**Thermal Energy Systems Resilience in Cold/Arctic Climates Consultation Forum**

**Thermal Energy System Resilience Scope, Definitions and Concepts - Dr. Alexander Zhivov**

Organizers: ERDC, CCHRC, UAF, Fort Wainwright, EBC

Co-Sponsors: International District Energy Association, abaa, Cold Climate Engineering, Chena Hot Springs Resort

Forum Materials: 32 white papers, 4 Nat. Codes, 4 guides and 6 references.

Forum Objectives

* buildings in cold climates face unique challenges, not only due to the cold outside temperature, but also remoteness, limited utilities (resulting in many cases in a single point of failure), permafrost and seasonally frozen or thawed soils, and extreme temperature shifts

Thermal Energy System

* thermal energy system discussed is comprised of both demand and supply side
* demand side: mission related active and passive systems including thermal
* supply side: energy conversion, distribution and storage

Demand side – Requirements to thermal/environmental conditions

* thermal comfort and health criteria
* process related criteria
* building materials and furnishings requirements
* thermal requirements to unoccupied spaces

Resilience

* resilience of the energy system impacts the primary functionality of the building and the installation, during disruptions
* a resilient energy system is one that can prepare for and adapt to changing conditions, and recover rapidly from disruptions including deliberate attacks, etc

Energy Availability and System Recovery

* using availability concepts, we can quantify the overall resilience of a system in two phases: absorption of the event and recovery.

Difference between Resilience and Reliability

* the primary difference between reliability-focused planning and resilience-focused planning is the type of events included in the process and the methods used to quantify the impact of the events
* reliability-focused planning limits itself to high-probability evens with relatively low consequences

Energy Resilience Metrics

-energy quality

- energy availability

- reliability (maintainability)

Energy Availability

* Energy availability is defined as the percentage of time that an energy system is available to perform its required functions.

Reliability

* Reliability is concerned with the probability and frequency of failures.

Maintainability

* maintainability is defined as the measure of the ability of an item to be restored or retained in a specific condition

Maximum Time to Repair of Thermal System

* MTTR can be defined in terms of how long the process can be maintained or the building remains protected against damage from freezing of water pipes, sewer, fire suppression system
* MTTR can be estimated based on a building’s total heat consumption per the unit of time

Major factors affecting MTTR

* difference between inside and outside air temperature
* building envelope leakage rate
* internal thermal heat
* thermal mass of the building structures composed of concrete or stone materials is that constitute a high level of embodied energy enables the building to absorb and store heat to provide inertia against temperature fluctuation.

Improving Thermal Energy Resilience

* temperature reduction in mission critical and non-mission critical areas/buildings

Topics to be addressed during the forum

* specifics of construction in Arctic climate
* international experiences from Nordic Defense Agencies
* major natural, unintentional, and manmade threats
* resilience of thermal energy systems serving mission critical facilities
* current and best practices of building envelope designs
* air barrier in cold and arctic climates
* current and best practices of HVAC system designs

**Specifics of construction in Arctic climate – Panel Discussion**

**Building in Alaska (Robbin Garber-Slaght)**

Challenges in Alaska – it’s cold, it shakes, it’s vast, it burns, it’s far away, it’s thawing (the ground under our feet), it’s aging

Climate Zones: 4 climate zones in Alaska (zone 6, 7, 8, 9) – based on permafrost

Existing Public Buildings

* 72% of the cost == space heating

There are no statewide building or energy codes in Alaska. You can build any fool thing you want in Alaska. The closest thing to an energy code we have in the Alaska Housing Finance Authority. It’s voluntary.

BEES Code – close to 90.1

Question: What are the full units of measurement? IP units but we should state whether to use IP units or metrics

There are state opted codes for commercial buildings.

**Craig Fredeen – Cold Climate Engineering, LLC - Overview of share’s Cold-Climate Buildings Design Guide**

How the Design Guide Became

* international cold climate HVAC conference
  + every three years
  + march 13-16, 2021 in Tallinnn
  + 2012 it was in Calgary
* international group

why is a Guide needed?

