50 Years Tropical Storms in Asia-Pacific: 1968 - 2018.* Retrieved from https://reliefweb.int/map/world/asia-pacific-regional-hazard-map-last-50-years-tropical-storms-asia-pacific-1968-2018
United States Census Bureau. (n.d.). *2020 Census Results*, Populations of American Samoa, CNMI, Guam, and USVI. Retrieved January 24, 2022, from Census.gov: https://www.census.gov/programs-surveys/decennial-census/decade/2020/2020-census-results.html
University of Hawaii. (December 2014). *Evaluating the Effects of Tsunami Loading on Prototypical Steel Structures.*
US Army Corps of Engineers. (2022). *Guide for Resilient Energy Systems Design in Hot and Humid Climates.*
US Geological Survey. (2015, December). *Volcanic Ashfall Impacts: Roof Loading*. Retrieved from Volcanic Ashfall Impacts Working Group: https://volcanoes.usgs.gov/volcanic_ash/density_thickness.html
USACE. (2014, June). *ETL 1100-2-1 Procedures to Evaluate Sea Level Change:.* Retrieved from https://www.publications.usace.army.mil/portals/76/publications/engineertechnicalletters/etl_1100-2-1.pdf
USACE. (June 2019). *ER 1100-2-8162 Incorporating Sea Level Change in Civil Works Programs.*
USAG-KA Public Works Engineering. (Oct 2020). *Installation Design Guide, US Army Garrison - Kwajalein Atoll.*
USGS. (2019, July). *Monitoring storm tide, flooding, and precipitation from Huricane Maria in Puerto Rico and the U.S. Virgin Islands, September 2017*. Retrieved from USGS: https://www.usgs.gov/publications/monitoring-storm-tide-flooding-and-precipitation-hurricane-maria-puerto-rico-and-us

USGS. (2019, October). *U.S. Seismic Hazard Maps - Puerto Rico and the U.S. Virgin Islands, Samoa and the Pacific Islands, and Guam and Northern Mariana Islands.* Retrieved from USGS Earthquake Hazards: https://www.usgs.gov/programs/earthquake-hazards/science/us-seismic-hazard-maps-puerto-rico-and-us-virgin-islands-samoa

USGS. (2019, March). *Volcanic Ash Impacts and Mitigation - Buildings.* Retrieved from Volcanic Ashfall Impacts Working Group: https://volcanoes.usgs.gov/volcanic_ash/buildings.html

USGS. (2022). *Earthquake Hazards Program*. Retrieved from The ShakeMap Atlas: https://earthquake.usgs.gov/data/shakemap/atlas/

USGS, United States Geological Survey. (2003, 09). *USGS Fact Sheet FS-087-03 - ShakeMap.* Retrieved from USGS: https://pubs.usgs.gov/fs/fs-087-03/FS-087-03-508.pdf

Volcanic Ashfall Impacts Working Group. (2015, December). *Case Studies: Pinatubo 1991*. Retrieved from Volcanic Ashfall Impacts Working Group: https://volcanoes.usgs.gov/volcanic_ash/pinatubo_buildings.html

Volcanic Ashfall Impacts Working Group. (2015, December). *Volcanic Ashfall Impacts: Roof Loading*. Retrieved from Volcanic Ashfall Impacts Working Group: https://volcanoes.usgs.gov/volcanic_ash/density_thickness.html

Waka Kotahi - NZ Transport Agency. (July 2001). *Bridge Inspection and Maintenance Manual - 3: Reinforced and Prestressed Concrete.* Waka Kotahi - NZ Transport Agency.

Wen Zhou, P. F.-Q. (2020). Advances in coral aggregate concrete and its combination with FRP: A state-of-the-art review. *Advances In Structural Engineering*, 1162 - 1181.

Whole Building Design Guide. (2017, June 9th). *Flood Resistance Of The Building Envelope*. Retrieved from Whole Building Design Guide: https://www.wbdg.org/resources/flood-resistance-building-envelope

Whole Building Design Guide. (2017, June 15). *Wind Safety Of The Building Envelope*. Retrieved from https://www.wbdg.org/resources/wind-safety-building-envelope#:~:text=Most%20of%20the%20U.S.%20has,170%20mph%2C%20occurs%20in%20Guam.

Whole Building Design Guide. (2019, July). *Tsunami Inundation Mapping For At Risk OCONUS DoD Installations*. Retrieved from Whole Building Design Guide: https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/tsunami-inundation-mapping

Whole Building Design Guide. (2022). *Structural Load Design Tool For UFC 3-301-01*. Retrieved from Whole Building Design Guide: https://www.wbdg.org/additional-resources/tools/ufcsldt

Whole Building Design Guide. (February 2022). *Unified Facilities Criteria.* Whole Building Design Guide.

World Bank Group. (n.d.). *GDP per capita (current US$)*. Retrieved January 24, 2022, from data.worldbank.org: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD

Appendix – List of Persons Consulted and Contributing

The following persons contributed through discussions leading to the FDGTI and/or in providing comments on the drafts.

