US Army Corps of Engineers

ERDC Engineer Research and Development Center

Thermal Energy System Resilience Scope, Definitions and Concepts

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ERDC-CERL

Fairbanks, AK

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Organizers

ERDC Engineer Research and Development Center

Cold Climate Housing Research Center CCHRC

UAF University of Alaska Fairbanks

U.S. Army Fort Wainwright

EBC Energy in Buildings and Communities Programme

Organizing Committee: Alexander Zhivov (chair) and Elon Slaughter (ERDC- CERL), Kevin Bjella, Dragos Vas (ERDC- CRREL) and Gary Larson, Robbin Garber-Slaght and Sandee Mayo (CCHRC), Dayne Broderson (UAF), William Chedister (Ft. Wainwright) and Deilia Wiliasenor (CHSR)

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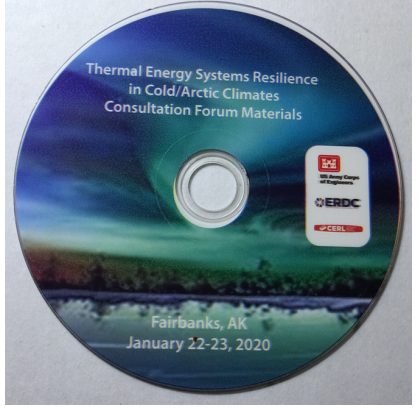
Where hospitality and sustainability go hand in hand

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



THERMAL ENERGY SYSTEMS RESILIENCE IN COLD/ARCTIC CLIMATES
CONSULTATION FORUM
Fairbanks, AK
January 22-23, 2020

Agenda
List of Participants

1. **INTRODUCTION**

   Alexander Zhivov (ERDC-CERL)
   Thermal Energy System Resilience Scope, Definitions, and Cor

2. **SPECIFICS OF CONSTRUCTION IN ARCTIC CLI**

   Craig Fredeen (Cold Climate Engineering, LLC)
   Operations and Maintenance, a Critical Part of Resilience

   Robbin Garber-Slaght, Nathan Wiltse, and Dustin Madden (C
   Buildings in Alaska

   Eva Møller and Martin Kotol (Technical University of Denmar
   Building Strategies in Greenland

   Rafal Turek (USACE – CENAN, New York District)
   Thule Projects

3. **INTERNATIONAL EXPERIENCES FROM NORDIC SUB-ARCTIC AND ARCTIC INFRASTRUCTURE I**

   Oddgeir Gudmundsson (Danfoss)
   Camps in the Arctic

   Andrea Mengual (AECOM)
   Case Studies and Lessons Learned from Implementing the Air Framework at Installations in Cold and Arctic Climates

   Sonny Turpin (Joint Base Elmendorf-Richardson [JBER])
   Thermal Energy Systems Resilience at Joint Base Elmendorf R

4. **RESILIENCE OF THERMAL ENERGY SYSTEMS**

   Kevin Bjella (ERDC-CRREL)
   Innovations in Permafrost Ground Ice Characterization

   Brent Goering (US Army Corps of Engineers, Alaska)
   Thermal Hardening – Arctic and Sub-Arctic Regions

   Aylin Ozkan and Ted Kesik (John Daniels Faculty of Architecture), William O'Bri
   Toronto, Toronto, Canada)
   Thermal Resilience of Buildings and Related Metrics

5. **CURRENT AND BEST PRACTICES OF BUILDING ENVELOPE**

   Axelarris (Design Alaska)
   Moisture Risks Associated with Current State of UFC Compliance Enforcement i and 8

   Tamra Nygaard, USACE Alaska District
   Arctic and Subarctic Thermal Protection Practices

   William Rose (University of Illinois, Urbana-Champaign)
   Protecting Arctic Commercial Buildings during Periods of Electrical and Therma

   Peter Spafford (Air Barrier Association of America)
   Best Practices for Air Barriers in Cold Climates

6. **AIR BARRIER IN COLD AND ARCTIC CLIMATES**

   Peter Spafford and Laverne Dalgleish (Air Barrier Association of America)
   Air Barriers in Cold and Arctic Climates

   Emmett Leffel (Alaska Thermal Imaging L)
   Ten Years of Building Enclosure Testing on Alaska Military Base Projects

7. **CURRENT AND BEST PRACTICES OF HVAC SYSTEM DESIGI**

   Lon Fiedler (TKDA)
   District Cooling and Heating System Concept: Utilizing Low Temperature Waste

   Martin Kotol and Eva Møller (Technical University of Denmark)
   Ventilation Strategies in Greenland

   Tom Marsik, Vanessa Stevens (Cold Climate Housing Research Center [CCHRC]
   Air Source Heat Pumps in Cold/Arctic Climates

   Robin J Rader and Emily Winfield (Design Alaska)
   Mechanical Design Best Practices for the Interior Subarctic

   Steven Taylor(WARE)
   Temporarily Boilers - Contingency Plan Check Off Sheet

8. **ENERGY GENERATION, STORAGE, AND DELIVERY STRATE**

   Anders Dyrelund (Ramboll Denmark)
   Specifics of Construction in Arctic Climate - Experience from Greenland, Qaanaa