* unqualified designers taking on projects in cold climates
* very little written guidance for practitioners
* costs of ignorance are high
  + excessive energy usage
  + property damage
  + life safety related to improper cold design

CCBDG Topics

* what is a Cold Climate?
  + If you are cold, then you are in a cold climate.
* Sustainability
  + Specific to how it’s related to human region
* Human comfort
  + Interior but also affects to those work outside
  + User
  + Construction worker
* Utilities
  + Water
  + Sanitary sewer
  + Fuel
    - Natural gas
    - Propane
    - Fuel oil
    - Biomass
    - Renewable/Electricity
* Strategic Design
  + Project location (southern exposure, coastal, permafrost, etc)
  + Weather (snow, wind speed/direction, etc)
  + Operation and maintenance
  + Construction logistics
    - Barges
    - Ice roads
    - Air cargo
    - Room and board
* Design Process
  + Design guides
  + Cultural considerations
* Design Calculations
  + Unique to cold climates
* Building envelope
* HVAC Design
* Equipment selection
* Controls
* Commissioning
* Case studies.

There was and continues to be a need for Best Practices guides for cold region design. Collaboration between cold region designers and operators benefits everyone. (Second printing of the Guide is due out Summer 2020).

**Rafal Turek (USACE – CENAN)**

**Thermal Energy Systems Resilience in Cold/Arctic Climates – Building Air Tightness and Thermal Bridging in Construction at Thule AB**

Thule AB – about 2 miles long and

Challenges

* contractors and craftsmanship of the work
* quality control/management
* adherence to details
* Arctic Hood Design
* Danish & Greenlandic Requirements (have to satisfy Danish Regulations as long as US regulations)

They extend the insulation to a several feet to prevent condensation.

Use thermal isolations to minimize the amount of thermal bridge going into the buildings.

What can go wrong? If not enough insulation, pipes can burst.

Arctic Hood: ice started to form and clogged up the air intake. They couldn’t find a design guide or mathematical solution/equation to actually design the hood like they had designed.

**Discussion**

Greenland does not use steel frames (like the Americans do), mainly use concrete. == Danish way of building. There are no trees in Greenland, so different from Alaska, but many of the cold climate challenges are the same.

Question: does anyone have a good design for arctic hood?

For a project in Antarctica: designed a hood that works well in South Pole. It might work well here too. The hood itself that they made in South Pole, standard, the hood comes out of the wall, you have a 6 inch offset, standard turn down, then you have a 45degree cut, 1 inch (2.54cm) burn screen.

350 ft/min. 🡪 it might clog up the filter because of dust.

Speeding up the airspeed to take up the dust? Maybe another piece of equipment needed.

Once you get inside, maybe you can slow down the air to 100 ft/min and then let it just fall out.

In Greenland, insulation is outside and the concrete will act as vapor barrier. They do have permafrost problems for their buildings. Some of the buildings have cracks because of permafrost. Here, they build buildings on piles because of permafrost.

The interior or wall is not cold, but humid, and that’s where the mold develops.

**Experience from Greenland, Quaanaaq – Anderse**

Greenland, world’s largest island, local government, part of Danish Kingdom

* 75% is permanently covered by ice
* 60,000 inhabitants
* 20 towns
* long winter

Heat Sources

* Excellent cheap low carbon heat source from hydro, power generation and/or waste incineration, which can over all heat demand

District Heating

* hydro powers is dominating

Surplus of Hydro power at some locations

* 5 hydro power plants
* Nuuk 45 MW
* Total capacity 91 MW

Utilized heat from power generation

* high potential waste heat from power
* 25% utilized waste heat

Quanaaq – new town for the population near the Thule air base

* have hot water systems

Data of Energy Plant

* district heating floor area: 14,500 sqm
* heat demand an net: 5,227 MWh
* Electricity demand: 2752 Mwh

District heating hot water network – above ground in arctic’s

* total efficiency of power and heat generation = 90%
* total efficiency of the DH-network = 85%
* total efficiency of the power grid = 95%
* total efficiency of heat and electricity at end-user level: 80-85%
* heat losses keep waster and waste water pipes from freezing

heat loss is a huge problem. District pipes keep the buildings from freezing, to minimize heat loss.

**Dr. Martin Kotol (DTU, Denmark) – Ventilation Systems in Greenland**

Older buildings (built before 1990) are better than the newer buildings in Greenland. IAQ based on CO2 levels.

Problem cannot be solved without some kind of mechanical ventilation solution.

