1 | INSTALLATION ENERGY PLANS: RESILIENCE FRAMEWORK

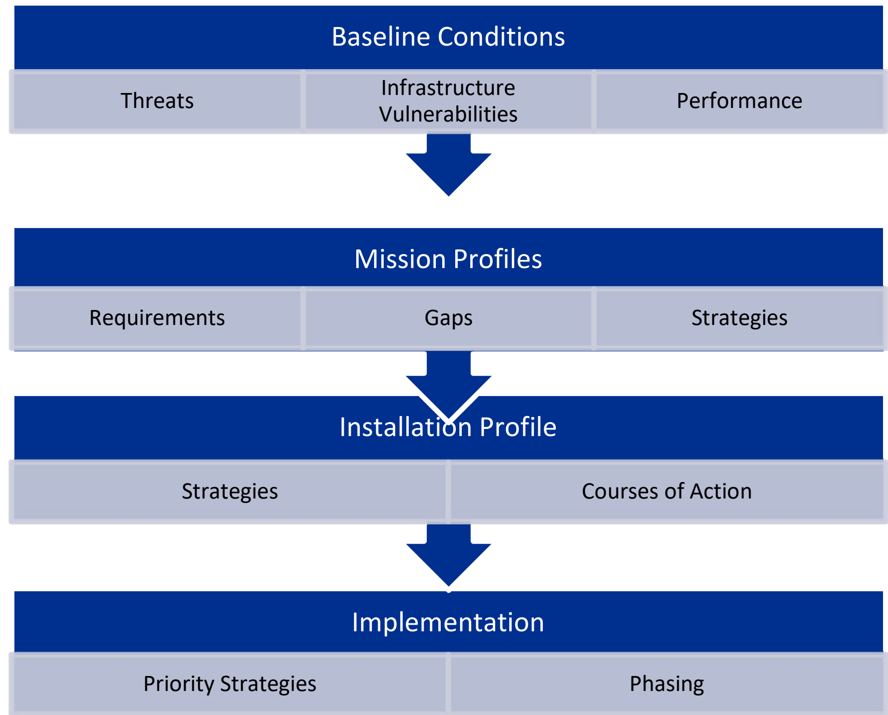
Buildings in cold climates face challenges ranging from extreme temperature shifts to utility limitations due to remote locations. AECOM's work conducting Installation Energy Plans for U.S. Air Force installations in a variety of cold climates has highlighted some of the strategies that can help mitigate these challenges, particularly as it concerns building construction, HVAC practices, and utility interconnection.

1.1 Installation Energy Plans for the United States Air Force

In 2018 AECOM was tasked with developing an installation energy plan framework for the United States (U.S.) Air Force (USAF) following the Office of the Secretary of Defense's 2016 memorandum establishing a policy to require installation-level energy plans for all Department of Defense (DoD) components. The Installation Energy Plan (IEP) creates a decision-making framework to assist installations in achieving their energy goals and ensuring that energy and water resilience meet critical mission assurance requirements and is intended to be used in tandem with the IDP and associated Area Development Plans (ADPs). In the context of the IEP, energy systems include not only power systems but also building thermal systems such as Heating, Ventilation, and Air Conditioning (HVAC) systems and building envelopes.

The IEP incorporates input from mission owners, installation planners, engineers, and other key stakeholders; includes long-range plans for energy resilience capabilities; ensures available and reliable utilities for each installation's critical missions; and defines energy requirements to maintain mission during power/ water outage events. Figure 1-1provides an overview of the components of the IEP.

Figure 1-1: Components of the IEP



Energy resilience for the USAF is driven by an enterprise approach focused on mission. The USAF uses five key resilience attributes to prioritize energy projects and ensure targeted enabling system investments are effective in supporting mission needs: Robustness, Redundancy, Resourcefulness, Response, and Recovery (5Rs). These 5Rs of resilient projects address planning for a crisis as well as performance in a crisis. The 5Rs are defined by qualities in Table 1-1.