   Oddgeir Gudmundsson and Jan Eric Thorsten (Heating Segment, Denmark), Anders Dyrelund (Ramboll Denmark)
   District Energy – The Resilient Energy Infrastructure

   International Energy Agency (IEA)
   Subtask D. Integration of Energy Systems Resilience Analysis into Energy Master Plan

   Kurt Knitter (University of Alaska – Fairbanks)
   Resilience of Thermal Energy Systems Serving Mission Critical Facilities

   George Roe (ACEP)
   Estimating Alaska Community Heat and Power Requirements

9. **ENERGY EFFICIENCY AND RENEWABLE ENERGY STRATEGIES**

   Whit Hicks (RESET)
   Syngas-Alaska Style

   Bernie Karl (CHSR)
   400kW Geothermal Power Plant at Chena Hot Springs, Alaska

   Dan Sambor (Stanford University)
   Predicting Thermal Load Profiles for Integration of Renewable Energy in Islanded

10. **THERMAL ENERGY RESILIENCE STUDIES AT FORT GREELY / WAINWRIGHT**

    Jonathan Goebel (ERDC-CERL)
    Fort Wainwright Energy and Resilience Thermal Degradation Testing Protocol

    Richard Liesen (ERDC-CERL)
    Energy and Thermal Resilience Analysis Fort Wainwright Building 3013

11. **NATIONAL CODES**

    Decree of the Ministry of the Environment (Finland) on the Energy Performance c Buildings. 2014.

    Finnish Government Decree on the Numerical Values of Coefficients for Forms of Buildings. 2016.

    Greenland Building Code. BR2006DK. Bygningsreglement 2006.

    Norwegian Building Authority. 2017.
    Regulations on Technical Requirements for Construction Works. An unofficial Eng of the regulation "Forskrift om tekniske krav til byggverk (Byggteknisk forskrift -

12. **GUIDELINES**

    Canada Mortgage and Housing Corporation
    Optimal Northern Wall Design Guidelines. RDH Project 8017.300

    Headquarters, Department of the Army (HQDA)
    TM 5-698-1. 2007. Technical Manual Reliability/Availability of Electrical and Mechanical Systems for Command, Control, Communications Computer, Intelligence, Surveillance and Reconnaissance (C4ISR) Facilities

    Ted Kesik, Liam O'Brien and Aylin Ozkan (University of Toronto)
    Thermal Resilience Design Guide

    Ted Kesik (University of Toronto) and Liam O'Brien (Carleton University)
    Enhancing the Livability and Resilience of Multi-Unit Residential Buildings (MURBs) MURB Design Guide

13. **OTHER USEFUL REFERENCES**

    Richard Armstrong (Alaska Housing Finance Corporation)
    A White Paper on Energy Use in Alaska's Public Facilities.

    Peter Erler (Copenhagen School of Design and Technology)
    Passive Houses in a Cold Climate

    Alex Ferguson (RDH)
    Energy Efficient Housing Guidelines for Whitehorse, YT: Energy Optimized House

    Kaishan
    Renewable Energy Technologies: ORC and Steam Expanders

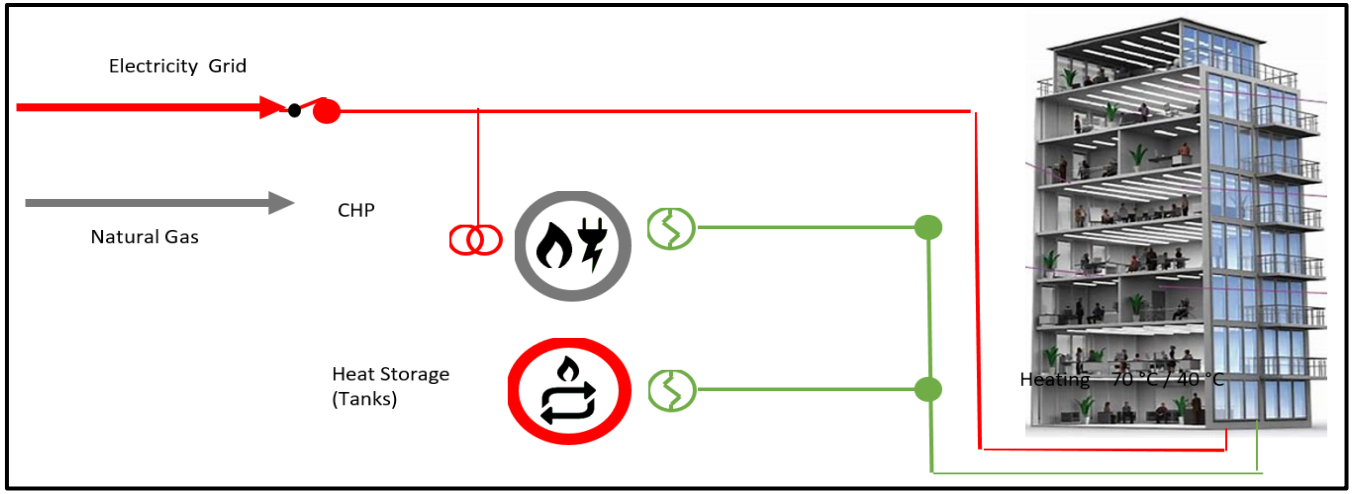
    Bernie Karl (CHSR)
    Cat Trail Plastic Recycling Project Located at Chena Hot Springs Resort

    Petra Vladyková
    An Energy Efficient Building for the Arctic Climate. Is a Passive House Sensible Solution for Greenland?