Renovation solution - Having some kind of moisture recovery was essential.

Mechanical ventilation == necessity for comfort.

* IAQ in Greenland is poor
* natural ventilation is not a solution
* not all marketed solutions are ideal
* some are good enough
* obstacles
  + skills
  + economy
  + knowledge
  + legislation

**Five high-performance walls that work in Alaska – Aaron Cooke**

Sustainable village – lab, CCHRC tests air-tightness, with colleges students living in it, part of UAF.

All good arctic walls should eliminate thermal bridging if possible. Look for continuous external installation.

The Arctic Wall System – used for high desert environment, less humidity. Our humidity level is low. Great for people, tough for buildings.

Could be one of the tools we use for thermal barrier. In Fairbanks, out average winter humidity is sub 30%. Very difficult to get enough humidity. In coastal Alaska, high humidity due to different physical environments, 70-80% humidity.

Why do we have mold issues in the arctic? Humidity.

The Quinhagak Wall System - Build on a table, use steel studs. Never use steel stud in arctic for a single home because it transfers heat fast. But steel studs provide remoteness == get fit two.

Using logistics for primary design constraint.

The integrated Truss Wall System - Addresses the short consistency. Entire Truss mechanism. Similar to regular envelope. Diagonal members are the ones doing the work in Truss. You must have a thick wall because of the structure.

**Dr. Aylin Ozkan – A New Approach to Guide Early Stages of Building Design to Improve Passive performance Through the Time-Based Thermal Resilience Metrics.**

Climate Disasters are Escalating

Freezing Rain can be deadly

Beware power outages during heat waves

Heat waves kill more people than fires.

At the peak of winter or summer, their new housing will become uninhabitable within several hours after the grid goes time.

What is Thermal Resilience?

Nothing contributes more to building resilience than passive systems, and the most important passive system in a building is

Thermal Resilience Recipe

* high levels of thermal insulation
* appropriate window-to-wall ratio

Need

* simpler evaluations for passive systems integration and optimization

what is thermal autonomy?

* only passive inputs
* fraction of time

what is passive survivability?

* extreme weather knocks out energy supply
* duration of time

implementation of the Approach

* annual space heating and cooling use intensity
* thermal autonomy analysis
* passive survivability analysis

Thermal Autonomy vs. EUI

* TA may be used as an approximate indicator of space heating and cooling energy demands a the early stages of design without the need for more sophisticated simulation models comprising active systems.

Future Research

* a common set of conventions, protocols and benchmarks are needed
* the comfort and survivability indoor temperature thresholds vary considerably in the literature.
* The correlation between individual suite behavior and whole building performance remains to be investigated

**Peter Spafford (ABAA) – Air Barriers in Cold and Arctic Climates**

Challenges to construction and air barrier installation during extreme cold conditions

* heavy snow falls
* extreme low temperatures
* frost heating
* damage to the structure from frost
* buried construction materials
* equipment breakdowns and failure
* material limitations
* material options for cold climates
* storage & handling of Air Barrier Materials

Heavy snowfalls buries much of the construction materials that were stored outside.

In some locations, security is an issue as well.

Cracking of CMU blocks resulting unheated building during construction. The floors heaved up and damaged many of the CMU walls.

Construction of the roof assembly – multiple layers of rigid insulation. Remove snow from the roof deck prior to the application of the deck board and torch grade / thermal-fusible air barrier. Make sure moisture does get through the deck. Install roof deck prior to the application of the roof air barrier. Most of the air barrier need to have some kind of support mechanism. It’s a huge cost to the construction process.

Install two layers of four inch thick rigid XPS foam insulation and plywood sheathing.

Roof to wall intersection requires the remaining rigid insulation to be installed. The air barrier should be properly sealed to maintain the continuity in critical areas.

Every penetration going through the roof assembly should be properly sealed to make sure that air is not going to leak.

They also test air leakage testing on roof/wall areas. (ASTME 1186)

Tenting & heating == highly recommended to allow construction to continue under severe low temperatures.

Cold weather options for air barrier materials and systems

* torch grade / thermo-fusible air barrier membranes
* factory bonded self adhered board membranes
* factory bounded fluid applied board membranes
* low temperature fluid applied & self adhered systems
* medium density spray polyurethane foam
* insulated board stock systems.

