Session 3. Thermal Energy Systems Resilience in Extreme Climates P.1

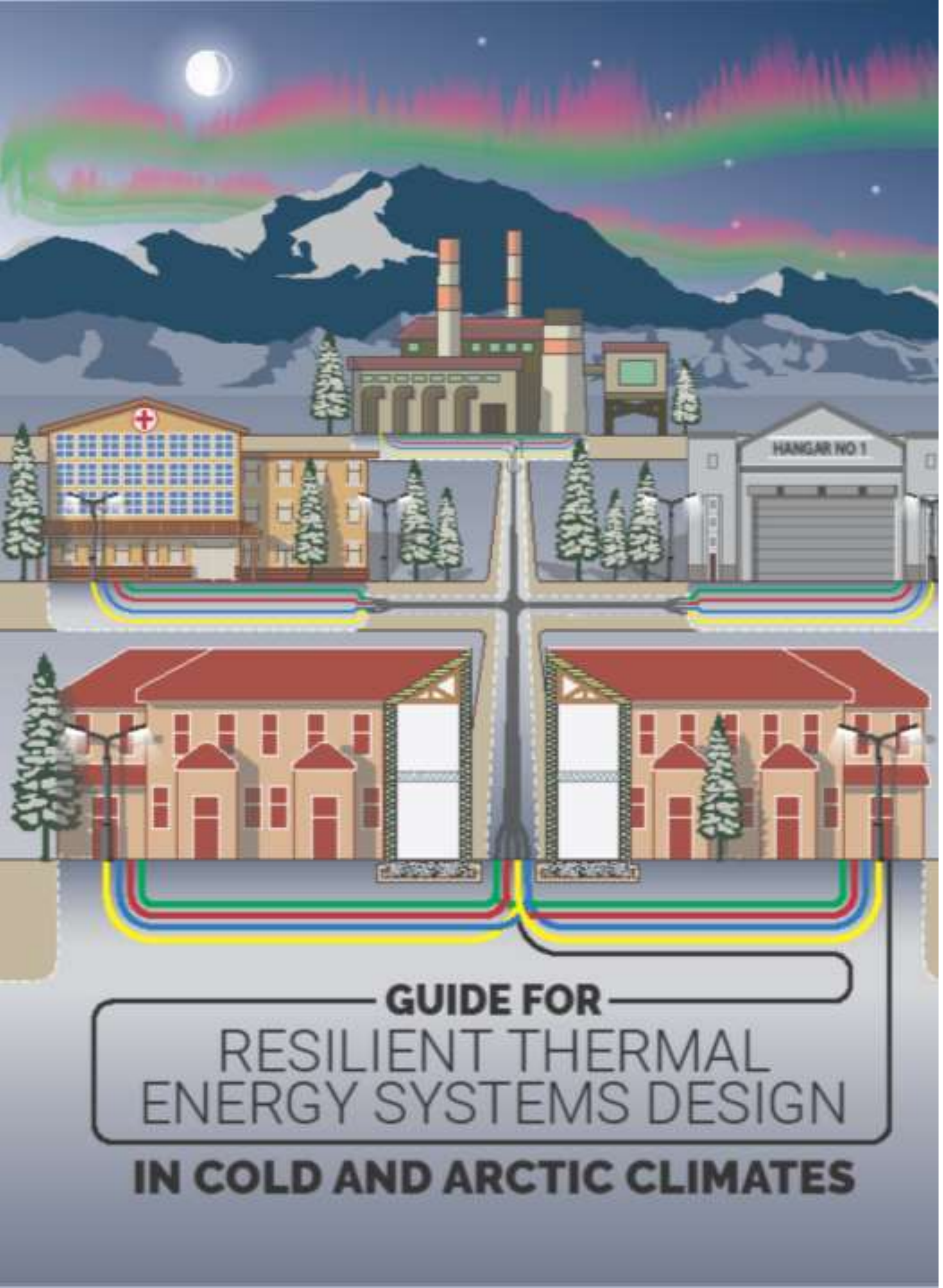
- **Introduction.** Dr. Alexander Zhivov, Senior Research Engineer, USACE ERDC CERL
- **Panel Discussion: Requirements for Building Thermal Conditions under Normal and Emergency Operations in Extreme Climates.** Dr. Alexander Zhivov, ERDC CERL
  - ***Threshold Conditions for Human Environment***: Dr. Jon Williams, Senior Research Physiologist, National Institute for Occupational Safety and Health/Centers for Disease Control and Prevention
  - ***Requirements for a Long-Term Integrity of the Building and Building Materials***: Mr. William Rose, Principal, William B. Rose & Associates, Inc.; and Mr. Raymond Patenaude, Managing Member, Holmes Engineering Group LLC
- **Construction in Arctic Climates.** Ms. Robbin Garber-Slaght, Senior Research Engineer, Cold Climate Housing Research Center