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.
- Special consideration must be paid to efficiency of envelopes, reliability of mechanical systems and their maintenance needs, durability of piping systems, robustness of building controls, and commissioning.
- In addition to reliable and resilient power supply, mission critical operations in Cold and Arctic climate require reliable and resilient thermal energy supply systems
- This Forum was organized to bring together researchers, practitioners and facilities managers to present and discuss different aspects of thermal systems resilience and reliability, that can result in practical information for developing a Planning Guide on Resilient Thermal Energy System for Cold and Arctic Climates.
- This Forum contributes to projects funded by the U.S. Congress, DASA, ESTCP and IEA EBC Program

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 demand by the process, HVAC systems maintaining required environmental conditions for the process and comfort for people, and a shelter/building that houses them.
- **Supply side:** energy conversion, distribution and storage system components.

Demand Side - Requirements to thermal/environmental conditions

- Thermal comfort and health criteria
- Process related criteria (IT technologies, medical facilities, industrial, etc.)
- Building materials and furnishings requirements (mold, mildew, freeze protection, etc.)
- Thermal requirements to unoccupied spaces (energy conservation and sustainability)

Requirements to dry bulb temperature and relative humidity for occupied and unoccupied fac**ilities**

Occupancy/Use	Humidity not to exceed	Maximum Dry Bulb Temp	Minimum Dry Bulb Temp
Occupied	50%	75 °F	70 °F
Unoccupied (Short term)	50%	85 °F	55 °F
Unoccupied (Long term)	50%	No Max	40 °F
Critical Equipment	50% or equip requirement if less	Equip max allowed	Equip min allowed

Resilience Vs. Reliability

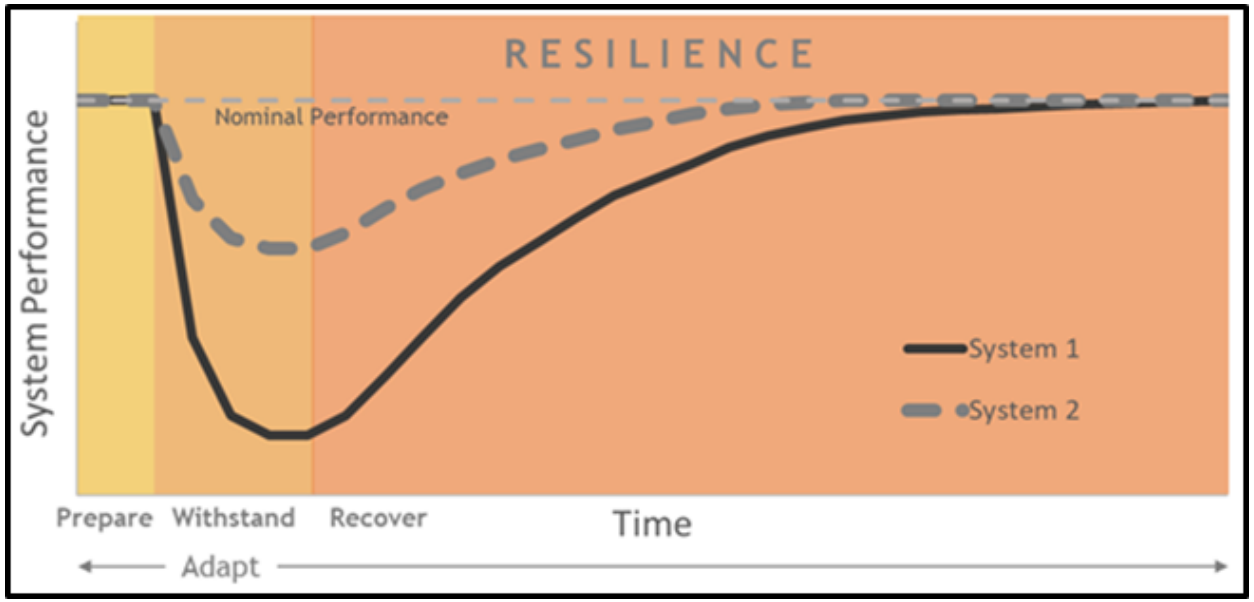
Resilience

- 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, accidents, and naturally occurring threats (PPD-21, U.S. Army 2015).
- A resilient energy system prioritizes and maintains performance of important services such as mission-oriented functions, and safety and health oriented functions, food, water, shelter, etc.
- Resilience is contextual – defined in terms of threats or hazards. It applies to hazards with low probability with a potential for high consequence and therefore naturally fits within a risk-based planning approach.

The performance-based resilience metric "system impact" (SI) is the integral over time of the actual system performance minus the target (or nominal) system performance:

$$SI = \int_{t0}^{tf} [TSP(t) - SP(t)]dt.$$

where TSP(t) is the targeted system performance through time – the nominal performance of the system without a disruption, and SP(t) is the system performance subject to the disruption (Vugrin et al. 2010).