Air Barrier Materials & Systems

* most manufactures have “LOW TEMP” materials that would be able to be used in many environments

**William Rose (UIUC) – White Paper – Protecting arctic commercial buildings during periods of electrical and thermal systems outage**

Some of the loose ends that need to be addressed:

* In Rafal’s presentation, we saw failures at corners. We need to consolidate on how to make sure that 3 dimensionality of a corner is able to be conveyed to the contractor and can be done appropriately.
* Mold growth. Any need for an additional membrane toward the interior of the construction tends to go away. Vapor barrier – original intent was to prevent mold growth. The appearance of mold growth == essentially comes down to where we got thermal bridges and that’s where the risk occurs.
* Insulated panels – failure of joints at these insulated panels. Cam locks are uncommon element of lateral tension. They are intended to pull the assembly together. We want to minimize thermal bridging. Can we use tension?
* Foundation insulation in cold climates. We are looking for continuity of insulation at the outside of structure in order to reduce likelihood of heat flow from outside.
* Dryers. Dryer vents. We can get away from resistant closed dryers.
* Pipers. Measure the water pressure. Pressure relief can solve the problem.
* Logistics.

**JBER - Ms. Tamera**

Military construction

* Making a wall that has a hard exterior and good insulation inside
* Needs to be non-combustible
* Ground with no permafrost
* Involves a lot of careful details
* Balancing out budget for maintaining, constructing, etc
* Determine what can be maintained overtime
* Don’t build things to the latest technology due to challenges

**Miles**

UFC requires compliance with building envelope.

In arctic, (zone 7, zone 8) adhering to proper moisture design is important

Because of dry air, we can get away with bad moisture design here. What we’re seeing a lot is the call for building humidification to have moderate amount of humidification. But this creates problem for building design. (mold growth)

We need to make sure we’re not causing moisture problems. What’s appropriate is to take a deeper look at hydro thermal design not just the R values.

**Lome – Optimal Northern Wall Design**

How to increase R-values in walls?

* stuff it with more insulation or wrap it

Walls Selected for Analysis

* cavity insulated
* exterior insulated
* split insulated
* insulated structure

Hygrothermal performance

* in very cold climates, having sheathing below interior dew point creates a high risk of failure due to air leakage condensation
* for SPS walls, detailing of the joints is critical to achieving performance with respect to air leakage condensation
* well installed and fully bonded spray foam can provide some assistance in limiting potential for air leakage to sheathing
* maintaining sheathing above interior dew point by providing exterior insulation significantly decreases risk

Constructability

* used interview with builders who operate in Canada’s North to quantitatively assess constructability on a scale of 1 to 10
* ease of achieving airtight detailing was a key consideration
* specific techniques such as a temporary ledge at the base of t he wall to facilitate exterior insulation installation can significantly improve constructability.

Cost

* weight and volume are a major factor due to shipping cost
* location matters a lot
* Many materials available in the South are not readily available in the North or are prohibitively expensive.

Split-insulated walls come out to be the winner in many situations.

**Building strategies in Greenland – Professor Eva Moller**

Greenland – island operated community, no road between towns or settlements, all transport by ship or plane

Few resources in Greenland, no trees, almost everything must be imported.

Energy supply: 20% from hydropower plants, rest from fossil fuels.

Harsh climate – colder, dryer, and less windy in the north.

Nuuk (capital of Greenland ) – wet, cold, windy

Single-family houses

* mass-produced wooden standard houses 1960s-1970s
* assembly kit shipped from Denmark
* owned by the government

modern houses

* standard wooden houses
* privately owned

multi-story houses

* high levels

Three current strategies

* traditional building style:
  + concrete and timber based
  + Filigree floor divisions
  + Lightweight facades
  + Process:
    - Concrete works
    - Timber framing and roof
    - Wind barrier + windows
    - Heat for drying + cladding
    - Vapor barrier
    - Interior boards
* non-organic building materials
  + mold need nutrients to grow 🡪 need organic material e.g. wood, paper or cardboard
  + can grow on dust
  + no wind barrier
  + cold surfaces
* using elements
  + precast concrete
  + CLT elements
    - Organic materials
  + Lightweight elements with timber or steel frames
    - Tightness can be a problem