Timani Samau	Branch Manager McConnell Dowell Constructors Ltd	Construction in American Samoa and Pacific
Kelly Tagarino		
Isagani (Gani) Salazar	Acting Building Safety Code Official CNMI Department of Public Works, Saipan	OIA Contact for CNMI
Erin Derrington	Office of Planning and Development - lead planner	OIA Contact for CNMI
Sanjata Basu	Structural Engineer, PMO, Chuuk State	PMO engineer for project delivery in Chuuk State
Melanie Vicente		
Pohnpei		
Daniel Isaac,	Program Manager, PMO, Pohnpei State	OIA Contact for Pohnpei State PMO compliance manager
Dayn Darin Iehsi,	Project Engineer, PMO Pohnpei State	PMO engineer for project delivery in Pohnpei State
David Hawkins	Electrical Engineer PE, PMO, Pohnpei State	PMO Compliance officer and Building Inspector
Yap		
Samuel Luzano	PMO, Yap	OIA Contact for Yap State Yap PMO Compliance officer and Budiling Inspector

STAKEHOLDER	POSITION / STAKE	EXPERTISE
Rachelle Anne Verdejo	Project Architect, PMO Yap State	Yap PMO Design verifier and checker
Mark Padua	Electrical Engineer, PMO Yap State	Yap PMO Design verifier and checker
William Domingo	Civil Engineer, PMO Yap State	Yap PMO Design verifier and checker
FSM National		
Robert Goodwin	FSM National Director, PMU, Pohnpei State	OIA Contact for FSM
Guam		
Stephanie Flores	Administrator for the Guam State Clearinghouse and the Chief of Staff to the Lt Governor	Compliance for all federal funds (grants, loans, emergency aid)
Jose Quinata	Chief Planner, Department of Public Works	Guam PMO Design verifier and checker
Lynden Kobayashi	Chief Engineer, Bridges Public Works	Guam PMO Design verifier and checker
Marshall Islands		
Jefferson Barton	Secretary of Works, Infrastructure and Utilities	OIA Contact for RMI
Melvin Dacillo	PMU Manager	Programme manager for project delivery
Palau		
Brian Melerai	Director, Bureau of Public Works	OIA Contact for Palau Management of capital improvement projects
US Virgin Islands		
JP Oriol	Commissioner Department of Planning & Natural Resources	Head of Department responsible for building control
Marlon Hibbert	Director Department of Planning & Natural Resources	Coastal Zone Management
Amanda Jackson-Acosta	Director Department of Planning & Natural Resources	Building Permit control
Kevin Vollnogle	Senior Landscape Architect, Project Manager, Stantec	Design, and disaster damage
John Prorock	Structural Engineer, Stantec	Design, and disaster damage
Daryl LeBlanc	Architect, Stantec	Experience working in USVI
General		
Morgan Holtom	Beca	Designers, FSM and RMI
Graeme Roberts	Beca	Designers, FSM and RMI
Matthew Holland	Structural Engineer, Stantec	Building Code review and support in USVI and CNMI
Tim Reinhold	Structural Engineer, Stantec	Damage assessment for FEMA in USVI and Puerto Rico

STAKEHOLDER	POSITION / STAKE	EXPERTISE
Stuart Adams	Structural Engineer, Stantec	Damage assessment for FEMA in USVI and Puerto Rico
Ken Rekdahl	DCA Engineering - Duenas Camaho & Associates, Inc.	Engineering Consulting for Guam and Saipan
Jonathan Westcott	FEMA Building Science	Building performance assessment
Mariam Yousuf	FEMA Building Science	Building performance assessment
Bianca Perez	FEMA Building Science	Building performance assessment
Juan Nieves	FEMA Building Science	Building performance assessment, Puerto Rico field deployment
Daniel Bass	FEMA Building Science	Building performance assessment
Gregory Wilson	FEMA Building Science	Building performance assessment, CNMI field deployment
Shane Crawford	FEMA Building Science	Building performance assessment
Ian Roberston	FEMA Building Science	
Anne Rosinski	FEMA Building Science	
Yana Tukvachin	FEMA Building Science	
Gabriel Jugo	Structural Engineer, JSE Guam	Structural design of buildings in multiple areas
David Amende	Church of Jesus Christ of Latter-day Saints	Building projects across multiple Pacific countries
Mikael Gartner	PRIF – Pacific Region Infrastructure Facility	Building Codes Specialists, Structural and Earthquake Engineer
Timothy Stats	PRIF - Pacific Region Infrastructure Facility	Technical Assistance Officer
Alexander M Zhivov	USACE	
Alan Kato	USACE POH	
Bert Kami	USACE POH	
Brendon Hayashi	USACE POH	
Jessica Podoski	USACE POH	
Kenneth Mocko	USACE POH	