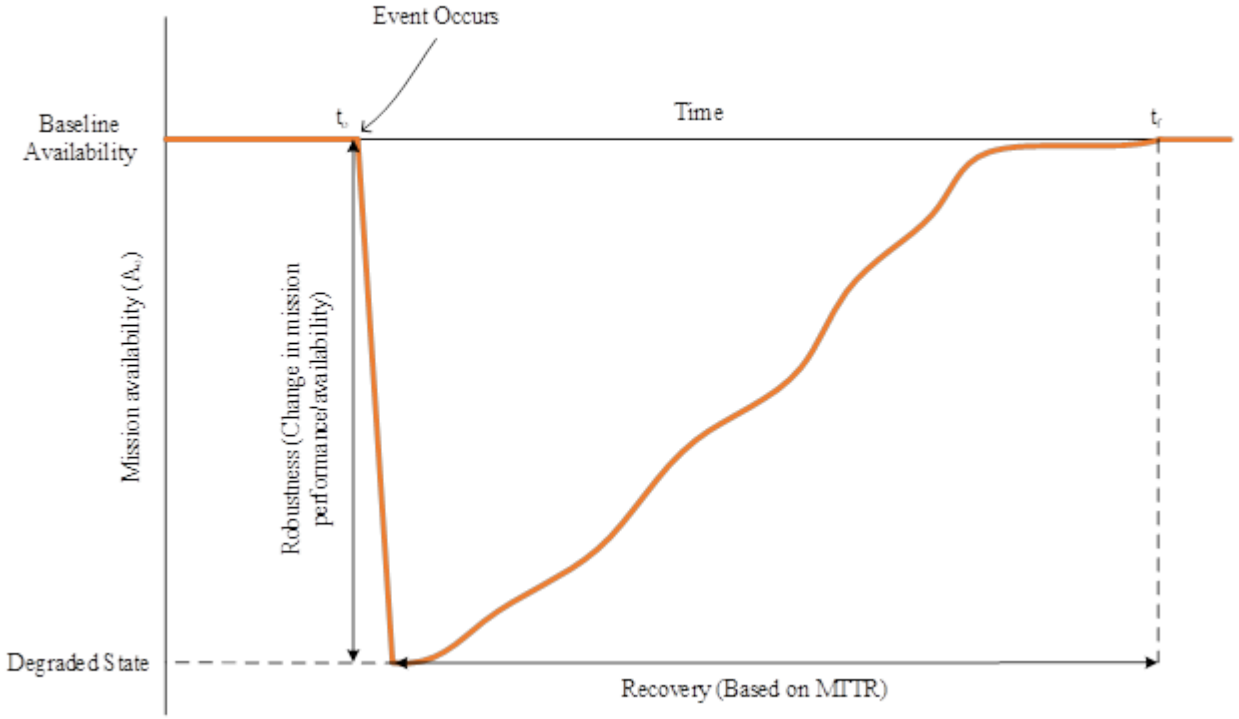


Energy Availability and System Recovery

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

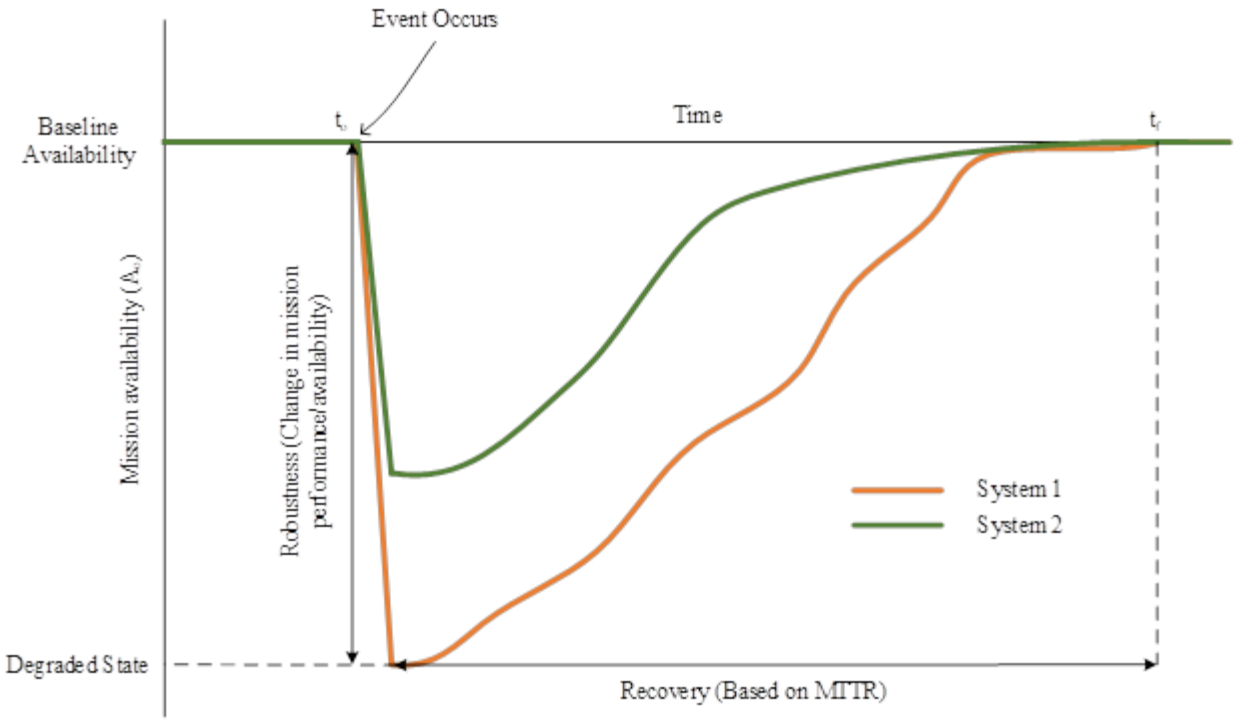
Consider an event occurring as shown in Figure below. Immediately following the event, there is a sharp drop in mission availability. The change in mission availability from the baseline to the degraded state represents the robustness of the system to that particular event. The lower the change in mission availability, the more robust the system.