Session 3. Thermal Energy Systems Resilience in Extreme Climates P.2

- **Best Practices for Building Enclosures in Cold Climates.** Mr. Lyle Axelarris, Building Enclosure Specialist, Design Alaska
- **Best Practices for HVAC Systems in Cold Climate.** Ms. Emily Winfield, Chief Mechanical Engineer, Design Alaska
- **Temperature Decay Test and Maximum Time to Repair.** Mr. Bjorn Oberg, Research Electrical Engineer and Dr. Richard Liesen, Senior Research Engineer, USACE ERDC CERL
- **Q&A Time.** *Moderator:* Dr. Alexander Zhivov, Senior Research Engineer, USACE

Session objectives

- This session addresses thermal energy systems resilience in extreme climates: cold/Arctic and hot and humid.
- With the understanding that there are similarities in approaches to address both extremes, emphasis will be made on implementation in cold and Arctic climates.
- 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 session will present different aspects of thermal systems resilience, resulting in practical recommendations for indoor air requirements, characteristics of the building envelop and thermal energy systems, summarized in the Guide …..
- At the end of this session, results of unique studies of indoor air temperature decay conducted this winter in Alaska at outdoor air temperatures ranging between -20^{o}F and -40^{o}F will be presented and discussed. These results have been used to establish maximum allowed down time for thermal energy systems.



Chapter 1. INTRODUCTION
Chapter 2. REQUIREMENTS FOR BUILDING THERMAL CONDITIONS UNDER NORMAL AND EMERGENCY OPERATIONS IN COLD AND ARCTIC CLIMATES
Chapter 3. PARAMETERS FOR THERMAL ENERGY SYSTEM RESILIENCE
Chapter 4. BUILDING ENVELOPE
Chapter 5. CONSIDERATIONS FOR FOUNDATION CONSTRUCTION ON PERMAFROST
Chapter 6. BEST PRACTICES FOR HVAC, PLUMBING AND HEAT SUPPLY
Chapter 7. DISTRICT HEATING SYSTEMS
Chapter 8. EVALUATION MAXIMUM TIME TO REPAIR
Appendices
Appendix A Building Enclosure Testing on Alaska Military Base Projects
Appendix B . Thermal Energy System Resilience: Thermal Decay Test (TDT) in Cold/Arctic Climates
~ 150 pp.

Temperature Decay Test Sites

Ft. Wainwright

Ft. Greely

Requirements for Building Thermal Conditions under Normal and Emergency Operations in Extreme Climates

- *Moderator:* Dr. Alexander Zhivov, Senior Research Engineer, USACE ERDC CERL
- ***Threshold Conditions for Human Environment***:

Dr. Jon Williams, Senior Research Physiologist, National Personal Protective Technology Laboratory, National Institute for Occupational Safety and Health/Centers for Disease Control and Prevention

- ***Requirements for a Long-Term Integrity of the Building and Building Materials***:

Mr. William Rose, Principal, William B. Rose & Associates, Inc.; and Mr. Raymond Patenaude, Managing Member, Holmes Engineering Group LLC