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1. Summary of the mornings topics : Aaron, CCHRC
   1. Strengths of the conference:
   2. Definitive audience of the DOD is helpful to guide the conference
      1. Informed decisions for location
         1. Avoid permafrost locations
      2. Participants from many arctic communities
      3. Is it possible to develop a guideline from this conference?
         1. Agreed upon values
            1. Recommended R-value
            2. Air-tightness standard

Residential, commercial, military

* + 1. Developing standards from the conference
       1. CCHRC Recommended minimums: R40 for the walls, R60 for roof for Interior and N. Alaska. Coastal Alaska is R30-35 walls, R45-50 for the roof. These are attempts to balance performance and economics.
       2. Air-tightness: 0.35 CFM50/SF is a reasonable approach for residential building
          1. Old building of the RTF – 0.1 CFM50/SF. New RTF – 0.02 CFM50/SF
       3. Window to wall ratio a concern? (audience question)
          1. Not as much of a concern (JBER folks)
          2. Hangar doors and overhead doors are more of a concern than a building having too many windows
          3. Emmett – window leakage isn’t as much of a concern anymore. Knowledge base from the trades has increased.
       4. How do we enforce these standards through design and build process?
          1. Builders have caught up to the standards and can cut corners because they know they can hit air-tightness targets with min. effort
          2. Standards need to become more stringent since the trades have caught up
          3. How do we have a pre-check before final testing to prevent costly repairs to attain air-tightness?
       5. Building envelope insulation values
          1. 90.1 and more stringent standards are not proving to be life-cycle cost effective

Audience member - Consider delta T and fuel costs more than a set amount of insulation

Aaron- fuel costs fluctuate more than delta T

Consider institutional ownership more than traditional homeownership.

* + - * 1. Audience member – Thermal resilience is more effective with higher R value. Lifecycle costs ignore the resiliency factor.

Alexander K. – 3 hours is the time available to repair in bad envelope. Over 12 hours is the time available to repair in a good envelope.

Mission is always priority over lifecycle costs.

RMI employee – We’re in danger of forgetting the real objective of the building by focusing on small, gritty details. A guide has to be system focused.

Aaron – priority

Can we apply energy efficiency into mission priority? Are some buildings allowed to be leakier or thermally weaker than others?

UFC should establish thermal resiliency standard. Makes more sense to couch it this way as your building must last 6 hours or so without heat rather than saying you must have insulation that meets a certain standard. Steam and natural gas make it so higher insulation looks unappealing, but being able to survive a no heat/power situation resonates

* + - * 1. A vote will be taken to create a building working group to establish metrics at the end of the day