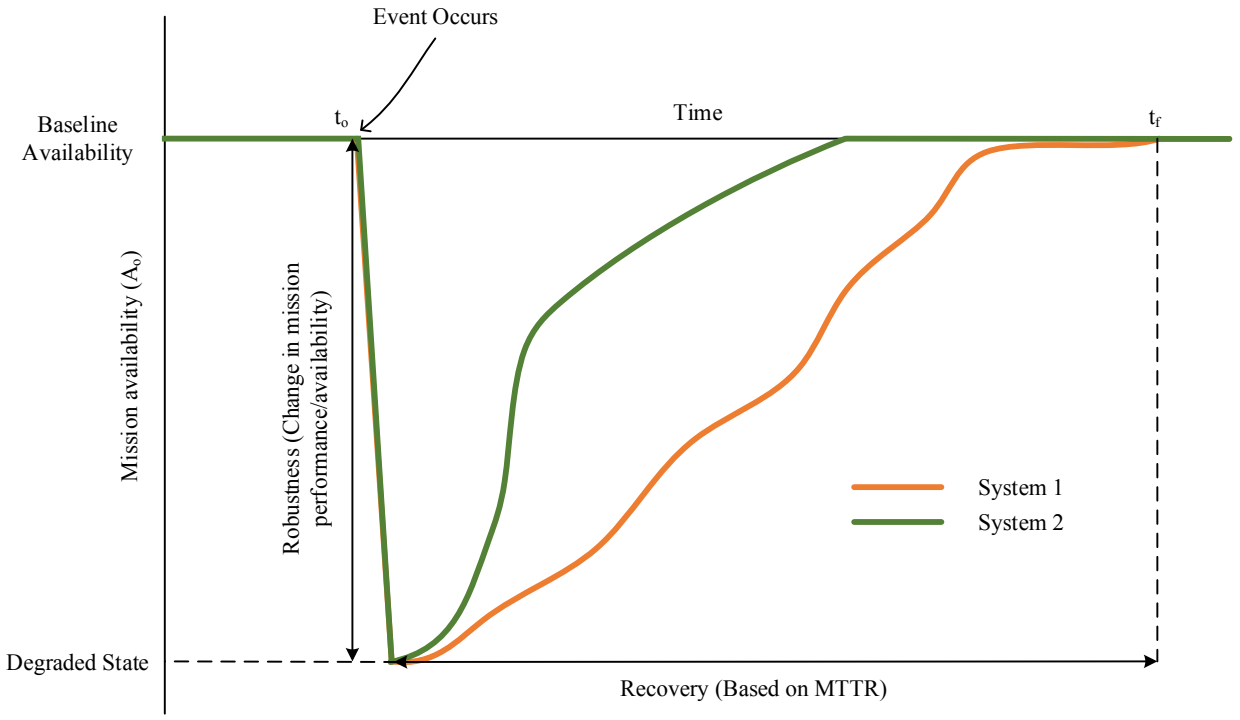
The time required to restore the system to its baseline state is referred to as recovery. This is based on the mean-time-to-repair (MTTR) of any assets affected by the event, and may be affected by several factors including site remoteness, event severity, and environmental conditions.



Energy Availability Vs Energy System Recovery

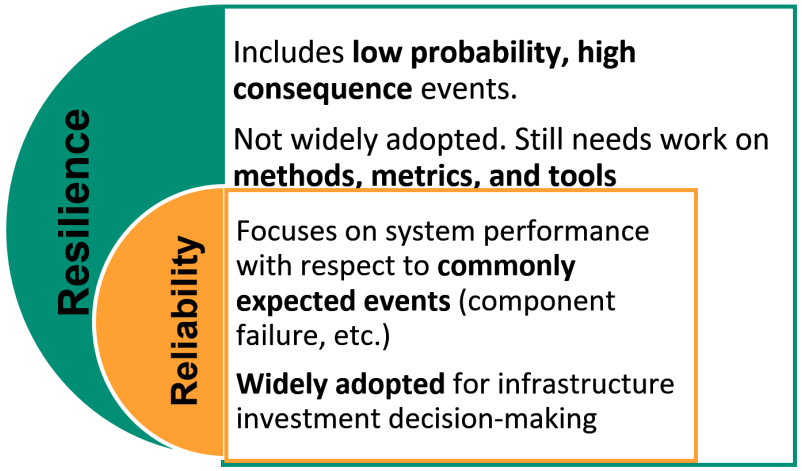
Depending on mission needs, it may be more important to prioritize either robustness or recovery. For example, Figure 2 shows two systems with different levels of resilience. The two systems have the same recovery time, but System 2 has a lower initial decrease in mission availability. System 2 is more resistant to the postulated event, and is more resilient than system 1 despite having the same recovery time. This may be beneficial for improving overall resilience at remote sites where recovery time is limited by the physical demand of getting replacement parts to the site.