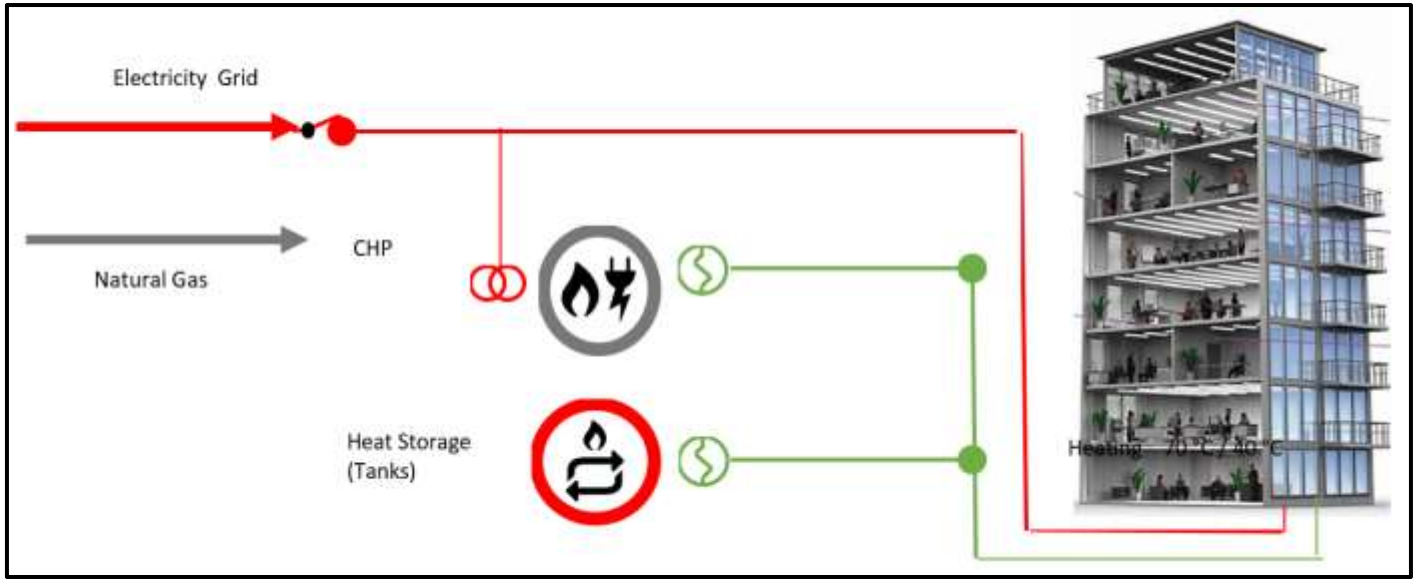
Why do we care about thermal systems resilience?

Damage to buildings

Uncomfortable environment, low productivity, jeopardized mission

Frozen water pipes, damaged furniture and other property, jeopardized mission

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.

Maximum Single Event Downtime (MaxSEDT) of Thermal System

- **MaxSEDT** 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. It can be estimated based on a building's total heat consumption per the unit of time using the following equation:

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

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

$\mathbf{Q_{vent}}$ - heat flow to heat ventilation air
$\mathbf{Q_{int}}$ = 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.