Table 1-1: Resilience Attributes and Qualities

RESILIENCE ATTRIBUTE	RESILIENCE QUALITY
ROBUSTNESS (R1)	• Performance monitoring • Hardened infrastructure • Physically secure
REDUNDANCY (R2)	• Energy and water source diversity • Supply path alternatives • Distributed generation topology
RESOURCEFULNESS (R3)	• Available power generation • Energy storage • Demand reduction
RESPONSE (R4)	• Automated • Self-healing • Forecasting / threat assessment • Performance indicators
RECOVERY (R5)	• Standardized components and spares inventory • Damage Assessment • Prioritization of re-powering • Recurring and relevant training and exercises

To provide more comprehensive coverage of all aspects of energy and water infrastructure resilience, the 5Rs are divided into sub-categories as shown in Table 1-2.

Table 1-2: Resilience Sub-Categories

COMPONENT OF RESILIENCE	R	RESILIENCE SUB-CATEGORY	DESCRIPTION
ROBUSTNESS (R1)	R1A	Cybersecurity of Energy Systems	Level of compliance with cyber security protocols
	R1B	Physical Hardening	Protection of physical infrastructure
REDUNDANCY (R2)	R2A	Supply Path Alternatives in Energy & Water Systems	Alternative resource supply routes
	R2B	Energy and Water Source Diversity	Alternative resource supply sources
RESOURCEFULNESS (R3)	R3A	Energy and Water Demand Reduction	Reduction of resource use
	R3B	Loads Sustainment Capacity	Ability to store, maintain and manage resource supply on site
RESPONSE (R4)	R4A	Emergency Management Protocols	Level of emergency response plan and trained personnel
	R4B	Analytics, Smart Controls and Islanding Capabilities	Access to information and infrastructure to enable island (off-grid) operations
RECOVERY (R5)	R5A	Availability of Personnel for Assessment and Repair	Ability to access staff of appropriate expertise for recovery and repair
	R5B	Equipment, Parts, and Procurement	Ease of access to replacement equipment

1.2 Measuring Resilience

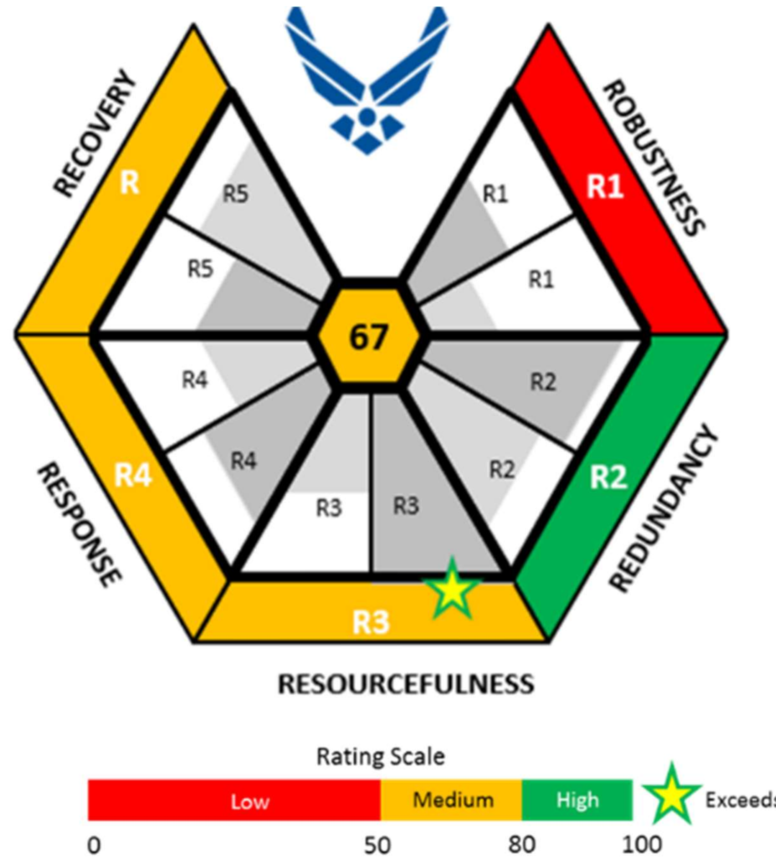
To quantify the benefit of resilience strategies in the IEP, a resilience scorecard is used. This scorecard is based on a model that measures the level to which existing installation and mission infrastructure meets facility-based resource requirements, including power, fuel, heating, cooling, water, communications, and personnel. The model takes into consideration the probability and severity of threats -both natural and manmade- to the installation and the potential consequences each of these threats can have on the energy and water systems sources, supply and distribution lines, and control systems. Disruptions to communications or personnel access to the installation as well as damage to critical equipment are also considered.