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 events with relatively low consequences (U.S. DOE 2017). System reliability is the desired level of system performance. Besides information on statistical system element failure, it should be adjusted for commonly expected threats and hazards for the locality of interest, which are called Design Basis Threats (DBTs).
- Resilience planning is based on low probability. High consequence events.



Energy Resilience Metrics

- Energy Quality
- Energy Availability
- Reliability
  - Maintainability

Energy Quality

- **Power systems**

Parameter	Performance Class			
	G1	G2	G3	G4
Frequency Deviation (Percent) for 100 Percent Load Increase	<-15	<-10	<-7	TBD
Frequency Deviation (Percent) for 100 Percent Load Decrease	<+18	<+12	<+10	TBD
Frequency Recovery Time (Seconds) for 100 Percent Load Change	<10	<5	<3	TBD
Voltage Deviation (Percent) for 100 Percent Load Increase	<-25	<-20	<-15	TBD
Voltage Deviation (Percent) for 100 Percent Load Decrease	<+35	<+25	<+20	TBD
Voltage Recovery Time (Seconds) for 100 Percent Load Change	<10	<6	<4	TBD
Frequency Droop (Percent)	<-8	<-5	<-3	TBD
Steady-State Frequency Band (Percent)	<2.5	<1.5	<0.5	TBD
Steady-State Voltage Regulation (Percent)	<5	<2.5	<1	TBD
Note that column for performance class G4 states “TBD,” which means that a site-specific analysis is required to determine the voltage and frequency limits.				

- **Thermal systems** energy quality can be described in terms of type of thermal energy required by the process and thermal comfort systems. This may include: steam, high temperature, medium temperature or low temperature hot water, chilled water, water-antifreeze mixture, electricity for heating or cooling, gas, or other fossil fuel, etc.

Energy Availability (based on TM 5-698-1)

- *Energy* Availability is defined as the percentage of time that an energy system is available to perform its required function(s). It is measured in a variety of ways, but it is principally a function of downtime. Availability (EA) can be used to describe a component or system but it is most useful when describing the nature of a system of components working together: $0 < EA < 1$ (e.g., 0.99999, or 99.999%
- Energy availability can be calculated using one of two equations:

$$\mathbf{EA = MTBF/(MTBF + MTTR) \times 100\%}$$

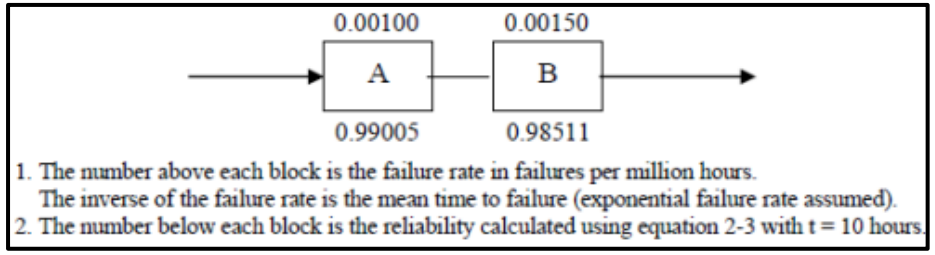
or

$$\mathbf{EA = Uptime/(Uptime + Downtime)}$$

where: MTBF = mean time between failures, MTTR = mean time to repair

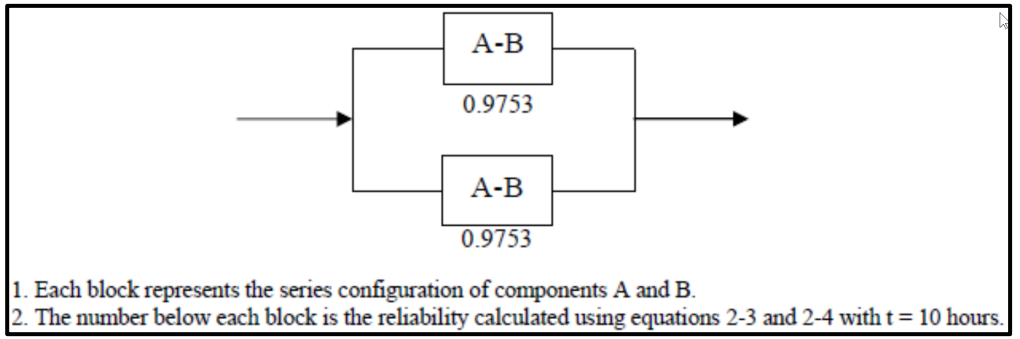
Reliability

- Reliability is concerned with the probability and frequency of failures (or more correctly, the lack of failures). A commonly used measure of reliability for repairable systems is the mean time between failures (MTBF) or mean time to failure (MTTF). Reliability is more accurately expressed as a probability of success over a given duration of time, cycles, etc. For example, the reliability of a power plant might be stated as 95% probability of no failure over a 1000-hour operating period while generating a certain level of power.
- Reliability of the system with components installed in series: Rs = R1 x R2 x . . . x Rn



1. The number above each block is the failure rate in failures per million hours.
   The inverse of the failure rate is the mean time to failure (exponential failure rate assumed).
2. The number below each block is the reliability calculated using equation 2-3 with t = 10 hours.