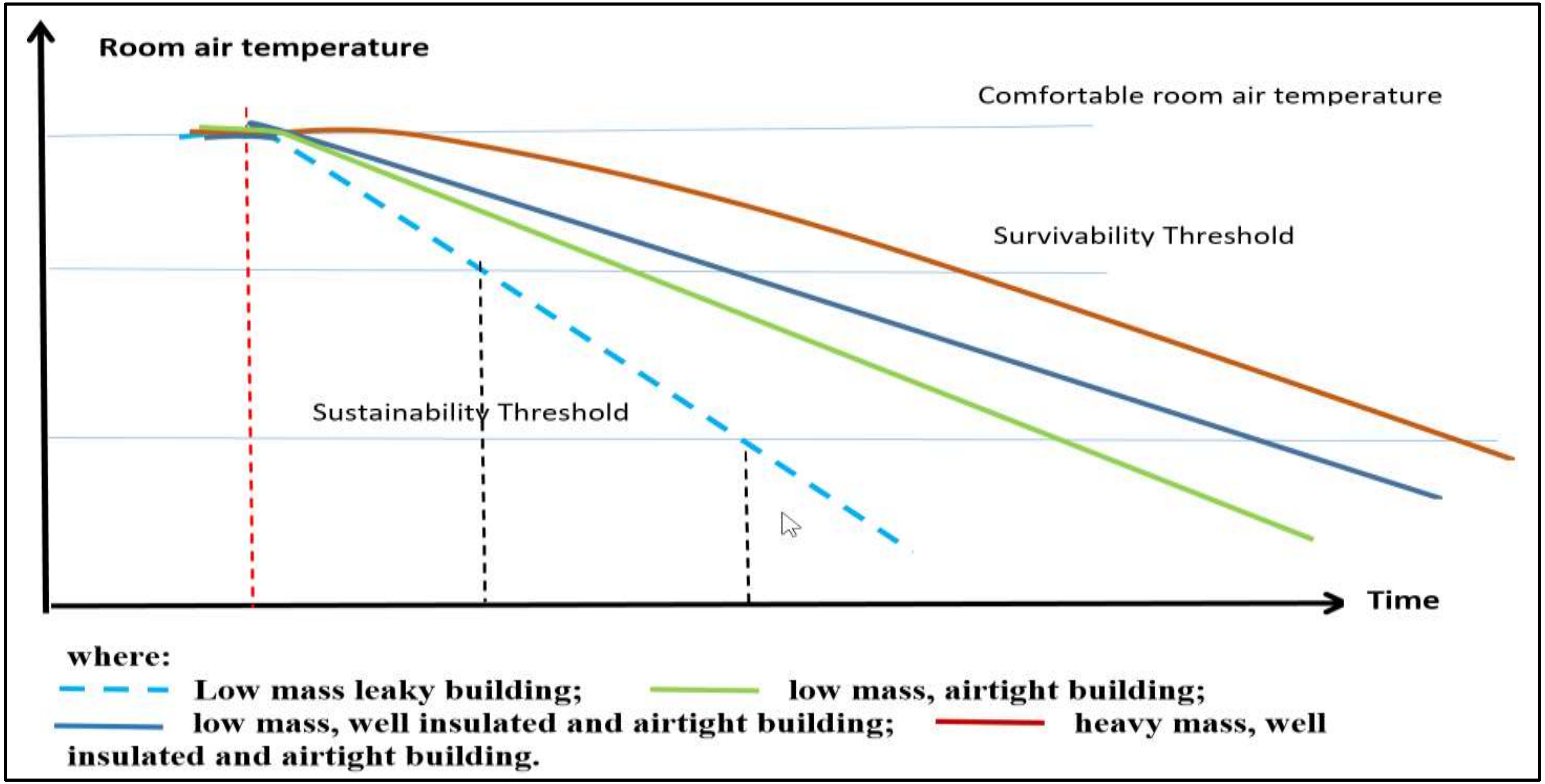
$Q_{inf} = AL\ A\ C_p\ (T_{out} - T_{in})$, where:
AL = air leakage rate
C_p = specific heat of air.
$Q_{vent} = L\ C_p\ (T_{out} - T_{in})$, where
L = outside air ventilation rate.

Major Factor Affecting MaxSEDT

- 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:

$Q_{storage} = M\ Cp\ \Delta T$, 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 Envelopes



Demand Side - Requirements to Thermal/Environmental Conditions Define Maximum Allowable Downtime:

- Thermal comfort and health criteria: ASHRAE Std 55, IS0 7730 for normal operations. **What are habitability limitations (cold or hot stress) for emergency conditions?**
- Process related criteria (IT technologies, medical facilities, industrial, etc.)
- **Building materials and furnishings requirements (mold, mildew, freeze protection, etc.)**
- **Thermal requirements to occupied and unoccupied spaces (sustainability)**

Recommended and allowable conditions for Classes A1-A4, and Network Equipment-Building System environments