The model includes a list of applicable building, district, and installation-level strategies in categories ranging from backup power to energy (electrical and thermal) supply that have been associated with one or more resilience attributes as described in Section 1.1. Each strategy is assigned a weight value and each of the 10 R segments can be assigned a maximum score of 100 based on the strategies selected for each mission. To arrive at an overall mission score, the model assigns a cumulative average of the 5Rs. The overall installation score is based on the average of all overall mission scores.

Missions with more stringent resource availability requirements, or those installations subject to greater threat levels, may have higher resilience targets in some R areas than those mission sets who can relocate or are in less threatening environments. The value of the scorecard is in its ability to quantify improvements in resilience posture for a particular mission set or installation, and not as comparison tool between different missions or installations. Figure 1-2 shows an example resilience scorecard.

Performance within each of the 10 resilience ‘segments’ is shown by the relative fill of the grey bar. For each of the 5Rs, this rating is averaged, with performance communicated by the color of the heading (as seen in the legend). The color is used as an indicator of mission or installation performance against its mission requirements. Red, a low level of performance, is used when less than 50 percent of the capabilities needed to adequately meet mission requirements are in place. Orange denotes between 50 and 80 percent of required capability is achieved, and green, a high level of performance, indicates that more than 80 percent of required capabilities are in place.

Figure 1-2: Sample Scorecard 5Rs of Resilience



R1A	Cybersecurity	R3B	Sustainment Capacity
R1B	Physical Hardening	R4A	Emergency Protocols
R2A	Supply Path Alternatives	R4B	Analytics, Controls and Islanding
R2B	Source Diversity	R5A	Availability of Response Personnel
R3A	Demand Reduction	R5B	Equipment, Parts and Procurement

2 | CASE STUDIES AND LESSONS LEARNED

The IEP framework developed by AECOM was tested and refined between 2018 and 2019 at seven pilot installations throughout the continental U.S., including installations in cold and arctic climates. Installations will remain anonymous to ensure the confidentiality of their information, and will henceforth be referred to as Installation A, Installation B, and Installation C. These three installations will be referenced to highlight lessons learned on the resilience of thermal systems in cold and arctic climates.

2.1 Building Envelope Condition

Installations A, B and C have a wide variety of building types with construction dates ranging from World War II to 2010 and beyond. Facility visits and interviews with facility managers at these installations showed that many of the older facilities have not received renovations to the original building envelope, resulting in widespread use of facilities that do not meet modern construction standards for envelope performance. This has caused issues at some of these installations, where civil engineering personnel interviewed indicated that there are facilities at both those installations that have experienced freezing of fire suppression and plumbing systems within hours of losing heating. Anecdotal data collected is summarized in Table 2-1.

Table 2-1: Facility Freezing Timeline

Installation	Outdoor Temperature	Time to Freezing
Installation A	15 F – 20 F	8 Hours
Installation B	28 F	4 Hours

Note: This is based on anecdotal data obtained during interviews, not on actual tests.

Buildings such as aircraft maintenance and staging hangars are at increased risk of freezing due to their large volume and the continuous exposure to the environment caused by the opening and closing of hangar doors.

2.2 Heating System Types and Fuel Source

The heating system types observed at Installations A, B, and C are shown in Table 2-2.