- Reliability of the system with redundant or parallel components: $R = 1 - (1 - R_s) \times (1 - R_s) = 0.9994$



1. Each block represents the series configuration of components A and B.
2. The number below each block is the reliability calculated using equations 2-3 and 2-4 with t = 10 hours.

Maintainability

- Maintainability is defined as the measure of the ability of an item to be restored or retained in a specified condition. A commonly used measure of maintainability in terms of corrective maintenance is the mean time to repair (MTTR).
- US Army Corps of Engineers - Power Reliability Enhancement Program (PREP) database:

CATEGORY	CLASS	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
Hot Water		0.764449454	0.999879234	0.997655390	2561.4	688	0.268599373	32614	3.94	6.48	7.02	2987	20.54
H08-100	Boiler, Hot Water	0.764449454	0.999879234	0.997655390	2561.4	688	0.268599373	32614	3.94	6.48	7.02	2987	20.54
Steam		0.556019215	0.998367529	0.994011997	2559.0	1502	0.586952425	14925	24.40	6.70	9.37	1556	52.45
H08-210	Boiler, Steam, High Pressure (> 15 psig)	0.436732634	0.996253408	0.989627339	942.7	781	0.828434093	10574	39.77	5.52	6.84	653	90.86
H08-220	Boiler, Steam, Low Pressure (<= 15 psig)	0.640121314	0.999325624	0.994945943	1616.2	721	0.446097568	19637	13.25	48.03	40.86	8044	44.27

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 habitable or protected against damage from freezing of water pipes, sewer, fire suppression system, protect sensitive content, or the start mold growth during extended loss of energy supply with extreme weather events
- MTTR can be estimated based on a building's total heat consumption per the unit of time using the following equation:

$Q_{tot} = Q_{loss\ tr} + Q_{inf} + Q_{vent} - Q_{int}$, where

$Q_{loss\ tr}$ = heat flow to compensate for thermal losses due to heat transfer by conduction
Q_{inf} = heat flow to heat outside air due to infiltration,

Q_{vent} - heat flow to heat ventilation air
Q_{int} = internal heat flow from people and internal processes.

$Q_{loss\ tr} = U\ A\ (T_{out} – T_{in})$, where:
U = overall coefficient of heat transfer
A = total area of fenestration
$(T_{out} – T_{in})$ = a difference between inside and outside air temperatures.

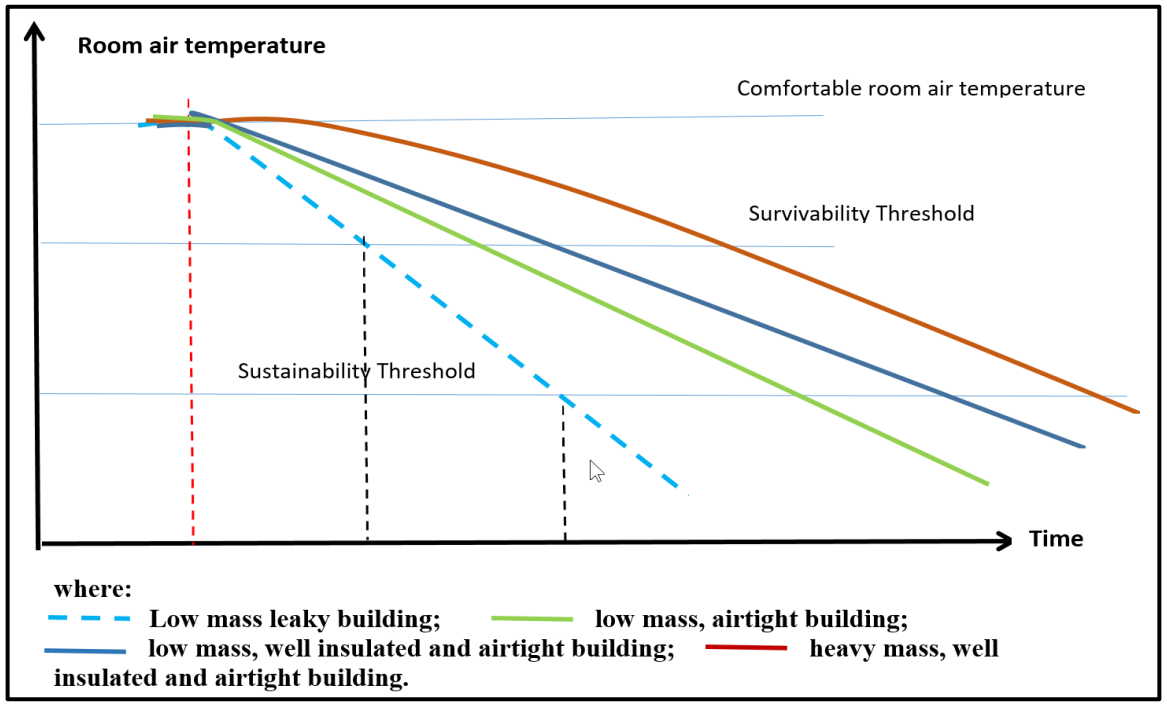
$Q_{inf} = AL\ A\ C_p\ (T_{out} – T_{in})$, where:
AL = air leakage rate
C_p = specific heat of air.
$Q_{vent} = L\ C_p\ (T_{out} – T_{in})$, where
L = outside air ventilation rate.