<table>
<tr><th rowspan="2">Conditions</th><th colspan="2">ClassA1/ClassA2 [ASHRAE 2019]</th><th colspan="2">NEBS [ASHRAE 2005]</th></tr>
<tr><th>Allowable level</th><th>Recommended level</th><th>Allowable level</th><th>Recommended level</th></tr>
<tr><td>Temperature control range</td><td></td><td rowspan="3">64.4 °F-80.6°F
(18 °C–27 °C)</td><td rowspan="3">41 °F-104 °F
(5 °C–40 °C)</td><td rowspan="3">65 °F-80 °F
(18 °C–27 °C)</td></tr>
<tr><td>A1</td><td>59 °F - 89.6 °F
(15 °C – 32 °C)</td></tr>
<tr><td>A2</td><td>50 °F – 95 °F
(10 °C – 35 °C)</td></tr>
<tr><td>Maximum temperature rate of change</td><td>9 °F/hr [36 °F/hr][1]
(5 °C/hr [2.2 °C/hr])</td><td></td><td>2.9 °F/hr
(1.6 °C/hr)</td><td></td></tr>
<tr><td>RH control range</td><td></td><td rowspan="3">15.8 °F – 59 °F DP
(-9 °C – 15 °C) DP
and 60% RH</td><td rowspan="3">5%-85%
82 °F (28 °C)
Max DP</td><td rowspan="3">Max 55%</td></tr>
<tr><td>A1</td><td>10.4 °F (-12 °C) DP and 8% RH to
62.6 °F (17 °C)DP and 80%RH</td></tr>
<tr><td>A2</td><td>10.4 °F (-12 °C) DP and 8% RH to
69.8 °F(21 °C) DP and 80%RH</td></tr>
<tr><td colspan="5">[1] 9 °F/hr (5 °C/h) for tape storage, 36 °F/hr (2.2 °C/hr) for all other IT equipment and not more than 9 °F (5 °C/h) in any 15 min period.</td></tr>
</table>

ASHRAE. 2005. *Design Considerations for Datacom Equipment Centers*. ASHRAE Datacom Series. Atlanta, GA: ASHRAE.

ASHRAE. 2019. “HVAC Applications.” *ASHRAE Handbook*. Atlanta, GA: ASHRAE.

Thermal environment requirements for selected spaces in medical facilities

Space	T °F	T °C	RH, %
Class B and C operating rooms	68-75	20-24	30 to 60
Operating/surgical cystoscopic rooms	68-75	20-24	30 to 60
Deliver room	68-75	20-24	30 to 60
Critical and intensive care	70-75	21-24	30 to 60
Wound intensive care (burn unit)	70-75	21-24	40 to 60
Radiology	70-75	21-24	Max 60
Class A operating/procedure room	70-75	21-24	20 to 60
X-ray (surgery/critical care and cath)	70-75	21-24	Max 60
Pharmacy	70-72	21-22	Max 60

Recommended thermal conditions for buildings located in hot and humid climate – Normal operations (Blue skies)

<table>
<tr><th rowspan="4">Type of Requirement</th><th colspan="8">Space Occupancy</th></tr>
<tr><th colspan="4">Occupied</th><th colspan="2">Unoccupied
(Short Term)</th><th colspan="2">Unoccupied
(Long Term/ Hibernated)</th></tr>
<tr><th colspan="4">Normal Operations
(Regular Business Hours)</th><th colspan="2">Unoccupied for
a Short Time Period
(e.g., Few Days)</th><th colspan="2">Unoccupied for Extended Period of Time (e.g., Weeks)
Building Freezing/
Not Freezing</th></tr>
<tr><th>Humidity Not to Exceed</th><th colspan="2">Maximum Dry Bulb Temp</th><th>Minimum Dry Bulb Temp</th><th>Humidity Not to Exceed</th><th>Maximum Dry Bulb Temp</th><th>DP
Not to Exceed</th><th>Maximum Dry Bulb Temp</th></tr>
<tr><td>Human Comfort</td><td>60%[1]</td><td colspan="2">82 °F
(27.7 °C)[1]</td><td>68 °F
(20 °C) [1]</td><td>70%[4]</td><td>85 °F (29 °C)[4]</td><td colspan="2">N/A</td></tr>
<tr><td>Process Driven</td><td colspan="4">Process specific – see examples in Tables D-1 & D-2</td><td colspan="2">Process specific – see examples in Tables D-1 & D-2 (unless specified otherwise)</td><td colspan="2">N/A</td></tr>
<tr><td rowspan="2">Building Sustainment</td><td colspan="2">DP</td><td colspan="2">RH</td><td>Humidity not to exceed</td><td>DP</td><td>DP</td><td>RH</td></tr>
<tr><td colspan="2">≤60 °F (15.6 °C)[3,6]</td><td colspan="2">< 70%[3]</td><td><70%[3]</td><td><60 °F
(15.6 °C)[3,6]</td><td>≤60 °F
(15.6°C)[3,6]</td><td><70%[3]</td></tr>
</table>