1. Paul Volkman ASA Army (Intro/moderator for the next panel presentation)
   1. Propagates policy on thermal resilience and sustainability throughout the Army
   2. 2009 – Congress first asked DOD to report on grid stability for military installations. Sparked the conversation on resiliency.
   3. 2012 – National Defense Act; began talking about access to power and how to recover. This has caused them to move away from efficiency and conservation to a framework of resilience.
   4. Up until 2019, electricity has been the focus of the resiliency and grid conversation. Natural gas has only become a concern as of late. Thought to be ever-present
   5. 2017 – Alexander brought the topic of thermal resiliency to the forefront of the DOD’s thought process.
   6. Now electric, gas, and thermal resilience are an issue.
      1. Not just the North, but the South. i.e. Heat waves and power outages
   7. Resiliency is only a focus on mission critical buildings
      1. Library can go without heat and power, but the missile defense building cannot
      2. FTWW mission is to deploy soldiers to the Pacific. Buildings that contribute to this mission are priority.
   8. 14-day resiliency is the target (water, power, thermal)
2. Panel Presentation on energy and resiliency at the installation level
   1. Bill Chedister (FTWW)
      1. Get information on the installation from the meters, building automation systems, competent maintenance crew
         1. How to quantify costs of resiliency? is a major point of concern. Costs to recover
   2. John Wentz (FTWW)
      1. FTWW started a resiliency campaign in 2008. Began with changing thermal envelope designs. 25-year lifespan design parameter, so mission critical buildings began getting R60 and R90 systems because it’s known that buildings will be used beyond lifespan
      2. In the event of a power/heat failure, building is not just a concern. Personnel usage (doors opening) leads to infiltration issues, especially aircraft doors and vehicle doors. No way to recover from that kind of heat loss at severe (-40) temps.
      3. Distribution systems can present an issue in the order of operations from restarting buildings or building systems, as well as presenting a vulnerable point for sabotage from adversaries
         1. i.e. if the goal is to make sure soldiers don’t get sent off FTWW then someone will make sure to cut steam/power at the same time. Must stay one step ahead
   3. Sonny (JBER)
      1. Joint base of Army and Airforce.
      2. Most heat is from natural gas. Small percentage of electric resistance or fuel oil. Facility boilers use natural gas.
      3. $35 million/year in energy costs base-wide
      4. Ft Richardson
         1. Landfill methane to electricity conversion at that facility (7MW).
         2. 9 MW diesel generators
         3. 11.5 MW peak electric requirements in the winter
      5. Natural gas has only one pipeline from cook inlet to Anchorage, so vulnerable. Peak demand at extreme temperatures (subzero) is also a concern
      6. Must have emergency plan for loss of natural gas
         1. JBER demo’d two former central heat and power plants, creating a resiliency issue
      7. Geothermal can be an option for thermal resiliency. Even though it may not be cost effective to have geothermal, it may be possible to implement at mission critical
      8. Microgrids or clusters of plants with dual fuel may be option for JBER
      9. Bernie Carl – geothermal is the resilient solution
   4. Lars Truelsen (Danish Ministry of Defense)
      1. Station North (1 of 5 stations on Greenland)
         1. Mission is observation and to maintain sovereignty
         2. 900 km from the north pole, 200 person station
         3. Climate and energy strategy for arctic installation
         4. All wood buildings from the 50’s. 51 buildings
         5. Fly-in only for materials and fuel
            1. Gravel runway, so people are left during the winter
         6. Use fuel oil to generate electricity, which is used for heating, fueling vehicles and aircraft.
            1. Next step is for them to figure out how much fuel goes to heating and electricity versus how much is used for fueling vehicles
         7. No sewer systems on site. Honey bucket/incinerator
         8. Freshwater lagoon to supply water to buildings
      2. Steps to increase resiliency at Station North
         1. Need to establish a meter structure to determine electricity usage
         2. Temperature logging (interior and exterior)
         3. 3 years worth of fuel oil available as back-up
         4. Fuel transportation costs must be realized before economic savings can be calculated
         5. Next closest base takes 1.5 month to travel via dog sled (at normal pace). That base has water access, but has no harbor.
3. Panel presentation on threat assessments and risk
   1. Mark Adams (Chief of Operations at FTWW)
      1. Old, steam powered coal plant at FTWW.
      2. Design for resiliency from power loss, seismic issues, wildfire issues,
         1. FTWW and Fairbanks are isolated. Stockpiled coal for 90 days
      3. FTWW has a summer and winter threat matrix to identify and prioritize threats
         1. Summer: floods and wildfires
         2. Winter : cold weather, snow, ice
   2. David Bragg (Army Corps stationed at Eielson)
      1. Program manager of construction related to F35 deployment
      2. Steam, power, water, and fire suppression are priorities
      3. High groundwater levels and lots of water contamination at Eielson
      4. Threat priority list based on most dangerous and most likely
         1. Base level: the environment. Steady state operations, but all risks associated with weather are lumped here
         2. Redundancy is key to resiliency. Tough to negotiate from a funding standpoint.
      5. Combined heat and power plant, utilidors are mission critical for instance. What is good enough to maintain the mission? 70% capacity, 60%, etc.?
      6. No back-up for key nodes from powerplant, no water back-up, only fuel back-up.
      7. Anticipate weather and climate issues ahead of time other mission falls apart
         1. For example, radiant slab at hangar door to prevent mission critical personnel from scraping ice
      8. Red, green, and amber chart is the generic risk assessment protocol without going into classified information
   3. Nick Janssen (Doyon Utilities)
      1. Utility side delivers to within 5’ of a building
      2. Specific threat of freeze-ups
         1. Most things are in utilidors
      3. Doyon is in year 11 of a 50 year DOD contract for FTWW, Greely, JBER
         1. electricity, steam, condensate, water, sewer
      4. Pipe freezing considerations
         1. Snow cover, incident sunlight, flowing water over ground, frost depth miscalculations, burial depth, and ground conductivity
      5. Methods of freeze protection
         1. Utilidors
            1. 30 miles at FTWW. Heat loss from steam lines essentially keeps it frost free
            2. Most expensive, but most robust
         2. Direct Shallow Bury
            1. Min. 4ft burial. Polyurethane spray foam for insulation
            2. Relies on circulation to prevent freezing rather than thermal protection. This includes if there is no demand; the liquid must flow
            3. Works best to connect utilidors as opposed to an entire network
         3. Direct Deep Bury
            1. Most common at JBER. Buried at min. 10’
            2. Polystyrene foam board insulation
            3. Piping is kept out of freezing soils and relying on ground heat
         4. Failure countermeasures
            1. Heat trace (effective, but not best practice)
            2. AC thaw machine (like a welder) – no longer used for safety reasons
            3. Draining the pipe
            4. Excavation
      6. Case study : FTWW Hangar 4
         1. Fire suppression loop around the hangar
         2. Water pipe was relying on circulation for freeze protection.
         3. Pipe was placed in the active layer under a runway
         4. No alarms on the pump system
         5. Installed under structural concrete (runway), so excavation is expensive
         6. 6-8 million repair cost
   4. Kevin Bjella (CRREL) - Threat from permafrost
      * 1. Permafrost – High arctic and subarctic permafrost
           1. Ground ice is the problem, not frozen rocks or soil
        2. We know how to build on permafrost ($$$)
           1. Either keep ground frozen
           2. Or get rid of ground ice
        3. Identification of ground ice is changing the conversation for building placement
           1. Buildings used to be built where the mission wanted them built regardless of site conditions
        4. Thaw stable vs. Thaw unstable
           1. Ice-poor: no problems
           2. Ice-ruch: high bearing capacity when frozen, but zero bearing when thawed
        5. DoD Arctic Construction
           1. Not much different from temperate climate construction
           2. Major difference is elevating the structure and passively or mechanically freezing the ground
        6. Revised techniques
           1. Surface geophysics