Major Factor Affecting MTTR

- Major factors affecting the time, when the internal temperature reaches threshold based on building habitability or sustainment include:
  - Difference between inside and outside air temperature
  - Building envelope leakage rate
  - Building envelope insulation properties, including insulation levels of its components, and thermal bridging
  - Internal thermal load (people and appliances/equipment connected to electric power).

- Also, thermal mass of the building structures composed of concrete, masonry, or stone materials that constitute a high level of embodied energy enables the building to absorb and store heat to provide "inertia" against temperature fluctuation. The amount of heat that can be absorbed by the building mass and stored can be calculated using the following equation:

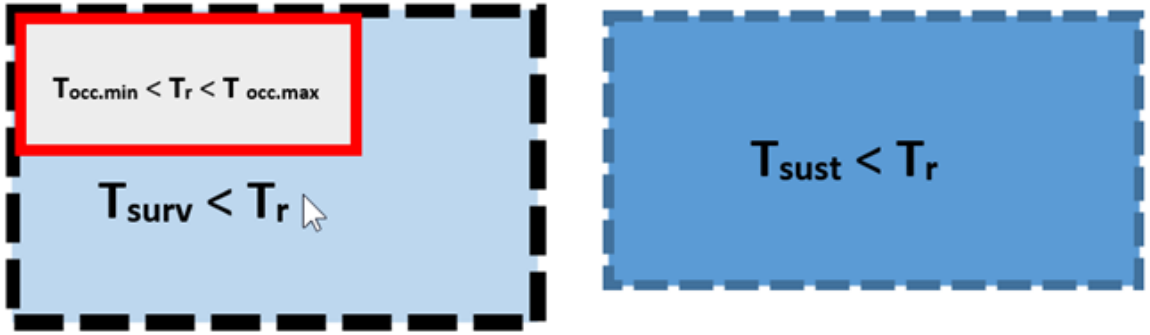
$Q_{storage}$ = M Cp ΔT,
where: M = building mass,
C_p = specific heat of the building material
ΔT = is allowable change in the room air temperature.



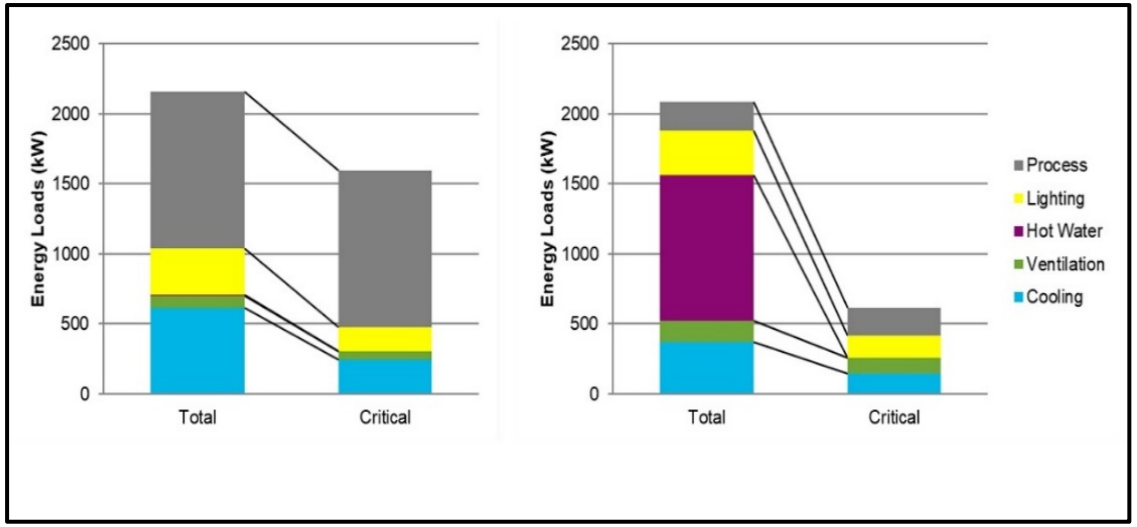
Notional example of temperature decay rate for different types of building envelope

Improving Thermal Energy Resilience

- Temperature reduction in mission critical and non-mission critical areas/buildings



- Total and critical load control (example for a notional data center and a barracks building.



Major Topics to be Addressed during the Forum

- Specifics of construction in Arctic climate
- International experiences from Nordic Defense Agencies and sub-Arctic and Arctic infrastructure managers
- Major natural, unintentional, and manmade threats
- Resilience of thermal energy systems serving mission critical facilities – Requirements and Best Practices
- Current and best practices of building envelop designs
- Air Barrier in Cold and Arctic Climates
- Current and best practices of HVAC system designs
- Energy generation, storage, and delivery strategies
- Energy efficiency and renewable energy strategies
- Thermal energy resilience studies

Thank you.

Questions?

Welcome to the Forum!