Recommended thermal conditions for buildings located in hot and humid climate – Emergency operations (Black skies).

Type of Requirement	Space Occupancy					
	Mission-Critical		Tertiary Space around Mission-Critical		Hibernated Can Be Unoccupied for Extended Period of Time (from Days to Weeks)	
	WBGT		WBGT		WBGT	
Human Activity Broad Range	< 87.8 °F (31 °C)[5]		NA		N/A	
Process Driven	Process specific – see examples in Tables D-1 & D-2		N/A (unless specified otherwise)		N/A	
	DP	RH	DP	RH	DP	RH
Building Sustainment	≤60 °F (15.6 °C)[3,6]	< 70%[3]	≤60 °F (15.6 °C)[3,6]	< 70%[3]	≤60 °F (15.6 °C)[3,6]	<70%[3]

[1]ASHRAE Standard 55 (2017)

[2]To prevent water pipe rupture, with factor of safety

[3]To prevent interior surface mold growth, with no factor of safety

[4]To prevent long time recovery and significant energy losses

[5] ACGIH TLV, Thermal stress recommendations

[6]ASHRAE Standard 62.1

Recommended thermal conditions for buildings located in cold/Arctic climate – Normal operations (Blue skies)

<table>
<tr><th rowspan="4">Type of Requirement</th><th colspan="7">Space Occupancy</th></tr>
<tr><th colspan="3">Occupied</th><th colspan="2">Unoccupied
(Short Term)</th><th colspan="2">```</th></tr>
<tr><th colspan="3">Normal Operations
(Regular Business Hours)</th><th colspan="2">Unoccupied for
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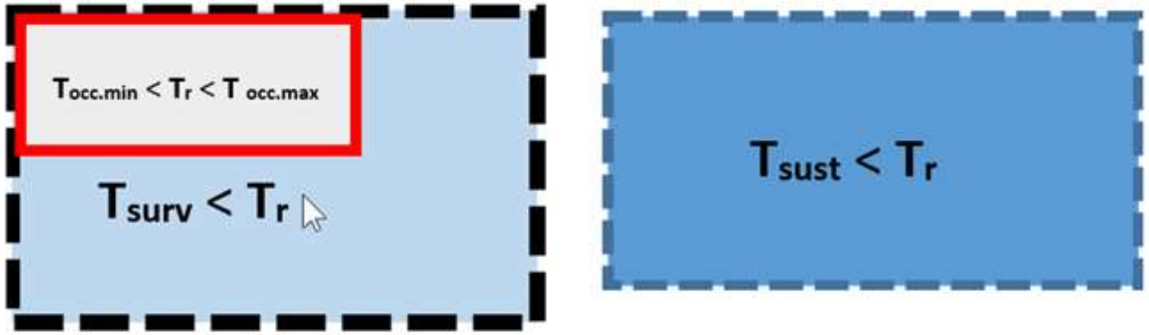
<tr><th>DP</th><th>Maximum Dry Bulb Temp</th><th>Minimum Dry Bulb Temp</th><th>DP</th><th>Minimum Dry Bulb Temp</th><th>Humidity Not to Exceed</th><th>Minimum Dry Bulb Temp</th></tr>
<tr><td>Human Comfort</td><td>< 63 °F
(17.2 °C)[1]</td><td>82 °F
(27.8 °C) [1]</td><td>68 °F
(20 °C) [1]</td><td>< 63[1]</td><td>55 °F
(12.7 °C) [4]</td><td colspan="2">N/A</td></tr>
<tr><td>Process Driven</td><td colspan="3">Process specific – see examples in Tables D-1 & D-2</td><td colspan="2">Process specific – see examples in Tables D-1 & D-2 (unless specified otherwise)</td><td colspan="2">N/A</td></tr>
<tr><td></td><td colspan="2">Humidity not to exceed</td><td>Minimum Dry Bulb Temp</td><td>Humidity not to exceed</td><td>Minimum Dry Bulb Temp</td><td>Humidity not to exceed</td><td>Minimum Dry Bulb Temp</td></tr>
<tr><td>Building Sustainment</td><td colspan="2">80%[3]</td><td>40 °F
(4.4 °C)[2]</td><td>< 80%[3]</td><td>40 °F
(4.4 °C) [2]</td><td>80%[3]</td><td>40 °F (4.4 °C), or N/A if drained</td></tr>
</table>