Ground penetrating radar, measuring electric resistivity or conductivity to find ice

* + - * 1. Borehole drilling – best if happens after geophysics. Allows for targeted drilling

Direct push technology

Continuous sampling

* + - 1. Optimal locations
         1. Case of two types of soils in one area

CCHRC sustainable village

Ice poor area has the ability to bear slab on grade structures

Ice rich area necessitate a piling foundation

* + - * 1. Thule AB hangars

Design constraints from the equipment stored there necessitated a slab on grade structure

Used GPR to find ice and allow targeted excavation and refill with NFS gravel

* + - * 1. White Painted Airfield at Thule

Removing the white paint

Created melting conditions

The resistivity measurements allowed for an exact spec on how much insulation to bury over the points sensitive to thaw

* + - 1. Remediation of Thaw Affected Structures
         1. Generally thaw affected structures do not fail overnight. Slow process
      2. Thermokarst
         1. Upland thermokarsting

Creates a confluence of warming permafrost and increase in precipitation that will lead to thermal erosion events

* + - 1. Climate change and permafrost
         1. Tough to forecast changes to the permafrost
         2. Design standards need to change to accommodate for compromised permafrost
  1. Andrea (ACOM)
     1. Contractor for the Airforce to develop installation energy plans (JBER)
     2. Installation energy plans (IEP)
        1. Establish baseline conditions
           1. Threats, infrastructure vulnerabilities, and performance
        2. Mission profiles
           1. Requirements, gaps, and strategies
        3. Installation profiles
           1. Strategies and courses of action
        4. Implementation
     3. Resilience (5 Rs)
        1. Robustness, redundancy, resourcefulness, response, and recovery
     4. JBER was able to use the 2019 earthquake as a test run for its resilience
     5. Developed a resilience scorecard that measures level for existing installations
        1. Start at the mission level and then work backwards to an installation level
     6. Case studies/Lessons Learned
        1. Collected anecdotal data on installation history
           1. 4-8 hours for certain facilities
           2. Didn’t have to be that cold for some facilities to have a short time to freezing
        2. Heating system and fuels
           1. Vulnerabilities

Natural gas

System decentralization

Distribution vulnerabilities

Limited system redundancy

Especially for heating

* + 1. Best practices
       1. Design and renovate with the 5 Rs in mind
       2. Diversify heating fuels
       3. Maintenance planning and training