Table 2-2: Heating System Types

Installation	System Types
Installation A	- Decentralized (building-level) gas-fired hot water boilers - Decentralized gas-fired forced air systems - Decentralized gas-fired infrared systems - Decentralized electric resistance heating
Installation B	- Centralized dual-fuel (oil and natural gas) steam boilers - Decentralized gas-fired hot water and steam boilers - Decentralized gas-fired forced air systems - Decentralized gas-fired infrared systems - Decentralized electric resistance or heat pump heating
Installation C	- Decentralized (building-level) gas-fired hot water boilers - Decentralized gas-fired forced air systems - Decentralized gas-fired infrared systems - Decentralized electric resistance heating

These systems present several vulnerabilities:

1. Reliance on natural gas as the primary source of fuel
   a. One the installations has a single natural gas line serving the entire region it is located in. This pipeline is at risk of damage due to the surrounding geological conditions, and heating systems at the installation do not have the capability to use an alternate fuel source.
   b. Natural gas supply can be curtailed by the utility during the winter to ensure service can be provided to critical customers such as hospitals and residences.
      i. Some installations visited by AECOM have opted to install a Propane Air Mixture plant to provide an alternative to natural gas during curtailment periods. However, using a propane-air tends to

result in increased maintenance needs for boilers and can be two to three times more costly.

2. Centralized systems
    a. Centralized systems have the advantage of reducing equipment maintenance needs and, when operated properly, provide greater heat generation efficiency than decentralized systems. However, not all centralized heating plants visited had enough redundancy in either power supply, fuel supply, or heating equipment, resulting in a potential single point of failure that can affect multiple buildings simultaneously.
    b. Centralized heating steam or hot water distribution systems are ageing and require extensive maintenance. Large distribution networks can be more prone to suffering disruptions and resource constraints can limit the amount of preventative maintenance that can be performed on the system.
        i. Heating distribution located underground can present significant maintenance challenges, particularly in regions at risk of earthquakes. Above-ground distribution is preferred where possible.
3. Minimal electrification
    a. Most of the heating systems observed used either natural gas or oil as fuel.
    b. Installations where natural gas curtailment is a concern use a higher proportion of electric systems such as electric resistance boilers or heat pump systems such as Variable Refrigerant Volume (VRV, also known as VRF) or ground source heat pumps.
    c. Civil engineering staff indicated that systems such as VRV or ground source heat pumps are difficult and costly to maintain.
    d. One installation indicated that the VRV and ground source heat pump systems they own do not appear to have been properly sized during design, resulting in frequent instances of loss of heating to the facility.
4. Limited heating system redundancy
    a. While it is common to have redundant cooling systems for critical communications equipment, very few of the critical facilities visited had redundant heating systems.
    b. Not all the installations had mobile heating units that could be deployed as backup in case of failure of the primary heating system at a facility.
5. Equipment age
    a. Much of the HVAC equipment at the installations visited - everything from boilers, to distribution, to air handling units- is well past the end of its useful life. Resource limitations prevent the timely replacement of this equipment.

2.3 Relationship between Backup Power and Thermal Systems

It is standard practice in DoD installations to provide backup power in the form of diesel-powered generators to critical mission facilities. However, DoD branches differ on the sizing approach for backup power generators and on the type of loads that are considered critical. Interviews with mission partners at Installations A, B, and C showed that HVAC-related loads, particularly when not required for providing cooling to servers and communications equipment, are not always covered by backup power generators nor have secondary sources of power such as an Uninterruptible Power Supply (UPS). This has resulted in the inability to maintain heating in certain facilities during power outages

3 | RECOMMENDATIONS AND BEST PRACTICES

Based on the observations at the installations A, B, and C the following best practices have been identified as having the potential to enhance resilience of thermal systems in arctic and cold climates:

1. Conduct a resilience assessment of existing and new construction building designs that evaluates performance in terms of principles of resilience. Using the Air Force framework as an example, ask the following questions:
    a. Robustness
        i. Is building and utility infrastructure robust enough to withstand the elements?
        ii. Are critical building and resilience components (for example, backup power generators) adequately protected from adverse weather conditions or other sources of physical damage?
    b. Redundancy
        i. Are there single points of failure in the utility supply systems, both from a source and a distribution perspective? This question can be considered at multiple scales: building, district/municipality, installation/regional level.
        ii. Do centralized heating systems have enough redundancy in capacity and distribution to maintain continuity of operations in case of failure?
    c. Resourcefulness
        i. Are there opportunities to reduce energy and water demand as to reduce the amount of resources required?
        ii. Are there sufficient resources locally to sustain critical loads in the building? For example, sufficient fuel storage, backup power, etc.
    d. Response
        i. Has a comprehensive emergency response plan been developed? The plan should consider how the response process would unfold, including how personnel would obtain access to facilities; how damage and repair tracking would be carried out; required response times for external contractors; communication protocols; etc.
    e. Does the local electric grid have the ability to respond intelligently to a disruption? For example, are there controls in place to enable load-shedding and increase sustainment time?
    f. Are there distributed energy resources and other electrical infrastructure that can be leveraged to island parts of the installation from the grid?

The framework can be expanded and modified to suit the needs of each DoD branch. The goal is to identify existing gaps and corresponding mitigation strategies.

2. Enhance the building envelope
    a. Loss of heating in cold and arctic climates can cause potentially irreparable damage to facilities and can place building occupants at risk. The quality of the building envelope plays a major role in increasing the amount of time from building heating loss to freezing, which can allow personnel more time to conduct repairs.

        In addition, an improved envelope can significantly reduce the amount of energy required to condition a building. One construction standard with interesting application to arctic climates is the Passive House standard. This standard uses passive design principles to minimize the amount of energy required to maintain comfort within a building.

        Some of the passive design principles and best practices for envelopes in cold and arctic climates include:
        i. Minimize thermal bridges, i.e. areas of the building where there is a direct conduction path between the interior and exterior of the building that can lead to increased heat loss from the conditioned space.

            Thermal bridges can be minimized during design by selecting wall systems such as double stud walls or those with rigid exterior insulation, and by paying close attention to details such as connections between structural elements, floors, roofs, and other areas of the building that may be exposed to the exterior.

ii. Super-insulate the building envelope, i.e. provide more insulation than the minimum required by code. The level of insulation required for a super-insulated envelope varies by location.

iii. Provide continuous exterior wall insulation paired with a high-performing air barrier. This can help minimize both thermal bridges and air infiltration.

iv. Insulate floor slabs, particularly when on-grade or exposed to the exterior.

While these strategies are most effective when applied during initial design and construction, existing buildings can be retrofit to achieve a higher envelope performance.

3. Diversify heating system fuels

   a. In remote areas where access to natural gas and other fossil fuels depends on a single supply source, relying on a single fuel type for heating systems can be a significant vulnerability. Strategies for addressing this risk include:

      i. Determine which fuels are available in the region and investigate the supply chain for those fuels. Natural gas may be more economical, but if there is only one single supply to the region its loss can be catastrophic. Consider whether other fuel types, such as oil or electricity may be easier to recover in case of an emergency.

      ii. Specify dual fuel systems in design. Dual-fuel boilers using natural gas with a diesel backup are one example.

      iii. Consider the electrification of heating systems, particularly in areas where there is a reliable electricity supply. Electric heating systems can be supplied by the utility grid, renewable energy resources, and fuel-based backup power generation sources, reducing dependency on the availability of fuels.

      iv. Evaluate the installation of alternative fuel sources that can serve as backup to the primary fuel being used by the heating system (non-electric). Examples include a propane-air mixture plant, liquified natural gas storage, or renewable natural gas (upgraded landfill gas) to replace natural gas. Heating equipment upgrades may be required to ensure compatibility with the alternative fuel.

4. Heating system design and maintenance

   a. Ensuring that heating systems are optimally-sized and adequately maintained is crucial for preventing critical equipment failures during periods of adverse weather. Strategies for addressing this include:

      i. Take a systems-based approach to design and conduct design reviews to ensure that equipment is adequately sized. Work with knowledgeable HVAC personnel to ensure that all equipment is properly installed.

      ii. Develop a maintenance plan for each heating system type. Ensure that HVAC personnel is properly trained in the skills needed to conduct repairs. Where possible, standardize equipment type and manufacturer to prevent obsolescence and ease the acquisition of replacement parts.

      iii. Ensure heating systems are tied to the backup power systems serving the facilities.