Recommended thermal conditions for buildings located in cold/Arctic climate – Emergency operations (Black skies)

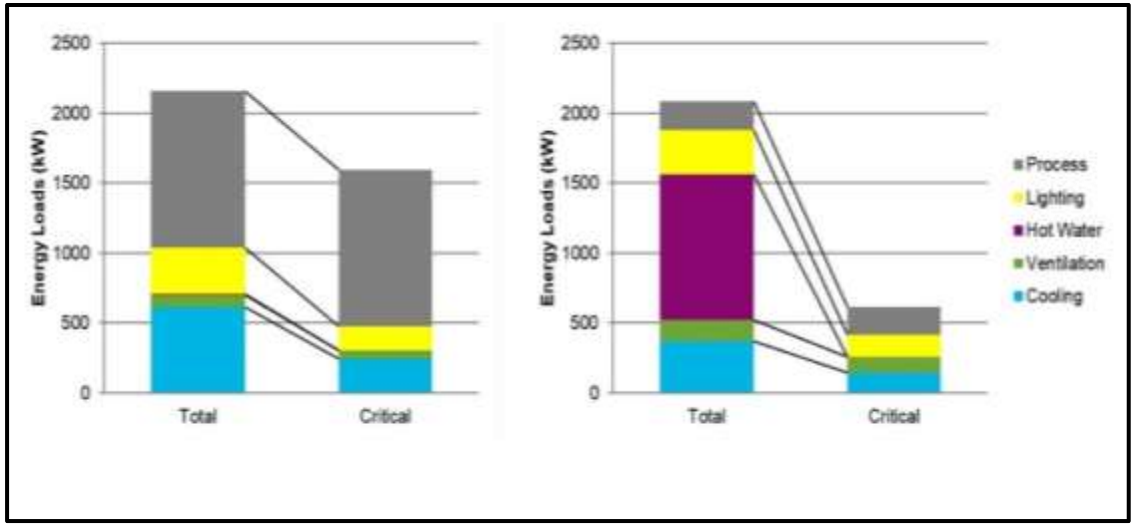
Scenario Type of Requirement	Emergency (Black Skies) Space Occupancy					
	Mission-Critical Operation		Tertiary Space (Non-Mission-Critical Bordering Mission-Critical Space)		Hibernated: Can Be Unoccupied for Extended Period of Time (from Days to Weeks) Building Freezing/ Not Freezing	
	DP	**Minimum Dry Bulb Temp**	**Humidity Not To Exceed**	**Minimum Dry Bulb Temp**	**Humidity Not to Exceed**	**Minimum Dry Bulb Temp**
Human Comfort	< 63 °F (17.2 °C)[1]	> 60 °F (16 °C)[5]	N/A		N/A	
Process Driven	Process specific – see examples in Tables D-1 & D-2		N/A		N/A	
	Humidity not to exceed	Minimum Dry Bulb Temp	Humidity not to exceed	Minimum Dry Bulb Temp		
Building Sustainment	80%[3]	40 °F (4.4 °C)[2]	80%[3]	40 °F (4.4 °C)[2] 55 °F (12.7 °C)[4]	80%[3]	N/A 40 °F (4.4 °C)[2] or N/A if drained

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.



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